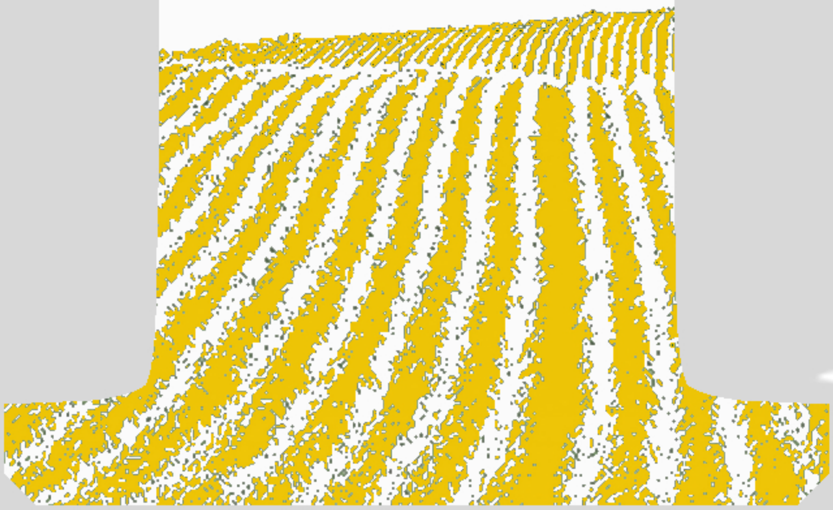
VOLUME 37

Editors Jacob M. Elkins, MD
J. Joseph Gholson, MD

Business Manager Craig Akoh, MD



THE IOWA ORTHOPEDIC JOURNAL

2017

Published by the Residents and Faculty of the
Department of Orthopedics and Rehabilitation

THE IOWA ORTHOPEDIC JOURNAL

2017 • Volume 37

Erratum: The article titled "Case report: Absence of the Long Head of the Biceps Brachii Tendon" published in the 2016 Iowa Orthopedic Journal should list Abdullah Foad, MD as the first author of the manuscript. We apologize to Dr. Foad and his co-authors and appreciate their contribution to the previous volume of the Iowa Orthopedic Journal.

INSTRUCTIONS FOR AUTHORS, 2017 EDITION

http://www.uiortho.com/index.php/education/iowa-orthopaedic-journal.html

We will consider any original article relevant to orthopedic surgery, orthopedic science or the teaching of either for publication in *The Iowa Orthopedic Journal*. Articles will be enthusiastically received from alumni, visitors to the department, members of the Iowa Orthopaedic Society, residents, and friends colleagues.

Published articles and illustrations become the property of *The Iowa Orthopedic Journal*. The journal is peer reviewed and referenced in PubMed, *Index Medicus* and MEDLINE. Articles previously published will not be accepted unless their content has been significantly changed. The IOJ receives approximately 57,000 downloads per month.

When submitting an article, send the following:

1. TITLE PAGE: The title page should list the authors' names in the order in which they should appear. The **corresponding author** must be clearly identified with mailing address, telephone/fax number and an e-mail address. A statement including conflicts of interest must also be included. Manuscripts will not be returned unless requested.

2. **ABSTRACT**: Word count is limited to 350 words. The abstract should consist of five paragraphs, with the headings *Background* (which states the primary research question), *Methods, Results, Conclusions,* and *Level of Evidence* (for clinical articles) or *Clinical Relevance* (for basic-science articles).

2. **BIBLIOGRAPHY**: The bibliography must list references ***in order of their use*** (not alphabetically), and be double-spaced. References must be presented in the text by superscript numbers. All references must be cited in the text.

3. **ILLUSTRATIONS/IMAGES/LEGENDS:** Each figure and table should be submitted on its own, separate page. Legends for all illustrations should be listed in order of appearance and single spaced. Color illustrations may not be used unless it is the opinion of the journal that they convey information not available in grayscale. All images **must have resolution of 300 pixels per inch (ppi)**. Web page images are to be avoided. Set digital cameras to their highest quality (ppi) setting for photographs. When submitting an illustration that has appeared elsewhere, give full information about previous publication and credit to be given, and state whether or not permission to reproduce it has been obtained.

4. **PREPARATION OF MANUSCRIPT:** Manuscripts must be typewritten and double spaced using wide margins. Write out numbers under 10 except percentages, degrees or numbers expressed as decimals. Direct quotations should include the exact page number on which they appeared in the book or article. All measurements should be given in SI metric units. The body of the manuscript should contain an Introduction, Methods, Results, and Discussion. The Source of Funding should be listed at the end of the manuscript.

5. **SUBMISSION OF MANUSCRIPT:** Authors may submit a single manuscript file (word file or PDF) or may submit a primary manuscript and as many additional files (figures, illustrations, legends, etc.) as needed. Please visit https://ioj.scholasticahq.com to submit your manuscript.

6. Additional information may be obtained by visiting http://www.uiortho.com/index.php/education/iowa-orthopaedic-journal.html or by e-mailing the Iowa Orthopedic Journal at ioj@uiowa.edu.

Printed on acid-free paper effective with Volume XV, 1995.

2017 IOJ EDITORS' NOTE

It is with great pleasure that we present the 37th edition of the Iowa Orthopedic Journal (IOJ). This year has been a remarkably successful edition, as we have transitioned the journal to a modern electronic submission process which has streamlined both the submission of articles and improved the quality and efficiency of the review process. **Based on the record number of submissions and interest this year, we will be transitioning the journal from an annual publication to a biannual publication.** We are hopeful that the ongoing PubMed exposure as well as the streamlined submission process will continue to increase the IOJ readership and promote ongoing growth.

Since the inception of the Iowa Orthopedic Journal in 1981, the IOJ has had steady increase in its recognition, prestige, and the number of citations attributed to published articles. All articles published in the Iowa Orthopedic Journal are indexed in PubMed and freely available to anyone in the world. The impact factor of the Iowa Orthopedic Journal has continued to increase over time, from 0.18 in 1999 to 1.0 in recent years, and we hope for this trend to continue to increase over time.

We would like to acknowledge the graduating senior residents Drs. Kyle Duchman, Matthew Hogue, Joshua Holt, Daniel Koehler, Nathan Nicholson, and Zachary Ries. During their five years at Iowa they have contributed greatly to a culture of quiet excellence while providing leadership by example. We will miss their guidance, and wish them the best as they head off to fellowship and their future careers.

The IOJ would not be possible without the help of the residents and faculty in the Department of Orthopedics and Rehabilitation. The residents are responsible for reviewing the articles thoroughly, suggesting revisions, and recommending publication decisions to the editors. Dr. Chike Akoh deserves recognition for securing corporate sponsorship for the journal to help fund publication. Ms. Teagan Von Seggern deserves special recognition for taking on the new role of Executive Publisher as we transitioned to in-house publication. We would also like to thank the faculty advisor, Dr. Jose Morcuende, for his continued guidance and support.

Finally, we would like to thank our wives Le Gholson and Jaymie Elkins, as well as our families, who have been endlessly patient and supportive as we have pursued excellence in research, scholarship, and clinical care.

It has been an honor and a privilege to serve as the editors of the 37th edition of the Iowa Orthopedic Journal. The University of Iowa continues to be a beacon of excellence in orthopedic training, and we are humbled to have been given the opportunity to train here and contribute to its legacy. We genuinely hope the readers enjoy reading this year's publication of our Iowa Orthopedic Journal.

Sincerely,
J. Joseph Gholson
Jacob M. Elkins
Co-Editors in Chief
Iowa Orthopedic Journal
Department of Orthopedics and Rehabilitation
University of Iowa Hospitals and Clinics

IOWA ORTHOPEDIC JOURNAL EDITORS EMERITI

1981
Frederick R. Dietz
Randall F. Dryer

1982
John J. Callaghan
Randy N. Rosier

1983
Don A. Coleman
Thomas J. Fox

1984
Fred G. McQueary
Nina M. Njus

1985
Patrick M. Sullivan
Mark D. Visk

1986
John J. Hugus
Randall R. Wroble

1987
Thomas C. Merchant
Mark C. Mysnyk

1988
Richard A. Berger
David M. Oster

1989
James L. Guyton
Peter M. Murray

1990
Craig G. Mohler
Joseph E. Mumford

1991
Devon D. Goetz
Thomas K. Wuest

1992
Robert L. Bass
Brian D. Mulliken

1993
Kenneth J. Noonan
Lacy E. Thornburg

1994
George J. Emodi
James C. Krieg

1995
Steven M. Madey
Kristy L. Weber

1996
Jay C. Jansen
Laura J. Prokuski

1997
James S. Martin
Todd M. Williams

1998
R. Dow Hoffman
Darron M. Jones

1999
Matthew B. Dobbs
Dennis P. Weigel

2000
Gregory N. Lervick
Jose Morcuende
Peter D. Pardubsky

2001
Daniel Fitzpatrick
Erin Forest
Rola Rashid

2002
Karen Evensen
Stephen Knecht

2003
Mark Hagy
Christopher Sliva

2004
Timothy Fowler
Michael Sander

2005
Kirk D. Clifford
Anthony V. Mollano

2006
Mohana Amirtharajah
Christina M. Ward

2007
Michael S. Chang
Matthew R. Lavery

2008
Jaren M. Riley
Christopher J. Van Hofwegen

2009
Jonathan Donigan
Ryan Ilgenfritz

2010
Christopher E. Henderson
Bryan A. Warme

2011
William D. Lack
Matthew J. Teusink

2012
Julian Carlo
Jaron Sullivan

2013
Cameron W. Schick
Michael C. Willey

2014
Mai Nguyen
Andrew Pugely

2015
Christopher Martin
Robert Westermann

2016
Joshua Holt
Kyle Duchman

2017
Jacob Elkins
J. Joseph Gholson

2017 IOWA ORTHOPEDIC JOURNAL DEDICATION

DR. ERNEST "ERNIE" FOUND

J. Lawrence Marsh, MD

Ernest "Ernie" Found, MD

It is hard to believe I am writing a dedication to Ernie Found at the end of his career; the years do slide away. Ernie retired from the Department of Orthopedic Surgery in January of 2017. He had a remarkable career as a spine surgeon, educator and perhaps most of all as best friend to everyone. It is appropriate and fitting that the Iowa Orthopedic Journal should be dedicated to him in the year of his retirement and that he was nominated by the current residents. He has been an icon of orthopedic surgery at the University of Iowa.

Ernie was born in Batavia, NY and was a star basketball player at Hamilton College in Clinton, NY. I met Ernie in medical school in Syracuse and we lived together in our final year and later during orthopedic residency at Boston University. During those Boston years Ernie and I were great Celtics fans, a passion he has carried through his life. Those were some of the finest years.

Shortly after I arrived in Iowa City in early 1987 (yes that was thirty years ago), it was clear the department I had recently joined needed a spine surgeon. I remember telling Ernie, "Why not just come for a visit? After all it is March madness season, a little basketball…." He did and six months later, he arrived with his wife Ellyn and young son Greg to start a 30 year career. Of course, if Ernie and Ellyn were coming to Iowa they would not do it halfway. If you are going to try life as an Iowan, what better way than in a farmhouse? For decades their farm, just south of Iowa City, with its barn and rope swing, orchard and pool that lured the unsuspecting for a quick fully clothed dip courtesy of a cadre of gloating residents, became symbolic of the orthopedic residency by hosting the spring senior residents' day picnic. The picnic always included John Deere tractor rides with Ernie for the residents' children, and games of "corn hole" and Dr. Bonfiglio's bocce ball. Ernie's descriptions prior to the hog roast of "Bacon and Makin" were Iowa residency tradition.

Ernie spent the majority of his career as the senior spine surgeon in the department. He was the go to person for eastern Iowa VIP spine care. He was the conservative voice for spine problems, but also the expert surgeon. He loved going slice by slice through complex MRI images tracing the path of the various nerve routes from proximal to distal and from medial to lateral; always great lessons for the residents and at times for me when I developed disc problems in recent years. Anyone would want Ernie to take care of their spine problem and I convinced him to do my spine surgery just a year ago. I experienced first-hand that Ernie sometimes had difficulty making records of clinic visits and discussions. I remember getting a repeat MRI and looking in Epic to see what he had thought of my MRI six months ago. There was nothing there; just a memory of a thoughtful and entertaining discussion. It was just that way with Ernie. To say that Ernie and Epic were not good friends is an understatement and relinquishing his password forever was a great and positive life event for Ernie.

Despite this being the orthopedic journal dedication it would be wrong to describe Ernie's legacy as only a spine surgeon and faculty member. He was and is much more than that. At his recent retirement party at Wilson's Orchard over 350 people attended, a strong testament to the fact that Ernie was much more to the Iowa City community than just a senior spine surgeon. His personality attracted other people like a magnet. A long series of adjectives describe Ernie each of which would have a full story, they include: humble, mischievous, crude, caring, lovable, funny, entertaining, unreliable (at times), amusing and lovable.

Ernie had a multitude of interests and his hobbies are broad and diverse. He was and is the ultimate St. Louis Cardinals baseball fan and remains a lifelong Boston Celtics fan. His Cardinal collection is currently on display in the lobby of the University Hospital. Many years ago he developed an interest in card tricks and has become a skilled amateur magician which allows him to be the center of attention at many gatherings. Anyone that has seen his routine will agree he has an uncanny knack for the showmanship of magic; his famous bra trick is a prime example. He has a passion for old vehicles, particularly John Deere tractors and red Ford pickup trucks. He loves jazz music and is a skilled pianist. He has a strong personal attachment to the New Hampshire Mountains and late in his career has become fascinated with growing hops despite the fact that he does not drink beer. If you can figure that out let me know.

Ernie is a friend to many in Iowa City, current residents, former residents, other hospital personnel and too many others to count. I am sure there are many that consider him their best personal friend and I am proud to say that I am one of those. During his years in Iowa City he was the father to three and a husband to one. This is about Ernie and he would say those were his most important accomplishments.

Ernie will long be remembered for his remarkable career as a spine surgeon in our department. But even more, he will be remembered for some of the other things that he brought to our department that I have only so briefly touched on. They are what have made him such a remarkable part of the Iowa Orthopedic Family and have enriched the Iowa Orthopedic Residency throughout all of these years. We wish he would have stayed longer but he just has too much to do!

2017-2018
DEPARTMENT OF ORTHOPEDICS AND REHABILITATION
SCHEDULE OF LECTURESHIPS AND CONFERENCES

(Larson Conference Room, 01090 JPP, unless otherwise noted)

Carroll B. Larson Shrine Memorial Lecture
May 19-20, 2017

Larson Conference Room
University of Iowa Hospitals and Clinics
Department of Orthopedics

Michael B. Millis, MD
Professor of Orthopaedic Surgery
Harvard Medical School
Founding Director, Child and Adult Hip Program
Boston Children's Hospital
300 Longwood Avenue, Fegan 140
Boston, MA 02115-5724
Spring 2018 to be arranged. Contact Nancy Love @ (319) 356-1872

2017 Senior Residents' Day
June 16-17, 2017

Craig J. Della Valle, MD
Professor of Orthopaedic Surgery
Chief, Division of Adult Reconstructive Surgery
Rush University Medical Center
1611 West Harrison, Suite 300
Chicago, IL 60612

Dr. David Templeman
Professor of Orthopaedic Surgery
University of Minnesota
Staff HCMC

33rd Annual Hawkeye Sports Medicine Symposium
December 7-8, 2017

Marriott Hotel & Conference Center
300 East 9th Street, Coralville
Guest Speaker – to be arranged
Contact Kris Kriener @ (319) 353-7954

2018 Senior Residents Day
June 15-16, 2018

Discussants to be arranged.

Department of Orthopedics

Arthur Steindler
1912-1949
Theodore Willis
1917-1918
Joseph Milgram
1926-1932
Ernest Freund
1932-1936
Thomas Waring
1932-1939
James Vernon Luck
1936-1939
Ignacio Ponseti
1946-2009
Eberly Thornton
1946-1952
Robert Newman
1948-1956
Michael Bonfiglio
1950-1995
Carroll Larson
1950-1978
Adrian Flatt
1956-1979
Reginald Cooper
1962-present
Howard Hogshead
1964-1965
Maurice Schnell
1964-1965
Richard Johnston
1967-1970,
1998-2016
Donald Kettelkamp
1968-1971
Gerald Laros
1968-1971
Richard Stauffer
1970-1972
John Albright
1972-present
Doug Mains
1972-1973
Bruce Sprague
1972-1979
Richard Brand
1974-2002
Mike Mickelson
1976-1981
Stuart Weinstein
1976-present
Thomas Lehmann
1978-1987
Joseph Buckwalter
1979-present
William Pontarelli
1980-1984; 1999-2004
Charles Clark
1980-present
William Blair
1980-1997
Barbara Campbell
1982-1984
James Weinstein
1983-1996
James Nepola
1984-present
Fred Dietz
1984-2015
Curtis Steyers
1985-2006
Ernest Found
1987-2017
Lawrence Marsh
1987-present
David Tearse
1989-2000
John Callaghan
1990-present
Charles Saltzman
1991-2005
Brian Adams
1993-2014
Leon Grobler
1996-1999
R. Kumar Kadiyala
1998-2004
Todd McKinley
1999-2012
Joseph Chen
2000-present
Annunziato Amendola
2001-2015
Jose Morcuende
2001-present
Sergio Mendoza
2003-2015
Michael O'Rourke
2003-2007
Brian Wolf
2003-present
Neil A. Segal
2004-2014
Jin-soo Suh
2004-2005
Joseph D. Smucker
2005-2014
John E. Femino
2005-present
Ericka Lawler
2006-present
Robert Yang
2007-2010
Nicolas O. Noiseux
2007-present
Phinit Phisitkul
2008-present
Heather Bingham
2008-present
Christina Ward
2008-2009
Benjamin Miller
2010-present
Matthew Bollier
2010-present
Matthew Karam
2011-present
Ryan Ilgenfritz
2011-2014
Carolyn Hettrich
2011-present
Mederic Hall
2011-present
Melissa Willenborg
2012-2016
Apruva Shah
2012-2015
Eric Aschenbrenner
2012-present
Heather Kowalski
2014-present
Cassim Igram
2015-present
Lindsey Caldwell
2015-present
Andrew Pugely
2016-present
Timothy Fowler
2016-present

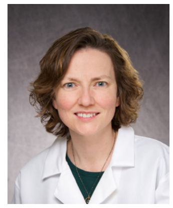
The University of Iowa
Roy J. and Lucille A. Carver College of Medicine

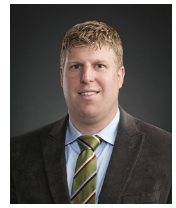
DEPARTMENT OF ORTHOPEDICS AND REHABILITATION STAFF 2016-17

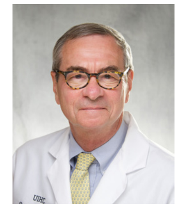

Dr. John Albright

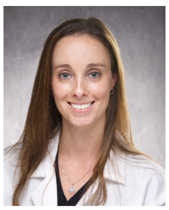

Dr. Donald Anderson

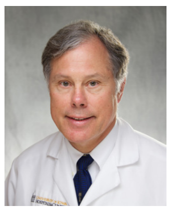

Dr. Eric Aschenbrenner

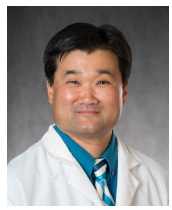

Dr. Heather Bingham


Dr. Matthew Bollier


Dr. Joseph Buckwalter


Dr. Lindsey Caldwell


Dr. John Callaghan


Dr. Joseph Chen


Dr. Charles Clark


Dr. Mitchell Coleman


Dr. Reginald Cooper
Emeritus

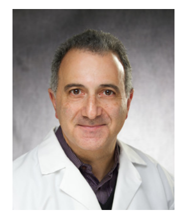

Dr. John Femino


Dr. Timothy Fowler


Dr. Jessica Goetz

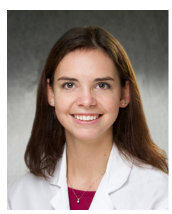

Dr. Mederic Hall

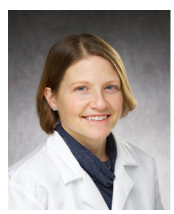

Dr. Carolyn Hettrich


Dr. Cassim Igram


Dr. Matthew Karam


Dr. Valerie Keffala


Dr. Heather Kowalski


Dr. Ericka Lawler


Dr. J. Lawrence Marsh


Dr. James Martin


Dr. Benjamin Miller

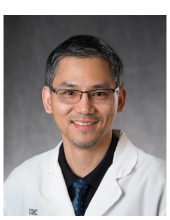

Dr. Jose Morcuende

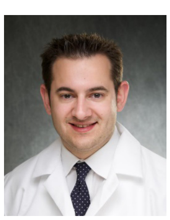

Dr. James Nepola


Dr. Nicolas O. Noiseux

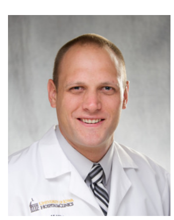

Dr. Doug Pederson


Dr. Chester Pelsang


Dr. Phinit Phisitkul


Dr. Andrew Pugely

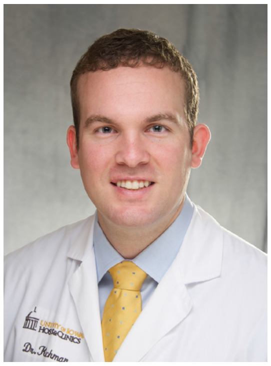

Dr. Stuart Weinstein


Dr. Michael Willey


Dr. Brian Wolf

1. Matthew Karam, MD
2. Timothy Fowler, MD
3. Molly Day, MD
4. Emily Connor, MD
5. Heather Kowalski, MD
6. Elizabeth Scott, MD
7. Jessell Owens, MD
8. Joshua Holt, MD
9. John Callaghan, MD
10. Brian Wolf, MD
11. Tyler Carllee, MD
12. Josef Tofte, MD
13. Elizabeth Fitzpatrick, MD
14. Joseph Buckwalter, MD
15. Blake Dowdle, MD
16. Cassim Igram, MD
17. John Yanik, MD
18. Donald Anderson, MD
19. Craig Akoh, MD
20. Reginald Cooper, MD
21. Kyle Duchman, MD
22. J. Lawrence Marsh, MD
23. Cameron Barton, MD
24. John Albright, MD
25. Nicolas Noiseux, MD
26. Ben Miller, MD
27. Zachary Ries, MD
28. Jocelyn Compton, MD
29. Ericka Lawler, MD
30. Jaya Shanmugam, MD
31. Phinit Phisitkul, MD
32. James Gholson, MD
33. Jose Morcuende, MD
34. Lindsey Caldwell, MD
35. Jessica Hanley, MD
36. Matthew Hogue, MD
37. Kyle Hancock, MD
38. Sarah Bergkamp, MD
39. John Femino, MD
40. Brandon Wilkinson, MD
41. Chris Anthony, MD
42. Nathan Hendrickson, MD
43. Yanin Plumarom, MD

2017 GRADUATING ORTHOPEDIC RESIDENTS

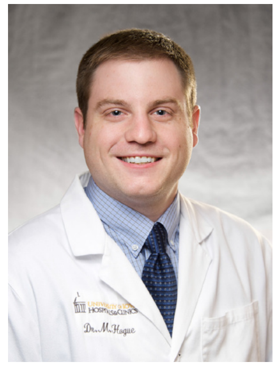


Kyle Duchman, MD

Kyle was born and raised in Cedar Falls, IA. He graduated from Cedar Falls High School as valedictorian and continued his education at Wartburg College in Waverly, IA, where he majored in Biology and was a four-year starter, two-time Academic All-American, and team captain for the football team. After college, Kyle attended medical school at the University of Iowa where he took an early interest in orthopedic research, which, in addition to increasingly poor performances on the intramural athletic fields, only further solidified his career choice.

Throughout his residency training, Kyle has been surrounded and supported by some of the best people in the world, including his co-residents and staff within the Department of Orthopedics. He would like to thank them for their time and commitment to his education and overall growth as a person while undoubtedly serving as his second family. Kyle would also like to thank his family, including his parents, Connie and Loren, who still reside in Cedar Falls, brother Bryce, an Internal Medicine resident here at the University of Iowa, sister Allison, a PICU nurse in Denver, CO, and his girlfriend Julia, who he first met during an interesting epidural abscess consult in the MICU as an intern.

Kyle is incredibly thankful for the world class training he has received as well as the multiple opportunities afforded to him as part of the Iowa Orthopedic family. After his fifth year of residency, Kyle will be moving to Durham, NC to complete a Sports Medicine Fellowship at Duke University.



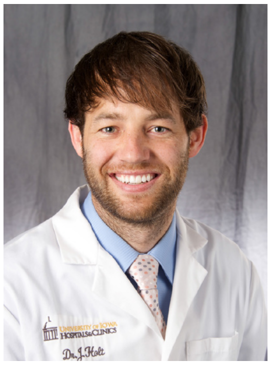
Matthew Hogue, MD

Matt was born in Jacksonville, FL to Greg and Tal Hogue. His father was a commander in the Navy and he spent much of his youth moving to various cities on the east coast. In third grade, his family was stationed in Corpus Christi, TX and they've been in Texas ever since. He ultimately moved to New Braunfels, TX where he went to high school and was the captain of the basketball team. He then played on the Trinity University men's basketball team in San Antonio. After graduating with a degree in Chemistry, Matt moved to Houston for medical school. He has always had a passion for orthopedics, and was fortunate enough to match at the Orthopedic Department at the University of Iowa.

Matt is interested in academics and education. He has been involved in multiple research projects in a variety of different sub-specialties. Most recently, his research has focused on complications related to severe tibial plateau and pilon fractures.

After residency, Matt plans to pursue further training in orthopedic traumatology at the R Adams Cowley Shock Trauma Center in Baltimore, MD. His ultimate plan is to remain involved with the education of orthopedic residents, and this fellowship is the first step towards accomplishing that goal.

Matt would like to acknowledge his wife, Shayna, who he met here as a 1st year resident. She is wonderful and he couldn't imagine this journey without her. He would also like to acknowledge his fellow graduating residents, who are the coolest freakin' dudes he's ever met.



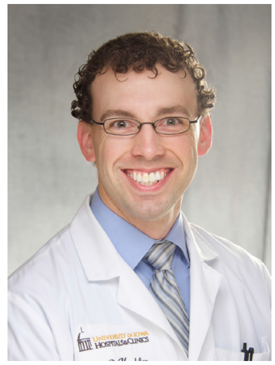
Joshua Holt, MD

Dr. Joshua Holt came to Iowa for his residency training with his wonderful wife Ali and their son Boston (7) in 2012. They have been fortunate to add two more boys to their family, Nixon (4) and Ryker (1), and are happy to call Iowa home. Josh grew up in Salt Lake City, Utah where he enjoyed many outdoor activities including wakeboarding, snowboarding, longboarding, and multiple team sports. After graduating high school he was blessed to spend 2 years as a missionary for the LDS church in Australia before earning his degree in Exercise Physiology from the University of Utah, graduating Summa Cum Laude with special distinction as a Research Designation Scholar. It was during this time that Josh was first exposed to academic medicine and clinical research, being recognized as the undergraduate chemist of the year and publishing his first peer reviewed manuscript evaluating the effects of inhaled heparin/N-acetylcysteine on inhalation injury. After volunteering/working at Shriners Hospital for Children and in the Burn Trauma ICU while completing his undergraduate studies, Josh elected to pursue a medical degree with the dream of becoming a pediatric orthopedic surgeon.

Josh and Ali decided to attend medical school at the University of North Carolina at Chapel Hill. During this training he continued his research endeavors, receiving the Pillsbury Award for most outstanding clinic research for his work evaluating the effects of nitric oxide releasing nanoparticle coatings on external fixation pins in a rat model. He also studied the early clinical markers of neurologic disease in mucopolysaccharidosis type II and carrier agents for desferoxamine. Josh and Ali thoroughly enjoyed their time in Carolina but recognized the unique privilege of completing his orthopedic training at the University of Iowa so their young family left Chapel Hill and moved to Iowa City to begin another chapter of their adventure together.

During his residency training Josh has undertaken multiple research projects and has been privileged to work with and learn from several faculty. His projects have focused on hand disorders in mucopolysaccharide storage disease, developmental dysplasia of the hip, tibialis anterior tendon transfers in relapsing idiopathic clubfoot, minimizing blood transfusion in joint arthroplasty, complex clubfoot, nationwide treatment trends in pediatric elbow fractures, imaging modalities in hip dysplasia, and posterior spinal fusion for scoliosis in spinal muscular atrophy.

Josh, Ali, and their boys are excited to continue their adventure in San Diego, CA this summer where Josh has taken a fellowship position in Pediatric Orthopaedics and Scoliosis at Rady Children's Hospital. Josh is eternally grateful for the never ending love and support of his wife and children. Although Ali will say that she works hard each day just to keep the boys alive, the truth is that she is the glue that keeps their family together, the support that lifts them all to new heights, and the perfect partner for life's journey. Josh would like to thank his parents, Rick and Sue, for their love and support and for instilling in him the values of hard work and integrity as a young man.



Daniel Koehler, MD

Daniel Koehler grew up in Pickerington, OH, with one younger brother. He could often be found during his childhood summers teamed up with his maternal grandfather working in his garage-turned-workshop on charitable projects for a friend, family member, or fellow parishioner in a time of need. He became quickly enraptured by his grandfather's dedication, craftsmanship, and indefatigable altruism and to this day he still points to these formative years as the basis for his decision to pursue a career rooted in service and coupled with technical proficiency.

After completing his high school education, Daniel pursued his undergraduate studies at the University of Notre Dame. He and his family are proud to be "Domers" as no less than eight academic degrees have been conferred to Daniel, his brother, and his in-laws. To this day Notre Dame remains a home away from home for them all. The unquestionable highlight of Daniel's collegiate years was meeting his future wife Susan. Their paths crossed by virtue of shared interest in biological sciences and trumpet performance. To this day you can still hear impromptu duet renditions of the Notre Dame Victory March on the north side of Iowa City if you listen closely. Daniel and Susan both pursued professional education beyond Notre Dame as Daniel obtained his medical doctorate from Vanderbilt University where he graduated AOA and class valedictorian, and Susan graduated with a doctorate in physical therapy from Creighton University. They were happily married in Nashville in 2010, and have since been blessed with three beautiful children, Madeline (4), Isaac (2), and Owen (2 months).

During residency Daniel has pursued multiple academic investigations with areas of interest ranging from surgical education to cost accounting methodologies, and peri-operative pain management optimization to defining risk factors for complications. He has been awarded four grants including funding from the National Institutes of Health, the Orthopaedic Research and Education Foundation, the American Board of Orthopaedic Surgeons, and the Iowa Orthopaedic Society. His research successes to date have driven his ambition to embark on a career as an academic orthopedic surgeon. Upon completion of his residency, Daniel will be completing a hand and upper extremity fellowship at Washington University in St. Louis.

Daniel is extremely grateful for the innumerable faculty mentors at the University of Iowa who have helped to shape his young career and define his passion for hand and upper extremity surgery. He would also like to acknowledge his co-residents as there can be no better group of colleagues with whom to share this journey. Finally, and most importantly, he is thankful for the love and support of his family: his mom, brother, in-laws, grandparents, and beautiful wife and three wonderful children.

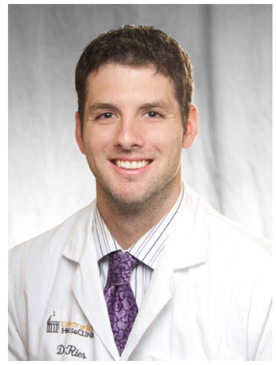
Nathan Nicholson, MD

Nate, son of Kevin and Janelle Nicholson, grew up in Ottumwa in southeast Iowa. Nate is the oldest of three children. His sister, Jennifer, teaches 4th grade in Waukee, Iowa, and his brother, Kyle, is a dental student at the University of Iowa College of Dentistry. Nate attended Ottumwa High School where he excelled in wrestling and powerlifting. He won a Greco-Roman state wrestling title and previously held the world squat record of 500 pounds for his age group (18-19) and weight (165 pounds). Through his experiences with sports and an injury himself, Nate developed an interest in medicine and built a relationship with his hometown orthopedic physician, Dr. Don Berg. After high school, Nate continued his wrestling career at the University of Iowa, where he was introduced to Dr. Todd McKinley who helped further affirm his interest in medicine and specifically orthopedics.

During his undergraduate years at the University of Iowa, Nate began volunteering weekly at the Ronald McDonald House of Iowa City. He later became a night manager and continued volunteering his time with the various fundraisers for the House. While working as a night manager, Nate met his future wife, Amy, who was a weekly volunteer at the House. Amy has provided a great deal of support during medical school and residency while being very busy herself working as a pharmacist and taking care of their beautiful children, Luke (4) and Carly (2). His family has provided him with much joy and love over the years, and are happily expecting a baby boy in May. He enjoys spending time outside with his family during his free time.

During residency, Nate has worked on many research projects in all areas of orthopedics. His main project is his senior resident basic science project, entitled "Direct Delivery of Bone Morphogenetic Protein-2 and Fibroblast Growth Factor-2 Plasmid Genes for Diabetic Fracture Healing in a Rabbit Model." His interest for all areas of orthopedics has led him to focus on a career as a general orthopedic surgeon, and he will begin his practice after graduation in Ottumwa, Iowa.

Nate was fortunate to attend the University of Iowa for undergraduate, medical school and residency and would like to thank each and every staff member he has worked with over the years. The skills and knowledge he has gained will allow him to provide excellent orthopedic care to the people of the State of Iowa. The faculty and residents make the University of Iowa Orthopedic Residency program the best in the nation. He is truly thankful for a great class and to his fellow residents for their guidance and support. Lastly, he would like to thank Amy and his entire family for all of their support during these busy years.



Zachary Ries, MD

Zach was born and raised in Dubuque, Iowa, where he attended Wahlert High School. He was fortunate to develop a close bond with both grandfathers, who introduced him to his passions for golf and the outdoors. The lessons learned from these hobbies served him well as he made his way through undergraduate and medical school at the University of Iowa. During this time, he waited tables at a local restaurant in Dubuque where he developed his ability to deal with "complicated" customers.

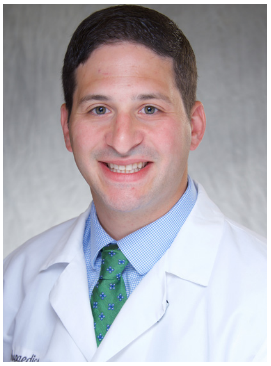
After medical school, Zach was fortunate to match to the University of Iowa Orthopedic Department for residency. While residency has taken a toll on his golf game, it did provide him the opportunity to meet his girlfriend, Lauren. As an R2, Zach was consulted to debride a diabetic foot ulcer on the Medicine floor where Lauren works as a nurse.

During his time in medical school and residency, Zach has been fortunate enough to work with several great research mentors. Prior to medical school, he worked with Dr. Mendoza and Dr. Weinstein on several spine projects and continued spine research into residency. He has also examined healing rates of distal femur periprosthetic fractures using far cortical locking screws with Dr. Marsh, rotator cuff tears with Dr. Hettrich, ACL tunnels with Dr. Bollier, sarcoma surveillance strategies with Dr. Miller, and complications following amputation with Dr. Phisitkul.

After graduation, Zach will pursue a career in spine surgery beginning with completion of a spine fellowship at Leatherman Spine Center in Louisville, Kentucky. He hopes to permanently settle down in the Midwest so he can continue to experience great golf, hunting, Hawkeye sports and Midwestern values.

Lastly, Zach would like to acknowledge all the great people he has met and been influenced by during his time in the department. He would like to thank his parents, Shawn and Teresa, and siblings, Kaitlyn and Cody, for their continuous support. He would like to thank his girlfriend Lauren for her support/fabulous home-cooked meals through the grind of residency. Lastly, Zach would like to thank his co-residents for inspiring him to never stop learning.

2017 GRADUATING FELLOWS



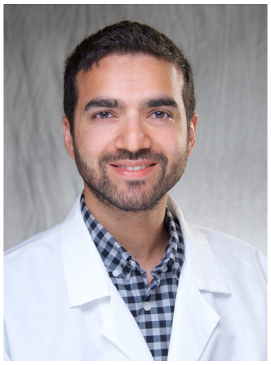
Jonathan Katz, MD

Jonathan grew up in Roanoke, Virginia. He attended the University of Georgia for his undergraduate degree. He then completed his medical degree at the Medical College of Virginia prior to moving to Charleston, SC for orthopedic residency at the Medical University of South Carolina. Most recently, he joined the University of Iowa in August 2016 as the hand surgery fellow. Jonathan is joined by his beautiful wife, Alissa, 2 year old son Asher, and 6 month old daughter Leighton. Jonathan is grateful for his outstanding mentors, and the opportunity to be a part of the UIOWA family.

Jaya Prasad Shanmugam, MD

Dr. Jaya Prasad Shanmugam is our foot and ankle fellow for the year 2016-17. He is from Erode, India. He earned his medical degree from Madras Medical College in Chennai, India in 2004. He then finished his orthopedic residency from King Edward Memorial Hospital and Seth G S Medical College in Mumbai, India in the year 2009. After practicing for some time as an attending physician in Chennai he moved to USA and started his fellowship in foot and ankle surgery with UIHC in September 2017. He is grateful to work with the amazing residents and staff of this hospital.

He would like to sincerely appreciate the able mentorship and guidance of Dr. Femino and Dr. Phisitkul through the year. He would also like to acknowledge the company and love of his wife Sathya and two daughters, Mathimalar and Pranavi. His wife is working as a research associate in the Department of OBGYN at UIHC. He feels happy and excited to be at UIHC.



Adnan Zaidi, MD

Adnan was born and raised in Chicago. He went to the University of Missouri for his bachelor's degree and medical school in a combined dual degree program (BA/MD) that he completed in 2011. Adnan then went to the University of Wisconsin Hospital and Clinics for his residency training in Orthopedic Surgery. He developed an interest in sports medicine during the course of his training there and sought further specialization at the University of Iowa. He will work as an assistant team physician for the Hawkeye football team. He is accompanied by his wife, Mehwish, who is also in health care and is very supportive. He feels very fortunate to have become a physician and to have received the training that he did at world class institutions.

Adnan enjoys spending time outdoors and has a special interest in traveling abroad and experiencing different cultures.

Piya Assawaboonyades

Piya is the current University of Iowa orthopedic oncology fellow for 2016-2017. He was born in Thailand and graduated with his medical degree from Chulalongkorn University in Thailand. Piya completed his orthopedic surgery residency training at The Institute of Orthopedic Lerdsin General Hospital in Bangkok, Thailand. He is practicing as an orthopedic surgeon in Naresuan University Hospital in Phitsanulok, a northern province in Thailand.

After his fellowship he will return to Naresuan University Hospital to treat patients with musculoskeletal tumors in the rural areas of Thailand. He is looking forward to seeing his parents and sister when he returns home to Thailand. He would like to thank his family and the faculty of medicine from Naresuan University for support. He extends special thanks to Dr. Miller, Dr. Phisitkul, Dr. Buckwalter and all University of Iowa staff and residents for giving him a great opportunity to be here, a very warm welcome, tons of experience, and inspiring him to improve himself. It has been a greatest year of his life.

NEW ORTHOPEDIC FACULTY

Mitchell Coleman, MD

Dr. Mitchell Coleman is a cell biologist with research interests in the redox biology and biochemistry of articular chondrocytes. He obtained his undergraduate degree in biomedical engineering and his PhD in free radical and radiation biology from the University of Iowa. He then joined the Department of Orthopedics and Rehabilitation for his post-doctoral work characterizing intracellular pathology following intraarticular fracture, meniscal destabilization and other injuries to articular surfaces. Additional research interests include aging- and diabetes-associated changes in articular cartilage as well as development of sarcoma therapies built around musculoskeletal cell biological concepts. He is currently an active member of the Orthopedic Research Society and the Society for Free Radical Biology and Medicine.

Timothy Fowler, MD

Dr. Timothy Fowler joined the hand/upper extremity team in October, 2016. An Illinois native, Dr. Fowler received his undergraduate degree from the University of Illinois and his medical degree from the University of Chicago. After graduating from the University of Iowa orthopedic residency in 2005, he completed a hand surgery fellowship at the Philadelphia Hand Center. After 10 years in private practice in southeast Wisconsin, Dr. Fowler and his family have returned to Iowa City. Dr. Fowler holds board certifications in orthopedics and in hand surgery.

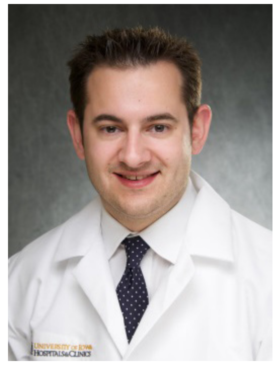
Valerie Keffala, MD

Dr. Valerie J. Keffala is a licensed psychologist and licensed health service provider. She completed her BA at the University of California at San Diego in 1989, and her Ph.D. at the University of Iowa in 1996. She has been seeing patients and teaching at the University of Iowa as a clinical health psychologist, with a specialty in pain management, for over 20 years. She is delighted to be a faculty member in the Department of Orthopedics and Rehabilitation, specializing in psychological approaches to pain management. She is currently involved in multidisciplinary research and education projects at the University of Iowa, including being a member of a Consortium of Excellence in Pain Education (CoEPE) Case-Based Scenario Development Team. She is also an adjunct faculty member in the University of Iowa Department of Psychological and Quantitative Foundations, for the Counseling Psychology Program. She has mentored and served on dissertation committees for doctoral students in the Counseling Psychology Program, Department of Physical Therapy, and the Department of Psychology and Brain Sciences at the University of Iowa. She is an active member of the Association for Contextual Behavioral Science, the American Pain Society and the Iowa Psychological Association.

Chester Pelsang, MD

Dr. Chester Pelsang is a Podiatrist who joined the Department of Orthopedics at the University of Iowa Hospitals and Clinics in the fall of 2016. Dr. Pelsang is a native of Iowa City where he graduated from City High School and the University of Iowa. He received his Doctor of Podiatric Medicine (DPM) degree from Des Moines University. He completed a surgical residency at Des Moines General Hospital before returning to Iowa City to enter private practice, most recently with the Steindler Orthopedic Clinic. He is board certified by the American Board of Podiatric Medicine. His wife, Retta, is a radiologist in the Quad Cities. They have 3 children, Rachel, Chester, and Charles.

Andrew Pugely, MD



Dr Andrew J Pugely is an Assistant Professor at the University of Iowa in the Department of Orthopedics and Rehabilitation. He is an orthopedic spinal surgeon that treats all conditions of the cervical, thoracic, and lumbar spine. Dr Pugely completed his orthopedic residency at the University of Iowa and did further fellowship training in complex adult and pediatric spinal surgery at Washington University in St Louis and Columbia University of New York. He treats patients with degenerative, traumatic, and deformity conditions of the neck and back using the latest technology and techniques. His research interests include crosscutting topics such as patient safety, patient outcomes, and healthcare delivery.

The 2017 Michael Bonfiglio Award for Student Research in Orthopaedic Surgery

The 2017 Iowa Orthopaedic Society Medical Student Research Award for Musculoskeletal Research

The University of Iowa Department of Orthopedics and Rehabilitation, along with the Iowa Orthopaedic Society, sponsors two research awards involving medical students.

The Michael Bonfiglio Award originated in 1988 and is named in honor of Dr. Bonfiglio who had an avid interest in students, teaching and research. The award is given annually at the medical convocation and consists of a plaque and a stipend. It is awarded to a senior medical student in the Carver College of Medicine who has done outstanding orthopedic research during his or her tenure as a medical student. The student has an advisor in the Orthopedic Department. However, the student must have played a major role in the design, implementation and analysis of the project. He or she must be able to defend the manuscript in a public forum. The research project may have been either a clinical or basic science project, and each study is judged on the basis of originality and scientific merit. The winner presents their work at the spring meeting of the Iowa Orthopaedic Society as well as at a conference in the Department of Orthopedics and Rehabilitation.

The Iowa Orthopaedic Society Medical Research Award for Musculoskeletal Research is an award for a student in the Carver College of Medicine who completes a research project involving orthopedic surgery during one of his or her first three years of medical school. The award consists of a $2000 stipend, $500 of which is designated as a direct award to the student and $1500 of which is designated to help defray continuing costs of the project and publication. The student must provide an abstract and a progress report on the ongoing research. The aim is to stimulate research in the field of orthopedic surgery and musculoskeletal problems. This award is also presented at a medical convocation. In addition, the student presents his or her work at the spring meeting of the Iowa Orthopaedic Society and at a conference in the Department of Orthopedics and Rehabilitation. This award is supported through the generosity of the Iowa Orthopaedic Society.

This year the selection committee consisted of Drs. Charles R. Clark, Joseph A. Buckwalter, John Femino, Timothy Fowler, Cassim Igram, Jose Morcuende and Peter Rink. They recommended that Richard Amendola, M4, receive the 2017 Michael Bonfiglio Student Research Award. Richard's award was based on his project, "Two- to 4- Year Followup of a Short Stem THA Construct: Excellent Fixation, Thigh Pain a Concern." His advisor was Dr. John Callaghan.

The selection committee recommended that the Iowa Orthopaedic Society Medical Student Research Award be given to Robert Burnett, M3, for his research titled "Timing of Anterior Cruciate Ligament Reconstruction and Implications for Meniscus Pathology and Treatment: Results from a Prospective Cohort." His advisor was Dr. John Callaghan.

The Michael Bonfiglio Award and the Iowa Orthopaedic Society Medical Student Research Award for Musculoskeletal Research are very prestigious, recognizing student research on the musculoskeletal system. These awards have indeed attained their goal of stimulating such research and have produced many fine projects over the years.

Charles R. Clark, M.D.
The Michael Bonfiglio Professor of Orthopedic Surgery

From left to right: Larry Marsh, MD, John Callaghan, MD, Richard Amendola, M4, winner of the Michael Bonfiglio Medical Student Research Award, Robert Burnett, M3, winner of the IOS Medical Student Research Award, Brian Wolf, MD, Charles Clark, MD

DYNAMIC FIXATION OF HUMERAL SHAFT FRACTURES USING ACTIVE LOCKING PLATES: A PROSPECTIVE OBSERVATIONAL STUDY

Steven M. Madey, MD[1], Stanley Tsai, MS[1], Daniel C. Fitzpatrick, MD[2], Kathleen Earley[1], Michael Lutsch[1], Michael Bottlang, PhD[1]

ABSTRACT

Background: Rigid locked plating constructs can suppress fracture healing by inhibiting interfragmentary motion required to stimulate natural bone healing by callus formation. Dynamic fixation with active locking plates reduces construct stiffness, enables controlled interfragmentary motion, and has been shown to induce faster and stronger bone healing in vivo compared to rigid locking plates. This prospective observational study represents the first clinical use of active locking plates. It documents our early clinical experience with active plates for stabilization of humeral shaft fractures to assess their durability and understand potential complications.

Methods: Eleven consecutive patients with humeral shaft fractures (AO/OTA types 12 A-C) were prospectively enrolled at a level I and a level II trauma center. Fractures were stabilized by using active locking plates without supplemental bone graft or bone morphogenic proteins. The screw holes of active locking plates are elastically suspended in elastomer envelopes inside the plate, enabling up to 1.5 mm of controlled interfragmentary motion. Progression of fracture healing and integrity of implant fixation was assessed radiographically at 3, 6, 12, and 24 weeks post surgery. Patient-reported functional outcome measures were obtained at 6, 12, and 24 weeks post surgery. The primary endpoint of this study was plate durability in absence of plate bending or breakage, or failure of the elastically suspended locking hole mechanism. Secondary endpoints included fracture healing, complications requiring revision surgery, and functional outcome scores.

Results: The eleven patients had six simple AO/OTA type 12A fractures, three wedge type 12B fractures, and two comminuted type 12C fracture, including one open fracture. All active locking plates endured the 6-month loading period without any signs of fatigue or failure. Ten of eleven fractures healed at 10.9 ± 5.2 weeks, as evident by bridging callus and pain-free function. One fracture required revision surgery 37 weeks post surgery due to late fixation failure at the screw-bone interface in the presence of a atrophic delayed union. The average Disability of the Arm, Shoulder and Hand (DASH) score improved from 31 ± 22 at week 6 to 13 ± 15 by week 24, approaching that of the normal, healthy population (DASH = 10.1). By week 12, the difference between Constant shoulder scores, expressed as the difference between the affected and contralateral arm (8 ± 8), was considered excellent. By week 24, the SF-12 physical health score (44 ± 9) and mental health score (48 ± 11) approached the mean value of 50 that represents the norm for the general U.S. population.

Conclusion: Absence of failure of the plate and locking holes suggests that dynamic fixation of humeral shaft fractures with active plates provides safe and effective fixation. Moreover, early callus bridging and excellent functional outcome scores suggest that dynamic fixation with active locking plates may promote increased fracture healing over standard locked plating.

1Legacy Research Institute, Portland, Oregon, USA

2Slocum Center for Orthopedics, Eugene, OR, USA

Corresponding Author:

Michael Bottlang, PhD,
Legacy Research Institute
1225 NE 2nd Ave, Portland, OR 97232
Phone: (503) 413-5457
Fax: (503) 413-4942
Email: mbottlan@lhs.org

Co-Authors:

Steven M. Madey, MD, Legacy Research Institute, 1225 NE 2nd Ave, Portland, OR 97232, phone: (503) 784 5088; email: madey@summitdocs.com

Stanley Tsai, MS, Legacy Research Institute, 1225 NE 2nd Ave, Portland, OR 97232, phone: (503) 413 5457; email: madey@summitdocs.com

Daniel C. Fitzpatrick, MS, MD, Slocum Center for Orthopedics, 55 Coburg Rd., Eugene, OR 97401, phone: (541) 510 3637; daniel.fitzpatrick@slocumcenter.com

Kathleen Earley, Legacy Research Institute, 1225 NE 2nd Ave, Portland, OR 97232, phone: (503) 413 5457; email: earleyk09@gmail.com

Source of Funding: Financial support for this study has been provided by Zimmer Biomet.

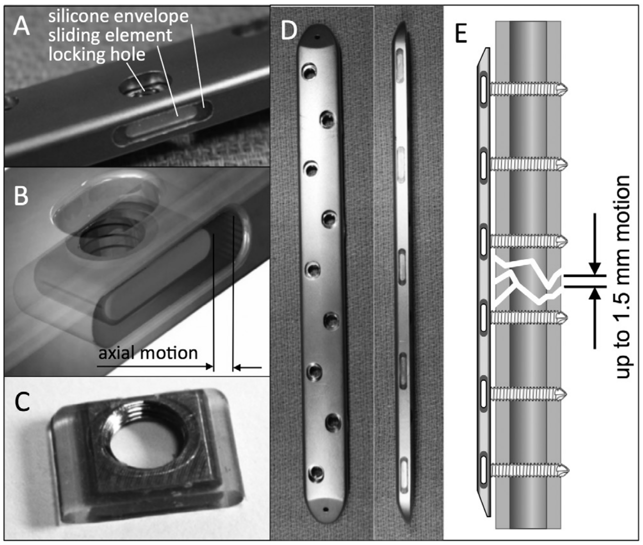


Figure 1. Elastic suspension of locking holes inside an active locking plate (A) provides controlled axial motion (B) by means of elastically suspended sliding elements (C). D) 9-hole active locking plate with staggered screw whole pattern. E) Active locking plates provide controlled axial motion of up to 1.5 mm across the fracture zone.

INTRODUCTION

Concerns that locking plate fixation of fractures might lead to an overly stiff environment for fracture healing resulted in the development of new fixation techniques and implants that promote controlled fracture motion.[1-3] These new approaches to fracture fixation, although different in application, have the common goal of producing a fracture environment that promotes secondary bone healing with callus.

Most commonly, surgeons use standard implants and attempt to alter the mechanical environment at the fracture by increasing the working length of the plate over the fracture.[4] This technique promotes fracture site motion by plate bending and primarily introduces shear motion to the fracture,[5] which may be detrimental to healing.[6,7] The use of long working lengths was correlated with increased shear motion and delayed unions after plate fixation of distal femur fractures.[7]

The introduction of Far Cortical Locking (FCL) technology allowed the use of an implant that was specifically designed to allow controlled axial motion at the fracture.[8] In a prospective trial, the use of FCL implants for distal femur fractures showed significantly increased callus formation and decreased nonunion rates relative historical controls.[9] Unfortunately, the use of screws as the motion element limits the use of FCL to larger diameter bones, as the flexibility of the screws decreases for shorter screw lengths.

To address this limitation, an active locking plate was developed with the screw holes in a sliding element that is elastically suspended in a silicone envelope.[1] The sliding element and screw move relative to the plate, allowing controlled motion at the fracture site. Bench-top testing has shown that active locking plates are at least as strong as standard locking plates under all three principal loading conditions of bending, torsion, and axial compression, while providing a 77% stiffness reduction and symmetric axial motion at the fracture.[1] Furthermore, in vivo studies using the sheep tibia osteotomy model demonstrated that comminuted fractures heal faster and four times stronger with active locking plates than with standard locking plates.[10] In a second in vivo ovine study, simple well-reduced fractures healed over two times stronger with active locking plates than with compression plating.[11] Bench-top and in vivo studies, however, can only predict clinical durability within the limitations of the experimental model. This prospective observational study documents our early clinical experience with active locking plates for stabilization of humeral shaft fractures. It serves to demonstrate the durability of active locking plates and their elastically suspended locking elements under routine clinical practice.

PATIENTS AND METHODS

From April 1, 2016 to August 10, 2016, eleven consecutive patients with 11 humeral shaft fractures (AO/OTA types 12 A-C) were prospectively enrolled in an observational cohort study at a level I trauma center (Legacy, Portland, Oregon) and a level II trauma center (Slocum, Eugene, OR). The internal review boards of both institutions approved the study protocol. Patients were included if they had an acute humeral shaft fracture amenable for surgical stabilization, were at least 18 years old, consented to the study protocol, and were willing and able to participate in scheduled follow-up visits for a minimum of 6 months. Exclusion criteria were pathologic fractures, revision surgery, pregnancy, and polytrauma with an Injury Severity Score (ISS) greater than 27.

Active Plating Constructs:

All fractures were stabilized with active locking plates (G3 Active Plating System, Incipio, Huntington, IN) made of titanium alloy. The cross-sectional geometry of active locking plates was representative of a standard 4.5 mm large fragment plate. In contrast to a standard locking plate, the locking holes of active locking plates were integrated in individual sliding elements that were elastically suspended in a silicone envelope inside lateral plate pockets (Figure 1A-C). Lateral pockets were arranged in an alternating pattern from both plate sides, resulting in a staggered locking hole configuration (Figure 1D). The pocket geometry combined with the silicone suspension allowed controlled axial translation, which enabled up to 1.5 mm of axial motion across a fracture while providing stable fixation in response to bending and torsional load-

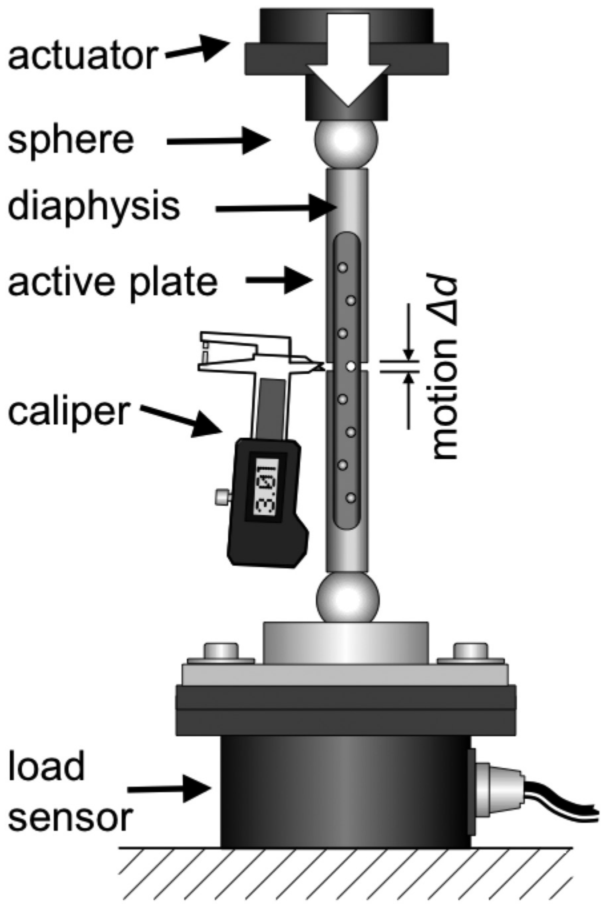


Figure 2. Stiffness characterization of active and standard locked plating constructs applied to bridge a gap osteotomy in a humeral diaphysis surrogate.

ing (Figure 1E).[1] The silicone suspension consisted of long-term implantable medical-grade silicone elastomer.

The effect of locking hole suspension in active plates was characterized with a biomechanical study in direct comparison to standard locking plates (Figure 2). Three active locking plates and three standard 4.5 mm locking plates made of titanium alloy that had a comparable cross-sectional geometry were applied to bridge osteotomies in a humeral diaphysis surrogate (#3403-21, Sawbones, Vashon Island, WA), using three bi-cortical locking screws on each side of the osteotomy. Axial compression was applied through spheres proximally and distally to permit physiological bending under axial loading. Constructs were stepwise loaded in 50-N increments up to 350 N, representing the axial humeral load required to lifting a gallon of milk at 90 degrees elbow flexion.[12] The resulting motion at the osteotomy was measured with calipers for calculation of construct stiffness.

Surgical Technique:

All fractures were stabilized with active locking plates without the use of supplemental bone graft or bone morphogenic proteins to solely rely on natural bone healing stimulated by controlled interfragmentary motion. Accordingly, all surgeries were conducted using biological bridge plating techniques that aimed for preservation of soft tissue and functional reduction. Active locking plates accommodated standard 5.0 mm diameter self-tapping locking screws, and were applied with three screws proximal and distal to the fracture in a standard bridge plating technique. Because active plating does not require a long bridge span to permit axial motion, one screw on each side was placed directly adjacent to the fracture. Based on the surgeons' preference, an anterior or posterior approach was used. To generate a dynamic fixation construct, the active locking plate was not compressed onto the diaphysis, and no screws were applied across the fracture that could inhibit interfragmentary motion.

Follow-up Visits:

Patients were scheduled for 3, 6, 12, and 24-week follow-up examinations. If fracture healing was not confirmed by week 24, follow-up visits were continued until fracture healing or revision surgery, whichever occurred first. None of the 11 patients were lost to follow-up. Patient demographics and injury data are summarized in Table 1. Progression of fracture healing and integrity of implant fixation was assessed on bi-planar radiographs that were obtained post surgery and at each follow-up visit. Patient-reported functional outcome measures were obtained at 6, 12, and 24 weeks post surgery, including the Disability of the Arm Shoulder and Hand (DASH) score,[13] and the Constant shoulder score.[14] In addition, the Short Form (SF-12) health survey was administered at week 24.

Radiographic Analysis of Fracture Healing:

Progression of fracture healing and formation of bridging callus was assessed by compiling serial radiograph summaries for each patient, containing biplanar radiographs obtained post-surgery and at each follow-up time point.[9] Two orthopedic surgeons independently evaluated the serial radiograph summaries to determine the timing and presence of callus bridging at weeks 6, 12, and 24 weeks post-surgery. Results of the independent bridging analyses were combined into a single outcome table. In cases where the surgeons' assessment of bridging callus differed, the patient was assigned the later time point for bridging or "absence of bridging callus" to generate a conservative summary assessment for radiographic fracture union.

TABLE 1 Demographics and Baseline Data

Parameters		n (%)	Mean (±SD)	Range
Gender	female	6 (55%)		
	male	5 (45%)		
Age (years)			40 ± 14	22-57
BMI (kg/m^2)			31 ± 7	19-41
Smoker		3 (27%)		
Diabetes		0 (0%)		
Injury mechanism:	Motor vehicle accident	5 (45%)		
	Ground level fall	2 (18%)		
	Fall down stairs	2 (18%)		
	Fall from height	2 (18%)		
Fracture type:	OTA/AO 12-A2	1 (9%)		
	OTA/AO 12-A3	5 (45%)		
	OTA/AO 12-B2	3 (27%)		
	OTA/AO 12-C1	1 (9%)		
	OTA/AO 12-C3	1 (9%)		
Closed/open fracture	Closed	10 (91%)		
	Open	1 (9%)		
Plate size:	7 hole	8 (73%)		
	9 hole	3 (27%)		

Endpoint Analysis:

The primary endpoint of this observational study was plate durability over a 6 months post-operative loading period. Plate failure was defined by bending or fatigue fracture of the plate, breakage of the elastically suspended sliding elements, or failure of the screw head locking interface. Secondary endpoints of this study documented fracture healing, complications, and functional outcome scores. Fracture healing was defined by resolution of pain at the fracture site during load bearing, and by bridging of at least two of the three cortices visible on bi-planar radiographs.[9,15,16] Complications were defined as screw breakage, screw pull-out, infection, non-union, and the need for revision surgery. The patients' return to function was assessed by the validated DASH, Constant, and SF-12 outcome scores.

Statistical Analysis:

Where applicable, observations are reported as mean ± one standard deviation. In the absence of a concomitant control group, statistical analysis was limited to interfragmentary motion and construct stiffness data of the biomechanical study that compared active to standard locked plating constructs, using 2-tailed unpaired Student t tests at a level of significance of $\alpha = 0.05$.

RESULTS

Fixation Construct:

The stiffness of active locking plates (463±177 N/mm) was 76% lower than that of standard locking plates (1,957±235 N/mm, $p<0.001$) (Figure 3A). At 350 N loading, active plating constructs delivered over three times more axial interfragmentary motion (0.86±0.43 mm) than standard locking plates (0.18±0.02 N/mm, $p<0.001$). At the 100 N load level, active locking plates exceeded the 0.2 mm fracture motion threshold known to promote callus formation (Figure 3B).[17-20] Even at 350 N peak loading, standard locking plates did not reach this 0.2 mm motion threshold.

Patient Cohort:

Patient demographics and fracture characteristics are summarized in Table 1. There were 6 male and 5 female patients with an average age of 40 ± 14 years and weight of 90 ± 22 kg. These eleven patients had six simple AO/

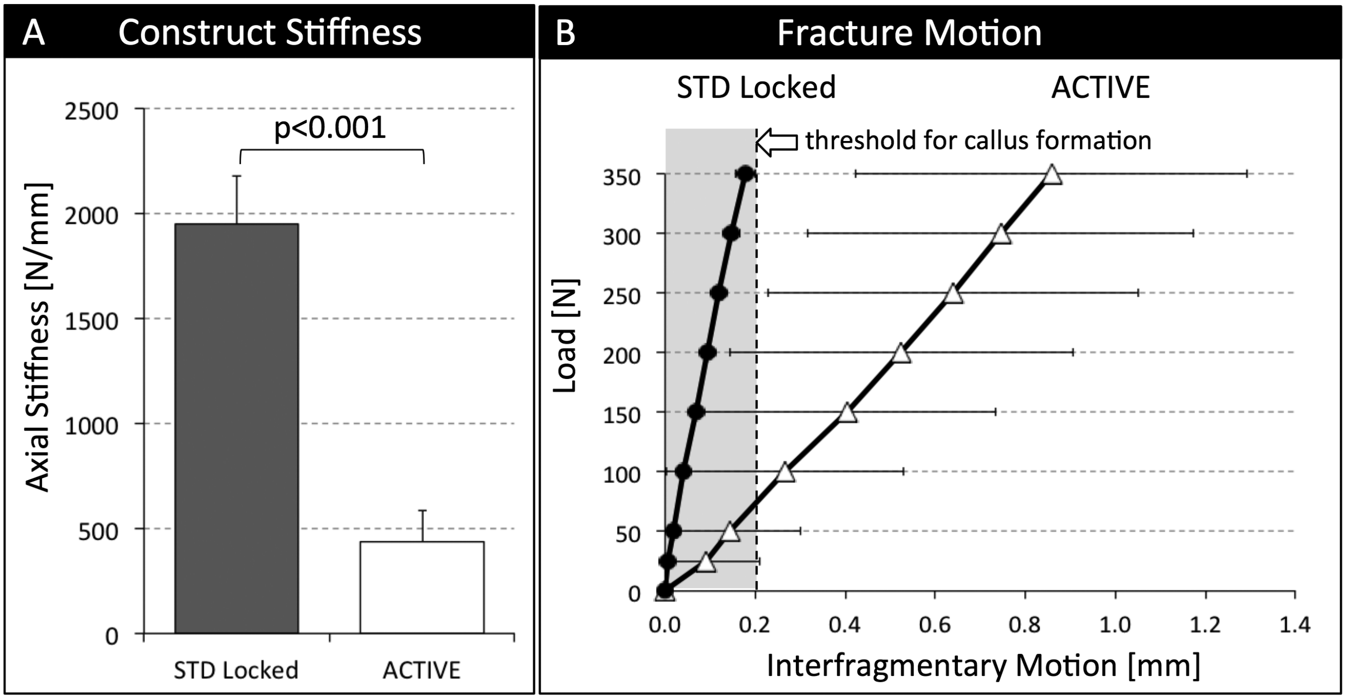


Figure 3. Biomechanical test results: A) active constructs had on average a 76% lower construct stiffness; B) fracture motion in response to axial loading.

OTA type 12A fractures, three wedge type 12B fractures, and two comminuted type 12C fracture, including one Gustillo type 1 open fracture. Two of the eleven fractures occurred because of a ground level fall, four fractures resulted from elevated falls or a fall down stairs, and the remaining five fractures resulted from motor vehicle and motorcycle accidents, and one bicycle accident. Three of the eleven patients were smokers. Four of the eleven fractures had poly-trauma with additional extremity fractures (2 patients) or pelvic fracture (2 patient). All eleven patients were available for each follow-up. One patient was not able to complete the Constant shoulder score at week 6, as he remained bedridden from co-morbidities.

Outcomes:

There was no incidence of plate breakage, plate bending, or failure of the elastically suspended locking hole mechanism. Ten of the eleven fractures healed within 10.9 ± 5.2 weeks, as evident by bridging callus and pain-free function (Table 2). One fracture required revision surgery 37 weeks post surgery due to late fixation failure at the screw-bone interface in presence of an atrophic delayed union. The average DASH score of all 11 patients improved from 31 ± 22 at week 6 to 13 ± 15 by week 24, approaching the DASH score of 10.1 representative of the normal, healthy population.[21] By week 12, the average Constant shoulder score was considered excellent. By week 24, there was no significant difference in the Constant shoulder score between the affected extremity (82 ± 12) and the contralateral extremity (85 ± 7, p=0.53). By week 24, the SF-12 physical health score (44 ± 9) and mental health score (48 ± 11) approached the mean value of 50 that represents the norm for the general U.S. population[22].

Durability and applicability of active plating for different fracture types is demonstrated by two examples of patients of this cohort that represent the opposite ends of the fracture pattern range: first, a patient with a comminuted fracture (patient 10), which is traditionally amenable to bridge plating or intramedullary nailing; and second, a patient with a simple, transverse fracture (patient 5), which is traditionally amenable to compression plating. Patient 10 was a 56 years old male with a history of tobacco use and coronary artery disease. He fell off a 25 foot scaffold and sustained a comminuted, multi-fragmentary AO/OTA type 12C-3 fracture. His fracture was bridged with a 9-hole active locking plate to restore length and anatomic alignment of the humeral shaft. Similar to intramedullary nailing, this biological plating technique aimed for preservation of soft tissue and did not seek to anatomically reduce fragments in the comminution zone. Week 3 radiographs indicated early callus formation, which was confirmed on week 6 radiographs by abundant callus that bridged the comminution zone (Figure 4). Decreasing callus size by week 24 indicated the onset of the callus remodeling

TABLE 2 Outcome Data

Parameter	Results	Comments
Enrolled:	11 patients with 11 fractures	
Follow-up:	Week 3: 11 patients	
	Week 6: 11 patients	
	Week 12: 11 patients	
	Week 24: 10 patients	One patient moved from area
Plate breakage:	0	
Fixation failure:	1	
Complications:	1 fixation failure requiring revsion	Atrophic delayed union in heavy smoker
Bridging (≥2 cortices):	Week 3: 0 fractures (0%)	
	Week 6: 4 fractures (36%)	
	Week 12: 10 fractures (91%)	
	Week 24: 10 fractures (91%)	
DASH score	Week 6: 31 ± 22	
	Week 12: 16 ± 17	
	Week 24: 13 ± 15	
Constant shoulder score	Week 6: 17 ± 11	1 patient omitted due to bed confinement
(difference from contralateral arm)	Week 12: 8 ± 8	
	Week 24: 3 ± 8	
SF-12 (Physical Health Score: PHS)	Week 24: 44 ± 9	Data from 9 of 11 patients
SF-12 (Mental Health Score: MHS)	Week 24: 48 ± 11	Data from 9 of 11 patients

phase. Patient 10 reported no pain from his arm at the 3 weeks follow-up, and full range of motion six weeks after surgery. Patient 5 was a 27 years old male without co-morbidities who sustained a simple transverse AO/OTA type 12A-3 mid-shaft fracture from a ground-level fall during football. The fracture was stabilized with a 7-hole active locking plate to achieve direct apposition without the need for inter-fragmentary compression (Figure 5). Despite absence of a fracture gap, clearly visible bridging callus was present by week 6. Week 12 and 24 radiographs confirmed circumferential callus formation and callus remodeling. This patient reported no pain and full range of motion by week 3, and full strength by week 6 post surgery.

Complications:

One of eleven patients (patient 4) required revision surgery due to failure of screw fixation in the diaphysis. The 22 year old female patient sustained a simple AO/OTA type 12A humeral mid-shaft fracture and an acetabular fracture in a motor vehicle accident. The patient was morbidly obese with a BMI of 38, and a heavy smoker with hidradenitis suppurativa of the ipsilateral axilla which was thought to increase the risk of local infection. She exhibited delayed, atropic healing of the humeral fracture, with callus bridging of one cortical aspect by week 24. She was allowed to weightbear on crutches immediately after surgery, which exposed the plate construct to early and high loading. At 37 weeks post surgery, one proximal screw broke and the remaining two proximal screws pulled out of the humerus, likely due to the combination of high loading and delayed healing. The patient was revised with a longer plate and bone graft.

DISCUSSION

Introduction of novel implants should be accompanied by an observational study for timely documentation of clinical performance to establish safety and to detect potential risks.[23] This observational study was designed to establish the clinical safety and durability of active locking plates by dissemination of our early clinical experience.

Rigid fixation of fractures was introduced to prevent hardware failure in the setting of conventional plates and screws.[20,24] Compression of the fracture fragments without interfragmentary motion is required for primary bone healing.[20] Compression plate fixation improved construct stability and allowed early mobilization, but introduced problems with fracture healing. In response, more biological fixation techniques, including bridge plate fixation with standard implants and locked plating were introduced to improve fracture healing.[25,26] These

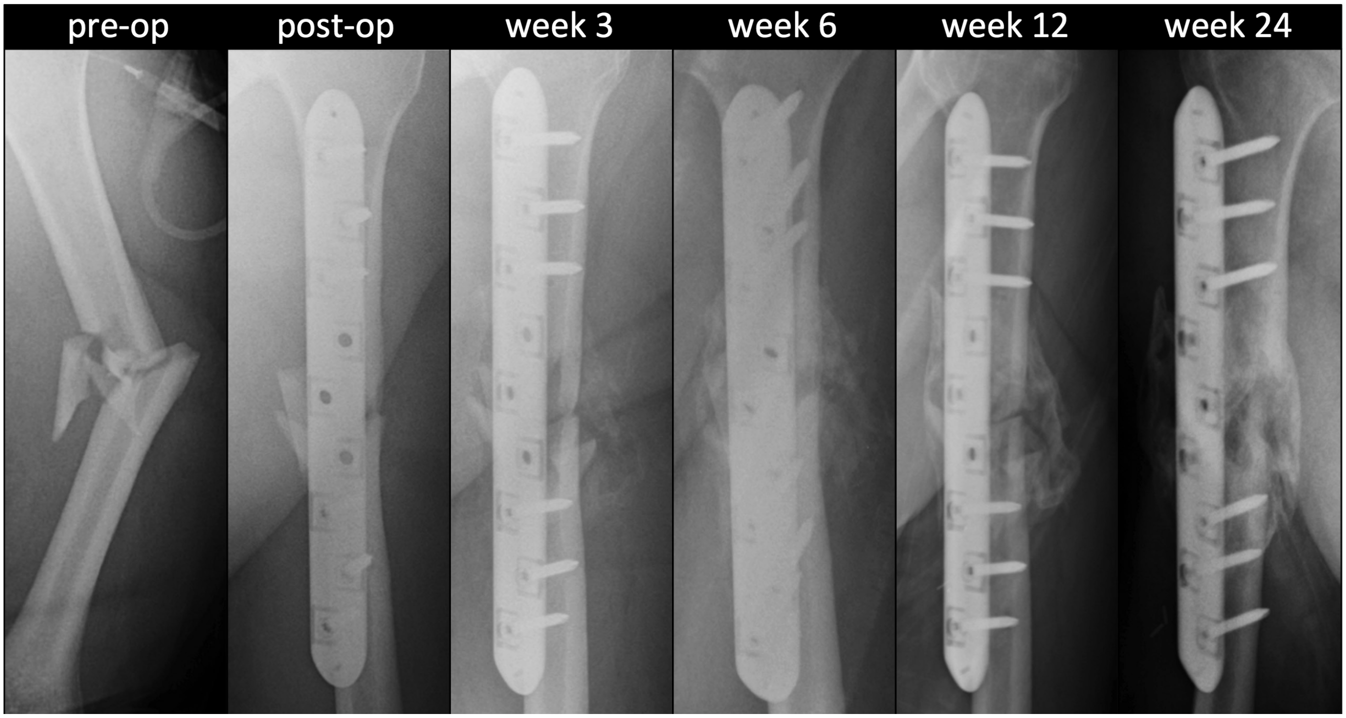


Figure 4. Example of a comminuted fracture, stabilized with an active locking plate in a 56 year old male patient with a history of tobacco use and coronary artery disease.

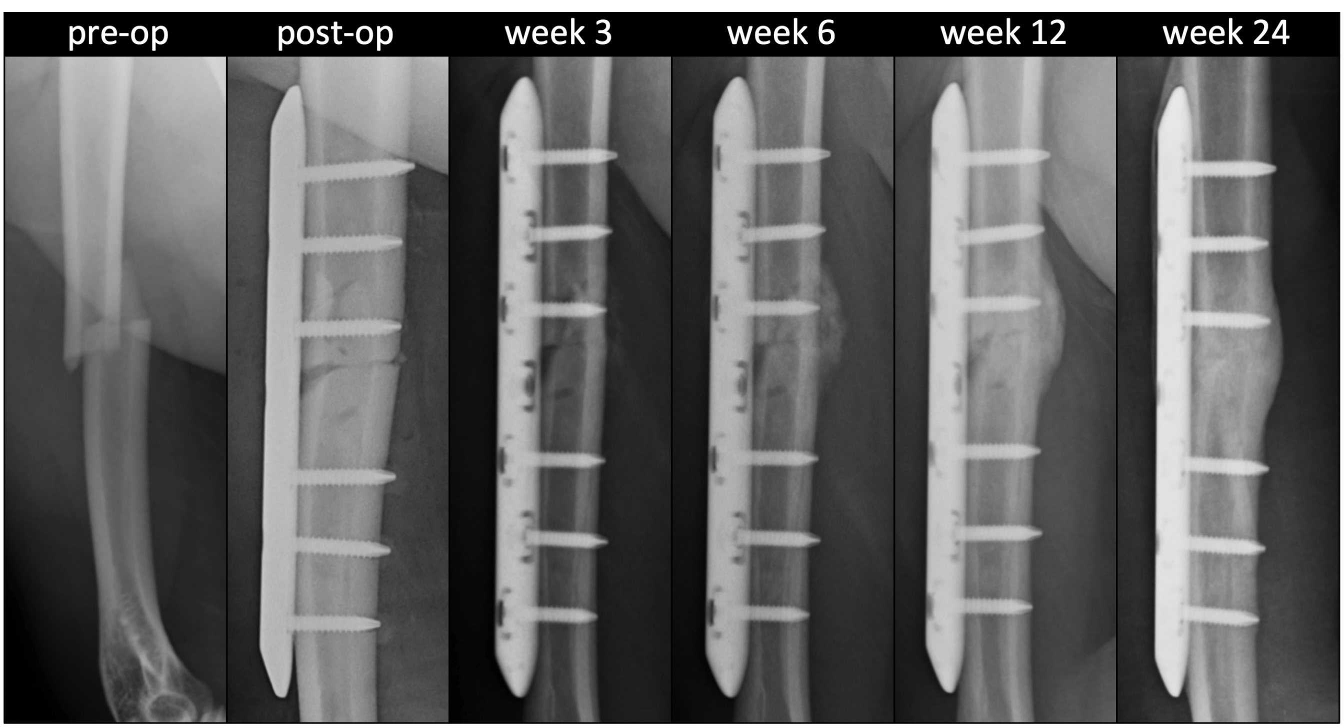


Figure 5. Example of a simple fracture in a 27 year old male patient without co-morbidities. Direct apposition of the fracture without compression yielded natural bone healing by callus formation.

newer techniques were thought to provide less rigid fixation and more motion at the fracture site for the formation of callus and secondary bone healing. Biomechanical studies, however, confirm that these techniques provide an initial fracture environment that is as stiff as conventional compression plating.[27,28] This initial stiffness inhibits callus formation and, in some cases, leads to fracture nonunion.[29,30]

In contrast, Goodship and Kenwright showed three times greater callus formation using an external fixator which allowed 1 mm interfragmentary motion relative to a rigid external fixator.[19] Additionally, they found early motion provided better healing relative to motion introduced later. More recent advances in dynamic fixation include the use of FCL technology which improved fracture healing with significant increases in callus volume relative to historical locked plate controls for distal femur fractures.[9] Biomechanical studies show that FCL constructs result in a 78% reduction in stiffness relative to a similar locked plate construct.[8] The active plate employed in the current study showed a similar decrease in stiffness, with a 76% decrease in stiffness relative to a similar titanium all locked screw construct.

Observations of this study suggest that active locking plates provide safe and effective stabilization of simple and comminuted humeral shaft fractures. These results are consistent with two in vivo studies of active locking plates using the established ovine tibia fracture healing model.[10,11] The first study investigated the effects of interfragmentary motion provided by bridging a 3-mm osteotomy gap with active locking plates in comparison to rigid bridging with standard locking plates.[10] The symmetric axial dynamization provided by active locking plates stimulated circumferential callus and yielded faster and stronger healing than standard locking plates. Nine weeks post-surgery, specimens of the active locking group had recovered 81% of their native strength and were 399% stronger than standard locked group specimens, which had recovered only 17% of their native strength.[10] The second study investigated the effects of dynamically loading a simple, well-reduced transverse osteotomy stabilized with active locking plates in comparison to standard compression plating.[11] Even in absence of a fracture gap, active locking plates stimulated circumferential callus formation by dynamic interfragmentary compression and yielded faster and stronger healing than standard compression plating. Nine weeks post-surgery, specimens of the active locking group had recovered on average 64% of their native strength and were over twice as strong as CP specimens, which recovered 24% of their native strength.[11] Those prior studies as well as the present study suggest that natural bone healing may be stimulated by dynamic interfragmentary motion or loading, indicating that active plating may be applicable for bridging of comminuted fractures as well as for stabilization of simple well-reduced fractures.

Not all humeral fractures require surgical treatment. Studies suggest that the nonunion rate after nonoperative treatment is below 10%.[31,32] Authors often cite the large range of motion at the shoulder and elbow as justification for accepting malunions of up to 30 degrees in the humeral shaft.[33] A recent investigation argued that malunions may be more functionally detrimental than once thought,[34] and suggested operative treatment for displaced or angulated fractures. Relative to nonoperative treatment, operative treatment of humeral shaft fractures using intramedullary nails or plates results in a slightly higher nonunion rate of 10-15%.[35] Nonunions of long bone fractures, including the humerus, are devastating to patient outcomes.[36] Additionally, treatment of a humeral nonunion as a complication of attempted fixation is much more difficult than treatment of a nonunion after non-operative treatment,[37] meaning that when surgical intervention is chosen, it is imperative to obtain a union after the index surgery. Compared to intramedullary nailing of comminuted fractures, active plating precludes insertion site morbidity and may provide improved control of rotational alignment. Compared to compression plating of simple fractures, active plating may not only provide faster and stronger healing, but may also be more forgiving, since it does not require perfect anatomic reduction and compression necessary to achieve absolute stabilization.

This study was limited to the use of a large fragment plate, as a small fragment plate was not yet commercially available. No patients reported discomfort related to the plate. Clinically, the use of large fragment plates is recommended to allow early mobilization using crutches in the multiply injured patient. The strategy of using thin plates has been proposed as a technique to achieve a flexible fixation construct. This approach provides dynamization at cost of strength, which necessarily will increased the risk of plate fatigue and fixation failure. For this reason, allowing immediate weight bearing on a humeral fracture fixed with a small fragment plate is only recommended in patients below 70 kg.[38] Large fragment plates should sustain crutch weight-bearing of comminuted humeral shaft fractures in patients weighing 90 kg or less.[39] Active plating can provide dynamization without reducing construct strength, allowing the use of large fragment plates. The early return to function, with reported post-operative week 3 activities including push-ups, baseball, and resuming a full work schedule as a hair dresser, demonstrates the benefits of combining dynamization with a strong fixation construct. However, the foremost challenge for any osteosynthesis construct is the concurrence of prolonged excessive loading and delayed healing. Even in the presence of these coinciding adverse events in patient 4, weighing 109 kg, the active locking plate supported the prolonged and elevated loading without failure.

Several additional limitations should be considered when interpreting the study results. For timely dissemination of our early clinical experience with active plating constructs, this observational study has a relatively short follow duration of six months. This limited follow-up was considered acceptable based on precedence[9,40] and given the fact that 10 out of 11 fractures had healed without complications. After fracture healing, active locking plates are effectively unloaded and prevent stress shielding of the diaphysis due to the elastic suspension of the locking screws. Most importantly, this observational study was only designed to evaluate the safety and efficacy of fracture stabilization with active locking plates. In addition to providing our early clinical experience in a timely manner, results of this study provide pilot data for the design and sample size estimation of a future randomized controlled trial required to evaluate differences in clinical outcomes between active plating and rigid locked or compression plating.

In conclusion, absence of plate failure suggests that dynamic fixation of humeral shaft fractures with active plates provides safe and effective fixation. Moreover, early callus bridging and functional outcome scores suggest that dynamic fixation with active locking plates may promote increased fracture healing over standard locked plating, enabling earlier return to function. However, this hypothesis on the stimulatory effect of dynamic fixation on fracture healing requires investigation in a future randomized controlled trial.

REFERENCES

1. **Tsai S, Fitzpatrick DC, Madey SM, Bottlang M.** Dynamic locking plates provide symmetric axial dynamization to stimulate fracture healing. J Orthop Res 2015;33-8:1218-25.
2. **Doebele S, Horn C, Eichhorn S, Buchholtz A, Lenich A, Burgkart R, Nuessler AK, Lucke M, Andermatt D, Koch R, Stoeckle U.** The dynamic locking screw (DLS) can increase interfragmentary motion on the near cortex of locked plating constructs by reducing the axial stiffness. Langenbecks Arch Surg 2010;395:421-8.
3. **Bottlang M, Feist F.** Biomechanics of far cortical locking. J Orthop Trauma 2011;25 Suppl 1:S21-8.
4. Stoffel K, Dieter U, Stachowiak G, Gachter A, Kuster MS. Biomechanical testing of the LCP–how can stability in locked internal fixators be controlled? Injury 2003;34 Suppl 2:B11-9.
5. **Mardian S, Schaser KD, Duda GN, Heyland M.** Working length of locking plates determines interfragmentary movement in distal femur fractures under physiological loading. Clin Biomech (Bristol, Avon) 2015;30-4:391-6.
6. **Augat P, Burger J, Schorlemmer S, Henke T, Peraus M, Claes L.** Shear movement at the fracture site delays healing in a diaphyseal fracture model. J Orthop Res 2003;21-6:1011-7.
7. **Elkins J, Marsh JL, Lujan T, Peindl R, Kellam J, Anderson DD, Lack W.** Motion Predicts Clinical Callus Formation: Construct-Specific Finite Element Analysis of Supracondylar Femoral Fractures. J Bone Joint Surg Am 2016;98-4:276-84.
8. **Bottlang M, Doornink J, Fitzpatrick DC, Madey SM.** Far cortical locking can reduce stiffness of locked plating constructs while retaining construct strength. J Bone Joint Surg Am 2009;91-8:1985-94.
9. **Bottlang M, Fitzpatrick DC, Sheerin D, Kubiak E, Gellman R, Vande Zandschulp C, Doornink J, Earley K, Madey SM.** Dynamic fixation of distal femur fractures using far cortical locking screws: a prospective observational study. J Orthop Trauma 2014;28-4:181-8.
10. **Bottlang M, Tsai S, Bliven EK, von Rechenberg B, Klein K, Augat P, Henschel J, Fitzpatrick DC, Madey SM.** Dynamic Stabilization with Active Locking Plates Delivers Faster, Stronger, and More Symmetric Fracture-Healing. J Bone Joint Surg Am 2016;98-6:466-74.
11. **Bottlang M, Tsai S, Bliven EK, von Rechenberg B, Kindt P, Augat P, Henschel J, Fitzpatrick DC, Madey SM.** Dynamic Stabilization of Simple Fractures With Active Plates Delivers Stronger Healing Than Conventional Compression Plating. J Orthop Trauma 2017;31-2:71-7.
12. **Bottlang M, Fitzpatrick DC, Augat P.** Musculoskeletal Biomechanics. In: Flynn JM, ed. Orthopaedic Knowledge Update 10. Vol. 10. Rosemont, IL: American Academy of Orthopaedic Surgeons, 2011:59-72.
13. **Hudak PL, Amadio PC, Bombardier C.** Development of an upper extremity outcome measure: the DASH (disabilities of the arm, shoulder and hand) [corrected]. The Upper Extremity Collaborative Group (UECG). Am J Ind Med 1996;29-6:602-8.
14. **Constant CR, Murley AH.** A clinical method of functional assessment of the shoulder. Clin Orthop Relat Res 1987-214:160-4.
15. **Bahari S, Lenehan B, Khan H, McElwain JP.** Minimally invasive percutaneous plate fixation of distal tibia fractures. Acta Orthop Belg 2007;73-5:635-40.
16. **Harrington P, Nihal A, Singhania AK, Howell FR.** Intramedullary hip screw versus sliding hip screw for unstable intertrochanteric femoral fractures in the elderly. Injury 2002;33-1:23-8.

17. **Claes L.** Biomechanical principles and mechanobiologic aspects of flexible and locked plating. J Orthop Trauma 2011;25 Suppl 1:S4-7.
18. **Claes LE, Heigele CA, Neidlinger-Wilke C, Kaspar D, Seidl W, Margevicius KJ, Augat P.** Effects of mechanical factors on the fracture healing process. Clin Orthop Relat Res 1998-355 Suppl:S132-47.
19. **Goodship AE, Kenwright J.** The influence of induced micromovement upon the healing of experimental tibial fractures. J Bone Joint Surg Br 1985;67-4:650-5.
20. **Perren SM.** Physical and biological aspects of fracture healing with special reference to internal fixation. Clin Orthop Relat Res 1979-138:175-96.
21. **Hunsaker FG, Cioffi DA, Amadio PC, Wright JG, Caughlin B.** The American academy of orthopaedic surgeons outcomes instruments: normative values from the general population. J Bone Joint Surg Am 2002;84-A-2:208-15.
22. **Ware J, Jr., Kosinski M, Keller SD.** A 12-Item Short-Form Health Survey: construction of scales and preliminary tests of reliability and validity. Med Care 1996;34-3:220-33.
23. **Castillo RC, Scharfstein DO, MacKenzie EJ.** Observational studies in the era of randomized trials: finding the balance. J Bone Joint Surg Am 2012;94 Suppl 1:112-7.
24. **Uhthoff HK, Poitras P, Backman DS.** Internal plate fixation of fractures: short history and recent developments. J Orthop Sci 2006;11-2:118-26.
25. **Gerber C, Mast JW, Ganz R.** Biological internal fixation of fractures. Arch Orthop Trauma Surg 1990;109-6:295-303.
26. **Perren SM.** Evolution of the internal fixation of long bone fractures. The scientific basis of biological internal fixation: choosing a new balance between stability and biology. J Bone Joint Surg Br 2002;84-8:1093-110.
27. **Fitzpatrick DC, Doornink J, Madey SM, Bottlang M.** Relative stability of conventional and locked plating fixation in a model of the osteoporotic femoral diaphysis. Clin Biomech (Bristol, Avon) 2009;24-2:203-9.
28. **Gardner MJ, Brophy RH, Campbell D, Mahajan A, Wright TM, Helfet DL, Lorich DG.** The mechanical behavior of locking compression plates compared with dynamic compression plates in a cadaver radius model. J Orthop Trauma 2005;19-9:597-603.
29. **Henderson CE, Lujan TJ, Kuhl LL, Bottlang M, Fitzpatrick DC, Marsh JL.** 2010 mid-America Orthopaedic Association Physician in Training Award: healing complications are common after locked plating for distal femur fractures. Clin Orthop Relat Res 2011;469-6:1757-65.
30. **Lujan TJ, Henderson CE, Madey SM, Fitzpatrick DC, Marsh JL, Bottlang M.** Locked plating of distal femur fractures leads to inconsistent and asymmetric callus formation. J Orthop Trauma 2010;24-3:156-62.
31. **Hierholzer C, Sama D, Toro JB, Peterson M, Helfet DL.** Plate fixation of ununited humeral shaft fractures: effect of type of bone graft on healing. J Bone Joint Surg Am 2006;88-7:1442-7.
32. **Rutgers M, Ring D.** Treatment of diaphyseal fractures of the humerus using a functional brace. J Orthop Trauma 2006;20-9:597-601.
33. **Anglen J, Kyle RF, Marsh JL, Virkus WW, Watters WC, 3rd, Keith MW, Turkelson CM, Wies JL, Boyer KM.** Locking plates for extremity fractures. J Am Acad Orthop Surg 2009;17-7:465-72.
34. **Crespo AM, Konda SR, De Paolis A, Cardoso L, Egol KA.** Posttraumatic Malalignment of the Humeral Shaft: Challenging the Existing Paradigm. J Orthop Trauma 2016;30-2:e48-52.
35. **Chapman JR, Henley MB, Agel J, Benca PJ.** Randomized prospective study of humeral shaft fracture fixation: intramedullary nails versus plates. J Orthop Trauma 2000;14-3:162-6.
36. **Schottel PC, O'Connor DP, Brinker MR.** Time Trade-Off as a Measure of Health-Related Quality of Life: Long Bone Nonunions Have a Devastating Impact. J Bone Joint Surg Am 2015;97-17:1406-10.
37. **Konda SR, Davidovitch RI, Egol KA.** Initial Surgical Treatment of Humeral Shaft Fracture Predicts Difficulty Healing when Humeral Shaft Nonunion Occurs. HSS J 2016;12-1:13-7.
38. **Tingstad EM, Wolinsky PR, Shyr Y, Johnson KD.** Effect of immediate weightbearing on plated fractures of the humeral shaft. J Trauma 2000;49-2:278-80.
39. **Patel R, Neu CP, Curtiss S, Fyhrie DP, Yoo B.** Crutch weightbearing on comminuted humeral shaft fractures: a biomechanical comparison of large versus small fragment fixation for humeral shaft fractures. J Orthop Trauma 2011;25-5:300-5.
40. **Streubel PN, Gardner MJ, Morshed S, Collinge CA, Gallagher B, Ricci WM.** Are extreme distal periprosthetic supracondylar fractures of the femur too distal to fix using a lateral locked plate? J Bone Joint Surg Br 2010;92-4:527-34.

OPTIMIZING HYBRID PLATE FIXATION WITH A LOCKED, OBLIQUE END SCREW IN OSTEOPOROTIC FRACTURES

Aaron Wynkoop, MD, Osy Ndubaku, MD, Paul M. Carpentier, MD,
Jeffrey B. Peck, MD, Norman E. Walter, MD, Patrick Atkinson, PhD

ABSTRACT

BACKGROUND: The end screw in a fracture plate creates the greatest resistance to bending. For osteoporotic fractures treated with plates, there is some question as to the optimal screw insertion technique for the screw farthest from the fracture. A locked, oblique end screw was previously shown to increase resistance to periprosthetic fracture. It is unknown, however, how this end screw configuration would resist pullout when subjected to bending.

METHODS: Narrow, low contact 3.5 mm locking compression plates with 6 and 12 holes were anchored to simulated bone material with material properties representing osteoporotic bone. Four configurations were evaluated for the end screw: perpendicular and angulated 30 degrees away from the fracture for both non-locked and locked screws (n=6 per group). The constructs were subjected to 3 point bending until the peak load and finally total construct failure was achieved.

RESULTS: Peak force, stiffness, energy to peak load, and the failure mode of each construct were determined. All four 12-hole construct groups failed by gross plastic bending deformation of the plate at the fulcrum past a previously established clinically relevant limit for failure (15°). All 12-hole plate constructs failed at statistically higher loads and energy than any of the 6-hole plate constructs, with the exception of the 6-hole locked, oblique construct.

CONCLUSION: The locked, oblique end screw provides equivalent pull out strength for 3.5 mm low contact plates regardless of plate length. Combined with its resistance to periprosthetic fracture, this end screw configuration appears to be the best option for the construct integrity of hybrid plating for osteoporotic fractures.

CLINICAL RELEVANCE: Osteoporotic fractures are challenging to treat. The current study and the existing literature show that resistance to both bending loads and refracture at the end of a plate are minimized with a locked screw angled away from the fracture.

McLaren-Flint
McLaren Regional Medical Center
Orthopaedic Surgery
Flint, MI 48532

Corresponding Author:
Patrick Atkinson, PhD
Kettering University, Mechanical Engineering
McLaren Regional Medical Center
Orthopaedic Surgery
Flint, MI 48532
Phone: (248) 563-4558
patkinso@kettering.edu

The authors have no corporate conflicts of interest.

The authors received a grant from the McLaren Foundation to complete the study.

INTRODUCTION

Osteoporosis has a significant role in fractures of the elderly, contributing to 75% of fractures caused by low energy mechanisms.[1] In 2010, 10 million people had osteoporosis in the United States with more than 2 million fractures related to osteoporosis or osteopenia annually.[2] The weakened bone presents difficulties with fixation, including failure of plate fixation. One mode of non-locked plate failure includes the sequential pull out of screws starting with the end screw.[3] This failure mode has been attributed to bending loads;[4] such loading is a common mechanism for the initial injury as well.[5] Since non-locked plate fixation relies on the screw to bone fixation to compress the plate to the bone, failure of screw fixation leads to catastrophic failure of the construct.[3,6] Given its lower density, osteoporotic bone is at risk for this mode of failure since it cannot withstand significant insertion torque and the potential for stripping of the screws is increased.[7,8] In addition, the quality of bone is an important factor in the pull out strength of a screw.[1,9] To strengthen construct fixation in osteoporotic bone, both the length of the plate and number of screws have been shown to increase the strength of the construct.[10,11,12] Inserting the end screw at an angle away from the fracture has also been shown to increase the resistance to screw pullout.[4,13]

The introduction of locked plates was seen as a potential solution for many of the problems associated with osteoporotic fractures.[14] As the screw heads purchase into the plate holes, a fixed angle is created and obviates the need for plate to bone compression.[3] The fixed

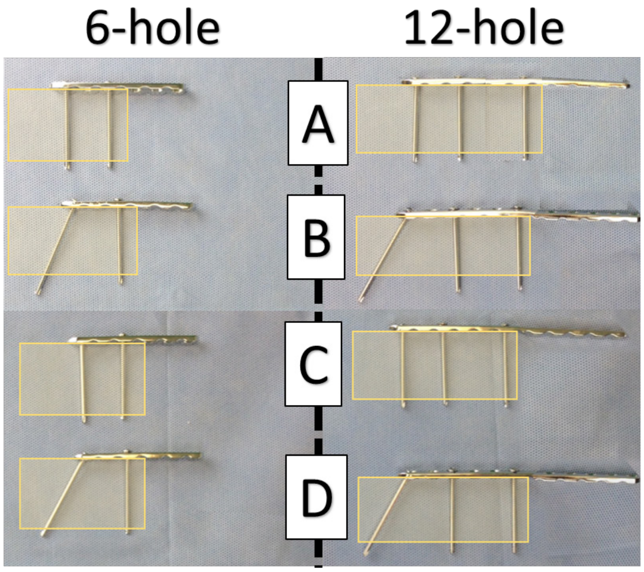


Figure 1. Six and 12-hole plates were used to evaluate 4 different end screw configurations: non-locked, perpendicular (A), non-locked, oblique (B), locked, perpendicular (C), and locked, oblique. The rectangles represent the size and position of the bone blocks which exhibited the material properties of osteoporotic bone.

angle construct does not require the high insertional torque of screws needed in conventional plating, making locked plating an effective tool in osteoporotic bone that is unable to accommodate such torque.[3,7] That said, the benefits of locked plating in osteoporotic bone have not translated into obvious superiority over conventional plating across all fractures.[15,16,17] Though increased stability has been the goal of many biomechanical studies and novel constructs, excessive stability can lead to stress shielding.[10] The lack of a sufficient magnitude of interfragmentary motion can inhibit bone healing, create a nonunion, and, ultimately, a fatigue failure of implant.[18] Hybrid plating sought to combine aspects of locked and conventional plating to address the drawbacks of the use of an all-locked plate.[19,20,21] Non-locked screws are first used to reduce the fracture to the plate and locked screws are used to increase the construct's stability.[22]

With hybrid plating techniques, details regarding the optimal screw type and orientation are somewhat unclear, particularly with regards to the screw farthest from the fracture and often in the end of the plate. After the introduction of locked plates, periprosthetic fractures occurring through the end screw were a concern.[23,24,25] This is not surprising in light of data which shows that the bone stresses are greatest at the end hole.[26,27] Bottlang et al. suggested that a non-locked screw at the end of a plate created a more gradual transition between the plate and bone.[25] This construct was significantly more resistant to peri-plate fracture than an all locked construct. Peck et al. showed that additional fracture resistance could be attained with a hybrid plate that used non-locked inboard screws and a locked end screw angled away from the fracture.[28] While all fractures still occurred through the end hole, the increased fracture resistance was attributed to two factors. First, there were more screw threads engaged in the oblique hole and thus more bony tissue had to fail versus a perpendicular hole. In addition, the fixed angle feature of the end screw augmented implant stability to produce higher failure loads and failure energy.[28] While the locked, oblique end screw provided the greatest resistance to peri-plate bone fracture, the influence of this technique on screw pullout resistance is unknown.

The objective of the current study was to evaluate non-locked and locked end screws in both perpendicular and oblique orientations in loading to determine construct pullout strength. The constructs were thus subjected to 3 point bending. More specifically, it was hypothesized that the locked, oblique end screw would have the greatest pull out strength. The data from the current study was then compared to companion studies using the same test methodology to propose guidelines for screw insertion techniques in osteoporotic bone.

METHODS

The experiment design and test rig were adapted from the literature.[4] A polyurethane foam model (model 1522-01; Pacific Research Laboratories, Vashon Island, Washington) with osteoporotic properties (=0.16 g/cm3) was utilized as it limited inter-sample and intra-sample variability. The number of samples per plate construct (n=6) was based on previous literature and confirmed with a power analysis.[4] Eight different plate constructs were tested for a total of 48 specimens (Figure 1). All plates and screws were 3.5 mm and constructed of 316L stainless steel. Twenty four plates were stock, commercially available low contact compression plates and 24 were modifications of the commercial plate (VOI; models 3.506 LCCP, 3.512LCCP, and custom; Florida). In all stock plates, all holes were non-locked and designed for non-locked screws. In these plates, the end screw was either placed perpendicular or angled 30° away from the fracture site (Figures 1, 2). In the custom plates, the inboard holes were also non-threaded, however, the end hole was modified with a locked hole. This locked end hole was designed for either a perpendicular, locked screw or an oblique, locked screw angled 30° away from the fracture site.

In all constructs the inboard screws were non-locked and tightened to 300 N-mm of torque based on pilot testing that indicated this torque was 75% of the minimum torque required to strip the 3.5 mm screw in the

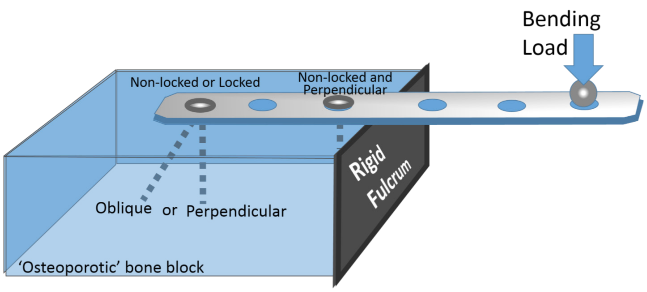


Figure 2. A bending load was delivered to the third hole from a rigid fulcrum for all tests. A rigid fulcrum prevented crushing damage to the bone block to focus the failure to either the end screw or plate. Only the end screw varied for the four groups, the inboard screw(s) was perpendicular and non-locked for the 6 hole (shown) and 12 hole plate groups.

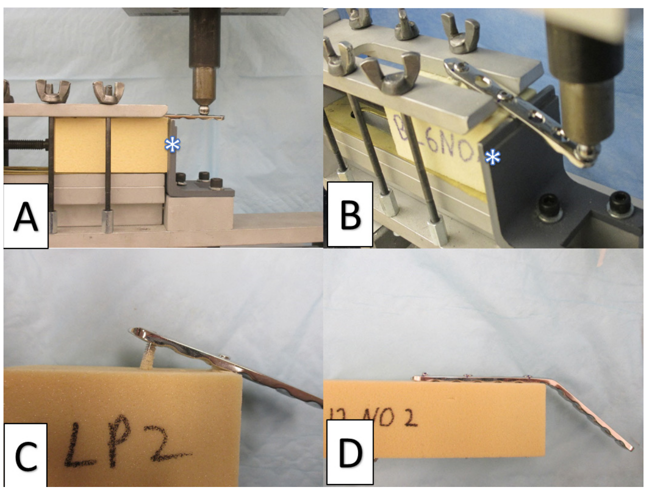


Figure 3. The testing rig (A) subjected the constructs to 3 point bending until failure of the construct (B). The plates failed by screw pullout (C: 6-hole) and plastic deformation (D: 12-hole). (* A rigid fulcrum prevented crushing damage to the bone block to focus the failure to either the end screw or plate.)

osteoporotic bone block.[29] To isolate the effect of the end screw, all inboard screws were identical. Screws were placed after drilling pilot holes of 2.5 mm and 2.8 mm for non-locked and locked screws, respectively, in compliance with manufacturer and literature guidelines.[30] The non-locked, perpendicular end screw groups served as controls for each plate length, as this construct was previously used it allows for comparison to prior literature. The three remaining groups described above served as three test groups by altering the end screw implantation parameters: 30º angulated non-locked, perpendicular locked, and 30º angulated locked.

The constructs were evaluated in cantilever gap closing three point bending with a materials testing machine (Figure 3, Test Resources 8304, Shakopee MN). A hardened steel sphere attached to the test machine's actuator delivered the bending load to the third cantilevered hole (Figure 2, 3) of each plate.[29,31] The construct was attached to a mobile carriage to ensure the load remained centered in the plate hole as the plate rotated about a rigid fulcrum.[4] The bending load was delivered with the actuator in position control mode (0.3 mm/second) until failure of the construct was observed.[32, 33] Failure for all 6-hole plates was observed to be a gradually increasing load which peaked just prior to loss of stable fixation of the end screw. The load then dropped acutely; the test was allowed to continue until the end screw was grossly loosened from the artificial bone block. Following failure, all 6-hole constructs continued to resist the continuing deformation as the actuator continued to move downward. The post-failure load was documented for all 6-hole constructs. In contrast, the 12-hole plates plastically deformed in bending such that the load continued to increase without a loss of fixation of the end screw. To establish a threshold for failure, the limit for clinically acceptable bone angulation was considered. The 3.5 mm plate used in the current study would be suitable for fixation of the forearm. Prior studies have shown that angulation of ~15º represents a limit above which there would be interference to pronosupination.[34,35,36,37] Thus, in the current study, angulation of the plate greater than 15º was considered a failure even though the screws were still intact. Evaluation of plate deformation or damage to surrounding bone was performed via visual inspection by two observers. The load data was recorded by a transducer (Model M211-119, Test Resources, Shakopee, MN, Resolution = 1N) attached to the machine actuator. Displacement of the cross head was recorded by a transducer (LVDT, Test Resources, Shakopee, MN, Resolution = 0.01 mm). All data were sampled at 30 Hz.

The bending load versus displacement was used to determine the peak load, stiffness, and the energy to failure. As noted above, the 6-hole plates were observed to have a focal, readily identifiable peak load which correlated with loss of stability for the end screw. The area under the load-displacement curve prior to this peak load was taken as the energy to failure. In contrast, for the 12-hole plate, the peak load was taken as the load that occurred when the plate had grossly deformed 15°. The energy was likewise calculated to this same peak load. For both length plates, the stiffness was taken as the slope of the linear portion of the curve (R2>0.99 for all constructs). The data from the eight groups were compared using an ANOVA with Student-Newman-Keuls post-hoc testing (SigmaStat, SPSS) after confirming normal distribution of data (= 0.05). In cases of non-normal data, ANOVA on ranks was used.

Figure 4. Close inspection of the failed 12-hole perpendicular, non-locked plates revealed that the plate bent at the rigid fulcrum such that an arc extended over the bone block. Compared to the gross bending of the plate concentrated at the fulcrum, this more subtle arc lifted the plate off the bone block and pulled out the two screws proximal to the fulcrum. This phenomenon was not observed in the other 12 hole groups.

RESULTS

For all 6-hole plates, construct failure resulted in screw pullout without gross deformation of the plate (Figure 3). In contrast, all 12-hole plates failed by plastically deforming past the 15o threshold.[34,35] In the 12-hole non-locked, perpendicular end screw constructs, the screws closer to the fracture pulled out of the bone slightly as the plate bent into an arc shape centered over the fulcrum (Figure 4), however, this occurred after the plate had surpassed the 15o deformation limit.

There was a trend for the locked, oblique construct to exhibit the highest peak to load failure of any 6-hole plate (Table 1), which was significantly stronger when compared to the non-locked, perpendicular construct. The 6-hole non-locked, oblique construct also had a significantly higher load to failure than the non-locked, perpendicular construct (Figure 1). All of the 12-hole constructs had significantly greater loads to failure than all of the 6-hole constructs, except for the 6-hole locked, oblique construct. While there was a trend for the locked oblique 12 hole construct to exhibit the most robust performance, none of the 12 hole groups differed significantly from the other 12 hole groups for all data.

There were no significant differences for stiffness within each plate length subgroup. There was a trend or significant difference for all 12-hole groups to be less stiff than all of the 6-hole groups. The energy to failure for all 12-hole plates was greater than the 6-hole groups except the 6-hole locked, oblique design. In general, the 12-hole plate failure energies were 2 to 3 times magnitudes of the 6-hole non-locked and perpendicular locked groups. In contrast, the 6-hole locked, oblique construct energy magnitudes were only ~20% lower than the failure energies from the 12 hole groups.

The 6-hole plates demonstrated a post-failure phenomenon in which the constructs continued to provide resistance to the advancing machine actuator after the peak load was achieved (Figure 5, Table 2). The maximum post-failure loads for the locked constructs were approximately twice as great as the non-locked groups. As a percentage of the peak load, the locked constructs were able to resist the moving actuator with loads which were 81-87% of the peak failure load. In contrast, the non-locked constructs' post-failure loads were significantly less at 36-56%.

Table I.

Plate length	End Screw Orientation (See Figure 1)	Peak Load (N)	Stiffness (N/mm)	Energy to Peak load (N-mm)
6 Hole	6A: Non-locked, perpendicular	343±50	111±7	588±164
	6B: Non-locked, oblique	429±40*	124±13	902±283
	6C: Locked, perpendicular	399±37	111±7	834±192
	6D: Locked, oblique	470±58*	119±5	1,250±512*
12 Hole	12A: Non-locked, perpendicular	499±49*@	100±9#&	1,560±346*#@
	12B: Non-locked, oblique	480±42*@	101±15#&	1,469±417*@
	12C: Locked, perpendicular	490±23*@	98±5#&	1,522±205*#@
	12D: Locked, oblique	516±12*#@	104±6	1,656±165*#@

Table 1. Four different end screw configurations were evaluated for 6- and 12-hole plates in 3 point bending until failure of screw fixation was achieved. The plates were attached to bone blocks representing osteoporotic bone.

*** Significantly different than Group 6A**
 # Significantly different than Group 6B
@ Significantly different than Group 6C
& Significantly different than Group 6D
None of the 12 hole plate groups were significantly different from the remaining 12 hole groups

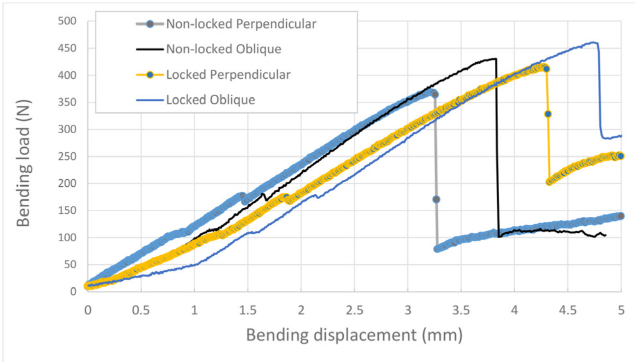


Figure 5. For all 6-hole plates, a post-failure phenomenon was observed in which the construct continued to resist load after the peak load was achieved. The test was allowed to continue following the peak load and the post-failure load was determined. Locked end screws exhibited post-failure loads which were nearly as great as the failure loads (Table 2).

Table II.

End Screw Orientation for 6-hole plates (see Figures 1)	Average Post Failure Peak Load (N) (see Figure 4)	Normalized post Failure Peak Percentage
A: Non-locked, perpendicular	187±19	56% ± 11%#
B: Non-locked, oblique	150±34	36% ± 10%*
C: Locked, perpendicular	320±10*#	81% ± 8%*#
D: Locked, oblique	406±21*#@	87% ± 9%*#

Table 2. Following the peak bending load, the 6-hole plate constructs maintained a post-failure phenomenon in which the load did not diminish to zero. Rather, the constructs continued to provide resistance to continued bending at lower load than the peak magnitude (see Figure 4). The normalized peak is a ratio of the post-failure peak load to the peak load for initial failure (Peak Load in Table 1).

*** Significantly different than Group A**
 # Significantly different than Group B
@ Significantly different than Group C
& Significantly different than Group D

DISCUSSION

The current study compared the construct strength of four plate constructs with the following end screw configurations: non-locked in perpendicular and 30° oblique orientations, and locked in the same orientations. All four constructs were tested in osteoporotic bone models in 3 point bending with 6-hole and 12-hole 3.5 mm low contact compression stainless steel plates.

In the current study all 6-hole constructs failed via pullout of the end screw with no gross deformation of the plate. The 12-hole constructs all failed via gross plastic bending of the plate with no loss of fixation of the end screw. Somewhat surprisingly, the failure loads of the 6-hole plates were lower, but similar to the load for the 12-hole plates at 15° of bending. The magnitude of angular deformation was used as a threshold to distinguish a plate which could potentially remain functional in a clinical setting (as described earlier). There was a trend for the locked oblique end screw constructs to exhibit the highest peak loads in both 6 and 12-hole groups. However, the 6-hole locked, oblique was significantly greater than only the perpendicular, non-locked controls. The 12-hole plates required significantly more energy to failure than the 6-hole plates, with the notable exception of the 6-hole locked, oblique construct. There was no difference in stiffness between constructs of the same length. In general, the 12-hole plates were significantly less stiff than the 6-hole constructs. A post-failure phenomenon was observed for the 6-hole constructs in which there was a second peak load after failure with the locked constructs sustaining a significantly higher percentage of the load after failure.

In the 6-hole constructs, both locked and non-locked oblique screws had improved pullout compared to the non-locked perpendicular screw. This finding is consistent with previous studies which showed that an oblique end screw increases pull out strength in non-locked plating.[4,29] The locked, oblique end screw constructs for the 6- and 12-hole plates in the current study tended to have the greatest pullout strength and failure energies for the respective plate lengths. Additionally, the 12-hole locked, oblique group did tend to exhibit a greater failure load and failure energy than the 6-hole locked oblique, though this difference was not significant. This outcome is consistent with prior data demonstrating that longer plates are associated with increased pullout strength.[11,10]

By using non-locked and locked screws in the same construct in the hybrid plating technique, previous studies have demonstrated improved periprosthetic fracture resistance compared to an all locked plate.[25,24] Additional investigation revealed that a hybrid construct with non-locked inboard screws and a locked, oblique end screw had the greatest resistance to periprosthetic fracture.[28] Non-locked inboard screws allow for compliance with described plating techniques for the first screw in a fragment. It is recommended that the non-locked first screw be placed in an inboard position for hybrid constructs.[21,19] The current study shows that the hybrid construct with a locked oblique end screw is equivalent or stronger than the conventional construct in regards to screw pull out. The optimal end screw would therefore be a locked, oblique screw employed in a hybrid construct with non-locked in board screws, as it offers improved resistance to periprosthetic fracture and the best or equivalent pull out strength.

Charpentier et al. used the same experimental method as in the current study and described a post failure phenomenon by which plated constructs maintained some load after failure had occurred.[29] The locked, oblique construct in the current study not only trended toward greater load to failure but also had the highest percentage of this load maintained after failure. More than 80% of the failure load was observed following failure for both locked 6-hole plates with the locked, oblique being superior. Thus, the locked, oblique configuration may offer some residual stability to a failed hybrid plate construct. Clinically, this may translate into a construct that still provides some fixation after failure to prevent a fracture from grossly displacing before revision. Such stability could help limit pain as well as prevent deformity that would be difficult to correct at a subsequent surgery.

A limitation of the current study is that it is concentrated on a single mode of failure, namely 3-point bending leading to screw pullout or plate bending or a combination of the two. This mode was chosen because a previous study already evaluated the same end screw configurations and their influence on bone fracture at the plate ends.[28] Thus, the current study added to those previous findings as to the superior overall performance of an locked, oblique end screw. An additional limitation is related to the plates used in the current study (3.5 mm low contact compression plates) which revealed that the failure data for 6- and 12-hole locked, oblique plates were not significantly different. Additional testing would be needed with smaller and larger plates to determine if this phenomenon holds true with plates of other sizes. It is reasonable to assume that a thicker plate with greater bending resistance would be more likely to fail via screw pull out and not gross bending deformation, as seen in the 12 hole plates in the current study. The hybrid constructs in this study were compared against conventional constructs, as was done in previous studies. Though locked, oblique end screw constructs were shown to be superior to conventional constructs, they were directly compared to only one other hybrid construct, the locked, perpendicular end screw. Testing and directly comparing a greater variety of hybrid constructs to the locked, oblique end screw construct could be done in future studies for various modes of failure. Finally, the current study used bone blocks to represent osteoporotic bone. This method was adopted to reduce the variability of the specimens to aid in isolating any differences caused by the different end screw configurations. Similar studies have used artificial bone for the same reason.[25,24,29,28] That said, caution is warranted in extending the results from the current study to clinical application. For example, only one type of simulated bone was used in the current study to represent osteoporotic bone. Either stronger or weaker bone properties may lead to differing conclusions as to the influence of the end screw.

The data from the current study and the literature suggest that plate fixation of osteoporotic fractures with 3.5 mm low contact compression plates should use a locked, oblique end screw with hybrid fixation of the remaining screws. This construct has equivalent or greater screw pull-out strength when compared with other end screw configurations. Additionally, this design has demonstrated superior resistance to periprosthetic fracture.[28] Further investigations are needed to evaluate constructs of different length or plate design to determine if the locked, oblique end screw is superior in other settings. Fatigue testing the constructs from the current study could further elucidate the mechanical behavior of this design.

REFERENCES

1. **Cornell CN.** Internal fracture fixation in patients with osteoporosis. J Am Acad Orthop Surg. 2003;11(2)109-119.
2. **Favus MJ.** Bisphosphonates for osteoporosis. N Engl J Med 2010;363(21):2027-35.
3. Egol KA, Kubiak EN, Fulkerson E, et al. Biomechanics of locked plates and screws. J Orthop Trauma. 2004;18:488-493.
4. **Stoffel K, Stachowiak G, Forster T, et al.** Oblique screws at the plate ends increase the fixation strength in synthetic bone test medium. J Orthop Trauma. 2004;18(9):611-616.
5. **Johner R, Staubli HU, Gunst M, et al.** The point of view of the clinician: a prospective study of the mechanism of accidents and the morphology of tibial and fibular shaft fractures. Injury. 2000;31(Suppl 3):C45-C49.
6. **Ricci WM, Tornetta P 3rd, Petteys T, et al.** A comparison of screw insertion torque and pullout strength. J Orthop Trauma. 2010;24(6): 374-378.
7. **Perren, SM.** Evolution of the internal fixation of long bone fractures. J Bone Joint Surg [Br]. 2002;84-B:1093-1110.
8. **Borgeaud M, Cordey J, Leyvraz PF, et al.** Mechanical analysis of the bone to plate interface of the LC-DCP and of the PC-FIX on human femora. Injury. 200;31:SC29-SC36.
9. **Turner IG, Rice GN.** Comparison of bone screw holding strength in healthy bovine and osteoporotic human cancellous bone. Clinical Materials. 1992;9:105-107.
10. **Gardner MJ, Evans JM, Dunbar RP.** Failure of fracture plate fixation. J Am Acad Orthop Surg. 2009;17:647-657.
11. **Sanders R, Haidukewych GJ, Milne T, et al.** Minimal versus maximal plate fixation techniques of the ulna: the biomechanical effect of number of screws and plate length. J Orthop Trauma. 2002;16:166-171.

12. **Tornkvist H, Hearn TC, Schatzker J.** The strength of plate fixation in relation to the number and spacing of bone screws. J Orthop Trauma. 1996;10:204-208.
13. **Karadeniz E, Balcik C, Demirors H, et al.** Biomechanical comparison of conventional technique versus oblique screw placement in plate fixation. J Trauma. 2001;70:E84-E87..
14. **Tejwani NC, Guerado E.** Improving fixation of the osteoporotic fracture: the role of locked plating. J Orthop Trauma. 2011;25:S56-S60.
15. **Bariteau JT, Fantry A, Blankenhorn B, et al.** Biomechanical evaluation of locked plating for distal fibula fractures in an osteoporotic sawbone model. Foot and Ankle Surgery. 2014;20: 44-47.
16. **Roderer, G, Erhardt J, Kuster M, et al.** Second generation locked plating of proximal humerus fractures- a prospective multicenter observational study. International Orthopaedics. 2011;35: 425-432.
17. **Lo EY, Tseng SS, Christiansen BA, et al.** Locking versus nonlocking construct in an osteoporotic, segmental fibular defect model. Orthopedics. 2013;36:e1262-1268.
18. **Epari DR, Kassi JP, Schell H, et al.** Timely fracture-healing requires optimization of axial fixation stability. J Bone Joint Surg. 2007;89: 1575-1584.
19. **Freeman AL, Tornetta P, Schmidt A, et al.** How much do locked screws add to the fixation of “hybrid” plate constructs in osteoporotic bone. J Orthop Trauma. 2010;24:163-169.
20. **Stoffel K, Lorenz KU, Kuster M.** Biomechanical considerations in plate osteosynthesis: the effect of plate-to-bone compression with and without angular screw stability. J Orthop Trauma. 2007;21:362-368.
21. **Gardner MJ, Griffith MH, Demetrakopoulos D, et al.** Hybrid locked plating of osteoporotic fractures of the humerus. J Bone Joint Surg. 2006;88:1962-1967.
22. **Estes C, Rhee P, Shrader MW, et al.** Biomechanical strength of the Peri-Loc® tibial plate: a comparison of all locked versus hybrid locked/non-locked screw configurations. J Orthop Trauma. 2008;22:312-316.
23. **Sommer C, Gautier E, Muller M, et al.** First clinical results of the locking compression plate. Injury. 2003;34: SB43-SB54.
24. **Doornink, J, Fitzpatrick D, Boldhaus S, et al.** Effects of hybrid plating with locked and non-locked screws on the strength of locked plating constructs in osteoporotic diaphysis. J Trauma. 2010;69: 411-417.
25. **Bottlang M, Doornink J, Byrd G, et al.** A nonlocking end screw can decrease fracture risk caused by locked plating in osteoporotic diaphysis. J Bone Joint Surg. 2009;91:620-627.
26. **Cheal EJ, Hayes WC, White AA 3rd, et al.** Three-dimensional finite element analysis of a simplified compression plate fixation system. J Biomech Eng. 1984;106:295-301.
27. **Giannoudis PV, Schneider E.** Internal fixation in osteoporotic bone. In: Ruedi TP, Buckley RE, Moran CG, eds. AO principles of fracture management. Davos, Switzerland: Thieme Publishing; 2007:471-473.
28. **Peck JB, Charpentier PM, Flanagan BP, et al.** Reducing fracture risk adjacent to a plate with an angulated locked end screw. J Orthop Trauma. 2015: June 30
29. **Charpentier PM, Flanagan BP, Srivastava AK, et al.** Reverse oblique end screws in non-locking plates decrease construct strength in synthetic osteoporotic bone medium. J Orthop Surg Advances. 2015;24:130-136.
30. **Battula S, Schoenfeld AJ, Sahai V, et al.** The effect of pilot hole size on the insertion torque and pullout strength of self-tapping cortical bone screws in osteoporotic bone. J Trauma. 2008;64(4):990-995.
31. **Zehnder S, Bledsoe JG, Puryear A.** The effects of screw orientation in severely osteoporotic bone: a comparison with locked plating. Clinical Biomechanics. 2009;24:589-94.
32. **Robert KQ, Chandler R, Baratta RV, et al.** The effect of divergent screw placement on the initial strength of plate-to-bone fixation. J Trauma. 2003;55: 1139-1144.
33. **Bekler H, Bulut G, Usta M, et al.** The contribution of locked screw-plate fixation with varying angle configurations to stability of osteoporotic fractures: an experimental study. Acta Orthop Traumatol Turc. 2008;42:125-129.
34. **Matthews LS, Kaufer H, Garver DF, et al.** The effect on supination-pronation of angular malalignment of fractures of both bones of the forearm. J Bone Joint Surg. 1982;64: 14-17.
35. **Schulte LM, Meals CG, Neviaser RJ.** Management of adult diaphyseal both-bone forearm fractures. J Am Acad Orthop. 2014;22:437-446.
36. **Jayakumar P, Jupiter JB.** Reconstruction of malunited diaphyseal fractures of the forearm. Hand (NY). 2012;9:265-273.
37. **Stewart RL.** Operative treatment of radius and ulna diaphyseal nonunions. In: Wiesel SW, Hunt TR, Kozin SH. Operative Techniques in Orthopaedic Surgery. 1st ed. Philadelphia: Lippincott, Williams, and Wilkins; 2011.

FASCIA ILIACA BLOCK FOR REDUCTION OF ANTERIOR NATIVE HIP DISLOCATION: A CASE REPORT

Christopher West, MD[1]*, Yatish Ranganath, MD[2], Michael Willey, MD[1]

ABSTRACT

Native hip dislocations require urgent reduction in a setting where adequate sedation and analgesia is essential. We have recently implemented the use of fascia iliaca blocks at our institution for preoperative pain management for patients with proximal femur fractures. In the setting of limited resources, alternate modalities for sedation and analgesia may need to be implemented to obtain a timely reduction for hip dislocations. We present a case report where of the use of a fascia iliaca block along with light sedation to obtain a successful, atraumatic reduction of an anterior dislocation of a native hip joint. While many hip dislocations may require a deeper level of sedation and muscle relaxation for successful reduction, the current report suggests that fascia iliaca blocks provide adequate analgesia for the procedure and may be helpful in the setting of limited resources.

INTRODUCTION

The importance of urgent reduction of native hip dislocations has been shown to be important for long term outcomes in multiple clinical series.[1-6] Time to reduction longer than six hours results in higher rates of avascular necrosis and post-traumatic osteoarthritis.[5] Reports have also shown much worse clinical outcomes in patients that had delay to reduction greater than 24 hours.[4,6] The type of sedation and the setting for the reduction remains an area of controversy. Authors advocate for reduction in the operating room with sedation and muscle paralysis to minimize the risk of further cartilage damage to the femoral head.[7] Emergency room reduction can be considered if there is limited access or if associated injuries prevent the patient from going to the operating room. There have been previous case reports of fracture propagation or iatrogenic fracture from reduction attempts with inadequate sedation.[8]

Innovative modalities for improved pain management in patients that undergo elective orthopaedic surgery and suffer orthopaedic trauma has been a recent area of increased investigation. Anesthetic blocks after acute trauma, prior to surgical intervention, have been shown to be effective in management of early post-injury pain.[9,10] At our institution we have recently implemented the fascia Iliaca block for improved pre-operative pain management in patients that suffer proximal femur fractures. The effectiveness of this intervention is currently under investigation.

This case report describes a patient with a traumatic anterior simple hip dislocation with delayed presentation that underwent reduction with a fascia Iliaca block and light sedation.

Consent

Verbal consent was obtained from the patient described in this case report to report details of his injury, treatment, and clinical outcomes.

CASE REPORT

A 22 year old man with no previous history of hip pain or injury was a front seat passenger in a motor vehicle accident at highway speed. He was unrestrained and had been consuming alcohol prior to the accident. The patient was able to self-extricate and was taken home by friends that night. In the morning he was unable to ambulate, had severe hip pain, and was taken to the emergency room. He was evaluated in the emergency room 14 hours after the injury.

On evaluation he had a fixed flexion, abduction, and external rotation deformity of the left hip. He had severe hip pain. A trauma anterior-posterior (AP) pelvis radiograph demonstrated an anterior dislocation of the femoral head (Figure 1). After careful evaluation there was no evidence of fracture on the dislocated radiograph.

Due to timing of the operating room schedule the orthopaedic team was unable to take him immediately for general anesthesia. Conscious sedation in the emergency room was unavailable because of adequate nursing resources at the time. The treating physicians elected to perform a fascia iliaca block with light sedation (1 mg

1. University of Iowa Department of Orthopaedics and Rehabilitations, Iowa City, IA

2. University of Iowa Department of Anesthesia, Iowa City, IA

*Corresponding author
Email: christopher-west@uiowa.edu
Phone: (801)598-7807

The authors declare no conflicts of interest.

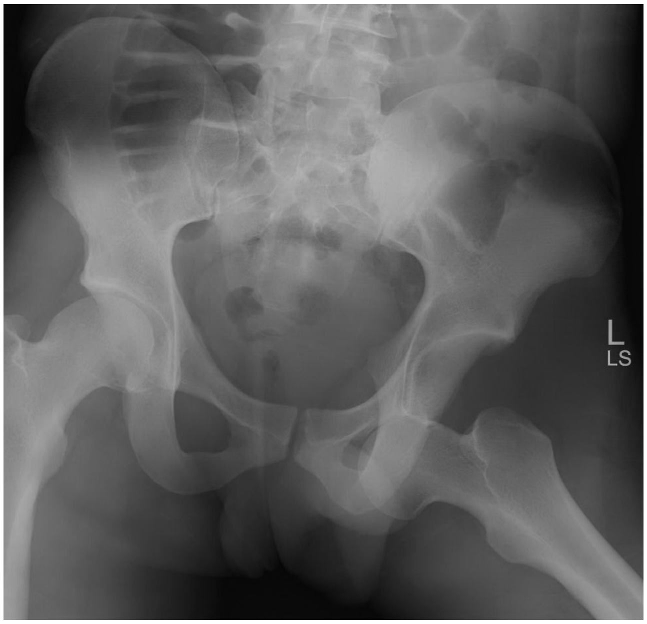


Figure 1: Trauma anterior-posterior pelvis radiograph demonstrating anterior hip dislocation

Figure 2: Anterior-posterior pelvis radiograph demonstrating concentric reduction of left hip after manipulation.

of Midazolam) with a gentle reduction maneuver in an attempt to reduce the femoral head in a timely fashion.

The left groin was prepped and draped at the bedside. ASIS and pubic tubercle were marked with a line between them over the ilioinguinal ligament. The site of the injection was marked one cm below the ilioinguinal ligament at the junction of the lateral and middle two thirds of our previously marked line. The skin was anesthetized with 1% lidocaine. Sterile ultrasound was used in a transverse plane superior to the inguinal ligament to visualize the femoral vessels and nerve medially, and then to identify the fascia layers laterally superior to our injection site. An 18 gauge, blunt tip needle was advanced through a two pop technique angled 60 degrees cranial. The needle was then visualized using an out of plane technique with our ultrasound probe, which remained in the transverse plane above the ilioinguinal ligament, aimed slightly caudal. After aspiration with no backflow, 40 cc of 0.2% ropivacaine was injected under sterile ultrasound guidance once a loss of resistance was felt and the plane between the fascia and iliacus muscle was noted to expand on infusion, confirming our location. We used 0.2% ropivacaine with the intention of producing less motor weakness compared to other agents commonly in use.

The hip was then reduced with a Howard reduction technique.[11] Gentle traction and laterally directed force was applied with external then internal rotation until the hip reduced. Reduction was confirmed on radiographs and the patient had full range of motion and adequate pain control in the left hip.

After the reduction was performed an AP pelvis radiograph demonstrated concentric reduction of the left femoral head with no evidence of fracture (Figure 2). The patient reported no pain five and ten minutes after the procedure. He was unattended for a short period of time in the emergency room, and despite instructions to remain in the hospital bed, he put on his clothes and walked unassisted to the restroom. We emphasized our intention to keep him toe-touch weight bearing for two weeks after the injury. He reported no pain with ambulation which we attribute partially to the block.

The patient was scheduled to follow up two weeks after the incident but failed to return for his appointment.

DISCUSSION

The FIB is a compartment block that attempts to block, with a large volume of dilute anesthetic, the lateral femoral cutaneous (LFCN) and femoral nerve. Injection occurs at a site laterally distant from the course of the femoral vessels or nerves. This technique was initially described by Danels in 1989 and landmark based, loss of resistance techniques have been employed as well as ultrasound guided techniques.[12-14]

With the ‘pop’ technique, a simple blunt tip needle is chosen and inserted perpendicular to the skin just below the inguinal ligament aiming 60 degrees cranial. As the needle penetrates through the two fascial pops are felt. These resistances are of the fascia lata and the fascia iliaca. At the second pop the drug is delivered. A large volume of anesthetic, typically between 30-50 ml is infused in order sufficiently fill the compartment and bathe the LFCN and femoral nerves.[13] We elected to use ultrasound guidance along with the established landmark based technique in order to visualize the anatomic structures to ensure safety during the procedure and technically successful execution of the block.

Fascia iliaca blocks have been shown to be safe and effective in treating pain in hip fracture patients.[14-16] Even when applied by individuals with varying levels of experience, clinically meaningful decrease in pain was achieved in a majority of patients within two hours from injection with significant opioid sparing effects.[14,16] Effectiveness of the block increases with utilization of ultrasound as was shown by Dolan, et al with increased frequency of sensory loss to the medial aspect of the thigh and femoral and obturator motor block.[17] Other randomized trials have demonstrated superior or equal pain management with FIB when compared to other forms of acute pain management.[15,18]

At our institution, acute traumatic native, simple hip dislocations are reduced in the operating room with muscle paralysis and adequate sedation. This allows for an atraumatic reduction of the dislocation and decreases the likelihood of causing further injury to the hip joint. Adequate resources for anesthesia were not immediately available for this patient with a simple, anterior hip dislocation and because of his delayed presentation we attempted to utilize an ultrasound guided block for reduction. The reduction was successful with a gentile maneuver. The patient had excellent pain control during the reduction maneuver and after the procedure, allowing for immediate mobilization. In a setting of limited resources, a fascia Iliaca block may be considered for pain management with reduction of a native, simple anterior hip dislocation when other resources are unavailable. The authors advocate that despite the technique used for anesthesia, physicians must use gentle maneuvers to prevent iatrogenic injury and this technique should not be used with posterior hip dislocations where deeper sedation with muscle relaxation is essential.

REFERENCES

1. **Dreinhofer KE, Schwarzkopf SR, Haas NP, Tscherne H.** Isolated traumatic dislocation of the hip. Long-term results in 50 patients. The Journal of bone and joint surgery British volume 1994;76:6-12.
2. **Vecsei V, Schwendenwein E, Berger G.** [Hip dislocation without bone injuries]. Der Orthopade 1997;26:317-26.
3. **Schlickewei W, Elsasser B, Mullaji AB, Kuner EH.** Hip dislocation without fracture: traction or mobilization after reduction? Injury 1993;24:27-31.
4. **Yang RS, Tsuang YH, Hang YS, Liu TK.** Traumatic dislocation of the hip. Clinical orthopaedics and related research 1991:218-27.
5. **Hougaard K, Thomsen PB.** Coxarthrosis following traumatic posterior dislocation of the hip. The Journal of bone and joint surgery American volume 1987;69:679-83.
6. **Upadhyay SS, Moulton A.** The long-term results of traumatic posterior dislocation of the hip. The Journal of bone and joint surgery British volume 1981;63b:548-51.
7. **Tornetta P, 3rd, Mostafavi HR.** Hip Dislocation: Current Treatment Regimens. The Journal of the American Academy of Orthopaedic Surgeons 1997;5:27-36.
8. **Polesky RE, Polesky FA.** Intrapelvic dislocation of the femoral head following anterior dislocation of the hip. A case report. The Journal of bone and joint surgery American volume 1972;54:1097-8.
9. **Kumie FT, Gebremedhn EG, Tawuye HY.** Efficacy of fascia iliaca compartment nerve block as part of multimodal analgesia after surgery for femoral bone fracture. World journal of emergency medicine 2015;6:142-6.
10. **Wathen JE, Gao D, Merritt G, Georgopoulos G, Battan FK.** A randomized controlled trial comparing a fascia iliaca compartment nerve block to a traditional systemic analgesic for femur fractures in a pediatric emergency department. Annals of emergency medicine 2007;50:162-71, 71.e1.
11. **Howard CB.** A gentle method of reducing traumatic dislocation of the hip. Injury 1992;23:481-2.
12. **Dalens B, Vanneuville G, Tanguy A.** Comparison of the fascia iliaca compartment block with the 3-in-1 block in children. Anesthesia and analgesia 1989;69:705-13.
13. **Diwan S.** Fascia iliaca block - an anatomical and technical description. Journal of Anaesthesia and Critical Care Case Reports 2015;1:27-30.
14. **Haines L, Dickman E, Ayvazyan S, et al.** Ultrasound-guided fascia iliaca compartment block for hip fractures in the emergency department. The Journal of emergency medicine 2012;43:692-7.
15. **Morrison RS, Dickman E, Hwang U, et al.** Regional Nerve Blocks Improve Pain and Functional Outcomes in Hip Fracture: A Randomized Controlled Trial. Journal of the American Geriatrics Society 2016;64:2433-9.
16. **Groot L, Dijksman LM, Simons MP, Zwartsenburg MM, Rebel JR.** Single Fascia Iliaca Compartment Block is Safe and Effective for Emergency Pain Relief in Hip-fracture Patients. The western journal of emergency medicine 2015;16:1188-93.
17. **Dolan J, Williams A, Murney E, Smith M, Kenny GN.** Ultrasound guided fascia iliaca block: a comparison with the loss of resistance technique. Regional anesthesia and pain medicine 2008;33:526-31.
18. **Chesters A, Atkinson P.** Fascia iliaca block for pain relief from proximal femoral fracture in the emergency department: a review of the literature. 2014;31:e84-7.

FEMORAL IATROGENIC SUBTROCHANTERIC FATIGUE FRACTURE RISK IS NOT INCREASED BY PLACING DRILL HOLES BELOW THE LEVEL OF THE LESSER TROCHANTER

Andrew G. Tsai[1], Timothy J. Ashworth[2], Randall Marcus[1], Ozan Akkus[1,3,4]

ABSTRACT

Background: Iatrogenic subtrochanteric fractures of the femur can occur postoperatively following placement of screws in the lateral femoral cortex. Drilling holes below the lesser trochanter is generally avoided to prevent fatigue failure; however, there is little biomechanical evidence to support this recommendation. We hypothesized that hole placement below the level of the lesser trochanter will not accelerate fatigue failure compared to holes at the level of the lesser trochanter.

Methods: Twelve matched-pairs of male fresh-frozen cadaveric femurs were used for biomechanical testing. A single screw hole was drilled through the lateral femoral cortex either at the level of the lesser trochanter (proximal-hole group) or below the lesser trochanter (distal-hole group). Each femur was cycled to failure using a physiologically-relevant loading model. Paired t-test was used to evaluate for a difference in cycles to failure between groups.

Results: There was no statistical difference in cycles to failure between the groups with the hole drilled at or below the lesser trochanter.

Conclusions: The traditional recommendation to avoid drilling holes below the level of the lesser trochanter is based mainly on experience and case reports in the literature. The results of this study indicate that placing holes below the level of the lesser trochanter, in and of itself, may not pose any additional risk of fracture. Other important factors need to be considered, such as tapering of the lateral femoral cortex.

Clinical Relevance: There are often situations where the patient's anatomy and fracture pattern is more conducive to placing a screw distal to the lesser trochanter. This study may allow surgeons greater flexibility in placing screws more distally in the lateral femoral cortex by demonstrating the safety of doing so, at least in the population studied.

INTRODUCTION

Several orthopaedic conditions may require the drilling of a hole in the lateral femoral cortex for placement of metal implants, with a notable one being cannulated screw placement for femoral neck fractures.[1-5] Patients treated with laterally placed screws or other implants are at risk for an iatrogenic fracture in the subtrochanteric region as a result of this new cortical defect (Figure 1).

Iatrogenic subtrochanteric fractures (ISF) are most commonly seen following screw placement for the treatment of femoral neck fractures,[1] but they may also be seen following core decompression for avascular necrosis (AVN)[2,3] of the femoral head or fixation of slipped capital femoral epiphysis (SCFE).[4,5] Up to 3% of patients who undergo cannulated screw placement for femoral neck fractures experience ISFs in the subacute period after surgery.[6] Considering there are over 280,000 hip fractures annually in elderly patients in the United States and approximately half occur through the femoral neck, many of which will undergo screw fixation, a large number of patients are at risk for this complication.[7,8] The incidence of this fracture is expected to rise given the increasing elderly population.[9-12] Subtrochanteric fracture following femoral neck fracture is a devastating complication that is technically difficult to repair with significant risk for healing complications.

The proximal femoral cortex is one of the most highly stressed regions in the body.[13] The creation of screw holes for fracture fixation exacerbates this situation by introducing stress risers in the lateral cortex.[14,15] It is currently recommended to avoid screw placement below the lesser trochanter during internal fixation for femoral neck fractures to avoid ISFs.[6] However, the biomechanics of ISFs have not been investigated sufficiently to

1 Case Western Reserve University, School of Medicine, Department of Orthopaedics, 10900 Euclid Avenue, Cleveland, OH USA 44106

2 University of North Carolina, School of Medicine, Department of Orthopaedics, 101 Manning Drive, Chapel Hill, NC USA 27514

3 Case Western Reserve University, Department of Mechanical and Aerospace Engineering, Musculoskeletal Materials and Mechanics Laboratory, 10900 Euclid Avenue, Cleveland, OH USA 44106

4 CWRU, Department of Biomedical Engineering, 10900 Euclid Avenue, Cleveland, OH USA 44106

Corresponding author:
Andrew G. Tsai
email: andrew.g.tsai@gmail.com
412-606-1055

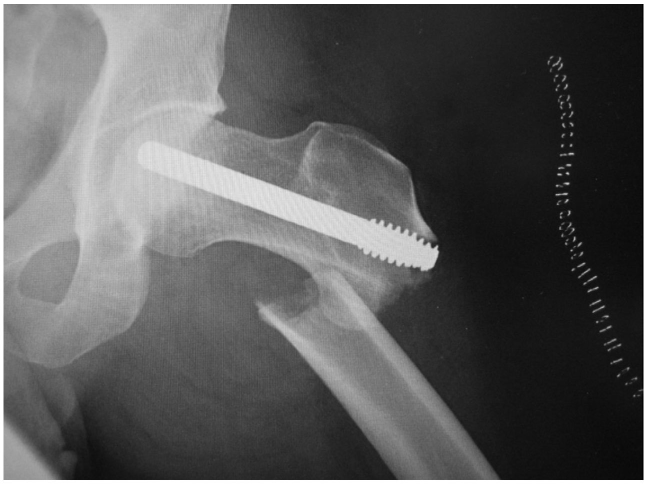


Figure 1. Anterior-posterior view of a left hip sustaining a subtrochanteric fracture 15 days after insertion of a porous tantalum strut. The fracture occurred during ambulation.

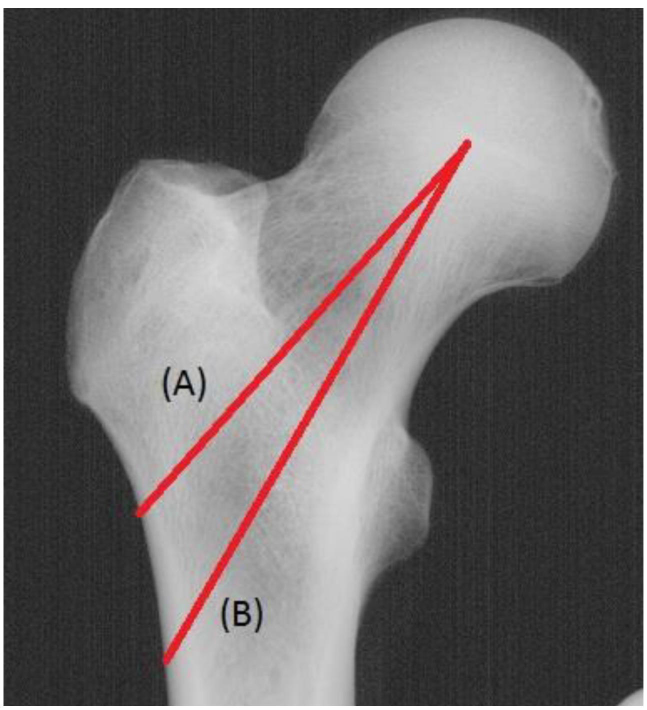


Figure 2. Xray of typical femur with projections of intended path for drill holes through femoral cortex. Line (A) represents a starting point at the apex of the lesser trochanter and aimed toward the center of the femoral head, and line (B) starts below the level of the lesser trochanter.

support this recommendation. It should be noted that osteoporosis predominately affects trabecular bone, which is more abundant in the trochanteric region than the subtrochanteric region of the femur.[16]

Many case studies have reported the occurrence of ISF in patients between 55-99 years of age with an average of 79 years old.[1,6,17-27] Placement of the most inferior screw was at or below the distal border of the lesser trochanter in 86% of cases, although distal hole locations in patients not experiencing ISF have not been specifically reported. Fractures occurred within 6 weeks postoperatively in the vast majority of cases, with less than half of patients reporting any trauma prior to the fracture. The only study to investigate the relationship between low screw placement and ISF had only two ISFs occur during the study period, one of which was through a screw hole below the distal border of the lesser trochanter.[17] A single study on the relationship between hole location and failure found that there was no relationship between distal, unused drill holes and failure in the proximal femur in overload situations.[28]

We hypothesized that hole placement distal to the lower border of the lesser trochanter is not necessarily a risk factor for ISF, particularly in younger, male patients who are more likely to have higher bone quality. We tested this hypothesis by fatigue analysis of paired femurs with single holes drilled in two locations, using a validated loading model designed to increase accuracy of testing the proximal femur by simulating both joint and abductor muscle loads.

METHODS

Preparation of cadaver femurs

Twelve pairs of fresh-frozen human femurs (24 total femurs) were prepared in an identical manner as previously described.[14] Patients with medical diagnosis of osteoporosis, known abnormalities, or prior surgery of the proximal femur were excluded. The proximal portion of each femur was x-rayed to rule out any obvious bony abnormality prior to testing. Before specimen preparation, each femur was allowed to fully thaw in moist gauze at room temperature. Once thawed, all soft tissues were carefully dissected to avoid injury to the cortex. Each femur was transected 15 cm distal to the inferior margin of the lesser trochanter and the distal 3 cm was potted in polymethylmethacrylate (PMMA, Henry Schein, Melville, NY USA). A 7.1 mm hole was drilled at the lateral cortex at either the level of the lesser trochanter apex (right femurs) or distal to the lesser trochanter (left femurs) and aimed toward the center of the femoral head (Figure 2). The center of the hole for the left femurs was determined as 25% of the vertical distance from the lesser trochanter to the intersection of the hip contact force on the surface of the femoral head; this method served to normalize the location of the inferior hole between different femora. Using a single rather than multiple drilled holes was more reproducible, and in all case reports, the fracture line in ISFs was noted to travel through the most inferior drill hole. The measurements

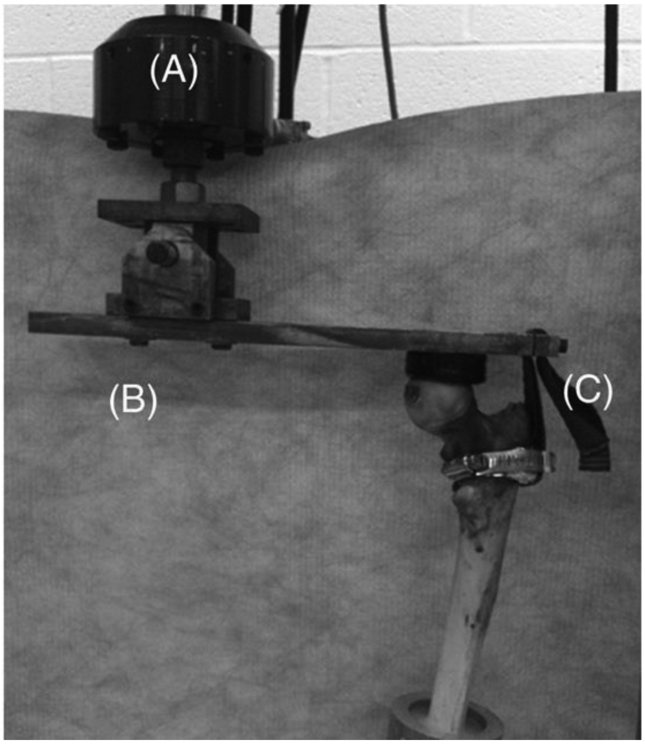


Figure 3. The physiologic loading model used in the experiments is shown. The actuator (A) applies a downward load to the bar (B), resulting in an inferiorly-directed load applied at the femoral head and a superiorly-directed load applied at the greater trochanter via an "abductor strap" (C).

were all performed by the same person, and the distance varied between 17.4 and 20.8 mm distal to the lesser trochanter (average 18.8 mm). The proximal femur was hydrated and stored in a –20 °C freezer. Prior to testing, each specimen was removed from the freezer and set at room temperature for approximately two hours until fully thawed. Each femur was wrapped in gauze during testing and kept hydrated by periodically spraying water onto the gauze and proximal femur.

Physiologically-relevant loading model for the proximal femur

The fatigue loading model for inducing subtrochanteric fracture has been previously described and validated.[14] All mechanical tests were conducted using an Instron 8501M (Instron, Norwood, MA USA). Custom-built aluminum fixtures were used for applying loads and fixing the femur specimens in position (Figure 3).

The actuator was fitted with a 1000 lb cell (model 1010AF-1K-B, Interface Mfg., Scottsdale, Arizona, USA) and applied a vertical load on a crosshead, transmitting the force to the near end of an adjustable aluminum bar measuring 1 × 5 × 29 cm^3. The bar's end opposite to the actuator was used to secure a polyester strap, the "abductor strap," which itself was secured to the proximal femur by a padded hose clamp placed around the intertrochanteric region. The padding was achieved by ten layers of aluminum foil as well as polyester strap. The hose clamp was lightly fastened around the femur just enough to prevent the assembly from slipping superiorly over the inferior border of the greater trochanter during loading. Except for the engagement at the inferior border of the greater trochanter, the clamp was loosely applied around the periphery of the proximal femur. A thick-walled cylindrical aluminum clamp was bolted to a base-plate with the cylinder angled 7° from vertical. The cylinder secured the potted, distal end of the femoral specimen, fixing the femoral shaft along its axis. A custom bearing molded from PMMA was positioned on the undersurface of the aluminum bar, which articulated with the femoral head. Since all fixtures were adjustable, the base-plate and bar were adjusted so the ratio of the length of the bar from the crosshead to the center of the femoral head was 2.5 times the length of the bar from the center of the femoral head to the abductor strap. By static analysis, the force of the abductor strap was estimated to be 71.4% of the joint contact force, which is similar to loads used previously in literature to mimic normal forces around the hip.[29,30] This model was chosen as it had been shown capable of inducing subtrochanteric femur fractures.[14]

Fatigue testing

Fatigue tests of the samples, using the aforementioned physiologic loading model, were performed under sinusoidal loading that initially peaked at 140% of the body weight of the donor. 140% of actual specimen body weight was chosen after pilot tests demonstrated prohibitively-long testing times with actual body weight. A force ratio of 0.1 was applied at a rate of 2 Hz during the cyclic loading. The force was increased by 10% every 36,000 cycles (five hours) to accelerate specimen failure. All specimens were cycled until fracture and the total number of cycles was recorded. Fracture was defined as the point at which the femur construct was unable to resist the maximum load provided by the actuator and the system stopped due to a displacement limit on the actuator. The loads and number of cycles at each load used fatigue loading protocol are summarized in Table 1.

Data analysis

Total cycles to failure were recorded for comparison. A paired, two-tailed t-test was calculated using Minitab 17 (Minitab, Inc. State College, PA, USA) to compare the cycles to failure of femurs for the proximal-hole vs. distal-hole groups. Statistical significance was set at $p < 0.05$. Outliers in the regression analyses were identified by data points exceeding a standardized residual value of 2.0 and there were 3 such data points out of the 24.

Table I. Loading Protocol for Anatomic Loading Model

	Peak force on femoral head	Number of cycles
Stage 1 (initial load)	F1 = 350% * (body weight * 140%) R = 0.1	36,000
Stage X (subsequent loads)	Fx = Fx-1 * 110% R = 0.1	36,000

Table II.

Specimen (age)		Cycles to Failure
1 (48)	Left	8855
	Right	11521
2 (56)	Left	63830
	Right	53641
3 (36)	Left	142409
	Right	122890
4 (21)	Left	114672
	Right	72001
5 (57)	Left	137961
	Right	104928
6 (57)	Left	24519
	Right	35993
7 (65)	Left	122891
	Right	127251
8 (60)	Left	3989
	Right	13705
9 (56)	Left	89225
	Right	58677
10 (58)	Left	37413
	Right	19230
11 (55)	Left	111245
	Right	72500
12 (50)	Left	12652
	Right	31562

Specimen data: calculated stress at hole location, cycles to failure, and log of cycles to failure. Left femurs have a distal screw hole, and right femurs have a proximal screw hole. All specimens belonged to male donors.

RESULTS

Cycles to failure for each specimen are recorded in Table 2. The average cycles to failure of the distal-hole femur group was 72,472 (standard deviation 53,262, 95% confidence interval 38,630-106,313). The average cycles to failure of the proximal-hole group was 60,325 (standard deviation 40,875, 95% confidence interval 34,354-86,296). This result was not a statistically significant difference ($p = 0.074$). The power of the test to detect a difference of 20% is 0.84. In all specimens, the fracture line was a transverse or short oblique, and all fracture traveled through the drilled hole.

DISCUSSION

ISFs may occur after drilling holes for implant insertion due to the stress concentrating effect of hole placement. It has been suggested that these fractures are associated with hole placement of hole location distal to the lower border of the lesser trochanter. We predicted that drilling holes below the level of the lesser trochanter, in and of itself, poses no risk of early fatigue failure, as the lesser trochanter has little to do with the stresses experienced on the lateral cortex. The drilled holes clearly acted as stress risers as all fractures traveled through the drill hole. But despite the inferior hole removing more cortical bone due to the more oblique/steep trajectory, it still did not cause a statistical decrease in fatigue life. There are likely other associated or causative factors of ISF, such as bone morphology and metaphyseal thinning that occurs in some patients with age.

One strength of the study was the use of a loading model that included both the joint reaction force and abductor muscle force,[14] under cyclic loading conditions representing ambulation. Most studies involving mechanical tests of the proximal femur include only the joint force, and test under monotonic loading conditions.[31-34] The literature shows that the addition of the abductor muscle forces at the greater trochanter yields a much more accurate representation of in vivo loading conditions. This is due to their significant contribution to the tensile stresses on the lateral cortex, while addition of other muscle groups produces minimal differences.[30,35,36] The paired-experimental design comparing femurs from the same donor accounted for donor-to-donor variations to some extent.

There are some limitations to this study. Our testing did not involve a femoral neck fracture fixed with three screws as would be seen in the clinical situation that predisposes to ISF. This alters the mechanics, but it still demonstrates the effect of the stress riser at the lateral cortex to ISFs as all fractures in this experiment travelled through the drilled hole. Furthermore, all ISF case reports in literature have occurred through the inferior-most hole, likely a result of the stiffened proximal segment spanned by hardware. No attempt was made to assess bone quality in individual femurs. The donor specimens in this study were demographically different than those normally associated with hip fracture, but the effect of that should be negated by the use of paired femurs to control for anatomic changes due to age. It should also be noted that osteoporosis predominately affects trabecular bone, which is more abundant in the trochanteric region than the subtrochanteric region of the femur, which was our area of interest.[16] Lastly, we were unable to account for the effects of bony remodeling in this cadaver study, which may differ with more distal hole placement as cortical bone predominates distally in this region of the femur.

The results support our hypothesis and show that there is no statistically significant difference in cycles to failure between the proximal-hole and distal-hole groups. This result implies that drilling screw holes below the level of the lesser trochanter is not likely to increase the risk of ISF. The more distal region could be more susceptible to fracture following hole placement in elderly patients, but this has not been demonstrated by any previous study and is out of the scope of the current study. We believe that the bone changes seen in some elderly patients largely account for the phenomenon of ISF occurring with more distal hole placement in such patients. With increasing age, cortical thickness in the femoral diaphysis decreases and width of the proximal metaphysis increases in some individuals, thus altering the biomechanics and stress/strain distributions.[37]

ISF after femoral neck fractures, although not a frequent event, remains a continuing issue. Recommendations for avoiding such fractures based on retrospective analysis of cases are generally given without the support of biomechanical evidence. The location of a drilled hold on the lateral cortex relative to the lesser trochanter does not predict early failure. To our knowledge, this study is the first to formally examine and challenge the long-held dogma to not drill below the level of the lesser trochanter in surgeries involving the lateral, proximal femur from a biomechanical standpoint. While we respect surgeons' experience in placement of screw holes more proximally in general, this study's findings positioning of the stress risers relative to the lesser trochanter does not necessarily correlate with accelerated fatigue failure. The lesser trochanter may be only a surrogate for other anatomic features, such as location of lateral cortical thinning, which may be a more useful landmark for preventing ISFs. Further study of early fatigue failure after creation of stress rises in the lateral femoral cortex needs to be performed to elucidate the causative factors and help to prevent their occurrence.

SOURCES OF FUNDING

This study was funded by a research grant provided by the Orthopaedic Research and Education Fund; the University Hospitals Case Medical Center Department of Orthopaedics (Cleveland, Ohio). Specimens were provided in part through the Research Tissue Program through the Musculoskeletal Transplant Foundation (Edison, NJ). Thanks to Jay Bensusan for his help with the testing setup.

REFERENCES

1. **Kloen P, Rubel IF, Lyden JP, Helfet DL.** Subtrochanteric fracture after cannulated screw fixation of femoral neck fractures: A report of four cases. J Orthop Trauma. 2003 Mar;17(3):225-9.
2. **Fung DA, Frey S, Menkowitz M, Mark A.** Subtrochanteric fracture in a patient with trabecular metal osteonecrosis intervention implant. Orthopedics. 2008 Jun;31(6):614.
3. **Stronach BM, Duke JN, Rozensweig SD, Stewart RL.** Subtrochanteric femur fracture after core decompression and placement of a tantalum strut for osteonecrosis of the femoral head. J Arthroplasty. 2010 Oct;25(7):1168.e5,1168.e7.
4. **Canale ST, Azar F, Young J, Beaty JH, Warner WC, Whitmer G.** Subtrochanteric fracture after fixation of slipped capital femoral epiphysis: A complication of unused drill holes. J Pediatr Orthop. 1994 Sep-Oct;14(5):623-6.
5. **Paloski M, Taylor BC, Willits M.** Subtrochanteric femur fracture after slipped capital femoral epiphysis pinning: A novel treatment. Adv Orthop. 2011;2011:809136.
6. **Jansen H, Frey SP, Meffert RH.** Subtrochanteric fracture: A rare but severe complication after screw fixation of femoral neck fractures in the elderly. Acta Orthop Belg. 2010 Dec;76(6):778-84.
7. Hip fractures among older adults [Internet].; 2010. Available from: http://www.cdc.gov/HomeandRecreationalSafety/Falls/adulthipfx.html.
8. **Karagas MR, Lu-Yao GL, Barrett JA, Beach ML, Baron JA.** Heterogeneity of hip fracture: Age, race, sex, and geographic patterns of femoral neck and trochanteric fractures among the US elderly. Am J Epidemiol. 1996 Apr 1;143(7):677-82.
9. **Brauer CA, Coca-Perraillon M, Cutler DM, Rosen AB.** Incidence and mortality of hip fractures in the united states. JAMA. 2009 Oct 14;302(14):1573-9.
10. **Cummings SR, Rubin SM, Black D.** The future of hip fractures in the united states. numbers, costs, and potential effects of postmenopausal estrogen. Clin Orthop Relat Res. 1990 Mar;(252)(252):163-6.

11. **Kannus P, Parkkari J, Sievanen H, Heinonen A, Vuori I, Jarvinen M.** Epidemiology of hip fractures. Bone. 1996 Jan;18(1 Suppl):57S-63S.
12. **Stevens JA, Anne Rudd R.** Declining hip fracture rates in the united states. Age Ageing. 2010 Jul;39(4):500-3.
13. **Sims SH.** Subtrochanteric femur fractures. Orthop Clin North Am. 2002 Jan;33(1):113,26, viii.
14. **Tsai AG, Reich MS, Bensusan J, Ashworth T, Marcus RE, Akkus O.** A fatigue loading model for investigation of iatrogenic subtrochanteric fractures of the femur. Clin Biomech (Bristol, Avon). 2013 Nov-Dec;28(9-10):981-7.
15. **Brooks DB, Burstein AH, Frankel VH.** The biomechanics of torsional fractures. the stress concentration effect of a drill hole. J Bone Joint Surg Am. 1970 Apr;52(3):507-14.
16. **Chen H, Zhou X, Fujita H, Onozuka M, Kubo KY.** Age-related changes in trabecular and cortical bone microstructure. Int J Endocrinol. 2013;2013:213234.
17. **Hickey B, Jones HM, Jones S.** Is distal screw entry point associated with subtrochanteric fracture after intracapsular hip fracture fixation? ANZ J Surg. 2014 Apr;84(4):245-8.
18. **Yang JJ, Lin LC, Chao KH, Chuang SY, Wu CC, Yeh TT, et al.** Risk factors for nonunion in patients with intracapsular femoral neck fractures treated with three cannulated screws placed in either a triangle or an inverted triangle configuration. J Bone Joint Surg Am. 2013 Jan 2;95(1):61-9.
19. **Pelet S, Leyvraz PF, Garofalo R, Borens O, Mouhsine E.** Sub- or intertrochanteric fracture following screw fixation of an intracapsular proximal femoral fracture: True complication or technical error? Swiss Surg. 2003;9(2):82-6.
20. **Parker MJ.** Parallel garden screws for intracapsular femoral fractures. Injury. 1994 Aug;25(6):383-5.
21. **Blyme PJ, Kristensen G, Jensen CH, Torholm C.** Subtrochanteric fractures following osteosynthesis of femoral neck fractures with the VLC-femoral system. Orthopedics. 1992 Nov;15(11):1373-4.
22. **Neumann L.** Subtrochanteric fractures following gouffon pinning of subcapital femoral fractures. Injury. 1990 Nov;21(6):366-8.
23. **MacEachern AG, Heyse-Moore GH, Jones RN.** Subtrochanteric fractures of the femur through the track of the lower garden screw–treatment with a richards sliding screw. Injury. 1984 Mar;15(5):337-40.
24. **Andrew TA, Thorogood M.** Subtrochanteric fracture after garden screw fixation: A review of predisposing factors and management in nine cases. Injury. 1984 Nov;16(3):169-77.
25. **Karr RK, Schwab JP.** Subtrochanteric fracture as a complication of proximal femoral pinning. Clin Orthop Relat Res. 1985 Apr;(194)(194):214-7.
26. **Mackie IG, Leyshon RL.** Sub-trochanteric fracture (after garden-screw fixation of sub-capital fracture) treated with AO dynamic hip screw and plate. Injury. 1983 Sep;15(2):136-7.
27. **Howard CB, Davies RM.** Subtrochanteric fracture after garden screw fixation of subcapital fractures. J Bone Joint Surg Br. 1982;64(5):565-7.
28. **Stafford P, Goulet R, Norris B.** The effect of screw insertion site and unused drill holes on stability and mode of failure after fixation of basicervical femoral neck fracture. Crit Rev Biomed Eng. 2000;28(1-2):11-6.
29. **Lengsfeld M, Burchard R, Gunther D, Pressel T, Schmitt J, Leppek R, et al.** Femoral strain changes after total hip arthroplasty–patient-specific finite element analyses 12 years after operation. Med Eng Phys. 2005 Oct;27(8):649-54.
30. **Rohlmann A, Mossner U, Bergmann G, Kolbel R.** Finite-element-analysis and experimental investigation of stresses in a femur. J Biomed Eng. 1982 Jul;4(3):241-6.
31. **Booth KC, Donaldson TK, Dai QG.** Femoral neck fracture fixation: A biomechanical study of two cannulated screw placement techniques. Orthopedics. 1998 Nov;21(11):1173-6.
32. **Oakey JW, Stover MD, Summers HD, Sartori M, Havey RM, Patwardhan AG.** Does screw configuration affect subtrochanteric fracture after femoral neck fixation? Clin Orthop Relat Res. 2006 Feb;443:302-6.
33. **Selvan VT, Oakley MJ, Rangan A, Al-Lami MK.** Optimum configuration of cannulated hip screws for the fixation of intracapsular hip fractures: A biomechanical study. Injury. 2004 Feb;35(2):136-41.
34. **Zdero R, Keast-Butler O, Schemitsch EH.** A biomechanical comparison of two triple-screw methods for femoral neck fracture fixation in a synthetic bone model. J Trauma. 2010 Dec;69(6):1537-44.
35. **Cristofolini L.** A critical analysis of stress shielding evaluation of hip prostheses. Crit Rev Biomed Eng. 1997;25(4-5):409-83.
36. **Stolk J, Verdonschot N, Huiskes R.** Hip-joint and abductor-muscle forces adequately represent in vivo loading of a cemented total hip reconstruction. J Biomech. 2001 Jul;34(7):917-26.
37. **Noble PC, Box GG, Kamaric E, Fink MJ, Alexander JW, Tullos HS.** The effect of aging on the shape of the proximal femur. Clin Orthop Relat Res. 1995 Jul;(316)(316):31-44.

CONVERSION TOTAL HIP ARTHROPLASTY AFTER FAILED BASICERVICAL HIP FRACTURE FIXATION: A CASE REPORT AND REVIEW OF LITERATURE

Vineet Tyagi, MD[1], Oluwaseun Akinbo[2]

ABSTRACT

Proximal femur fractures are a common orthopedic injury, and it is estimated that their prevalence will continue to increase over the next twenty years. There has been much debate over the optimal management of basicervical fractures, which can be difficult to identify radiographically. There is also a role for conversion total hip arthroplasty in patients where fracture fixation fails. We present a case report of a proximal femur fracture managed as a basicervical fracture, and subsequently needing a conversion arthroplasty and revision surgery. We also review the literature to identify the complexities of basicervical fractures and conversion arthroplasty.

Key Words: fracture, basicervical, neck, conversion, arthroplasty

INTRODUCTION

Proximal femur fractures are becoming increasingly common as the patient population ages. There were approximately 340,000 hip fractures in 2008, with this number projected to increase to 580,000 by 2020[1]. These injuries often require operative management given the pain and functional limitations they cause for patients. Over half of these fractures are classified as intertrochanteric and approximately 1.8% are basicervical[2,3]. Basicervical fractures can be difficult to diagnose given their location, and as a result, they have varying definitions in the literature. Diagnostic descriptions include fractures that run along the anterior capsular attachment of the hip, to a fracture that runs through the base of the femoral neck where it meets the intertrochanteric region [4,5]. Another important consideration is the femoral calcar, which sits at the convergence of vertically-aligned trabeculae which travel superiorly and are involved with load-bearing in the femoral head[6]. This section of cortical bone is anisotropic and can withstand high loading forces in a longitudinal direction but is relatively weak when subjected to shear or tension forces in the transverse plane[7]. Fractures are classified as stable or unstable, with stability based on the structural integrity of the posterior femoral calcar.

There is also some debate whether these fractures are classified as intracapsular or extracapsular, and due to the difficulties in classification, there is considerable debate regarding the optimal surgical fixation of basicervical fractures. Intracapsular fractures can be treated with hemiarthroplasty or osteosynthesis screws. The main complications with intracapsular fractures are based on the vascularization of the femoral head and the lack of periosteum, which can contribute to impaired fracture healing and avascular necrosis[8]. Extracapsular fractures can be treated with sliding hip screws or cephalomedullary nails. In extracapsular fractures, the fixation construct is typically load-bearing as opposed to load-sharing. As a result, the main complication is typically screw cut-out[9]. The primary factors that predispose a patient to screw cut-out include low bone density, inadequate reductions, and fracture instability[10]. Certain radiographic features, such as lack of reduction in the sagittal plane and/or lack of medial support in patients with intramedullary fixation, may predispose to failure. Patients over 75 years old were also found to have rates of fixation failure and reoperation, possibly indicating that these patients should undergo hemiarthroplasty instead[11]. Conversion to total hip arthroplasty (THA) is typically a viable option in cases where there is osteonecrosis, nonunion, malunion, failure of fracture fixation, or post-traumatic arthritis[12].

CASE PRESENTATION

A 58-year-old male with a significant history of alcohol, polysubstance abuse, and suicidal attempts initially presented after sustaining a fall. He was diagnosed with a left basicervical femoral fracture and underwent surgical stabilization with a trochanteric cephalomedullary nail (Figure 1). He was subsequently lost to follow up until 10 months after his index surgery. Symptoms at this time

[1]Department of Orthopaedics and Rehabilitation, Yale University School of Medicine, New Haven, CT, USA

[2]Yale New Haven Hospital, New Haven, CT, USA

Corresponding Author:
Vineet Tyagi
800 Howard Avenue
New Haven, CT 06519
(551) 358-1959
vineet.tyagi@yale.edu

The authors have no conflicts of interest to disclose.

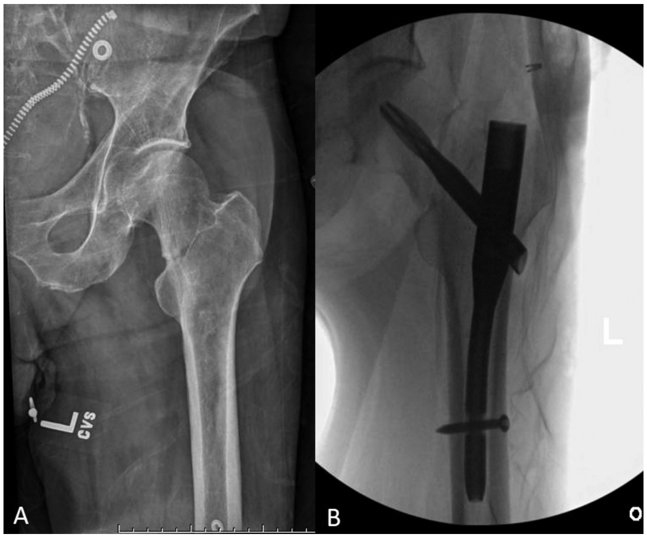


Figure 1. Radiographs showing the left hip (A) at time of fracture; (B) after placement of cephalomedullary nail.

Figure 2. Radiograph showing the left hip nine months postoperatively.

included pain with ambulation; ambulation was assisted with a cane. There was suspicion for a fracture non-union with plan to obtain confirmatory CT scan and surgical planning as necessary. A CT scan confirmed non-union, but did not show screw cut-out. He later presented to the medical intensive care unit for a suicidal attempt. During this admission the patient noted that his left hip pain had worsened and he had been nearly bedridden for the past few months. Radiographs revealed an impending screw cut-out of his fracture fixation (Figure 2). ESR, CRP levels were elevated (60mm/hr and 76.6mg/L respectively); he subsequently had a hip aspiration that was negative (no growth, no organisms seen on Gram stain). Following appropriate clearance, he was taken to the operating room for a conversion total hip arthroplasty through a posterior approach. Pre-operative plan was to implant a Stryker restoration modular stem to by-pass the distal screw hole of the nail, and a primary cup with revision shells and liner options available as necessary. Intraoperatively, he had cut out of his lag screw with multiple defects were noted in the anterior, posterior, and medial walls of the acetabulum. The femur was reconstructed with a Stryker restoration modular stem. The bone stock was poor, and good fixation could not be gotten in the acetabulum. A posterior wall fracture was then noted. Plan at this point was to fix the fracture, bone graft the defects, and obtain fixation with a revision shell with adjunct screw fixation. However, the fracture could not be fixed due to poor bone stock. Given this, adequate shell stability could not be obtained. As such, plan became to return at another time to perform a stable total hip arthroplasty utilizing an antiprotrusio cage for acetabular stability. Our facility does not keep antiprotrusio cages on shelf, and available pre-operative imaging studies did not indicate the need for one. Of note, radiographic studies performed days before surgery did not show cut-out or evidence of acetabular defects as encountered during surgery. Postoperative CT scan confirmed a posterior wall fracture (Figure 3). A pre-operative CT scan just prior to surgery might have evidenced findings encountered during surgery. The patient was brought back to the OR five days later for an implantation of an antiprotrusio cage. The defects were bone grafted. Multiple screws were used to affix the cage to the pelvis. The fixation was stable. A liner was then cemented in place. Fixation could not be achieved in the ischium because of an extremely poor bone stock (Figure 4). Post-operatively, he was made toe-touch weight bearing with posterior hip precautions. He was subsequently discharged home after approximately 2 weeks.

He returned to the hospital within a month from discharge, and was admitted for suicidal ideation. His course since surgery has been complicated by multiple and frequent admissions for various psychiatric issues including suicidal ideations, major depression, bipolar disorder, altered mental status, and substance abuse issues. However, he has done well with his hip. He

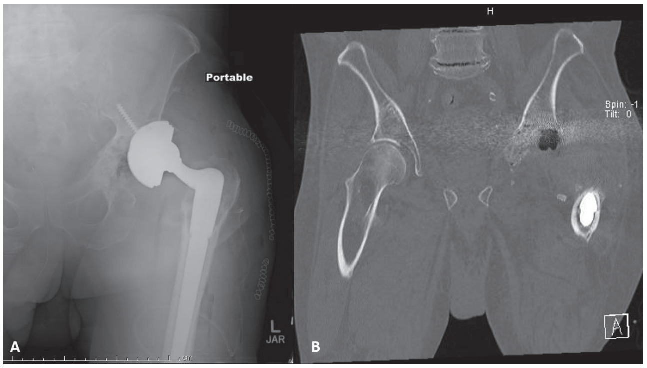


Figure 3: Images of the left hip (A) after conversion THA and (B) postoperative CT scan showing acetabular posterior wall defect.

Figure 4: Image of the left hip after removal of THA and implantation of acetabular cage and revision modular stem.

had physical therapy, and gradually progressed in his ambulatory status. At over a year from surgery, he has minimal pain, and ambulates with a cane.

DISCUSSION

Biomechanics of Treatments for Basicervical Femoral Fractures

Biomechanics play an important role in implant selection for basicervical fractures. Intramedullary devices such as gamma nails distribute loads from the hip through the entire femoral shaft, reducing concentrated forces that can cause implant failure. This provides the benefit of allowing patients to bear full weight in the immediate postoperative period. A cadaveric study of 24 femurs placed under hydraulic compression found that cephalomedullary nails were able to sustain more cycles of loading and a higher absolute load than DHS systems prior to failure[13]. Another study of six pairs of cadaveric femurs found that intramedullary constructs had no significant benefits over DHS systems with cyclical loading, but were superior in terms of varus/valgus angulation and rotation at the fracture site[14]. The stability of the fracture pattern has also been shown to play a significant role in the success of the implant. Intramedullary nails in unstable fracture patterns have been shown to fail with loads 28% lower than nails in stable fractures[15]. In addition, nails with multiple neck screws had less displacement under loads than those with one screw[16]. Another study of twelve cadaveric femurs found no difference in construct stiffness or failure under loading when comparing DHS and intramedullary nails, but recommended that intramedullary nails may be more suitable in unstable fracture patterns without medial support[17].

Extramedullary devices have also been analyzed for their effectiveness in fixation of femoral fractures. An experimental study of compression hip screws found that the load required to overcome the static frictional force between the plate and the femur was significantly higher with screw-plate angle of 130 degrees than with an angle of 150 degrees[18]. Therefore, the lower the screw-plate angle, the greater the compressive force that could be applied and provide fracture stability. In a study of twenty artificial femurs with stable and unstable intracapsular fractures, it was shown that sliding hip screw systems are not as effective as compression plates in unstable fractures when subjected to cyclic axial and torque loads. The screw systems which failed typically showed posterior rotation and retroverted varus deviation of the femoral head[19]. This may be due to the low rotational stability of DHS systems, which may be improved through additional cancellous screw placement[20].

Outcomes and Complications of Basicervical Fracture Fixation

The operative management of basicervical fractures varies based on whether they are approached as femoral neck fractures and treated with cancellous screws or hemiarthroplasty, or approached as intertrochanteric fractures and treated with DHS. Basicervical fractures, however, typically are more unstable than intertrochanteric fractures[21]. As a result, basicervical fractures treated with sliding hip screws do not address rotational stability[22,23]. A prospective study of 42 patients reported outcomes of patients with basicervical fractures, or equivalent fractures defined as trochanteric fractures where the head-neck section does not remain connected to the trochanters[24]. These patients, who were treated with a DHS and a derotational screw, were followed at preset intervals for 12 months postoperatively. 93% of patients had adequate reductions, defined as displacement less than 3 millimeters between fragments, and femoral neck angulation less than 10 degrees of varus or less than 15 degrees of valgus angulation compared to the contralateral side. There were no screw cut-outs, pull-outs, or breakage, and no patients required reoperation. In addition, 98% of patients reported no difference in range of motion compared to their other hip. A retrospective study of 28 basicervical fractures and 38 intertrochanteric fractures treated with DHS found that use of a derotational screw did not significantly affect fracture stability or clinical outcome[25]. Basicervical fractures had a higher rate of radiographic collapse than stable intertrochanteric fractures, but not unstable intertrochanteric fractures. These findings are likely secondary to the instability of basicervical fractures as shown in the above biomechanical studies.

A retrospective two-institution study of 28 patients concluded that cephalomedullary nail fixation had strong clinical outcomes in basicervical fractures[26]. With a mean follow-up time of 29 months, no screw cut-outs, femur fractures, or reoperations were required. Harris hip scores were good or very good in 67.9% of patients. The average time to clinical fracture healing, defined as no pain in the hip with mobilization, was six weeks. The study also found that the mean age of patients with a good reduction as defined by the Singh index on radiographs[27] was significantly lower than those with a poor reduction. These findings were confirmed by a retrospective review of 32 basicervical fractures treated with cephalomedullary nails[28]. 84% of fractures had no displacement or loss of reduction one year postoperatively. No patients had avascular necrosis of the femoral head or cut-out.

Pascarella et al looked at 321 intertrochanteric and basicervical fractures and found that the most common intraoperative complications were either incorrect fracture reduction or incorrect lag screw positioning. It was recommended that patients be appropriately positioned on a fracture table and reduction achieved preoperatively to avoid inadequate reductions. Another recommendation was 10 degrees of internal rotation of the extremity to aid with reduction. The femoral canal should be reamed 2 mm larger than the distal nail diameter to avoid intraoperative fractures. Axial fluoroscopic views were deemed essential to aid in lag screw position. Poor lag screw positioning led to the most common postoperative complication, which was implant cut-out. Ideal lag screw position is in the lower portion of the femoral head on the frontal plane and in the midline on the lateral plane. Entry points that are lateral to the tip of the greater trochanter can lead to medial cortex stress when the nail is inserted, leading to fractures. In obese patients, it may be useful to mark the greater trochanter with a Kirschner wire under fluoroscopy[29]. Other recommendations to improve outcomes include using tibial or distal femoral traction to aid with reduction and minimize soft tissue tension[28].

Outcomes and Complications of Conversion Total Hip Arthroplasty

In patients with non-displaced fractures or younger patients with displaced fractures, internal fixation has been shown to be highly successful[30]. Internal fixation, however, can still fail secondary to osteonecrosis, nonunion, infection, or symptomatic hardware. In cases of failure, conversion total hip arthroplasty can be a viable treatment option. A study of 102 conversion THAs for failed femoral neck fracture fixation found that clinical outcomes were promising, with a mean Harris hip score of 81.8 with an average follow-up of 3.2 years[12]. The study found that about 12% of patients suffered from early surgical complications, with the most common being infections and periprosthetic fractures. A retrospective review by Bercik et al compared outcomes of conversion THAs for femoral neck fractures initially fixed with DHS versus cephalomedullary nails. There was no difference in mean length of hospital stay or blood products used, but operative time was longer and blood loss was higher for patients in the CMN group. The study also found that that significantly more patients in the DHS group were implanted with metaphyseal-fit stems, compared to more diaphyseal-fit stems in CMN patients[31]. To implant an intramedullary nail, the metaphyseal cancellous bone must be reamed, often times precluding future metaphyseal fixation of a femoral stem if a conversion THA is necessary. Therefore, the authors concluded that conversions from CMN are similar to revision stem placement, and may be technically more difficult. CMN placement violates the abductor mechanism and this can cause persistent hip pain which may persist even after conversion THA[32,33].

CONCLUSION

Conversion total hip arthroplasties are complex surgical procedures now being increasingly recognized as revision arthroplasties[12]. Proper identification of fracture patterns and proper fixation could help reduce the incidence or need for conversion THA. In our case, a hemiarthroplasty might have been a better construct for a fracture that is arguably an intracapsular femoral neck fracture. Obtaining preoperative CT scans soon before surgery can aid in assessment of bone stock or the presence of fractures or acetabular defects. Typically, it can be expected that the bone stock in these cases will be deficient because these patients have been restricted weight bearing. A very strong press-fit might not be feasible, and screw fixation might be very important. Bipolar hemiarthroplasty should be a consideration. Lastly, cephalomedullary nails are difficult to remove and their removal can result in complications during conversion THA; as such it might be prudent to use sliding hip screw constructs in stable fracture patterns[31].

REFERENCES

1. **Pui, C.M., et al.**, Increased complication rate following conversion total hip arthroplasty after cephalomedullary fixation for intertrochanteric hip fractures: a multi-center study. J Arthroplasty, 2013. 28(8 Suppl): p. 45-7.
2. **Koval, K.J., et al.**, Patients with femoral neck and intertrochanteric fractures. Are they the same? Clin Orthop Relat Res, 1996(330): p. 166-72.
3. **Saarenpaa, I., J. Partanen, and P. Jalovaara**, Basicervical fracture–a rare type of hip fracture. Arch Orthop Trauma Surg, 2002. 122(2): p. 69-72.
4. **Blair, B., et al.**, Basicervical fractures of the proximal femur. A biomechanical study of 3 internal fixation techniques. Clin Orthop Relat Res, 1994(306): p. 256-63.
5. **Parker MJ, P.G., Thorngren K-G**, Extramedullary fixation of extracapsular fractures, in Handbook of hip fracture surgery. 1997, Butterworth-Heinemann: Oxford. p. 63-90.
6. **Lotz, J.C., E.J. Cheal, and W.C. Hayes**, Stress distributions within the proximal femur during gait and falls: implications for osteoporotic fracture. Osteoporos Int, 1995. 5(4): p. 252-61.
7. **Sheehan, S.E., et al.**, Proximal Femoral Fractures: What the Orthopedic Surgeon Wants to Know. Radiographics, 2015. 35(5): p. 1563-84.
8. **Damany, D.S., M.J. Parker, and A. Chojnowski**, Complications after intracapsular hip fractures in young adults. A meta-analysis of 18 published studies involving 564 fractures. Injury, 2005. 36(1): p. 131-41.
9. **Anglen, J.O. and J.N. Weinstein**, Nail or plate fixation of intertrochanteric hip fractures: changing pattern of practice. A review of the American Board of Orthopaedic Surgery Database. J Bone Joint Surg Am, 2008. 90(4): p. 700-7.
10. **Barrios, C., et al.**, Healing complications after internal fixation of trochanteric hip fractures: the prognostic value of osteoporosis. J Orthop Trauma, 1993. 7(5): p. 438-42.
11. **Weil, N.L., D. van Embden, and J.M. Hoogendoorn**, Radiographic fracture features predicting failure of internal fixation of displaced femoral neck fractures. Eur J Trauma Emerg Surg, 2015. 41(5): p. 501-7.
12. **Archibeck, M.J., et al.**, Total hip arthroplasty after failed internal fixation of proximal femoral fractures. J Arthroplasty, 2013. 28(1): p. 168-71.
13. **Rupprecht, M., et al.**, A comparative biomechanical analysis of fixation devices for unstable femoral neck fractures: the Intertan versus cannulated screws or a dynamic hip screw. J Trauma, 2011. 71(3): p. 625-34.
14. **Roderer, G., et al.**, Side plate fixation vs. intramedullary nailing in an unstable medial femoral neck fracture model: A comparative biomechanical study. Clin Biomech (Bristol, Avon), 2011. 26(2): p. 141-6.
15. **Eberle, S., et al.**, The stability of a hip fracture determines the fatigue of an intramedullary nail. Proc Inst Mech Eng H, 2010. 224(4): p. 577-84.
16. **Vidyadhara, S. and S.K. Rao**, Cephalomedullary nails in the management of ipsilateral neck and shaft fractures of the femur--one or two femoral neck screws? Injury, 2009. 40(3): p. 296-303.
17. **Weiser, L., et al.**, Extra- vs. intramedullary treatment of pertrochanteric fractures: a biomechanical in vitro study comparing dynamic hip screw and intramedullary nail. Arch Orthop Trauma Surg, 2015. 135(8): p. 1101-6.
18. **Kyle, R.F., T.M. Wright, and A.H. Burstein**, Biomechanical analysis of the sliding characteristics of compression hip screws. J Bone Joint Surg Am, 1980. 62(8): p. 1308-14.
19. **Brandt, E., et al.**, Biomechanical analysis of the percutaneous compression plate and sliding hip screw in intracapsular hip fractures: experimental assessment using synthetic and cadaver bones. Injury, 2006. 37(10): p. 979-83.
20. **Swiontkowski, M.F., et al.**, Torsion and bending analysis of internal fixation techniques for femoral neck fractures: the role of implant design and bone density. J Orthop Res, 1987. 5(3): p. 433-44.
21. **Gill, J.M., et al.**, Biomechanical aspects of the repair of intertrochanteric fractures. J Biomed Eng, 1989. 11(3): p. 235-9.
22. **Ort, P.J. and J. LaMont**, Treatment of femoral neck fractures with a sliding compression screw and two Knowles pins. Clin Orthop Relat Res, 1984(190): p. 158-62.
23. **Ly, T.V. and M.F. Swiontkowski**, Management of femoral neck fractures in young adults. Indian J Orthop, 2008. 42(1): p. 3-12.
24. **Massoud, E.I.E.**, Fixation of basicervical and related fractures. Int Orthop, 2010. 34(4): p. 577-82.
25. **Su, B.W., et al.**, Basicervical versus intertrochanteric fractures: an analysis of radiographic and functional outcomes. Orthopedics, 2006. 29(10): p. 919-25.

26. **Tasyikan, L., et al.**, Short-term results of surgical treatment with cephalomedullary nails for basicervical proximal femoral fractures. Acta Orthop Belg, 2015. 81(3): p. 427-34.
27. **BD Browner, J.J., AM Levine, PG Trafton, C Krettek**, Skeletal trauma. 4th ed, ed. S.E. Press. 2009, Philadelphia.
28. **Hu, S.-j., G.-r. Yu, and S.-m. Zhang**, Surgical Treatment of Basicervical Intertrochanteric Fractures of the Proximal Femur with Cephalomeduallary Hip Nails. Orthopaedic Surgery, 2013. 5(2): p. 124-129.
29. **Pascarella, R., et al.**, Methods to avoid gamma nail complications. Chir Organi Mov, 2008. 91(3): p. 133-9.
30. **Schmidt, A.H., et al.**, Femoral neck fractures. Instr Course Lect, 2005. 54: p. 417-45.
31. **Bercik, M.J., et al.**, Conversion total hip arthroplasty: a reason not to use cephalomedullary nails. J Arthroplasty, 2012. 27(8 Suppl): p. 117-21.
32. **Gardner, M.J., et al.**, Anatomy of the greater trochanteric 'bald spot': a potential portal for abductor sparing femoral nailing? Clin Orthop Relat Res, 2008. 466(9): p. 2196-200.
33. **Hesse, B. and A. Gachter**, Complications following the treatment of trochanteric fractures with the gamma nail. Arch Orthop Trauma Surg, 2004. 124(10): p. 692-8.

RADIOGRAPHIC RISK FACTORS FOR INTERPROSTHETIC FEMUR FRACTURES

Jason S Lipof, MD, Ari D Amitai, MD, Kyle T Judd, MS MD*, John T Gorczyca, MD

ABSTRACT

Purpose: Total hip arthroplasty (THA) and total knee arthroplasty (TKA) are among the most common orthopaedic procedures performed in the United States annually. As the number of patients undergoing these procedures increases so too does the incidence of periprosthetic femur fractures. A number of these periprosthetic fractures occur between two ipsilateral implants, so-called interprosthetic fractures. Recent biomechanical data has challenged the importance of these interprosthetic distances, relating that cortical width and osteoporotic bone are more closely correlated with fracture than interprosthetic distance. The purpose of the current study is to further define the presence of osteoporosis, cortical width (CW) and medullary diameter (MD) as potential predictive factors for interprosthetic femur fractures.

Methods: Current Procedural Terminology (CPT) codes were used to identify a cohort of patients undergoing operative treatment for periprosthetic femur fractures. A review of the medical records identified 23 patients (5 male / 18 female) with a femur fracture between two intramedullary implants. CPT codes were also used to identify a second cohort of 25 patients (8 male / 17 female) having undergone ipsilateral THA and TKA. The intact femoral isthmus was identified radiographically and the MD and CW (mm) were measured. A ratio of MD to CW was also determined. Chart review was undertaken and any diagnosis of osteoporosis was recorded. An independent sample T-test was performed comparing the mean MD, CW, and the ratio of MD:CW for these groups. Significance was set at p.

Keywords: trauma, periprosthetic, osteoporosis, femur fracture, interprosthetic

INTRODUCTION

Total hip arthroplasty (THA) and total knee arthroplasty (TKA) are among the most common orthopaedic surgical procedures performed in the United States, with over 1 Million combined procedures performed each year.[1] The population of "baby boomers" continues to age and the incidence of symptomatic end stage arthritis requiring total joint arthroplasty increases in turn. As the average life span continues to increase, the number of years spent living with total joint arthroplasty also increases. A 2010 study by Kremers et al.[2] estimated about 7 million Americans or about 2% of the American population is currently living with either total hip or total knee replacement. An estimated 620,000 of these individuals have undergone both a THA and TKA.

With an increase in the elderly population, the number of fragility fractures is also expected to continue to increase. Of these fragility fractures, fractures of the hip are of the most common with over 300,000 patients greater than 65 years of age being hospitalized for hip fractures in the United States each year[3] Despite the relatively high incidence of native hip fracture, periprosthetic femur fractures seem to occur at relatively low rates, with THA periprosthetic factures occurring at a rate of 0.1%-6% and TKA periprosthetic fractures occurring at a rate of 0.3%-5.5% in those having undergone the respective procedure. Kenny et al.[4] estimated the incidence of interprosthetic femur fractures to be about 1.25%. (Figure 1)

Historically, risk factors associated with periprosthetic femur fractures have included osteoporosis, osteomalacia, chronic steroid use, rheumatic disease, loosening of implants, press-fit implants, distance between implants, angular malalignment and surgeon experience.[5,6] Several studies have sought to understand the biomechanics of intact bone when ipsilateral femoral implants are present. These studies have reported that cortical width and osteoporotic bone are more closely correlated with fracture risk than interprosthetic distance.[7,8] To date, there have been limited clinical evaluations aimed at further defining the relationship of cortical width, medullary diameter, and presence of osteoporosis to the risk of interprosthetic femur fractures.

The purpose of the current study is to further define the presence of osteoporosis, cortical width and

*Corresponding author
Kyle T Judd, MS MD
601 Elmwood Ave, Box 665
Rochester, NY 14642
kyle_judd@urmc.rochester.edu
585-275-5321

The authors of this paper have no disclosures or conflicts of interest of any kind.

Figure 1. Example of an interprosthetic femur fracture – a fracture that occurs between two ipsilateral intramedullary implants

medullary diameter as potential predictive factors for interprosthetic femur fractures in patients with ipsilateral intramedullary implants.

Our hypothesis is that smaller cortical width and larger medullary diameter are risk factors for interprosthetic femur fractures.

Figure 2. Identification of the femoral isthmus and measurement of the medullary diameter in millimeters, utilizing the PACS system

METHODS

This study was approved by our local Institutional Review Board (IRB). Billing records were reviewed for Current Procedural Terminology (CPT) codes to identify patients who had undergone operative treatment of femur fractures over a ten year period from 2005 to 2015. A chart review was then conducted to identify a cohort of patients that had sustained interprosthetic femur fractures. Inclusion criteria were operative treatment of a periprosthetic femur fracture occurring between two ipsilateral femoral implants and sufficient perioperative radiographic studies. A total of 23 patients (5 male and 18 female) met inclusion criteria. CPT codes were then used to identify a second cohort of 25 patients, 8 male and 17 female, who had undergone ipsilateral THA and TKA who had not sustained a femur fracture.

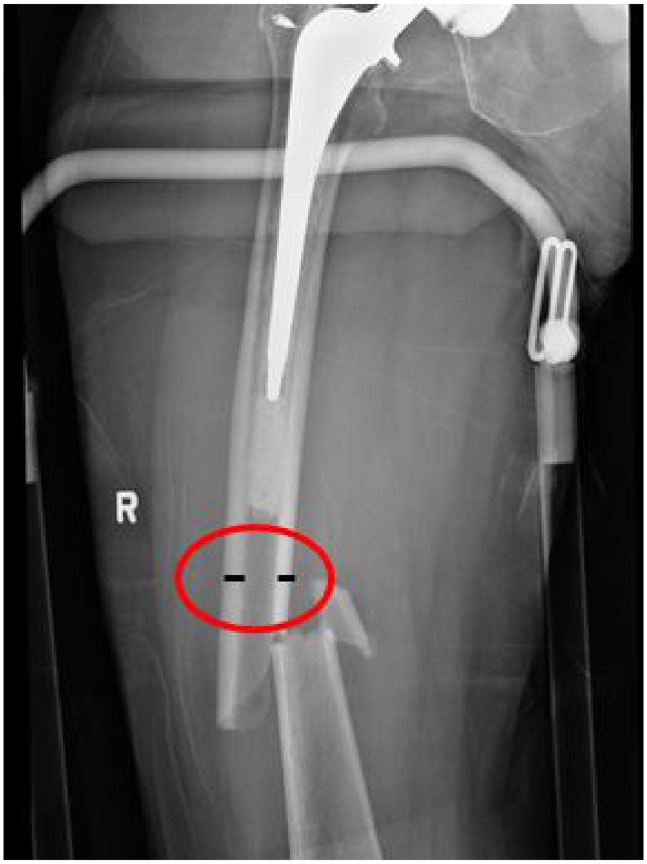


Figure 3. Identification of the femoral isthmus and measurement of the cortical width in millimeters, utilizing the PACS system

Radiographic measurement consisted of identification of the intact femoral isthmus on anteroposterior radiographs and measurement of the medullary diameter (mm) (Figure 2) and cortical width (mm) (Figure 3) utilizing the Picture Archiving and Communication System (PACS) measurement tool. A ratio of medullary diameter (MD) to cortical width (CW) was also determined for each patient at the point of measurement.

Further chart review was also undertaken to determine demographic information, presence of pre-existing diagnosis of osteoporosis and prior DEXA results if available. An independent sample T-test was performed, comparing the mean MD, CW, and the ratio of MD-to-CW for the two cohorts. Statistical significance was set at $P<0.05$ and confidence interval of 95%.

RESULTS

Of the 23 patients comprising the interprosthetic femur fracture group, 21 patients had undergone THA and 2 patients had non-arthroplasty intramedullary implants. Six of the 21 THA prostheses (26%) were cemented and 15 were press-fit implants. The two remaining implants were cephalomedullary devices. Seven patients (30%) in the fracture group carried a formal diagnosis of osteoporosis. Of the 25 patients comprising the control group that did not sustain a fracture, all had undergone press-fit THA, with the exception of one femoral implant which was cemented. Six patients (24%) in the control group carried a formal diagnosis of osteoporosis. (Table 1)

Table I. Demographic data of the Fracture and Intact cohorts

	Interprosthetic Fractures (n=23)	Intact Cohort (n=25)
Age	82	72
Sex	Female 18 Male 5	Female 17 Male 8
Cemented Implant	6 (26%)	1 (4%)
Diagnosis of Osteoporosis	7 (30%)	6 (24%)

Those patients sustaining an interprosthetic femur fracture were found to have significantly narrower cortices at the isthmus with a mean of 12.2mm compared to a mean of 16.7mm in the control group ($P<0.0001$). These patients were also found to have, on average, significantly wider medullary canals measuring 21.3mm compared to 14.8mm ($P<0.0001$) in the intact group. The significance of these variables were maintained when standardizing between patient radiographs using the ratio of medullary diameter to cortical width with a mean ratio of 1.86 compared to 0.96 in the intact group ($P<0.0001$) (Table 2). Intraclass correlation was evaluated between two experienced surgeons for measurement of both cortical width and medullary diameter. The intraclass correlation coefficient was calculated and demonstrated good-to-excellent agreement between the two surgeons (Table 3).

DISCUSSION

Total joint arthroplasty and intramedullary fracture fixation have become increasingly common over the past several decades. As the average life span continues to increase the portion of the population living with ipsilateral intramedullary implants is also likely to increase. The incidence of periprosthetic and interprosthetic fractures is projected to increase as the prevalence of ipsilateral intramedullary fracture fixation implants and total joint arthroplasty increase.[5,6] As a consequence, orthopaedic surgeons will be tasked with treating these complex fractures with increasing frequency.[10]

In the current study patients sustaining interprosthetic femur fractures were found to have significantly narrower femoral cortices at the isthmus compared to those with

Table II. Cortical Width, Medullary Diameter and MD:CW ratio for Fracture and Intact cohorts

Measurement	Interprosthetic Fractures (n=23)		Intact Cohort (n=25)		Statistical Significance	
	Mean	SD	Mean	SD	P-value	95% of difference
Cortical Width (mm)	12.26	2.55	16.74	3.9	<0.0001	(-6.42, -2.55)
Medullary Diameter (mm)	21.3	4.15	14.81	3.19	<0.0001	(4.34, 8.62)
MD:CW	1.86	0.76	0.96	0.41	<0.0001	(0.55, 1.25)

Table III. Intraclass Correlation Coefficient – assessment of intraobserver reliability

	CW Intraclass Correlation	95% Confidence Interval		MD Intraclass Correlation	95% Confidence Interval	
		Lower Bound	Upper Bound		Lower Bound	Upper Bound
Single Measures	.669	0.362	0.845	.871	0.721	0.943
Average Measures	.801	0.532	0.916	.931	0.838	0.971

ipsilateral implants and intact femurs (P<0.0001). Those sustaining interprosthetic fractures were also found to have significantly wider femoral medullary diameters at the isthmus (P<0.0001) compared to their uninjured counterparts. An increased medullary diameter to cortical width ratio was also found to be statistically significant (P<0.0001) demonstrating that this significance is maintained when standardizing for magnification.

These findings confirm our hypothesis and correlate with previous biomechanical data suggesting decrease in bone strength with narrowing of the cortical width and increase in medullary diameter. These simple radiographic markers of bone strength should be considered when indicating patients for either THA or TKA in the presence of a pre-existing ipsilateral femoral implant. Those with radiographically decreased cortical width, increased medullary diameter, and increased medullary diameter to cortical width ratio may be at increased risk of interprosthetic fracture as these findings may be indicative of an overall decrease in the strength of the remaining intact femur. The prevalence of osteoporosis may be underappreciated in patients sustaining interprosthetic femur fractures as highlighted by the fact that despite significantly narrower cortices and wider medullary diameters, the presence of a formal diagnosis of osteoporosis was similar between the two groups. Given the radiographic findings described in the fracture group, the presence of osteoporosis would likely be much higher than the rate at which it had been documented. These findings underscore the heightened need for metabolic bone screening in this at risk population, as this group of patients is likely undertreated for osteoporosis.

Limitations of this study include inability to effectively measure interprosthetic distance, as medical center radiographic imaging does not routinely obtain full limb-segment films. The radiographs were not electronically calibrated, and variation between them may exist. As this study was a retrospective review, the authors were limited by information available at the time of review and reliant on the accuracy of the medical record at the time of data collection.

CONCLUSION

Decreased cortical width and increased medullary diameter may be predictive of interprosthetic fracture as significant differences between fracture patients and those with intact femora exist.

REFERENCES

1. **Steiner C, Andrews R, Barrett M, Weiss A.** HCUP Projections: Mobility/Orthopedic Procedures 2003 to 2012. 2012. HCUP Projections Report # 2012-03. 2012 Sep 20. U.S. Agency for Healthcare Research and Quality.http://hcup-us.ahrq.gov/reports/projections/2012-03.pdf.. [Context Link]
2. **Kremers, Hilal Maradit, et al.** "Prevalence of total hip and knee replacement in the United States." J Bone Joint Surg Am 97.17 (2015): 1386-1397.
3. HCUPnet. Healthcare Cost and Utilization Project (HCUP). 2012. Agency for Healthcare Research and Quality, Rockville, MD. http://hcupnet.ahrq.gov. Accessed 5 August 2016
4. **Kenny, P., J. Rice, and W. Quinlan.** "Interprosthetic fracture of the femoral shaft." The Journal of arthroplasty 13.3 (1998): 361-364.

5. **Erhardt, J. B., et al.** "Treatment of periprosthetic femur fractures with the non-contact bridging plate: a new angular stable implant." Archives of orthopaedic and trauma surgery 128.4 (2008): 409-416.
6. **Berry, Daniel J.** "Epidemiology: hip and knee." Orthopedic Clinics of North America 30.2 (1999): 183-190.
7. **Iesaka, Kazuho, Frederick J. Kummer, and Paul E. Di Cesare.** "Stress risers between two ipsilateral intramedullary stems: a finite-element and biomechanical analysis." The Journal of arthroplasty 20.3 (2005): 386-391.
8. **Lehmann, Wolfgang, et al.** "Biomechanical evaluation of peri-and interprosthetic fractures of the femur." Journal of Trauma and Acute Care Surgery 68.6 (2010): 1459-1463.
9. **Dixon, T., et al.** "Trends in hip and knee joint replacement: socioeconomic inequalities and projections of need." Annals of the rheumatic diseases 63.7 (2004): 825-830.
10. **Sah, Alexander P., et al.** "Interprosthetic fractures of the femur: treatment with a single-locked plate." The Journal of arthroplasty 25.2 (2010): 280-286.

PERIOPERATIVE CONSIDERATIONS WHEN TREATING ISOLATED PERIPROSTHETIC DISTAL FEMUR FRACTURES

Michael S. Reich MD, Mindy Duong BS, Mary A. Breslin BA, Mai P. Nguyen MD, Heather A. Vallier MD

ABSTRACT

Background: Periprosthetic distal femur (PPDF) fractures occur most frequently via low energy mechanisms in elderly patients. This population is often frail and ill-suited to the physiologic burden of trauma and surgery. Here, we describe the perioperative and early hospital course for patients with PPDF fractures, and identify risk factors for poor outcomes.

Methods: Consecutive patients with isolated PPDF fractures from 2005 – 2015 were treated operatively at a Level I trauma center. Perioperative records were reviewed. Complications included wound complications, cardiac complications, pneumonia, thromboembolic events, urinary tract infections (UTIs), sepsis, multiple organ failure, death, and 90-day readmissions.

Results: Thirty-nine patients were treated operatively for isolated PPDF fractures. Mean age was 75.1 years old, 87.2% were women, and 92.3% occurred after falls from standing. Average American Society of Anesthesiologists score was 3.0. Thirty-six patients underwent open reduction and internal fixation with a mean operative time of 108 minutes. Excluding outliers, mean LOS was 4.6 days. Patients admitted to the ICU had longer LOS (p=0.03). Complications occurred in 17.9% of patients, including cardiac events (12.8%) and (5.1%) deaths.

Conclusions: Patients with PPDF fractures frequently have underlying medical comorbidities. A complicated and/or protracted hospital course is not uncommon. Further study to optimize treatment appears warranted.

Level of evidence: Prognostic, level 4.

Corresponding author:
Heather A. Vallier, MD,
Department of Orthopaedic Surgery
2500 MetroHealth Drive,
Cleveland, OH 44109
Tel: (216) 778-7361
Fax: (216) 778-4690
Email: hvallier@metrohealth.org

Affiliation (all authors):
Study performed at MetroHealth Medical Center, Department of Orthopaedic Surgery, affiliated with Case Western Reserve University, 2500 MetroHealth Drive, Cleveland, OH 44109, USA

INTRODUCTION

Periprosthetic distal femur (PPDF) fractures represent a devastating fracture pattern. With the frequency of total knee arthroplasty (TKAs) increasing,[1] so too will the incidence of PPDF fractures. When occurring in elderly patients, they can be considered a fragility fracture, and this patient population also has high rates of medical comorbidities. Treatment of these fractures is associated with extensive morbidity, mortality, and costs. As they become more common, it is imperative that the treating physicians understand how to optimize care.

Although perioperative morbidity and mortality for PPDF fractures may be extrapolated from similar fragility fractures such as non-periprosthetic distal femur fractures and hip fractures, there is a paucity of data focusing primarily on patients with PPDF fractures. In their cohort of distal femur fractures, Streubel et al. demonstrated a 23% one-year mortality for non-periprosthetic DF fractures and a 27% one-year mortality rate for PPDF fractures.[2] When compared to elderly patients undergoing open reduction internal fixation (ORIF) for femoral neck fractures, elderly patients undergoing ORIF for DF fractures were found to have similar rates of any adverse events, serious adverse events, infectious complications, hospital length of stay (LOS), and mortality rates.[3]

Similar to treating elderly patients with hip fractures, optimizing perioperative medical management and facilitating care to get these patients to the operating room expediently is of utmost importance. Perioperative pathways and multi-disciplinary management has been shown to decrease morbidity in hip fracture patients,[4-5] and it follows that this would affect patients with PPDF fractures, as well. Here we present over ten years of our experience in treating patients with PPDF fractures seeking to better characterize the perioperative course for patients with PPDF fractures and to define variables associated with poorer outcomes. In turn, this may lead to the future development of algorithms to optimize care.

METHODS

The protocol for this study was approved by the Institutional Review Board, and all patients or guardians provided consent for participation. We retrospectively reviewed consecutive patients who were treated for isolated PPDF fractures at a Level I trauma center from 2005 – 2015. Fifty-six patients suffered 60 PPDF fractures. Patients were excluded for either nonoperative treatment (N=8 patients, including one patient with bilateral PPDF fractures) or concurrent pathology that could reasonably affect the perioperative course (N=9 patients) including: seven patients with multiple lower extremity fractures including two with bilateral PPDF fractures; one patient with a recurrent, ipsilateral PPDF fracture; one patient with diffuse bodily burns; and one patient with a prior history of extensive knee surgery including extensor mechanism reconstruction. Thirty-nine patients had isolated PPDFs treated operatively and these patients are considered in the final data analysis.

Medical charts, including operative notes, preoperative radiographs, and anesthesia records, were reviewed. Demographic data, comorbidities, and MOI were noted. Total LOS and intensive care unit (ICU) stays were recorded. Perioperative data included estimated blood loss (EBL), surgery duration, surgical procedure, and total time of anesthesia care. Preoperative imaging was assessed using the Lewis and Rorabeck classification[6]. Complications were screened for 90-days after initial presentation and included wound complications, cardiac complications, pneumonia, deep vein thrombosis (DVT), pulmonary embolism (PE), sepsis, urinary tract infections (UTIs), multiple organ failure, death, and 90-day readmissions. Final dispositions were recorded, and if a patient was readmitted within 90-days, the level of care required at final discharge was used in analysis.

Data was analyzed using GraphPad (GraphPad Software, Inc., La Jolla, CA) and Microsoft Excel (Microsoft Corp., Redmond, WA). Chi-square tests, t-tests, Fisher exact tests, and Mann Whitney U tests were performed when appropriate. Statistical significance was set to $p<0.05$.

RESULTS

Demographics

Thirty-nine patients were treated operatively for isolated PPDF fractures. They were mostly female (87.2%) with an average age of 75.1±11.8 y/o (range: 46 – 92 y/o) who suffered falls from standing (92.3%). Mean body mass index was 30.1±8.8. Mean ASA score was 3.0±0.6; 46.2% had a cardiac comorbidities, 25.6% were diabetics, and 20.5% had chronic obstructive pulmonary disease (COPD). There were two patients (5.1%) each with chronic kidney disease (CKD) and moderately-severe aortic stenosis (AS). Substance use included: 18.2% (6/33) current smokers, 25.0% (7/28) consuming alcohol, and 4.3% (1/23) using illicit substances.

Fracture characteristics and operative treatment

Thirty-eight (97.4%) patients had closed fractures. Preoperative radiographs were available for 37 patients, and 35 (94.6%) had Rorabeck type II fractures; there was one type I and one type III fracture. Patients with stable prostheses (N=36) were treated with a locking condylar plate (N=21, 58.3%), angled blade plate (N=11, 30.6%), locking large fragment plate (N=1, 2.8%), or retrograde intramedullary nail (N=1, 2.8%). There were two patients who underwent primary trans-femoral amputations: one patient was septic with chronic peripheral vascular disease and cellulitis of the fractured extremity, and the amputation was performed in a life-saving effort; the other patient was on hospice care with an open PPDF fracture, and amputation was elected. The type III fracture was treated with a revision TKA. Overall, most patients (N=31, 79.5%) underwent surgical intervention within one day of presentation; most surgical delays were related to preoperative medical optimization. All patients who were delayed three or more days after presentation (hospital day four or five) had cardiac comorbidities ($p=0.01$). For patients who underwent ORIF, mean anesthesia time was 172±38 minutes and 94.4% had a general endotracheal intubation; operative time was 108±25 minutes with median estimated blood loss (EBL) of 200 mLs (interquartile range (IQR): 137.5 – 250 mLs, range 10 – 1000 mLs).

Perioperative hospitalization course and complications

Excluding one outlier patients who was admitted for 25 days, average initial LOS was 4.6±1.2 days. Five patients required ICU admissions, and ICU admission was associated with longer total hospitalization ($p=0.03$). Both patients with moderately-severe AS required ICU admission ($p=0.01$).

Seven (17.9%) patients had at least one perioperative acute medical complication (Table 1). The most common complications were cardiac events (N=5, 12.8%), including three patients with acute myocardial infarction (AMI), one with new onset of supraventricular tachycardia, and one with intraoperative cardiac arrest leading to anoxic brain injury. Patients with cardiac comorbidities ($p<0.001$) and moderately-severe AS ($p=0.01$) were more likely to have cardiac complications. No patients developed thromboembolic events or wound complications. Excluding one acute postoperative death and four patients with inadequate follow-up, four (11.8%) patients returned to the hospital within 90 days of their initial presentation. Reasons for readmission included: AMI,

Table I. Complications

	N (%)
Anoxic brain injury	1 (2.6%)
Cardiac	5 (12.8%)
Clostridium difficile infection	2 (5.1%)
Death	2 (5.1%)
Deep vein thrombosis	0 (0.0%)
Gastro-intestinal	1 (2.6%)
Pneumonia	1 (2.6%)
Pulmonary	3 (7.7%)
Pulmonary embolism	0 (0.0%)
Renal	1 (2.6%)
Sepsis	2 (5.1%)
Urinary tract infection	3 (7.7%)
Wound infections	0 (0.0%)

sequelae of anoxic brain injury, pain, pneumonia and septic shock; three patients required full admissions. In total, there were two (5.1%) deaths (one during the a patient's initial hospitalization and one after readmission) and one discharge to a long-term acute care facility.

DISCUSSION

Treatment of PPDF fractures is difficult, as complex fracture patterns are common and patients are medically complicated. Perioperative courses are challenging, and complications occur often. In order to provide our patients with the best care possible, multi-specialty collaborations are necessary, but care must be provided promptly.

Protocols are in place at our hospital to streamline care of patients who present to the emergency department.[7-8] A multi-disciplinary approach to treating trauma patients is involved, and care is initiated frequently even before the patients arrives (ie: after the trauma system has been activated or after the call from a transferring facility). For the geriatric population, medicine co-management is the norm and has been shown to decrease perioperative morbidity.[4-5] Patients are efficiently optimized for surgery, which is evidenced by the majority of patients having surgery on the day of, or the day after presentation. However, there is a delicate balance between medical optimization and expeditious surgery, as recent literature suggests some aspects of medical work-ups may lead to increased costs, surgical delays, and overall LOS without reducing complications or improving outcomes.[9-10] Surgical delays have been associated with increased mortality in this population,[11-14] emphasizing the need for communication and teamwork between medical and surgical services.

From the surgeon's perspective, how to treat these patients represents a difficult decision. After conversations among the treating surgeon, patients, and families, nonoperative care was elected in eight patients. Due to a number of factors including ambulatory status, comorbidities, fracture complexity, and quality of life expectations, these decisions were made. Two patients required trans-femoral amputations for life-saving and palliative reasons. Of those who underwent ORIF, the majority were treated with plate and screw constructs. In order to prevent implant failure prior to healing, two to three months of non-weight bearing is frequently necessary. Elderly patients have difficulty complying with restricted weight-bearing, and immobility and non-weight bearing cause further deconditioning.[15-16] In patients with hip fractures, prolonged immobility is associated with worse postoperative function and increased mortality.[17] However, unlike hip fracture patients who have more stable implant-osseous constructs or have prostheses, patients with PPDF fractures have the potential for a more difficult postoperative rehabilitation course.

Our data supports the premise that patients with PPDF fractures are frequently unwell at the time of injury. In elderly patients with fragility fractures, multiple preoperative comorbidities or an ASA class of 3 or 4 yields higher risk for postoperative complications and mortality.[18-19] Not unexpectedly, here we found that a preoperative cardiac comorbidity placed patients at increased risk of developing a cardiac complication. In general, patients with moderately-severe AS are particularly susceptible to perioperative complications. After non-cardiac surgery, AS has been shown to increase the risk of nonfatal AMI and mortality.[20-21] It follows that we found moderately-severe AS to be associated with cardiac complications and ICU admissions.

Substance use in known to affect outcomes in patients undergoing orthopaedic procedures. The effects of tobacco and alcohol use on perioperative complications in orthopaedic patients has been well described. In arthroplasty patients, patients who smoke and consume alcohol are at an increased risk of systemic postoperative complications;[22-24] smoking has been linked to increased ICU requirements.[25] Unfortunately, our data is underpowered to draw an association between either smoking or alcohol use and complications.

Available literature focusing directly on the perioperative course of patients with PPDF fractures is limited. To our knowledge, this represents the first dedicated study on this subject. Our data is strengthened in that we have 39 patients with isolated PPDFs, a fracture pattern that is going to become increasingly frequent as TKAs become more ubiquitous. Further, excluding the patient who died during the initial hospitalization, 89.5% of our patients had follow-up data available for review, minimizing bias from a lack of patient continuity. There are limitations to this study as well. We do not evaluate healing, including rates of union, malunion, or nonunion, which clearly have implications for outcomes. Functional scores are also not evaluated, as this is a more intermediate or long-term issue. This is also a retrospective study, which is not controlled for bias, sample heterogeneity, and inconsistencies in data available for abstraction.

Our findings highlight the medical and surgical complexity of treating patients with PPDF fractures and the need for a multi-disciplinary approach. Patients should be advised that there is a notable risk for complications, and prognosis is somewhat guarded. The majority of patients do well after a PPDF fracture; however, there were many who experienced complications and had readmissions. Our goal is to mitigate risk but to realize that despite optimization of patient status, surgical care does entail risk for complications. Continuous reassessment and refinement of treatment practices is essential. Consistent communication with patients and families regarding risks, benefits, and expectations, while weighing treatment options on an individual basis, is crucial.

REFERENCES

1. **Cram P, Lu X, Kates SL, Singh JA, Li Y, Wolf BR.** Total knee arthroplasty volume, utilization, and outcomes among Medicare beneficiaries, 1991-2010. JAMA. 2012 Sep 26;308(12):1227-36. PubMed PMID: 23011713.
2. **Streubel PN, Ricci WM, Wong A, Gardner MJ.** Mortality after distal femur fractures in elderly patients. Clin Orthop Relat Res. 2011 Apr;469(4):1188-96. PubMed PMID: 20830542.
3. **Konda SR, Pean CA, Goch AM, Fields AC, Egol KA.** Comparison of short-term outcomes of geriatric distal femur fracture and femoral neck fractures: results from the NSQIP database. Geriatr Orthop Surg Rehabil. 2015 Dec;6(4):311-5. PubMed PMID: 26623167.
4. **Beaupre LA, Cinats JG, Senthilselvan A, Lier D, Jones CA, Scharfenberger A, Johnston DW, Saunders LD.** Reduced morbidity for elderly patients with a hip fracture after implementation of a perioperative evidence-based clinical pathway. Qual Saf Health Care. 2006 Oct;15(5):375-9. PubMed PMID: 17074877.
5. **Kates SL, Mendelson DA, Friedman SM.** Co-managed care for fragility hip fractures (Rochester model). Osteoporos Int. 2010 Dec;21(Suppl 4):S621-5. PubMed PMID: 21058002.
6. **Rorabeck CH, Taylor JW.** Periprosthetic fractures of the femur complicating total knee arthroplasty. Orthop Clin North Am. 1999 Apr;30(2):265-77. PubMed PMID: 10196428.
7. **Nahm NJ, Como JJ, Wilber JH, Vallier HA.** Early appropriate care: definitive stabilization of femoral fractures within 24 hours of injury is safe in most patients with multiple injuries. J Trauma. 2011 Jul;71(1):175-85. PubMed PMID: 21336198.
8. **Vallier HA, Dolenc AJ, Moore TA.** Early appropriate care: a protocol to standardize resuscitation assessment and to expedite fracture care reduces hospital stay and enhances revenue. J Orthop Trauma. 2016 Jun;30(6):306-11. PubMed PMID: 26741643.
9. **Luttrell K, Nana A.** Effect of preoperative transthoracic echocardiogram on mortality and surgical timing in elderly adults with hip fracture. J Am Geriatr Soc. 2015 Dec;63(12):2505-9. PubMed PMID: 26659463.
10. **Marcantonio A, Steen B, Kain M, Bramlett KJ, Tilzey JF, Iorio R.** The clinical and economic impact of preoperative transthoracic echocardiography in elderly patients with hip fractures. Bull Hosp Jt Dis (2013). 2015 Dec;73(4):239-42. PubMed PMID: 26630466.
11. **Rogers FB, Shackford SR, Keller MS.** Early fixation reduces morbidity and mortality in elderly patients with hip fractures from low-impact falls. J Trauma. 1995 Aug;39(2):261-5. PubMed PMID: 7674394.
12. **Zuckerman JD, Skovron ML, Koval KJ, Aharonoff G, Frankel VH.** Postoperative complications and mortality associated with operative delay in older patients who have a fracture of the hip. J Bone Joint Surg Am. 1995 Oct;77(10):1551-6. PubMed PMID: 7593064.
13. **Moran CG, Wenn RT, Sikand M, Taylor AM.** Early mortality after hip fracture: is delay before surgery important? J Bone Joint Surg Am. 2005 Mar;87(3):483-9. PubMed PMID: 15741611.
14. **Tornetta P 3rd, Mostafavi H, Riina J, Turen C, Reimer B, Levine R, Behrens F, Geller J, Ritter C, Homel P.** Morbidity and mortality in elderly trauma patients. J Trauma. 1999 Apr;46(4):702-6. PubMed PMID: 10217237.
15. **Vasarhelyi A, Baumert T, Fritsch C, Hopfenmüller W, Gradl G, Mittlmeier T.** Partial weight bearing after surgery for fractures of the lower extremity--is it achievable? Gait Posture. 2006 Jan;23(1):99-105. PubMed PMID: 16311201.
16. **Hughe MA, Cooperman J, Peterson C, Duncan PW.** Partial weight bearing in the older person. Top Geriatr Rehabil. 1996 Mar;11(3):1-8.
17. **Siu AL, Penrod JD, Boockvar KS, Koval K, Strauss E, Morrison RS.** Early ambulation after hip fracture: effects on function and mortality. Arch Intern Med. 2006 Apr;166(7):766-71. PubMed PMID: 16606814.

18. **Roche JJ, Wenn RT, Sahota O, Moran CG.** Effect of comorbidities and postoperative complications on mortality after hip fracture in elderly people: prospective observational cohort study. BMJ. 2005 Dec;331(7529):1374. PubMed PMID: 16299013.
19. **Donegan DJ, Gay AN, Baldwin K, Morales EE, Esterhai JL Jr, Mehta S.** Use of medical comorbidities to predict complications after hip fracture surgery in the elderly. J Bone Joint Surg Am. 2010 Apr;92(4):807-13. PubMed PMID: 20360502.
20. **Kertai MD, Bountioukos M, Boersma E, Bax JJ, Thomson IR, Sozzi F, Klein J, Roelandt JR, Poldermans D.** Aortic stenosis: an underestimated risk factor for perioperative complications in patients undergoing noncardiac surgery. Am J Med. 2004 Jan;116(1):8-13. PubMed PMID: 14706659.
21. **Christ M, Sharkova Y, Geldner G, Maisch B.** Preoperative and perioperative care for patients with suspected or established aortic stenosis facing noncardiac surgery. Chest. 2005 Oct;128(4):2944-53. PubMed PMID: 16236971.
22. **Lee JJ, Patel R, Biermann JS, Dougherty PJ.** The musculoskeletal effects of cigarette smoking. J Bone Joint Surg Am. 2013 May;95(9):850-9. PubMed PMID: 23636193.
23. **Sadr Azodi O, Bellocco R, Eriksson K, Adami J.** The impact of tobacco use and body mass index on the length of stay in hospital and the risk of post-operative complications among patients undergoing total hip replacement. J Bone Joint Surg Br. 2006 Oct;88(10):1316-20. PubMed PMID: 17012420.
24. **Harris AH, Reeder R, Ellerbe L, Bradley KA, Rubinsky AD, Giori NJ.** Preoperative alcohol screening scores: association with complications in men undergoing total joint arthroplasty. J Bone Joint Surg Am. 2011 Feb;93(4):321-7. PubMed PMID: 21325583.
25. **Møller AM, Pedersen T, Villebro N, Munksgaard A.** Effect of smoking on early complications after elective orthopaedic surgery. J Bone Joint Surg Br. 2003 Mar;85(2):178-81. PubMed PMID: 12678348.

SHOULD ALL SHOULDER DISLOCATIONS BE CLOSED REDUCED? ASSESSMENT OF RISK OF IATROGENIC INJURY IN 150 PATIENTS

Olga Solovyova, MD, Rachel Shakked, MD, Nirmal C Tejwani, MD

ABSTRACT

Aims: The purpose of this study was to determine if there was an association between iatrogenic fractures and closed reduction of shoulder dislocations.

Patients and Methods: In a retrospective case series, 150 consecutive patients with acute first time shoulder dislocations were evaluated. Patient demographics, direction of dislocation, associated injuries, reduction methods, number of attempts, and type of anesthesia/analgesia were determined. Pre- and post-reduction radiographs and medical record were reviewed to identify the presence of proximal humerus fractures.

Results: There were thirty nine fracture-dislocations (26%) of the proximal humerus. Eight patients (5%) failed reduction on initial attempt. Four of these (3%) were unable to be reduced in the emergency room and were taken to OR for reduction. There was no statistically significant difference in reduction maneuver or type of anesthesia/analgesia used when comparing fracture-dislocations to dislocations only ($p<0.05$). No new fractures after reduction were identified.

Conclusion: Iatrogenic fractures of the proximal humerus due to reduction of a shoulder dislocation are extremely rare. None were identified in this review of 150 patients. We believe that closed reduction is safe even in the setting of fracture dislocations.

Hospital for Joint Diseases,
NYU Langone Medical Center
New York, NY

Please address correspondence to:
Nirmal C Tejwani, MD
NYU Langone Orthopaedics
550 First Avenue, CD4-102
New York, NY 10016
212-263-7198
Nirmal.tejwani@nyumc.org

No authors received anything of value in relation to this manuscript.

INTRODUCTION

The glenohumeral joint is the most mobile joint in the body and, therefore, the most predisposed to dislocation. The estimated incidence of glenohumeral dislocation is 11.2 to 56.3 per 100,000 person-years, most commonly occurring in males between the ages of 15 and 30 and in all individuals older than 80 years[1-7]. While it is possible for the glenohumeral joint to dislocate in any direction, up to 98% of dislocations occur in an anterior direction[8-10].

Dislocations and reductions are associated with a number of associated injuries including neurologic injury, vascular injury, labral tears, rotator cuff tears, injury to the joint capsule and ligaments, and fractures. The management of shoulder dislocation is affected by the condition of the patient, other injuries, and duration of dislocation. The incidence of iatrogenic injury and incidence of fractures on postreduction radiographs is extremely low. When fractures are noted on postreduction radiographs, the majority are Hill-Sachs and Bankart fractures[11-14]. It is the standard of practice to attempt closed reduction in all acute shoulder dislocations. However, there have been a number of case reports, case series, and a retrospective study in recent literature describing iatrogenic humeral neck fractures during closed reduction of shoulder dislocations, calling this practice into question[15-21]. The purpose of this retrospective case series is to determine if there is an association between iatrogenic fractures and closed reduction of shoulder dislocations. The secondary purpose is to determine if certain fracture-dislocation patterns are more prone to iatrogenic injury.

PATIENTS AND METHODS

This study was approved by the institutional review boards of two medical centers within our institution (S13-00952 and 496209-1). Consultation records of the orthopaedic surgery departments at two Level I trauma centers were reviewed to identify 150 consecutive patients with shoulder dislocations that presented to the emergency departments and required orthopaedic consultation from February 2011 through January 2014. Data collected included patient demographics, direction of dislocation, associated injuries, method of reduction, number of reduction attempts, and type of anesthesia/analgesia used. Additionally, the presence of proximal

Table I. Patient Demographics

Age	<19 y.o.	14 (9%)
	20-29	33 (22%)
	30-39	21 (14%)
	40-49	17 (11%)
	50-59	19 (13%)
	60-69	19 (13%)
	70-79	16 (11%)
	>80	11 (7%)
Gender	Male	101 (67%)
	Female	49 (33%)
Affected side	Dominant	46 (31%)
	Non-Dominant	55 (37%)
	Not Specified	49 (33%)
Mechanism of Injury	Fall	56 (37%)
	Fall from height	18 (12%)
	Seizure	9 (6%)
	Fight/assault	16 (11%)
	Pedestrian struck	19 (13%)
	MVA/MCA	7 (5%)
	Bicycle accident	6 (4%)
	Sports	12 (8%)
	Other/unknown	7 (5%)
Direction of Dislocation	Anterior	132 (88%)
	Posterior	12 (8%)
	Inferior	6 (4%)

Table II. Associated Fractures and Neurologic Dysfunction

Associated proximal humerus fractures	GT	OTA 11-B3	28
	HH	OTA 11-C3	2
	HN	OTA 11-B3	2
	GT/HN	OTA 11-B3	2
	GT/HH	OTA 11-C3	1
	HH/HN	OTA 11-B3	1
	GT/LT/HH	OTA 11-C3	1
	4-part	OTA 11-C3	2
Associated neurologic deficits	Axillary n. sensory only		13
	Axillary n. sensory and motor		3
	Ulnar n. sensory only		4
	Brachial plexus sensory only		8
	Brachial plexus sensory and motor		2

GT – greater tuberosity
LT – lesser tuberosity
HH – humeral head
HN – humeral neck

humerus fractures, whether pre- or post-reduction maneuver, was determined using the medical record and by reviewing radiographs with a fellowship-trained orthopaedic trauma surgeon. Data was analyzed using SPSS (SPSS Inc., Chicago, IL). Parametric data was analyzed using student's t-test; non-parametric data was analyzed using chi-square test. Statistical significance was set at $p < 0.05$.

RESULTS

One hundred and fifty acute shoulder dislocations were identified in 150 patients. Mean patient age was 46 (13-90) years and mean body mass index (BMI) was 28.3. 101 (67%) of the patients were male and 49 (33%) were female. There were 132 (88%) anterior (OTA 10-A1), 12 (8%) posterior (OTA 10-A2), and 6 (4%) inferior (OTA 10-A5) dislocations[22]. These and additional patient demographics are displayed in Table 1. Thirty nine (26%) were associated with fractures of the proximal humerus (OTA 11-B3 and 11-C3) which are detailed in Table 2 [22]. There were no open injuries about the shoulder. No patients presented with changes in vascular perfusion status of the affected extremity. Thirty (20%) patients were found to have neurologic dysfunction at the time of presentation. These are described in Table 2. After reduction, 17 patients experienced improvement in neurologic status while 13 had no change. Thirty patients had additional fractures not involving the shoulder.

142 (95%) of dislocations were successfully reduced on the first attempt and 8 (5%) failed reduction on first attempt. Of those that underwent multiple attempts, two patients did not tolerate the initial reduction attempt with local analgesia and had to be converted to conscious sedation with subsequent successful reductions; two were successfully close reduced in the emergency room on second attempt. The remaining four were fracture dislocations which failed initial closed reduction and were taken to the operating room for ORIF of the fracture, as it was felt that attempting another reduction maneuver in the ED was inappropriate; these are described later. There were no statistically significant differences in the age, BMI, or gender of the patients who required operative fixation.

Twenty seven patients (24%) with dislocations alone were reduced under conscious sedation and 61 (55%) were reduced with the use of an intraarticular block (10cc 2% lidocaine injected into the joint 2cm inferior to the posterolateral acromion), as compared to 10 (26%) and 19 (46%) with fracture-dislocations, respectively. Additionally, one patient with a greater tuberosity fracture

Table 3: Reduction Methods

		All patients (n=150)	Patients with fracture-dislocations (n=39)	Patients with dislocations alone (n=111)	P-value
Reduction Maneuver	Traction-Counter Traction	94 (63%)	22 (56%)	72 (65%)	0.21
	Reverse Stimson	26 (17%)	8 (21%)	18 (16%)	
	Stimson	9 (6%)	1 (3%)	8 (7%)	
	Milch	17 (11%)	4 (10%)	13 (12%)	
	ORIF	4 (3%)	4 (10%)	0	
Reduction on First Attempt	Successful	142 (95%)	35 (90%)	107 (96%)	0.22
	Failed	8 (5%)	4 (10%)	4 (4%)	
Anesthesia/ analgesia used	Conscious sedation	37 (25%)	10 (26%)	27 (24%)	0.12
	Intra-articular block	80 (55%)	19 (49%)	61 (55%)	
	Pain medication	26 (16%)	7 (18%)	19 (17%)	
	None	2 (1%)	0	2 (2%)	
	GETA	5 (3%)	3 (7%)	2 (2%)	

Table 4: Reduction Methods in Patients Over 50 Years Old with Greater Tuberosity Fracture Dislocations

		Number of patients (n=13)
Reduction Maneuver	Traction-Counter Traction	7 (53%)
	Reverse Stimson	4 (31%)
	Stimson	1 (8%)
	Milch	1 (8%)
Reduction on First Attempt	Successful	13 (100%)
Anesthesia/ analgesia used	Conscious sedation	4 (31%)
	Intra-articular block	5 (38%)
	Pain medication	4 (31%)

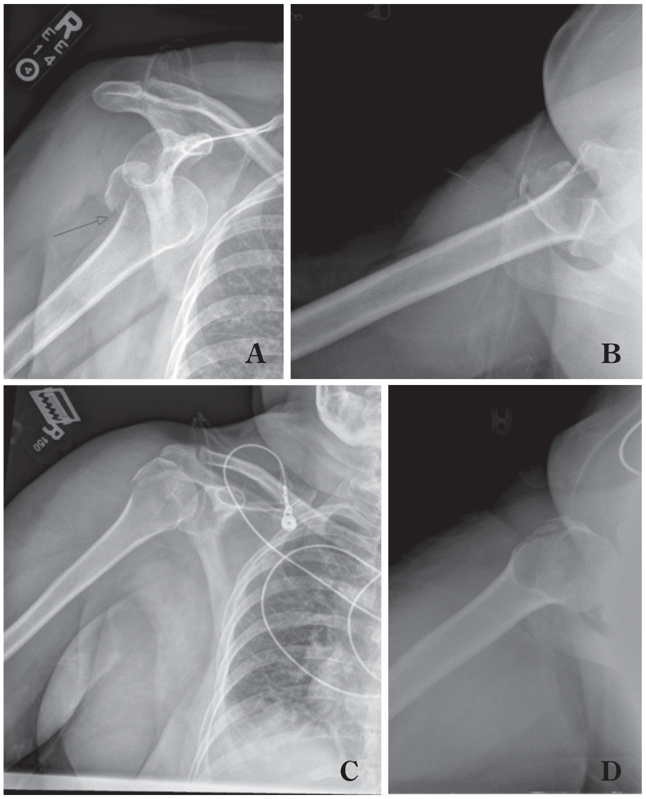
dislocation was reduced under general anesthesia, as he was taken to the operating room for irrigation and debridement of an open calcaneus fracture. Closed reduction was successful 96% of the time with no displacement of fractures, regardless of type of anesthesia.

146 dislocations were reduced successfully using a variety of reduction and anesthesia/analgesia techniques which are described in Table 3. There was no difference in the type of anesthesia/analgesia used and reduction ability (p=0.48).

There were thirteen patients over the age of 50 who sustained greater tuberosity fracture-dislocations. All dislocations were anterior except one, which was inferior. Five of these dislocations were reduced with intra-articular block (38%), four with conscious sedation (31%), and four with pain medication alone (31%). Traction counter traction was used for seven patients (53%), reverse stimson for four (31%), the Milch maneuver for one (8%), and the Stimson for one (8%). All dislocations were reduced on first attempt with no iatrogenic injuries. These findings are summarized in Table 4.

There were four patients who required operative fixation of their fracture-dislocations. Patient one is a 44 year old RHD male who sustained a left shoulder fracture dislocation, with fracture of the humeral head, after a syncopal fall. He underwent two unsuccessful reduction attempts with an intraarticular block, using the Milch maneuver and then traction-counter traction. At this time, it was determined that a third reduction attempt was unlikely to reduce the shoulder if the first two did not, and that the risk of additional sedation and further attempts at reduction outweighed the benefit. The patient underwent open reduction internal fixation one week later, after the medical syncope workup was complete. Fluoroscopy images and postoperative radiographs demonstrate acceptable reduction with a three-hole proximal humerus locking plate.

The three remaining patients were indicated for operative fixation after one reduction attempt, as the risk of further fracture displacement and possible avascular necrosis of the humeral head, in these young patients, outweighed the benefit. Patient two is a 33 year old RHD male who sustained a left posterior shoulder fracture dislocation, with fracture of the humeral head, during a seizure. After one attempt at closed reduction, using traction-counter traction with IV morphine. The patient was indicated for open reduction internal fixation. He underwent ORIF with a three-hole proximal humerus



Figures 1A-D: Pre-reduction AP (A) and axillary (B) views of a patient with an anterior shoulder dislocation and concomitant greater tuberosity fracture. Post-reduction AP (C) and axillary (D) views demonstrate a reduced glenohumeral joint and improved alignment of the fracture.

locking plate without complication with acceptable alignment demonstrated on intraoperative fluoroscopy and postoperative radiographs.

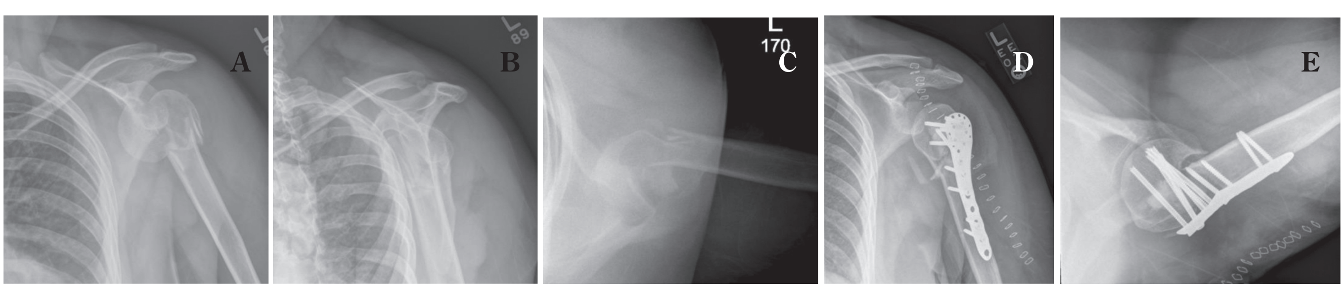
Patient three is a 26 year old RHD male bicyclist struck by a car door causing him to flip over his handlebars who sustained a right shoulder fracture dislocation with fracture of the humeral neck. After one reduction attempt with intraarticular block, using the reverse stimson maneuver, the patient was indicated for open reduction internal fixation, which he underwent without complication. Fluoroscopy and postoperative radiographs demonstrate acceptable reduction with a four-hole proximal humerus locking plate.

Patient four is 39 year old RHD female who sustained a left shoulder fracture dislocation during a seizure, with fracture of the greater tuberosity and humeral neck. Reduction was attempted under conscious sedation and after one unsuccessful attempt, using traction-counter traction, the patient was indicated for open reduction internal fixation. He underwent ORIF with a six-hole proximal humerus locking plate, and acceptable reduction was achieved on fluoroscopy and postoperative imaging. Pre- and post-operative radiographs are shown in Figure 2.

There were no iatrogenic injuries, including new neurologic deficits, identified as a result of closed reduction. All patients had pre- and post-reduction radiographs and there were no new fractures identified on the post-reduction films in any of the patients. Additionally, no post-reduction radiographs demonstrated further displacement of fractures identified on pre-reduction imaging. Figure 1 shows radiographs of a study patient with a greater tuberosity fracture with improved alignment following closed shoulder reduction in the emergency room.

DISCUSSION

Shoulder dislocations and reductions can be associated with a number of injuries. This study examines the incidence of iatrogenic humerus fractures after closed reduction of shoulder dislocations in our review of 150 dislocations in 150 patients at two Level I trauma centers. Our findings corroborate the epidemiology of shoulder dislocations described in previous studies[1-5,8,9], with 67% of dislocations occurring in male patients; almost a quarter of the patients were between 20 and 29 years old, and 95% of the dislocations were in the anterior direction. There were no iatrogenic humerus fractures in our data set. Based on the results of this study in our patient population, we believe it is safe to attempt closed reduction upon presentation in the emergency department using local anesthesia or conscious sedation, including older



Figures 2A-E: Injury radiographs, AP (A), scapular Y (B), and axillary (C) views of a patient with a four par shoulder fracture dislocation. Post-operative AP (D) and axillary (E) views demonstrate a reduced fracture and glenohumeral joint.

patients with a greater tuberosity fracture-dislocation.

As the large majority of the dislocations in our study were reduced on the first attempt, we cannot provide specific recommendations as to the number of reductions that should be attempted. However, as we did not find any iatrogenic fractures, we believe that a second reduction attempt would be safe (this has been our protocol at our institution), should the first one be unsuccessful. Additionally, we cannot comment as to which type of analgesia/anesthesia is best for reducing shoulder dislocations. We recommend starting out with pain medication or an intraarticular injection and proceeding to conscious sedation if the shoulder cannot be reduced; with the decision being made by the orthopaedic surgeon in conjunction with other physicians administering the anaesthesia.

To the best of our knowledge, this is the largest study to evaluate iatrogenic injuries during shoulder reduction. A literature search generated six studies which described iatrogenic fractures and fracture displacement upon reduction attempt. Hersche and Gerber report on seven patients who sustained fracture dislocations in which a reduction attempt displaced previously non-displaced humeral neck fractures. Three patients were reduced under sedation, three were reduced under general anesthesia, and one underwent open reduction under general anesthesia. The authors do not indicate which reduction maneuvers were used[17].

Ferkel et al provide case reports of two patients with displaced greater tuberosity fractures and missed non-displaced humeral neck fractures on initial radiographs. After closed reduction, radiographs demonstrated iatrogenic displacement of the humeral neck fractures in both cases. Neither patient appeared to have had axillary views of the shoulder. Reduction was attempted by the emergency department using traction-counter traction and intramuscular analgesics for pain control[16].

Ahmad et al report on a patient in whom a posterior dislocation was misdiagnosed as an anterior one. The proximal humerus was fractured when the Kocher method was used for attempted reduction under IV sedation by emergency department staff. The patient required ORIF for treatment of a posterior shoulder dislocation, reverse Hill-Sachs lesion, fractures of greater and lesser tuberosities extending into the humeral shaft[20].

Demirhan et al describe primary humeral head replacement in six patients referred from outside facilities due to displacement of anatomic neck fractures during attempted reduction of shoulder fracture dislocations. As the article's purpose was to evaluate outcomes of humeral head replacement, little detail is provided regarding the initial management of the fracture-dislocations[21].

Ranawat et al report on a case series of five fracture dislocations which resulted in fracture or displacement of a humeral neck fracture after closed reduction attempt. Four of the patients were reduced by orthopaedic staff and one was reduced by the emergency department; all cases required multiple reduction attempts. Conscious sedation and intraarticular anesthesia was used for three of the patients; one reduction was attempted under intraarticular anesthesia, and the type of anesthesia/analgesia was unspecified in the fifth case. All patients required subsequent operative intervention: four were treated with hemiarthroplasty and one with ORIF. Additionally, the authors report on a case in which a subacute shoulder dislocation underwent prophylactic percutaneous pinning to prevent fracture propagation from a large Hill-Sachs deformity. After percutaneous pinning, the shoulder was successfully reduced, and pins were removed[19].

Finally, Atoun et al retrospectively evaluated 92 patients greater than 40 years old with first time anterior shoulder dislocations to investigate the incidence of iatrogenic humeral neck fractures. Patients were evaluated with AP and either scapular-Y or Velpeau axillary views prior to reduction. The type of anesthesia/analgesia and reduction maneuver are not reported. The authors identified five patients with iatrogenic, displaced humeral neck fractures on post-reduction radiographs. All five of these patients had greater tuberosity fractures on pre-reduction radiographs. The authors concluded that patients older than 40 years who were first time shoulder dislocators with a greater tuberosity fracture on initial radiograph, were at a significantly increased risk of an iatrogenic humeral neck fracture when closed-reduced under conscious sedation[15]. In contrast, our study did not reveal any iatrogenic fractures on postreduction xrays.

In addition to the size of our cohort, strengths of this study include that it was conducted at two level 1 trauma centers, it was the same group of residents and attending who were managing patients, adequate pre- and post-reduction radiographs were obtained including axillary views in all cases, and type of anesthesia/analgesia and reduction maneuver was documented. There were several limitations identified during the course of this study. The retrospective design is dependent on accuracy and completeness of the medical record; as a result, some information, such as handedness and mechanism of injury was missing from several charts.

Additionally, at one trauma center, the orthopaedic service is consulted for every shoulder dislocation that presents to the emergency room. At the other trauma center, orthopaedics is only consulted for selected shoulder dislocations depending on the complexity of the case, the presence of a fracture, or the volume of patients being treated. This may have created two different patient cohorts within our study: one cohort encompassing all presenting shoulder dislocations and one cohort with more complex dislocations. We do not believe that this significantly affects our findings or the generalizability of our results; in fact, the bias in our data likely over-represented the incidence of fracture dislocations in our population. Despite this error, our data show no incident of iatrogenic fracture or fracture displacement. This bias strengthens our study recommendation to reduce all shoulder dislocations in the emergency room setting.

In conclusion, we believe that iatrogenic fractures of the proximal humerus as a result of a reduction of a shoulder dislocation are an extremely rare event, as we did not identify any in this review of 150 dislocations and reduction in 150 patients at two Level I trauma centers. In light of our findings, we believe that closed reduction should be attempted for all acute shoulder dislocations including fracture dislocations.

REFERENCES

1. **Kroner K, Lind T, Jensen J.** The epidemiology of shoulder dislocations. Arch Orthop Trauma Surg. 1989;108(5):288-290.
2. **Nordqvist A, Petersson CJ.** Incidence and causes of shoulder girdle injuries in an urban population. J Shoulder Elbow Surg. 1995;4(2):107-112.
3. **Simonet WT, Melton LJ, 3rd, Cofield RH, Ilstrup DM.** Incidence of anterior shoulder dislocation in Olmsted County, Minnesota. Clin Orthop Relat Res. 1984(186):186-191.
4. **Zacchilli MA, Owens BD.** Epidemiology of shoulder dislocations presenting to emergency departments in the United States. J Bone Joint Surg Am.92(3):542-549.
5. **Hindle P, Davidson EK, Biant LC, Court-Brown CM.** Appendicular joint dislocations. Injury.44(8):1022-1027.
6. **Ootes D, Lambers KT, Ring DC.** The epidemiology of upper extremity injuries presenting to the emergency department in the United States. Hand (N Y).7(1):18-22.
7. **Liavaag S, Svenningsen S, Reikeras O, et al.** The epidemiology of shoulder dislocations in Oslo. Scand J Med Sci Sports.21(6):e334-340.
8. **Leroux T, Wasserstein D, Veillette C, et al.** Epidemiology of primary anterior shoulder dislocation requiring closed reduction in Ontario, Canada. Am J Sports Med.42(2):442-450.
9. **Owens BD, Duffey ML, Nelson BJ, et al.** The incidence and characteristics of shoulder instability at the United States Military Academy. Am J Sports Med. 2007;35(7):1168-1173.
10. **Yeap JS, Lee DJ, Fazir M, Borhan TA, Kareem BA.** The epidemiology of shoulder dislocations in Malaysia. Med J Malaysia. 2004;59 Suppl F:19-23.
11. **Gottlieb M, Nakitende D, Krass L, et al.** Frequency of Fractures Identified on Post-Reduction Radiographs After Shoulder Dislocation. The western journal of emergency medicine. 2016;17(1):35-38.
12. **Hendey GW.** Necessity of radiographs in the emergency department management of shoulder dislocations. Annals of emergency medicine. 2000;36(2):108-113.
13. **Hendey GW, Kinlaw K.** Clinically significant abnormalities in postreduction radiographs after anterior shoulder dislocation. Annals of emergency medicine. 1996;28(4):399-402.
14. **Kahn JH, Mehta SD.** The role of post-reduction radiographs after shoulder dislocation. The Journal of emergency medicine. 2007;33(2):169-173.
15. **Atoun E, Narvani A, Even T, et al.** Management of first-time dislocations of the shoulder in patients older than 40 years: the prevalence of iatrogenic fracture. J Orthop Trauma.27(4):190-193.
16. **Ferkel RD, Hedley AK, Eckardt JJ.** Anterior fracture-dislocations of the shoulder: pitfalls in treatment. J Trauma. 1984;24(4):363-367.
17. **Hersche O, Gerber C.** Iatrogenic displacement of fracture-dislocations of the shoulder. A report of seven cases. J Bone Joint Surg Br. 1994;76(1):30-33.
18. **Kilicoglu O, Demirhan M, Yavuzer Y, Alturfan A.** Bilateral posterior fracture-dislocation of the shoulder revealing unsuspected brain tumor: case presentation. J Shoulder Elbow Surg. 2001;10(1):95-96.
19. **Ranawat AS, DiFelice GS, Suk M, Lorich DG, Helfet DL.** Iatrogenic propagation of anterior fracture-dislocations of the proximal humerus: case series and literature review with suggested guidelines for treatment and prevention. Am J Orthop (Belle Mead NJ). 2007;36(9):E133-137.
20. **Ahmad R, Ahmed S, Bould M.** latrogenic fracture of humerus - complication of a diagnostic error in a shoulder dislocation: a case report. J Med Case Rep. 2007;1:41.
21. **Demirhan M, Akpinar S, Atalar AC, Akman S, Akalin Y.** Primary replacement of the humeral head in iatrogenically displaced fracture-dislocations of the shoulder: a report about six cases. Injury. 1998;29(7):525-528.
22. **Marsh JL, Slongo TF, Agel J, et al.** Fracture and dislocation classification compendium - 2007: Orthopaedic Trauma Association classification, database and outcomes committee. J Orthop Trauma. 2007;21(10 Suppl):S1-133.

PROXIMAL HUMERUS FRACTURE-DISLOCATION WITH LACERATION OF THE AXILLARY ARTERY: A CASE REPORT

Steven J. Cotman[1], MD, Thai Q. Trinh[1], MD, Stephen Vincent[1], MD, Jeffrey R. Backes[1], MD

ABSTRACT

Background:Proximal humerus fractures account for approximately 4-6% of all fractures. While the majority of these fractures are treated non-operatively, the amount of fracture displacement, concomitant injuries, and patient factors often result in the need for surgical stabilization. Although concomitant neurovascular injury in the setting of low-energy trauma is rare, injury to the surrounding neurovascular structures have previously been reported.

Methods: We report a case of a 79-year-old male who sustained a low energy fall resulting in a two-part fracture dislocation of the proximal humerus with an associated brachial plexopathy and axillary artery laceration. The patient underwent emergent open reduction internal fixation of his fracture in addition to an axillary-brachial artery bypass using a reverse-saphenous vein graft. The current article reports the presentation, management and prognosis of this rare injury.

Results: At 6 months, the patient demonstrated limited active shoulder abduction with no observed motor function at this elbow, wrist or hand. Radiographic follow up demonstrated a reduced glenohumeral joint with evidence avascular necrosis of the humeral head.

Conclusion: Fracture-dislocations of the proximal humerus may be associated with significant neurovascular injury in the setting of low energy trauma. Despite early treatment, the prognosis of patients with this constellation of injuries is guarded.

Affiliation:
[1]Mount Carmel Medical Center
793 West State Street
Columbus, Ohio 43222.

Corresponding Author:
Jeffrey R. Backes MD
Mount Carmel Health System
Department of Orthopaedics, Columbus, Ohio
Phone: 614-234-5000, Fax: 614-234-2772
Email: jbackes28@gmail.com

Disclosures:
None of the authors received payments or services, either directly or indirectly, from a third party in support of any aspect of this work.

INTRODUCTION

Proximal Humerus fractures account for 4-6% of all fractures.[1] Concomitant neurovascular injury to the surrounding brachial plexus and axillary artery have previously been reported in 6.2% 2 and 0.09% 3 of patients respectively. The current evidence reporting the diagnosis and management of axillary artery injuries in the setting of proximal humerus fractures is limited.[4-7] The current paper details the presentation, diagnosis and management of a patient presenting with a brachial plexopathy and axillary artery laceration following a low energy proximal humerus fracture. Verbal consent was obtained from the patient prior to submission for publication.

CASE REPORT

A 79-year-old male presented with a chief complaint of right upper extremity pain with associated subjective weakness and paresthesias. The patient had sustained a mechanical fall from standing height while intoxicated approximately one hour prior to presentation. Physical exam findings included a hemodynamically stable patient with acute swelling and pain about the right shoulder. Dense paresthesias and a lack of motor function distal to the elbow were noted. Sensation in the axillary nerve distribution appeared grossly intact. The patient's right hand appeared pale with no appreciable pulses on palpation or doppler examination. Plain radiographs demonstrated an intra-articular two-part fracture-dislocation of the proximal humerus (Figure 1). A CT angiogram was notable for laceration of the axillary artery with the displaced humeral shaft located adjacent to the zone of injury (Figure 2). A closed reduction was not attempted given the presumed tamponade effect exerted by the displaced fracture fragment. The patient was emergently taken to the operating room by both the orthopedic and vascular surgery teams.

Operative Procedure

The patient was placed supine on an operative table with both the right upper and right lower extremities prepped into the surgical field. Utilizing an extended infra-clavicular approach, the vascular surgery team isolated the first and second portions of the axillary artery. No injuries were noted in these regions and proximal control was obtained. The initial approach was extended

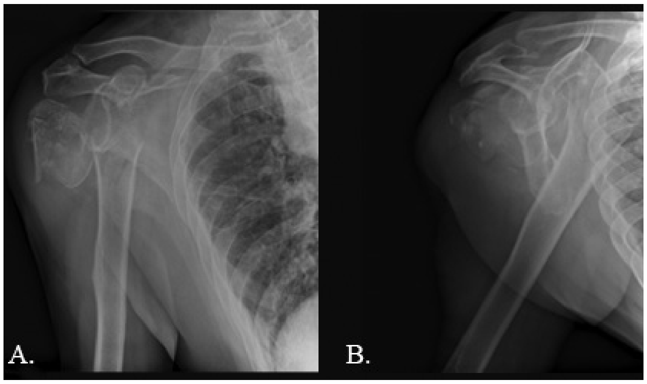


Figure 1: AP (A.) and Scapular Y (B) projections demonstrating a two-part proximal humerus fracture dislocation

Figure 2: CT- Angiogram demonstrating traumatic transection of the axillary artery by the displaced humeral shaft

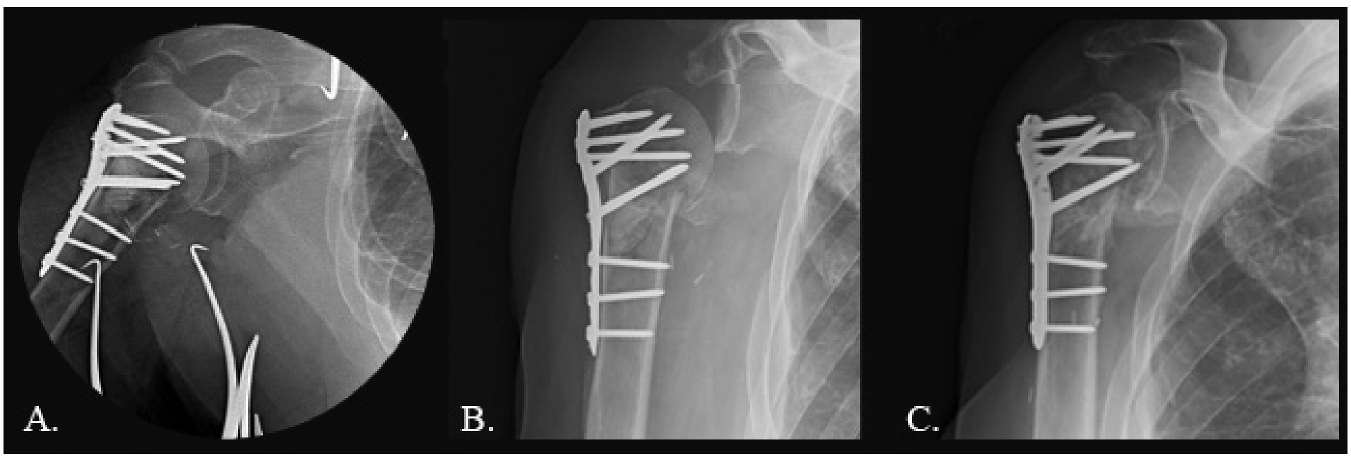


Figure 3: Intra-operative fluoroscopic image following open reduction internal fixation of the displaced proximal humerus fracture (A.). Post-operative images at 3 (B.) and 6 months (C.).

into a traditional deltopectoral approach for exposure of the fracture site. The humeral shaft was identified resting against the third portion of the axillary artery. A reduction maneuver was performed and a complex tear of the anteroinferior wall of the axillary artery was noted just proximal to the anterior and posterior humeral circumflex vessels. Despite the presence of a simple intra-articular split of the humeral head, it was elected to proceed with placement of a proximal humeral locking plate for fracture stabilization given the need for vascular bypass. Following stabilization of the fracture, an axillary-brachial arterial bypass was performed using a reverse-saphenous vein graft. Following completion of the bypass, prophylactic fasciotomies of the arm and forearm were performed.

Post-Operative Course

The patient was discharged from the hospital on postoperative day 21. At three months, the patient was unable to demonstrate any active shoulder, elbow, wrist or hand motion. Radiographs demonstrated inferior subluxation of the humeral head and increased subchondral sclerosis of the proximal humerus. At six months, the patient was able to demonstrate 30 degrees of active shoulder abduction. He did not regain any active motion of the elbow, wrist or hand and possessed only limited sensation to light touch along the ulnar border of his fifth digit. Postoperative films at six months demonstrated improved seating of his humeral head with signs of avascular necrosis including humeral head collapse and resorption of the greater tuberosity (Figure 3).

DISCUSSION

Neurovascular injury following low-energy fractures of the proximal humerus is a rare but important entity with both therapeutic and prognostic implications.[3] Although the injury can occur anywhere along the course of the artery, previous reports have documented a high rate of injury to the third segment of the artery in those patients presenting with isolated fractures of the proximal humerus.[8] The current case highlights the importance of identifying a potential vascular injury prior to any attempt at closed reduction. Based on intraoperative findings, a closed reduction may have removed the tamponade effect exerted by the displaced humeral shaft and potentially resulted in hemodynamic instability or death. The authors were unable to identify a reported case of a patient experiencing hemodynamic instability or death as a result of a closed reduction. In a retrospective case series of 3 patients with proximal humerus fractures and concomitant axillary artery injury, Thorsness et al.[7] highlighted the need for early vascular surgery involvement, especially in patients presenting on a delayed basis as the displaced fracture fragments may have scarred to the adjacent neurovascular structures.

Although the current patient presented with obvious signs of involvement of both the brachial plexus and axillary artery, the presence of a palpable pulse does not always exclude the presence of a vascular injury secondary to extensive collateral blood flow.[9] In a retrospective population-based study, Menendez et al.[3] reported that males, patients with atherosclerotic disease, and those patients with concomitant injuries to either the scapula, ribs or brachial plexus were more likely to present with injury to the axillary artery. The authors recommended that all patients presenting with a proximal humerus fracture with signs and symptoms of a brachial plexus injury undergo vascular testing to rule out involvement of the axillary artery.[3]

The long-term prognosis of patients presenting with brachial plexus and vascular injuries remains guarded.[8] In a retrospective review of twenty-one patients, neurologic recovery was universally poor with 86% of patients possessing neurologic deficits at final follow up.[8] The role of acute brachial plexus exploration and nerve repair remains unknown. Major orthopedic complications included a high rate of AVN (15%), delayed union (10%) and delayed shoulder arthrodesis (10%) secondary to inferior subluxation of the humeral head. Twenty-four percent of patients underwent secondary amputation between 4 days and 18 months.[8]

SUMMARY

The high association of brachial plexus and vascular injuries should reinforce the need for a detailed neurovascular exam in the setting of a proximal humerus fracture. Non-invasive vascular studies and early vascular consultation is recommended for any patient presenting with concerns for vascular injury. We recommend against performing a closed reduction in patients presenting with vascular injury in which the OR is immediately available. Despite early treatment, the prognosis of patients with this constellation of injuries is guarded.

REFERENCES

1. **McLaughlin, J.A., R. Light, and I. Lustrin**, Axillary artery injury as a complication of proximal humerus fractures. J Shoulder Elbow Surg. 1998; 7(3): p. 292-294.
2. **Stableforth, P.G.**, Four-part fractures of the neck of the humerus. J Bone Joint Surg Br. 1984; 66(1): p. 104-108.
3. **Menendez, M.E., D. Ring, and M. Heng**, Proximal humerus fracture with injury to the axillary artery: a population-based study. Injury. 2015; 46(7): p. 1367-1371.
4. **Gorthi, V., et al.**, Life-threatening posterior circumflex humeral artery injury secondary to fracture-dislocation of the proximal humerus. Orthopedics. 2010; 33(3).
5. **Inui, A., et al.**, Shoulder fracture dislocation associated with axillary artery injury: a case report. J Shoulder Elbow Surg. 2009; 18(2): p. e14-16.
6. **Papaconstantinou, H.T., et al.**, Endovascular repair of a blunt traumatic axillary artery injury presenting with limb-threatening ischemia. J Trauma. 2004; 57(1): p. 180-183.
7. **Thorsness, R., et al.**, Proximal humerus fractures with associated axillary artery injury. J Orthop Trauma. 2014; 28(11): p. 659-663.
8. **Ng, A.J., et al.**, Axillary Artery Injury Associated with Proximal Humeral Fractures: Review of Long-Term Vascular, Orthopedic, and Neurologic Outcomes. Ann Vasc Surg. 2016.
9. **Gallucci, G., et al.**, Late onset of axillary artery thrombosis after a nondisplaced humeral neck fracture: a case report. J Shoulder Elbow Surg. 2007; 16(2): p. e7-8.

TIBIAL PLATEAU FRACTURES: A NEW RANK ORDERING METHOD FOR DETERMINING TO WHAT DEGREE INJURY SEVERITY OR QUALITY OF REDUCTION CORRELATE WITH CLINICAL OUTCOME

Katie Freeman, M.D.,[1] Jared L. Michalson, M.D.,[2] Donald D. Anderson, PhD.,[2]
Thomas D. Brown, PhD.,[2] Thomas A. DeCoster, M.D.,[3] Douglas R. Dirschl, M.D.,[4]
Matthew D. Karam, M.D.,[2] and J. Lawrence Marsh, M.D.[2]

ABSTRACT

Background: Injury severity may be the most important factor in determining outcome after articular fractures, but there is a surprising paucity of clinical evidence to support this assertion. The purpose of this study was to utilize a new method for rank ordering a group of patient radiographs to assess the effect of injury severity and quality of reduction on patient outcomes after tibial plateau fractures.

Methods: Tibial plateau fractures in 64 patients were treated operatively or non-operatively based on physician preference from standard of care techniques. Fracture severity and reduction quality were stratified from radiographs by four expert clinicians using an iTunes-based rank ordering methodology. The images were distributed electronically, and the ranks were performed on local computers at three different institutions. Clinical outcomes were measured with the SF-12 health questionnaire and the Knee injury and Osteoarthritis Outcome Score (KOOS).

Results: There was excellent or very good agreement between raters for injury severity ranking (correlation 0.77-0.91) and quality of reduction (correlation 0.66-0.82). There was no correlation between the injury severity nor quality of reduction and general or joint-specific clinical outcomes.

Conclusions: Expert orthopaedic traumatologists strongly agree on how to rank order tibial plateau fractures based both on injury severity and quality of reduction. The novel electronic interface utilized allows an ever-expanding series of cases to be ranked quickly, conveniently, and across multiple centers. This interface holds great promise for establishing prospective, continuously expanding rank orders of various fracture types, which may have great value for clinical research, education about fracture severity, and for prognosis and treatment decisions. In the present study, neither injury severity nor quality of reduction correlated with the clinical outcomes. Other patient- and injury-related factors may be more important in determining clinical outcome of tibial plateau fractures than the appearances of the radiographs at the time of injury or after reduction.

Level of Evidence: level III evidence

Keywords: rank order, tibial plateau fracture

INTRODUCTION

Logic, surgeon opinion, and experimental evidence indicate that the severity of injury is the most important factor in determining outcome after articular fractures.[1-6] It makes sense that a comminuted displaced bicondylar fracture would have a worse prognosis than a minimally displaced lateral plateau fracture. However, there is a surprising paucity of clinical evidence to support this assertion, and very few studies have directly focused on the effect of injury severity on patient pain and function years after the injury. This lack of evidence is undoubtedly in part because of the difficulty in measuring fracture severity as the poor inter-observer reliability of fracture classification limits its utility for this purpose.

Quality of fracture reduction is considered to be a second important factor in determining outcome.[2,6-9] It makes sense that a well-reduced fracture will have a better prognosis than a fracture with residual mal-alignment after treatment, but there is not a lot of convincing data in the literature to prove this assertion. Measuring how well a fracture is reduced is difficult and unreliable; even more so than is initial fracture severity.

Rank order techniques have been shown to reliably stratify fracture severity and reduction quality. Unfortunately, this methodology has been limited to relatively small numbers of cases.[10-11] As typically utilized, rank or-

[1]Department of Orthopaedics, The University of Missouri

[2]Department of Orthopaedics and Rehabilitation, The University of Iowa

[3]Department of Orthopaedics and Rehabilitation, The University of New Mexico

[4]Department of Orthopaedic Surgery and Rehabilitation Medicine, The University of Chicago

Corresponding author:
Dr. Katie Freeman, freemanka@health.missouri.edu
Department of Orthopaedics
University of Missouri Hospitals and Clinics
1100 Virginia Avenue, DC953.00
Columbia, MO 65212
Phone: 573-882-5731

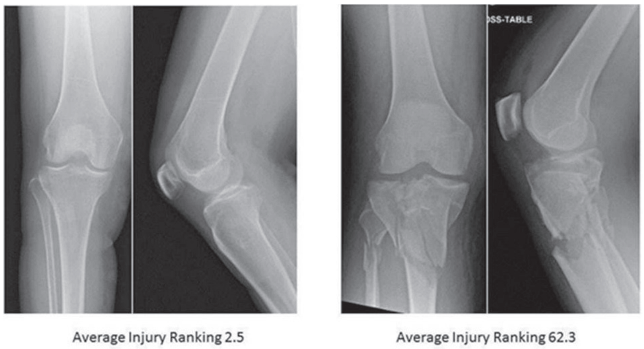


Figure 1. Two case examples demonstrating the spectrum of injury severity seen in the patient population and the average rank order selected by the traumatologists

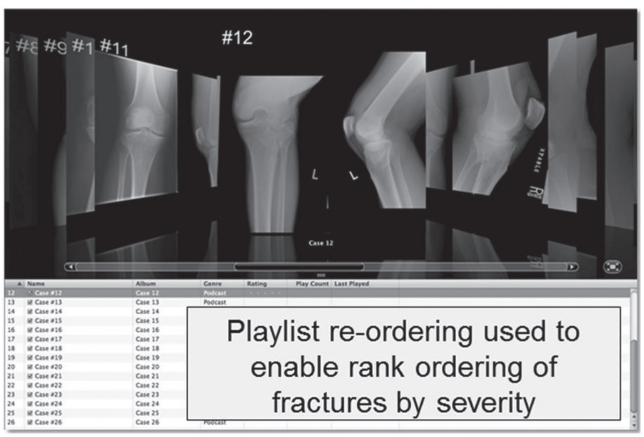


Figure 2. This screen capture shows the rank ordering interface as presented to the user from within the iTunes software.

dering has serious limitations: it applies only to a specific series of cases, allowing neither addition of new cases, nor multi-institutional pooling, nor case comparisons, and it is cumbersome and time consuming, limiting its practical use.

Furthermore, a convenient, user-friendly method to compare multiple radiographs for the purposes of rank ordering has not been previously available. To address these limitations, this study used an electronic technique to allow ever-expanding rank orders to be developed across multiple institutions. This electronic method holds potential to overcome some of the hurdles inherent in rank order studies.

Tibial plateau fractures were chosen for this study because they have a wide spectrum of injury severity. Few studies have focused on the effect of tibial plateau fracture severity or fracture reduction on patient outcome.

There were three purposes of this study:

1. Use an electronic technique to enable experienced observers to rank order tibial plateau fracture severity and quality of reduction and assess the correlation between the rankings.
2. Determine the clinical outcomes of the patients using general health status and joint-specific questionnaires.
3. Determine the degree to which the severity of injury and the quality of reduction assessed by the rank order technique correlate with the clinical outcomes.

We hypothesized that there is a high level of correlation between orthopaedic surgeon rankings of injury severity and reduction quality, and that these ranks correlate with clinical outcome measures. We also hypothesized that injury severity is a primary, and quality of reduction a secondary determinant of outcome.

MATERIALS AND METHODS

Ninety-one patients with tibial plateau fractures presenting to our institutions between December 2005 and December 2009 were eligible for the study. Eligible fractures were selected from a larger group based on (i) availability of at least a two-year follow-up, (ii) the desire to represent the full spectrum of injury severity (Figure 1), and (iii) the presence of adequate injury and reduction radiographs. Injury films were unavailable for one patient, and two patients had died. Twenty-four patients could not be contacted. All 64 patients who were contacted agreed to participate and were the final study group. Age at time of injury and comorbid diseases was assessed through electronic chart review.[12] The latter was categorized using the Charlson Comorbidity Index (CCI). These served as secondary independent variables for the study.

The initial injury and two to four month follow-up AP and lateral knee x-rays of the 64 patients were distributed to four fellowship trained orthopaedic traumatologists. Apple's iTunes software, and its cover flow format for browsing album artwork (Figure 2), were utilized to display and stratify de-identified radiographs. Using iTunes podcasting functionality, new cases were added to a growing rank ordering queue, dynamically updated on the computers of observers over the internet. Once received, cases from the queue were independently ordered into "playlists" on laptop computers at three centers by the traumatologists, using only their knowledge and experience. The continuous cover flow format allowed the surgeons to easily view the radiographs side-by-side and re-position them into a rank order. Surgeons were blinded to patient name, information, treatment, and outcome. They were asked to rank the fractures from "least to most severe." Specifically, raters were asked, "Which knee would you most or least like to have based on your experience with tibial plateau fractures?" The rank orders of each individual surgeon raters were electronically uploaded to a central server.

Table 1. Averages of key independent and dependent variables

Age	Charlson Comorbidity Index	SF-12 MCS[1]	SF-12 PCS[2]	KOOS Pain	KOOS Symptoms	KOOS ADL[3]	KOOS Sport & Rec	KOOS Quality of Life
50.6	1.03	53.7	42.3	75.7	72.0	64.8	48.4	53.0

[1]Mental component summary
[2]Physical component summary
[3]Activities of daily living

Table 2. Age and Charlson Comorbidity Index comparison in male vs. female

	Male	Female	p-value
Age	44.72	56.47	0.0011
Charlson Comorbidity Index	0.53	1.53	0.0050

Table 3. Clinical outcomes based on gender

	Male	Female	p-value
SF-12 MCS	54.3	53.1	0.56
SF-12 PCS	42.9	41.7	0.65
KOOS Pain	71.6	79.7	0.10
KOOS Sx	68.2	75.9	0.17
KOOS ADL	66.4	63.1	0.62
KOOS S&R	46.9	49.8	0.71
KOOS QOL	46.9	59.2	0.08

The same technique was utilized to assess reduction quality. Each clinician was provided AP and lateral radiographs of the proximal tibia at two to four month follow-up and asked to make the same rank order assessments with the same criteria. They ranked the radiographs with 1 representing "best reduction" and 64 "worst reduction" again using the question, "Which knee would you most or least like to have based on your experience with tibial plateau fractures?" The initial radiographs were not available at the time of assessment of reductions, and the ranking sessions were done in different months to avoid any recall of initial injury pattern. In order to determine the independent effect of quality of reduction, fractures that were initially minimally displaced were considered equivalent to displaced fractures that were reduced with minimal residual displacement.

Members of the research team contacted the 64 patients via telephone or mail. Clinical outcome was assessed using validated patient-based outcome measures. All patients completed the Short Form-12 (SF-12), a general health survey, to assess the effect of the fracture on physical and mental health.[13] From the SF-12, the physical composite score (PCS) and the mental composite score (MCS) were calculated. The Knee injury Outcomes and Osteoarthritis Score (KOOS) was also completed by the patients. The KOOS is a joint-specific outcome score that incorporates components of the Western Ontario and McMaster Universities Arthritis Index (WOMAC) assessing pain, function, and stiffness. The KOOS has additional questions about sport and function during recreation and quality of life.[14] The results of these questionnaires served as the dependent outcome variables for the study.

Pearson's correlation was used to measure agreement between the independent rate assessments of fracture severity and quality of reduction, from a possible -1 to +1, with -1 equaling a perfectly negative correlation and +1 representing a perfectly positive correlation. A value of 0 represented no correlation. Single factor analysis of variance (ANOVA) tests were performed to evaluate the independent effects of gender on the measured outcomes. Kendall's Tau-b (τ_b) is a correlation measure that assesses the likelihood of pair sets to follow an order. It was utilized to determine correlation of severity ranking, age, and CCI with the outcome measures.

RESULTS

The cover flow browsing format offered by iTunes allowed radiographs to be viewed in a continuous flip-through mode, or in a detailed full screen mode. It also permitted surgeons to easily place radiographs in the desired order and then quickly observe the images in sequence.

The study group reflected the typical patients who sustain tibial plateau fractures, with an average age of 50.6 years. The questionnaires were completed between 26-55 months after the injury. The thirty-two male patients were significantly younger than the female patients at the time of injury ($p<0.05$). The average CCI was 1.03. The average patient outcome scores for the entire group are listed in Table 1. Female patients had significantly higher comorbid disease score than males ($P<0.05$-Table 2). Gender did not significantly affect the outcomes (Table 3).

Correlation of fracture severity ranking between each of the four raters was between 0.77 and 0.91 (Table 4),

Table 4. Severity and reduction ranking correlation amongst the four orthopaedic traumatologist raters

Raters	Injury rank correlation	Reduction rank correlation
1-2	0.846	0.818
1-3	0.899	0.781
1-4	0.905	0.712
2-3	0.893	0.771
2-4	0.767	0.675
3-4	0.855	0.663

Table 5. Correlation values between injury severity ranking and the clinical outcome subscales with each of the four rankers.

	Ranker			
Outcome Subscale	1	2	3	4
SF-12 MCS	0.125	0.141	0.109	0.134
SF-12 PCS	0.101	0.108	0.114	0.139
KOOS Pain	0.034	0.051	0.004	0.07
KOOS Symptoms	-0.179	-0.154	-0.186	-0.100
KOOS ADL	0.109	0.243	0.134	0.118
KOOS Sport & Rec	0.058	0.123	0.093	0.070
KOOS Quality of Life	-0.054	0.030	-0.050	-0.029

Table 6. Correlation values between quality of reduction ranking and the clinical outcome subscales with each of the four rankers.

	Ranker			
Outcome Subscale	1	2	3	4
SF-12 MCS	-0.176	-0.096	-0.222	-0.005
SF-12 PCS	-0.054	0.012	-0.089	0.005
KOOS Pain	-0.073	0.011	0.007	0.054
KOOS Symptoms	-0.255*	-0.107	-0.084	-0.082
KOOS ADL	-0.002	0.169	-0.151	0.045
KOOS Sport & Rec	-0.145	-0.002	-0.143	-0.071
KOOS Quality of Life	-0.169	-0.068	-0.155	-0.079

*the only significant value with $p<0.05$

suggesting outstanding agreement. Correlation of reduction quality ranking also showed very strong agreement, with results ranging from 0.66 to 0.82 between each of the individual rankers.

Fracture severity did not correlate with clinical outcome (Table 5). Most of the values were positive, suggesting that worse injuries led to worse outcomes, but these positive values were very small and were not significantly different from zero.

Overall quality of reduction did not have significant correlation with clinical outcome (Table 6). Many of the values were negative, paradoxically suggesting that patients' symptoms improved with worse quality of reduction. However, only the correlation value of ranker number 1 for the KOOS Symptoms subscale was shown to be significant, although unlikely to be clinically significant. Figure 3 as well as the corresponding data in Table 7 demonstrate a case example illustrating how the clinical outcome scores did not closely correlate with the injury and reduction ranking.

Table 7. The Clinical outcomes of the two patients in Figure 3.

Scale Subscale	Score	Score
SF-12 MCS	55.9	48
SF-12 PCS	55.9	44.7
Pain	69.4	80.6
Symptoms	60.7	35.7
ADLs	48.5	48.5
Sports & Rec	15	65
Quality of Life	31.3	25

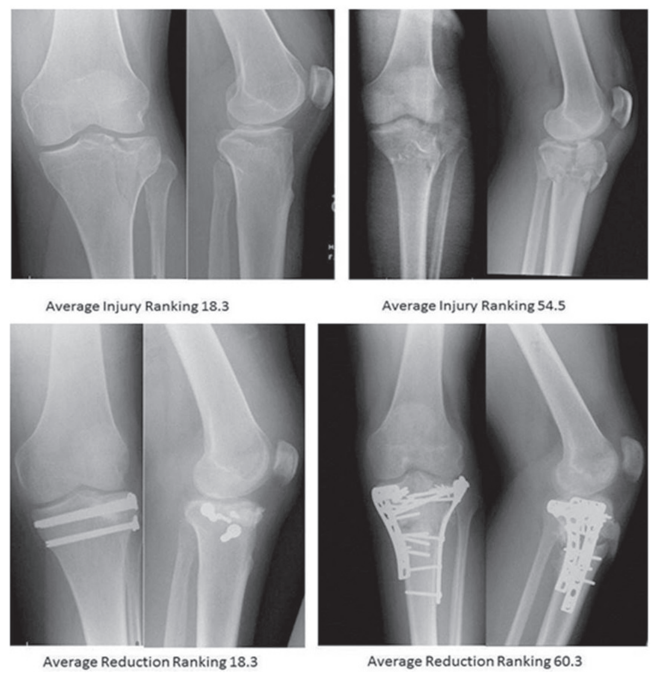


Figure 3. (a) The injury radiographs of two patients and the average injury severity ranks are shown. (b) The reduction radiographs and the average reduction ranks of the same two patients are shown. These cases illustrate that the clinical outcome measures do not closely correlate with the injury severity or quality of reduction ranking. The data are shown in Table 7.

DISCUSSION

Fracture severity and reduction quality were effectively assessed using an electronic rank ordering method. The four experienced orthopaedic traumatologists had a high level of agreement in ordering tibial plateau fracture injury and reduction radiographs based on fracture severity and reduction quality, respectively. This is in contrast to classification of tibial plateau fracture radiographs, whether using the AO/OTA or Schatzker classifications, which has only mild to moderate interobserver reliability.[15] To our knowledge, rank ordering of tibial plateau fractures has been performed only in one previous study, to assess bicondylar fractures for fracture severity (all AO/OTA 41-C3 or Schatzker V/VI).[16] In that study, inter-observer agreement was modest, with a weighted kappa statistic of 0.66. Tibial plateau fractures have not been assessed across the broader clinical spectrum of injury using a rank order analysis.

Good inter-observer agreement in stratifying the radiographic appearances using rank order methods may not be surprising. Similar high levels of agreement have previously been shown in the tibial plafond, where rank order analysis of fractures was shown to be much more reliable than fracture classification.[10,11] Electronic rank ordering holds promise as a method to reliably stratify arbitrarily large numbers of radiographs based on injury severity and or reduction quality in future fracture studies. In this study 64 radiograph pairs were assessed, but the technology would allow these ranks to be continuously increased by slotting in additional cases. As each new case arrives, the task amounts to placing that case between the two most comparably severe cases in the established ranking. In most previous fracture studies, inability to control or measure these variables has made it difficult to answer important questions about fracture treatment and prognosis.

Expert rank ordering of fracture severity did not significantly correlate with patient-reported outcomes obtained at a minimum of two years after injury in tibial plateau fractures. This is a surprising finding, particularly since cases were chosen to span the spectrum of severity; there were patients with minimally displaced fracture lines that were barely visible at one end of the spectrum and patients with high energy multi-fragmentary articular surfaces at the other end.

Similarly, expert rank ordering of reduction quality in tibial plateau fractures did not significantly correlate with either measure of patient outcome. This was equally surprising, especially in this series where a wide spectrum of reduction quality was included.

For tibial plafond fractures, rank orderings of both fracture severity and articular reduction have been shown to correlate with radiographic evidence of post traumatic osteoarthritis. However, neither fracture severity nor quality of reduction significantly correlate with clinical outcome scores, general health, or return to work.[17] Prior to the current study, we postulated that this was because distal tibial plafond fractures represent only the high end of the severity spectrum. However, the current study demonstrates the same lack of correlation between fracture severity and clinical outcome, as well as reduction quality and clinical outcome, for tibial plateau fractures across the full spectrum of injury severity. Patients in this series of proximal tibia fractures would have been expected to range from low rates of degenerative arthritis a long time after injury (minimally displaced or perfectly reduced unicondylar fractures) to high rates soon after a few years (severely comminuted displaced irreducible bicondylar fractures).

As an explanation, it is possible that clinician assessment of fracture severity is not very good. It is also possible that two-dimensional imaging is not fully capable of estimating articular injury. With images only presented as plain radiographs, expert raters may have difficulty in making distinctions between fractures that appear similar to them but are truly different and have different effects on patient outcome.[5] The results might have been different had the clinicians reviewed CT-based imaging or with more formal CT-based quantification of fracture energy. It is also possible that clinicians are not good at assessing the effect of various injury patterns on outcome. To identify the best method of determining injury severity, rank ordering could be compared to 3-D CT metrics of fracture energy, evaluating each method's correlation with outcome.[18] These computational assessments of injury severity and of reduction quality have been shown to correlate with patient outcome and PTOA in distal tibia fractures.[19]

Objectively measuring outcome is difficult and may contribute to difficulty in demonstrating a correlation between injury severity or quality of reduction and outcome. Patient based outcome measures that emphasize the patient perspective and are validated as effective and accurate measures of outcome are currently considered the most appropriate parameters to measure clinical outcome. Outcome could also be measured by appearance of radiographs at follow up, and it is possible that a correlation would then exist. However, patient based outcome is considered the most relevant and appropriate.

Currently, there are no validated instruments specifically for outcomes in tibial plateau fractures. The KOOS is a reliable instrument that can be used for both short and long term follow-up, and it has been validated for several knee injuries and procedures including osteoarthritis, focal chondral defects, total knee replacement, anterior cruciate ligament reconstruction, and meniscectomy.[20-22] The KOOS scores have been found to have the largest correlations with the general health survey of all knee score questionnaires.[16,23] The SF12 is a validated clinical outcome measure used in a large number of studies and is designed to detect the impact of various disease conditions (like fractures) on overall patient health. It is possible that the outcome measures are not sensitive enough to detect a meaningful clinical difference in outcome. The KOOS data are specific to the knee and would have been expected to detect smaller differences in outcome as a result of the fracture than the SF 12. Despite a wide range of KOOS scores between patients there was no correlation with injury severity or quality of reduction on clinical outcome.

There are limitations of this study. Outcome assessment did not include radiographs to assess for PTOA or a physical examination. In addition, multiple variables with known effect on outcome were not assessed in the study. These include the appearance of the soft tissues at time of injury, the type of operative treatment, complications of treatment, and the need for secondary operations. The radiographs were not ideal to assess for limb alignment, a factor that may be important in tibial plateau outcomes.

The results of this study suggest that something other than injury and treatment variables determine patient based outcome measures. Although some patient variables were measured there are many that were not or could not be assessed, such as workers' compensation status, drug or alcohol history, psychosocial profile, blue versus white collar labor, and others. An acknowledged limitation of assessing the effect of the injury on patient-based outcome measures at follow-up is that the patient scores prior to their injury are unknown. The patients' pre-morbid status prior to their fracture may be more important in determining outcomes at follow up than anything that can be measured on radiographs.

This study established that tibial plateau fractures can be reliably rank-ordered for severity. More importantly, the novel electronic interface introduced allows an ever-expanding series of cases to be ranked quickly, conveniently, and across multiple centers. The interface is easy to use and allows real-time retrieval of the most current case series data. Given the excellent inter-observer agreement, this interface holds great promise for establishing prospective, continuously expanding rank orders of various fracture types, which may have great value for clinical research, education about fracture severity, and for prognosis and treatment decisions.

In summary, this study showed a lack of correlation between clinician ranked assessments of fracture severity and reduction quality, and patient-reported outcome measures obtained several years after injury. Orthopaedic surgeons should consider the importance they place on these two criteria when determining prognosis for their patients with proximal tibia fractures. It may not be true that a more severe injury will predictably have a worse prognosis than a less severe injury and similarly that a well-reduced displaced proximal tibia fracture has a better prognosis than a poorly reduced fracture. It may be that other factors are so much greater determinants of outcome than injury severity or quality of reduction as to render either of those parameters to secondary importance in contrast to currently held belief that they are the most important factors in determining outcome. Future research is indicated to better understand what factors do determine and predict outcome and to assess factors other than the appearances of pre and post treatment radiographs.

SOURCE OF FUNDING

The research reported in this publication was supported by the National Institute of Arthritis and Musculoskeletal and Skin Diseases of the National Institutes of Health under Award Number 5 P50 AR055533 and by the World Arthrosis Organization. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

REFERENCES

1. **Kaukonen JP, Karaharju EO, Porras M, et al.** Functional recovery after fractures of the distal forearm. Anaysis of radiographic and other factors affecting the outcome. Ann Chir Gynaecol. 1988;77(1):27-31.
2. **Trumble TE, Schmitt SR, and Vedder NB.** Factors affecting functional outcome of displaced intra-articular distal radius fractures. J Hand Surg Am. 1994;19(2):325-340.
3. **Kundel K, Braun W, Wieberneit J, et al.** Intraarticular distal humerus fractures. Factors affecting functional outcome. Clin Orthop Relat Res. 1996;332:200-208.
4. **Leung F, Ozkan M, Chow SP.** Conservative treatment of intra-articular fractures of the distal radius—factors affecting functional outcome. Hand Surg. 2000;5(2):145-53.
5. **Anderson DD, Mosqueda T, Thomas T, et al.** Quantifying tibial plafond fracture severity: absorbed energy and fragment displacement agree with clinical rank ordering. Journal of Orthopaedic Research 2008;26:1046-1055
6. **Chen SH, Wu PH, Lee YS.** Long-term results of pilon fractures. Arch Orthop Trauma Surg. 2007;127(1):55-60.
7. **Batra S, Gupta A.** The effect of fracture-related factors on the functional outcome at 1 year in distal radius fractures. Injury. 2002;33(6):499-502.

8. **Finnan R, Funk L, Pinzur MS.** Health related quality of life in patients with supination-external rotation stage IV ankle fractures. Foot Ankle Int. 2005;26(12):1038-1041.
9. **Weil YA, Gardner MJ, Boraiah S, et al.** Posteromedial supine approach for reduction and fixation of medial and bicondylar tibial plateau fractures. J Orthop Trauma. 2008;22(5):357-362.
10. **Dirschl DR, Ferry ST.** Reliability of classification of fractures of the tibial plafond according to a rank-order method. The Journal of Trauma. 2006;61:1-4.
11. **DeCoster TA, Willis MC, Marsh JL, et al.** Rank order analysis of tibial plafond fractures: does injury or reduction predict outcome? Foot & Ankle International. 1999;20:44-49.
12. **Charlson ME, Pompei P, Ales KL, et al.** A new method of classifying prognostic comorbidity in longitudinal studies: development and validation. Journal of Chronic Disease 1987;40:373-783.
13. **Ware JE, Kosinski M, Keller SD.** SF-12: an even shorter health survey. Med Outcomes Trust Bull 1996;4:2.
14. **Roos EM, Roos HP, Lohmander LS, et al.** Knee injury and osteoarthritis outcome score (KOOS)—development of a self-administered outcome measure. Journal of Orthopaedic & Sports Physical Therapy. 1998;78:88-96.
15. **Walton NP, Harrish S, Roberts C, et al.** AO or Schatzker? How reliable is classification of tibial plateau fractures? Archives of Orthopaedic and Trauma Surgery. 2003;123:396-398.
16. **Barei DP, Nork SE, Mills WJ, et al.** Functional outcomes of severe bicondylar tibial plateau fractures treated with dual incisions and medial and lateral plates. JBJS. 2006;88:1713-1721.
17. **Williams TM, Nepola JV, DeCoster TA, et al.** Factors affecting outcome in tibial plafond fractures. Clinical Orthopaedics and Related Research 2004;423:93-98.
18. **Anderson DD, Mosqueda T, Thomas T, et al.** Quantifying tibial plafond fracture severity: absorbed energy and fragment displacement agree with clinical rank ordering. J Orthop Res. 2008;26(8):1046-1052.
19. **Thomas TP, Anderson DD, Mosqueda TV, et al.** Objective CT-based metrics of articular fracture severity to assess risk for posttraumatic osteoarthritis. J Orthop Trauma. 2010;24(12):764-769.
20. **Roos EM, Lohmander LS.** The knee injury and osteoarthritis outcome score (KOOS): from joint injury to osteoarthritis. Health Qual Life Outcomes. 2003;3(1):64
21. **Roos EM, Toksvig-Larsen S.** Knee injury and osteoarthritis outcome score (KOOS)- validation and comparison to the WOMAC in total knee replacement. Health Qual Life Outcome. 2003;25(1):17
22. **Wang D, Jones, MH, Khair MM, et al.** Patient-reported outcome measures for the knee. J Knee Surg. 2010;23(3):137-151.
23. **Weigel DP, Marsh JL.** High-energy fractures of the tibial plateau. JBJS. 2002;84:1541-1551.

INJURIES IN COLLEGIATE WRESTLERS AT AN ELITE DIVISION 1 NCAA WRESTLING PROGRAM: AN EPIDEMIOLOGICAL STUDY

Jesse E. Otero, MD, PhD,1 Christopher M. Graves, MD,1 Matthew J. Bollier, MD1*

ABSTRACT

Background: Injury is common in the sport of wrestling. More than 6000 athletes compete in NCAA wrestling yearly. Despite this popularity, little is known about the epidemiology of wrestlers' injuries and factors affecting return to competition. We hypothesized that patterns of injury and associated factors influence return to participation.

Methods: Retrospective database review of one Division I NCAA wrestling program over nine seasons (2002 to 2011).

Results: From 2002 to 2011, 125 wrestlers were varsity participants at a single NCAA Division I program. Among these wrestlers, there were 4275 exposures per year on average. We identified 1034 musculoskeletal injuries, skin injuries, and concussions in 120 athletes (96% of participants). Eighty-two percent of athletes missed at least one day secondary to these injuries, while 69% were unable to compete in at least one match. The injury rate was estimated at 19.6 (SD 16.5) per 1000 exposures. The rate of injuries requiring surgery was estimated at 1.4 (SD 2.1) per 1000 exposures. Weight class, record, age at injury, and eligibility status did not affect the rate or type of injury. A significant difference was noted in the athletes who returned to competition following surgery. Athletes who returned to competition after surgical treatment for an injury ultimately competed in more matches (62.4 vs 18.2, $p < 0.001$), had more wins (45.2 vs 12.1, $p<0.001$) and a higher win percentage (67.5 vs 51.2 $p < 0.01$) than those who did not return following surgery.

Conclusion: Return to competition in collegiate wrestling is dependent on many factors in addition to severity of injury and surgery type. There is a positive association between return to sport and success as a collegiate wrestler. Our findings will be helpful to wrestlers and coaches in guiding expectations after injury.

Level of Evidence: Level 4 diagnostic

INTRODUCTION

Wrestling is a physically demanding sport in which injury is common. Despite recent declines in participation,[1] it remains a popular sport at the collegiate level. In the 2011-12 season, 6622 athletes competed at the NCAA Division I, II and III levels.[1] There have been several previous studies regarding the epidemiology of injuries in wrestling.[2-7] These have been primarily reviews of national injury databases,[8] or focused at the high school,[9,10] primary school,[11] or Olympic levels.[7] There have been no published reviews of injuries from a single collegiate wrestling team in the modern era, and little data has been published regarding surgical treatment of wrestlers and the factors associated with return to competition following surgery. The purpose of this study is to describe the patterns of injury and associated factors in collegiate wrestlers, and examine the effect of surgical treatment on return to participation in one Division I NCAA wrestling program over nine seasons (2002 to 2011).

METHODS

Institutional review board (IRB) approval was obtained for this study. We conducted a retrospective review of training room and medical records of all injuries sustained by athletes on the wrestling team of a single NCAA Division I program during the 9 seasons from 2002 to 2011. All injuries were entered into the Sports Injury Monitoring System (SIMS - Med Sport Systems, Dimondale, Michigan) by an athletic trainer at the time of injury. SIMS is a computerized database in which details of the injury and injured athlete are entered. This database is monitored by the university as well as the wrestling conference.

The electronic medical records of injured athletes were reviewed to determine which injuries required surgical intervention and the date of surgery if applicable. Publically available competition records[12] were used to determine the dates that the athlete participated in var-

[1]University of Iowa Department of Orthopaedic Surgery and Rehabilitation
200 Hawkins Drive, Iowa City, IA 52242

*Corresponding Author:
Matthew J. Bollier
University of Iowa Department of Orthopaedic Surgery and Rehabilitation, 2701 Prairie Meadow Dr., Iowa City, IA 52242
Tel: (319)384-7070

Table 1: Distribution of Injuries and Number of Injuries Resulting in Missed Time and Surgery by Body Part

	All injuries		Injuries Causing Missed Time		Injuries that Required Surgery		Average Year of Eligibility
Location of injuries	Number	%	Number	%	Number	%	
Skin	181	17.5	63	16.4			2.8
Knee	177	17.1	97	25.2	43	58.1	2.8
Head and Face	173	16.7	18	4.7	3	4.1	2.7
Shoulder	101	9.8	46	11.9	17	23.0	2.5
Foot and Ankle	80	7.7	37	9.6	2	2.7	2.5
Spine, cervical	62	6.0	16	4.2			3.0
Spine, lumbar	55	5.3	16	4.2			3.0
Chest wall (not spine)	33	3.2	20	5.2			2.8
Hand and Wrist	32	3.1	12	3.1	2	2.7	2.7
Brain	30	2.9	28	7.3			2.5
Thigh	28	2.7	8	2.1	2	2.7	2.6
Elbow	27	2.6	13	3.4	2	2.7	2.9
Hip	17	1.6	4	1.0	2	2.7	2.6
Systemic	16	1.5	3	0.8	1	1.4	2.0
Spine, thoracic	10	1.0	1	0.3			2.9
Abdomen	7	0.7	3	0.8			1.9
Otero	5	0.5	0	0.0			3.2
TOTAL	1034		385		74		2.7

1=RS Freshman   4=Junior
2=Freshman   5=Senior
3=Sophomore

sity competition, confirm their weight class at the time of injury, as well as determine their overall win/loss record.

DEFINITIONS

An injury was defined as any skin problem, musculoskeletal problem or systemic illness that occurred during practice or competition and resulted in a visit to an athletic trainer or physician. Concussions or neurologic injury suffered as a result of these events were also included as an injury. A season was defined to reflect the academic year from August 1 to July 31 of the next year. The athlete's eligibility was defined using years one through five, with the final year (senior) eligibility listed as 5, and the inclusion of an additional year of eligibility as a freshman if a red-shirt year was taken. Weight class is defined by the highest weight class the wrestler competed in during a given year based on the official team roster. In the time period of this study, there was a change in heavyweight from 285 to 275 lbs, and these weight classes were combined for statistical purposes. An exposure was defined as participation in one of the 144 NCAA-sanctioned yearly practices or matches in which a wrestler participated. Injuries based on anatomic region were recorded if experienced as a result of any team-related activity such as matches, practices, or strength and conditioning sessions.

Injuries and conditions requiring medical attention were entered prospectively at the time of injury by athletic trainers into SIMS during the 9 seasons from August 2002 to July 2011. This injury data from the SIMS database was reviewed by two of the authors and systemic illnesses or injuries not related to team activities such as practices or matches were excluded. The injuries were categorized by body part injured. (Table 1) If an athlete was unable to compete or practice as a result of the injury, this was also recorded into SIMS as the data became available.

Using information from official team rosters, the athlete's age, year of eligibility, and weight class on the date of injury were obtained. Eligibility and weight wrestled were determined for each athlete and year by the official season summary published online.

Table 2: Characteristics of Injuries

Characteristic	All injuries	Injuries Causing Missed Time	Injuries that Required Surgery
Age at Injury	20.7 (1.4)	20.8 (1.4)	20.8 (1.5)
Average Eligibility	2.7 (1.3)	2.7 (1.3)	2.8 (1.3)
Number of Injuries per Athlete	8.6 (6.9)	-	-
Days on Injury List	13.6 (38.0)	36.5 (55.2)	109.2 (77.4)
Competitions Missed	1.6 (4.3)	3.6 (6.3)	8.9 (10.4)
Practices Missed	4.1 (10.6)	10.8 (15.1)	25.0 (23.4)

*Number in parenthes SD

Table 3: Distribution of Injuries and Surgery by Weight Class

Weight Class	# of Participants in 9 Years	All injuries		Injuries that Required Surgery	
		Number of Injuries	Risk per 1K Exposures	Number of Injuries	Risk per 1K Exposures
Low weights (125, 133, 141)	101	293	17.4 (12.2)	23	1.4 (2.1)
Mid Weights (149, 157, 165)	128	399	19.5 (15.7)	31	1.5 (2.2)
High Weights (174, 184, 197, 285)	99	342	22.2 (21.0)	20	1.2 (2.0)
Total	328	1034	19.6	74	1.4

*SD in parentheses

Exposures were calculated using team competition data to determine total number of matches competed in by rostered athletes, and it was assumed that all athletes on the roster were eligible to participate in the 144 NCAA-allowed team practices per year. Statistical analyses were performed to identify significant associations between demographic characteristics of the injured wrestler, individual records, and injury variables. For purposes of analysis, we grouped weight classes into three categories including Low (125,133,141), Middle (149,157,165), and High (174,184,197,285) weight athletes.

The Mantel-Haenszel 2 test and Tukey-Kramer adjustments for multiple comparisons were used to analyze for significant trends in the relationship of age, eligibility status, weight class, and competition statistics in relation to the frequency and location of injuries. Additionally, we examined the data for trends indicating whether or not these injuries required surgery, and if the injured athlete was able to return after surgery. The relative risk (RR) of injury was also calculated for year of eligibility and weight class. For all analyses, $p < 0.05$ was considered statistically significant.

RESULTS

In the nine seasons from 2002 to 2011, 125 athletes were varsity participants in Men's Wrestling at a single NCAA Division I institution. We identified 1034 musculoskeletal injuries, skin injuries, and concussions in 120 athletes (96% of participants). Eighty-two percent (102/125) of athletes missed at least a single day secondary to these injuries, while 69% (86/125) were unable to compete in at least one match. The average number of exposures per year was calculated at 4275 for all athletes. The injury rate was estimated at 19.6 (SD 16.5) per 1000 exposures. The rate of injuries requiring surgery was estimated to be 1.4 (SD 2.1) per 1000 exposures.

Ages of participants ranged from 18 to 25 years old, with 99.3% of the wrestlers being between 18-23. Eligibility status was fairly evenly divided between the five years, with slightly fewer redshirt freshmen and seniors (61 and 50, respectively) versus years two (79), three (72), and four (65) in eligibility.

There was no association found between age or eligibility and risk of suffering an injury, location of injury, missed time or missed competition (Table 2). Of those injured wrestlers who required surgery, neither age nor eligibility status was noted to have a significant effect on return to competition following surgery, although 3 of the 9 injured wrestlers in their final year of eligibility elected to delay procedures until the conclusion of their career.

With regard to weight class, there was no significant difference noted between injury frequency, time missed following injury, or location of injury when the three groups of weight classes were compared. Similarly, there was no difference in relative risk of injuries sustained that required surgery (RR = 1.2 to 1.5). There was, however, a higher percentage of middle-weight wrestlers who did not return after injuries which required surgery (12/29) when compared to the low (2/19) or high (3/17) weight wrestlers. (P=0.04) (Table 3)

There were 74 surgeries performed on 48 wrestlers during the time of our data collection (Table 4). Following 72% of these interventions (52/74), the injured athlete returned to compete following the surgery. The most common surgeries performed were meniscus repair/debridement (21), ACL reconstruction (15), and labral tear repair in the shoulder (10). There were no significant differences observed between type of surgery and likelihood of returning to competition.

The athletes in our cohort competed in an average of 43 varsity matches, with 29 wins and an overall win loss percentage of 68%. There was no significant difference noted in rate of injury, location of injury, or percentage

Table 4: Characteristics of Wrestlers With Surgery Comparing Wrestlers Who Return to Those Who Do Not Return

	TOTAL #	Wrestles Who Return	Wrestles Who Do Not Return	Surgery after 5th Year
Total Surgery	74	53	17	4
Knee Surgery	43	32	9	2
Meniscus	21	15	6	
ACL	15	11	2	2
Cartilage	2	2		
Infection	2	1	1	
Bursectomy	2	2		
PLC	1	1		
Shoulder Surgery	17	12	4	1
SLAP Repair	10	6	3	1
Bankart	3	3		
Capsulorrhaphy	2	1	1	
Bursectomy-other	1	1		
Muscle repair	1	1		
Other Surgery	14	9	4	1
Fracture	8	5	3	
Hip Impingement	2	1		1
Hamstring	2	1	1	
Bursectomy	1	1		
Infection	1	1		
Weight Class				
Low		19	2	2
Mid		17	12	2
High		17	3	
Number of matches		62.4 (48.0)	18.2 (23.4)	*p-value 0.00052*
# of winning matches		45.2 (37.5)	12.1 (18.2)	*p-value 0.00083*
Record Win %		67.5 (19.6)	51.2 (23.9)	*p-value 0.01275*
Practices Missed		21.0 (22.4)	32.8 (19.2)	*p-value 0.05*
Competitions Missed		7.4 (9.5)	11.9 (10.5)	*p-value NS*
Days on Injury List		101.7 (71.0)	124.0 (10.5)	*p-value NS*
Eligibility status		2.6 (1.2)	2.9 (1.3)	*p-value NS*
AGE at injury		20.6 (1.5)	20.9 (1.4)	*p-value NS*

Number in parenthesis is SD

Eligibility status: 1 = RS Freshman 2 = Freshman 3 = Sophomore 4 = Junior 5 = Senior

Low weights 125, 133, 141

Mid weights 149, 157, 165

High weights 174, 184, 197, 285

of injuries requiring surgery between athletes with differing numbers of matches, competitions, or win/loss percentages. A significant difference was noted however in those athletes who returned to competition following surgery, showing athletes that returned ultimately competed in more matches (62.4 vs 18.2, $p < 0.001$), had more total wins (45.2 vs 12.1, $p<0.001$) and a higher win loss percentage (67.5 vs 51.2 $p < 0.01$) than those who did not return following their intervention. (Table 4)

DISCUSSION

The rate of injury per exposure in our study (19.6 per 1000) is similar to national data previously described through review of the NCAA Injury Surveillance System,[8] and in other published reports of injury at the collegiate level.[5] Previous authors have described high rates of injury,[5] often attributed to the competitive nature of the sport.[13] In previous studies, a majority of injuries sustained occurred in the knee and shoulder, and skin injuries were third.[8] In our study, however, lacerations and infections of the skin were the most common injury encountered, and the second most likely to result in missed participation time. (Table 1) Of non-skin musculoskeletal injuries, injuries followed a similar pattern with knee and shoulder as the most commonly injured structures.

Similar to findings of Jarrett, et al,[5] no statistical significance was found in injuries to specific weight classes. Similar to the previous publication, our data shows a non-significant trend of higher injury numbers in middle-weight wrestlers. Year of eligibility and athlete age at the time of injury were noted to be non-significant, which mirrors previous results as well.[5] It was interesting to observe that despite some evidence that younger athletes and those in earlier years of eligibility in other sports show predilection to injury,[14] this was not evident in our cohort.

Perhaps the most interesting finding of our study was that despite having similar rates and locations of injuries as well as similar incidence of surgery, there was great disparity in the rates of return to competition amongst wrestlers with differing win percentages, total number of wins, and total number of matches. Namely, of the wrestlers who required surgery for their injury, those who ultimately returned to competition wrestled in a greater number of matches, had a higher number of total wins, and had a higher overall win percentage.

One possible explanation for these findings reflects the increased dedication to sport of those athletes able to achieve better records. The factors that motivate an athlete who has suffered a relatively significant musculoskeletal injury to return to the sport that cause it are complex, but our findings certainly lend credence to the theory that those who are more successful may be more devoted to the sport despite setbacks such as serious injury requiring surgery. Nevertheless, caution should be exercised in drawing conclusions from studies where return to sport is the primary outcome of a surgical intervention, since as was previously described, the factors that contribute to return are complex.

Another hypothesis presented by Yoon, *et al* [15] points to physical differences among Olympic wrestlers with better winning percentages. Perhaps wrestlers who are more successful are more likely to return to competition after surgery because of a genetically superior ability to heal. Previous authors have also suggested there is a psychological component in return to sport following ACL surgery that can be difficult to quantify.[16]

Limitations of our study include the nature of retrospective data collection, and the possibility of errors in reporting the injuries in the SIMS database. Additionally, the physical and psychological factors that affect return to competition are complex, so caution should be used when applying general data of this nature to individual athletes. Finally, injury evaluation and medical treatment at one institution may not be generalizable.

In summary, collegiate wrestling is a physically demanding sport with a high rate of injury. National injury databases may underestimate the prevalence of "minor" injuries such as skin laceration or infection, although these can have a significant impact on participation. Return to competition following injury is dependent on many factors including severity of injury and requirement of surgery, but the most predictive factor in return to competition after surgery is win percentage. Wrestlers, coaches, and physicians should use this data to guide expectations regarding return to competition after injury.

REFERENCES

1. National Collegiate Athletic Association. Sports Sponsorship and Participation Research. Available at: http://www.ncaa.org/about/resources/research/sports-sponsorship-and-participation-research.
2. **Lök V, Yücetürk G.** Injuries of wrestling. Am J Sports Med. 1974;2:324-328.
3. **Snook GA.** A survey of wrestling injuries. Am J Sports Med. 1980;8:450-453.
4. **Snook GA.** Injuries in Intercollegiate Wrestling A 5-year study. Am J Sports Med. 1982;10:142-144.
5. **Jarrett GJ, Orwin JF, Dick RW.** Injuries in collegiate wrestling. Am J Sports Med. 1998;26:674-680.
6. **Dick R, Agel J, Marshall SW.** National collegiate athletic association injury surveillance system commentaries: Introduction and methods. J Athl Train. 2007; 42:173.
7. **Shadgan B, Feldman BJ, Jafari S.** Wrestling Injuries During the 2008 Beijing Olympic Games. Am J Sports Med. 2010;38:1870-1876.

8. **Agel J, Ransone J, Dick R, Oppliger R, Marshall SW.** Descriptive epidemiology of collegiate men's wrestling injuries: National Collegiate Athletic Association Injury Surveillance System, 1988–1989 through 2003–2004. J Athl Train. 2007;42:303.
9. **Yard EE, Collins CL, Dick RW, Comstock RD.** An Epidemiologic Comparison of High School and College Wrestling Injuries. Am J Sports Med. 2007;36:57-64.
10. **Darrow CJ, Collins CL, Yard EE, Comstock RD.** Epidemiology of Severe Injuries Among United States High School Athletes: 2005-2007. Am J Sports Med. 2009;37:1798-1805.
11. **Myers RJ, Linakis SW, Mello MJ, Linakis JG.** Competitive Wrestling-related Injuries in School Aged Athletes in U.S. Emergency Departments. West J Emerg Med. 2010;11:442-449.
12. Hawkeye Sports. Wrestling History. Available at: http://www.hawkeyesports.com/sports/2016/6/13/sports-m-wrestl-archive-iowa-m-wrestl-archive-html.aspx?path=wrestling
13. **Halloran L.** Wrestling injuries. Orthop Nurs. 2008;27:189-194.
14. **Wolf BR, Ebinger AE, Lawler MP, Britton CL.** Injury Patterns in Division I Collegiate Swimming. Am J Sports Med. 2009;37:2037-2042.
15. **Yoon J.** Physiological profiles of elite senior wrestlers. Sports Med. 2002;32:225-233.
16. **Ardern CL, Taylor NF, Feller JA, Whitehead TS, Webster KE.** Psychological responses matter in returning to preinjury level of sport after anterior cruciate ligament reconstruction surgery. Am J Sports Med. 2013;41:1549-1558.

EVALUATING DIFFERENT CLINICAL DIAGNOSIS OF ANTERIOR CRUCIATE LIGAMENT RUPTURES IN PROVIDERS WITH DIFFERENT TRAINING BACKGROUNDS

Alexander CM Chong, MSAE & MSME[1, 2]; Chelsea Whitetree, PA-C[3]; Michael C. Priddy, MD[2];
Parker R. Zimmerman[2]; Paul R. Haeder, MD[2]; Daniel J. Prohaska, MD[2, 3]

ABSTRACT

Introduction: Previous studies have shown that provider training and the tests performed play a role in the accuracy of diagnosis of anterior cruciate ligament (ACL) injuries. The specific aim of the current study is to determine the examiner proficiency and accuracy in performing the different proactive tests of ACL rupture before and after the induction of anesthesia prior to a definitive surgical procedure.

Materials and Methods: A case series was performed from January of 2015 through July of 2015. Two examiners were included (an experienced orthopaedic sports surgeon with more than 16 years in practice and an experienced orthopaedic physician assistant with 6 years of clinical experience in orthopaedic sports medicine). Three different physical examination tests were used before and after the induction of anesthesia to the patient: 1) Lachman test, 2) pivot shift test, and 3) Lelli test. Relevant patient demographic information such as BMI, thigh girth, and calf girth were recorded. Diagnosis of ACL rupture had been established pre-operatively.

Results: Thirty three patients met the inclusion criteria (males: 21 (64%), female: 12 (36%)). High percent of false negative was found with pivot shift test for both before and after anesthesia when compared to the other two tests. The Lelli test seemed to be most favorable to both the surgeon and the physician assistant with at least 67% favorable, while the pivot shift was least often felt to be the most useful test. No relationship was found for either patients' thigh or patients' calf girths with the physical examination test results for both examiners for any of the three tests (p = 0.110).

Conclusion: The diagnostic accuracy and limitations of the various tests for ACL injury need to be understood. Clinically, it is recommended performing at least two different examinations, as each test has its own specific limitations.

Level of Evidence: III- Prospective Cohort Study without blinding

Keywords: Lelli Test; Lachman Test; Pivot Shift Test; Arthroscopic Surgery; Anterior Cruciate Ligament

INTRODUCTION

Anterior cruciate ligament (ACL) injuries are common athletic injuries of the knee with an annual incidence of 68.6 per 100,000 person-years in the United States[1]. They largely occur in sports which require a sudden change of direction on a weight-bearing knee. Accurate diagnosis of ACL rupture relies on a combination of the patient's history, a clinical examination, and by Magnetic Resonance Imaging (MRI) scanning and diagnostic arthroscopy if needed[2,3]. The initial presentation of ACL injuries often includes a history of non-contact injury and a hemorrhagic effusion[4,5]. The early diagnosis of an ACL injury is of importance as there is good evidence that a delay between ACL injury and reconstruction is associated with a higher risk of subsequent damage to the menisci, particularly the medial meniscus, and the articular cartilage[6-18].

[1]Department of Graduate Medical Education, Via Christi Health, 929 N. Saint Francis, Wichita, KS 67214

[2]Department of Orthopaedics Surgery, The University of Kansas School of Medicine - Wichita, 929 N. Saint Francis, Wichita, KS 67214

[3]Advanced Orthopaedics Associates, 2778 N. Webb Road, Wichita, KS 67226

Corresponding Author:
Alexander Chong
Research Engineer
Department of Graduate Medical Education
Via Christi Health – Saint Francis campus
929 N. Saint Francis
Wichita, KS 67214 USA
alex.chong.ortho@gmail.com
Phone: 316-832-8923
Fax: 316-291-7799

Investigation Performed at the University of Kansas School of Medicine–Wichita, Wichita, Kansas

Conflict of Interest Statement: This study did not receive any funding support for this research. The participants and authors of this study did not receive any payments or other personal benefit, or commitments or agreements that were related in any way to the subject of the research that was conducted. No benefits of any form have been received directly or indirectly to the subject of this article. The authors report no actual or potential conflict of interest in relation to this article.

After ACL rupture, most patients have detectable signs and symptoms of excess knee laxity and instability[19]. There are several commonly used physical examination applied tests to determine an ACL injury such as the anterior drawer test, the Lachman test, the pivot shift test, and the Lelli test ("lever sign" test)[20-23]. It is, however, difficult to ascertain the benchmark for diagnostic accuracy following an ACL injury, and a significant percentage of subjects are misdiagnosed due to the limitations of each of these physical examination tests. Most of the literature has reported on the sensitivity, reliability, and specificity of these different physical examination tests to detect an ACL injury[21-37], but most are reporting experienced surgeons performing the examination. There is limited data available in the literature on less-experienced physicians or surgeons or even physician assistants using these physical examination tests for the ACL lesion by their simplicity, reliability, and specificity. Geraets et al[28] performed a study to assess the diagnostic value of ACL-specific medical history assessment and physical examination between primary and secondary care medical specialists, and found that a primary care physician was able to correctly identify 62% of chronic ACL injuries compared to 94% by an orthopaedic surgeon. This suggests that different providers with different training can have different interpretations with the same patients. The specific aim of the current study is to determine the examiner proficiency and accuracy in performing the different clinical diagnosis of ACL ruptures before and after the induction of anesthesia.

PATIENTS AND METHODS

Institutional review board approval was obtained for the study and consent was obtained from the patients prior to enrollment in the study. A case series was performed looking at consecutive examiner's proficiency and accuracy in performing the different clinical diagnosis of ACL ruptures before and after the induction of anesthesia from January 2015 through July 2016. The inclusion criteria for this study were patients who presented to the lead orthopedic surgeon with a unilateral knee injury that resulted in symptomatic instability at two selected facilities. There was no prior history of knee problems or injuries on the involved side, no prior ACL reconstruction or repair, the knee injury was not sustained within 72 hours prior to data collection, and there had been no surgical procedures on the involved knee in the six weeks prior to data collection.

The exclusion criteria for this study included all patients who presented with an ACL injury outside of the collection period, patients who had a previous knee surgery or infection on the affected side, patients presenting within 72 hours after injury, patients with chronic knee pain, patients with associated ligament injuries, and patients complaining of hip, ankle and foot symptoms.

Two examiners were included in this study: a sports medicine fellowship-trained orthopaedic surgeon with more than 16 years in practice and the other examiner was an orthopaedic physician assistant with 6 years of clinical experience in orthopaedic sports medicine. Three different physical examination tests (Figure 1) were used to evaluate for an ACL injury on both the affected and the non-affected extremities: 1) Lachman test, 2) pivot shift test, and 3) Lelli test. These tests were performed in the operating suite before and after the induction of anesthesia to the patient, and examinations were performed independently, without the other provider in the room and without discussing the results prior to recording the examination. All ACL injuries were confirmed arthroscopically.

Lachman Test (Figure 1a)

The Lachman test was performed with the patient lying supine with the examiner on the side of the extremity to be examined. The knee was flexed between 15º and 30º while the heel remained on the table. The examiner placed one hand behind the tibia and with the other hand grasped the patient's thigh. The examiner's thumb was placed on the tibial tuberosity. With the femur thus stabilized, firm pressure was then applied to the posterior tibia in an attempt to translate it anteriorly. A positive test indicating disruption of the ACL is one in which there is proprioceptive and/or visual anterior translation of the tibia in relation to the femur with a characteristic "mushy" or "soft" end point. This is in contrast to the "hard" end point of an intact ACL36. The grades of laxity were defined by the amount of anterior tibial translation relative to contralateral knee: Grade I: 1-5mm; Grade II: 6-10mm; and Grade III: >10mm.

Pivot Shift Test (Figure 1b)

The pivot shift test was performed with the patient lying in the supine position. The leg was then picked up at the ankle with one of the examiner's hands while the other hand was placed behind the fibula, over the lateral head of the gastrocnemius. The knee is initially flexed to 30º then slowly brought to full extension, with a slight valgus strain combined with 20º of internal rotation of the leg. The hand placed at the lateral portion of the leg at the level of the superior tibiofibular joint gives a strong valgus strain to prevent easy reduction of the tibia on the femur. If the tibia's position on the femur reduces as the knee is flexed in the range of 30º to 40º or if there is an anterior subluxation felt during knee extension, the test is positive for instability.

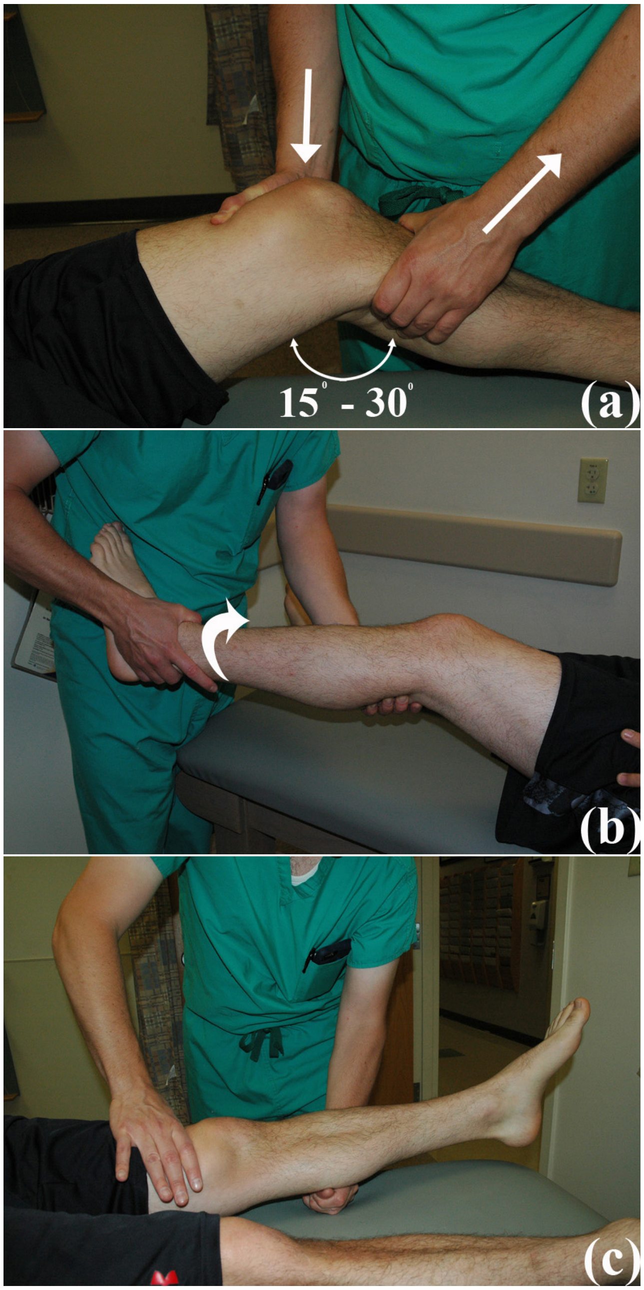


Figure 1. Physical Examination Test Performed. (a) Lachman Test, (b) Pivot Shift Test, and (c) Lelli Test

Lelli Test (Figure 1c)

The Lelli test, or the lever sign test, was described by Lelli et al[23]. The patient was placed supine with the knee fully extended on a hard surface. The examiner placed a closed fist under the proximal third of the patient's calf. The other hand of the examiner then applied a moderate downward force to the distal third of the quadriceps. An intact ACL allows the heel to lift off the examination table. Whereas an ACL deficient knee, the heel remain on the examination table.

Table 1. Patient Demographics

	Male (N = 21)	Female (N = 12)	P value
Age (Years)	30.9 ± 14.3 (11 – 62)	30.6 ± 17.0 (15 – 60)	0.299
Weight (kg)	95.2 ± 19.5 (43.1 – 127.0)	75.3 ± 19.8 (59.4 – 116.1)	0.690
Height (cm)	178 ± 10 (145 – 193)	163 ± 7 (150 – 175)	0.247
BMI (kg/m2)	29.8 ± 4.5 (20.6 – 36.9)	28.3 ± 8.1 (19.9 – 45.3)	0.024
Thigh girth (cm)	45.0 ± 6.0 (35 – 58)	43.7 ± 6.7 (35.1 – 60)	0.918
Calf girth (cm)	35.8 ± 4.3 (30 – 51)	37.8 ± 4.5 (31 – 46)	0.888

Data Collection

The size of the examinees' hand span from the tip of the thumb to the tip of the fifth digit (small finger) with the hand in maximal abduction was physically measured. The patient demographics including the patient's age, gender, height, weight, body mass index (BMI), and side of injury were collected. The girth of the patient's thigh and calf on the affected side (8cm above and below the midpoint of the patella) were also measured.

Statistical analysis

The independent sample t-test was performed using SPSS software (Version 19.0; SPSS Inc, Chicago, IL) and was used to determine if there were any observed differences between male and female with respect to patient demographics, thigh circumference and calf circumference. The level of significant difference was defined as $p<0.05$. The Kappa statistic using SPSS software (Version 19.0; SPSS Inc, Chicago, IL) was used to compare the inter- and intra-observer agreement for each of the three tests and for each provider. According to guidelines described by Landis and Koch[38], a value of ≤ 0.2 indicates "poor" agreement, 0.21-0.40 is "fair" agreement, 0.41-0.60 is "moderate" agreement, 0.61-0.80 is "substantial" agreement, and >0.80 is "excellent" agreement. Sensitivity was calculated by dividing the number of true positives by the number of subjects with ACL injuries.

RESULTS

Of the 33 patients that met the inclusion criteria, 21 patients (64%) were males and 12 patients (36%) were female. The mean age for the male and female groups were 30.9±14.3 years (range: 11-62 years) and 30.6±17.0 years (range: 15-60 years), respectively. The mean BMI for the male group (mean: 29.8±4.5 kg/m^2; range: 20.6-36.9 kg/m^2) was statistically significantly higher than the female group (mean: 28.3±8.1 kg/m^2; range: 19.9-45.3 kg/m^2;

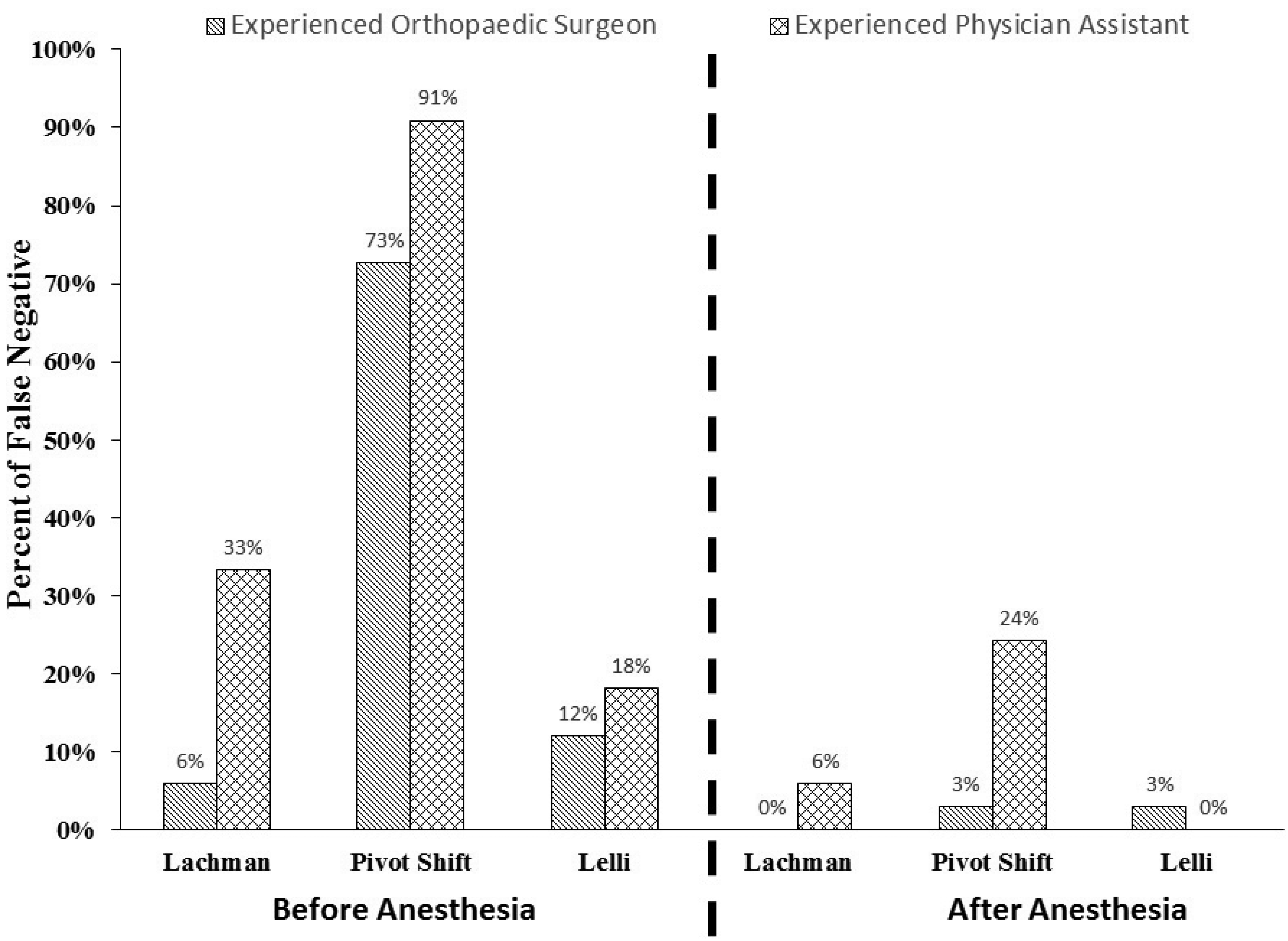


Figure 2. Validity For All Three Physical Examination ACL Tests Judgment of Negative Test

p=0.024). Statistically, there was no significant difference detected between males and females in terms of thigh girth and calf girth (Table 1). Of the 33 patients with ACL injuries, 32 patients were found to have complete tears during diagnostic arthroscopy, and only one patient was found to have a partial tear with the anteromedial bundle intact and a torn posterolateral bundle.

For the experienced sports medicine orthopaedic surgeon, prior to the induction of anesthesia, there was 2 (6%) false negatives with notable during Lachman test, 24 (73%) false negative during pivot shift testing (22 (67%) were guarding reaction from the patient due to pain, and 2 (6%) were tested negative) and 4 (12%) false negatives during Lelli test (2 (6%) with a guarding reaction, and 2 (6%) were tested negative). On the other hand, there were no false positives with any of the three tests. The sensitivity of the Lachman test, pivot shift test, and Lelli test were 94%, 27%, and 88 %, respectively. With the patient under general anesthesia, there were no (0%) false negatives with Lachman test, 1 (3%) false negative with the pivot shift maneuver, and 1 (3%) false negative with the Lelli test (Figure 2). There were no false positives on the contralateral limb. The sensitivity of the Lachman test was then determined to be 100%, and 97% for both the pivot shift test and Lelli test.

For the experienced orthopaedic physician assistant, prior to the induction of anesthesia, there were 11 (33%) false negatives with the Lachman test with guarding reaction noted in 10 (30%) patients, 30 (91%) false negatives with pivot shift testing with guarding reaction in 27 (82%) patients, and 6 (18%) false negatives with the Lelli test with guarding reaction in 2 (6%) patient. There were no false positives. The sensitivity for the Lachman test was 67%, for the pivot shift was 9%, and for the Lelli test was 82%. With the patient under general anesthesia, there were 2 (6%) false negatives with the Lachman test,

Table 2. Inter-observer reliability for judgments based on all three different physical examination tests to determine an ACL injury

	Before Anesthesia		After Anesthesia	
	Kappa coefficient	Percent of agreement	Kappa coefficient	Percent of agreement
Lachman test	0.23	73	N/A	94
Pivot shift test	0.23	76	0.18	79
Lelli test	0.30	82	N/A	97

Table 3. Intra-examination test reliability for judgments based on before or after anesthesia

	Experienced Orthopaedic Surgeon		Experienced Physician Assistant	
	Kappa coefficient	Percent of agreement	Kappa coefficient	Percent of agreement
Lachman test	N/A	94	0.23	73
Pivot shift test	0.02	30	0.06	33
Lelli test	0.05	85	N/A	67

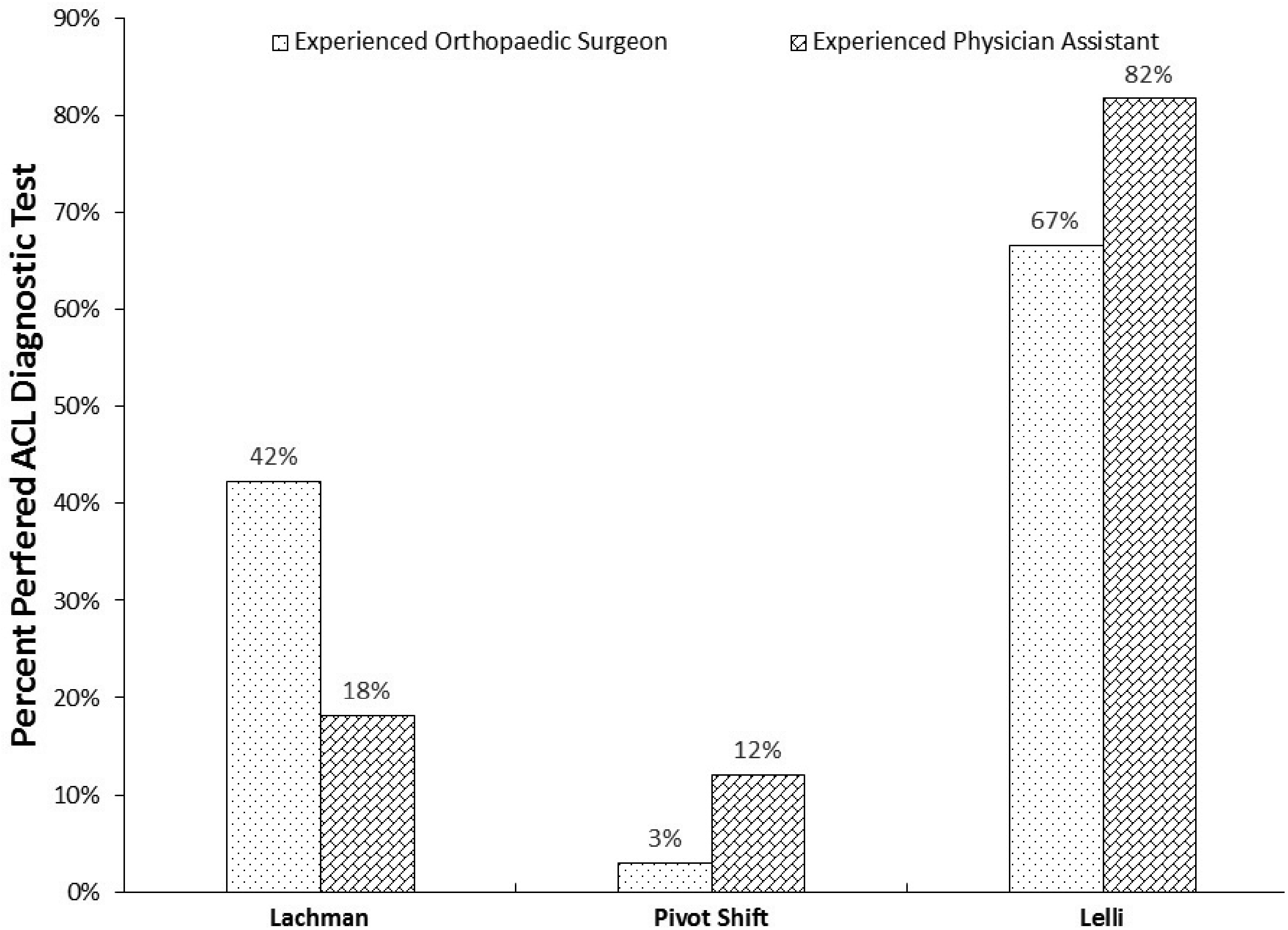


Figure 3. Examiners Preferred ACL Diagnostic Test

8 (24%) false negatives with the pivot shift with guarding in 1 (3%) patient, and no false negatives with the Lelli test (Figure 2). There were no false positives. The sensitivity for the Lachman test, pivot shift test and Lelli test was 94%, 76%, and 100%, respectively.

Inter-observer reliability testing prior to the induction of anesthesia for all the three tests showed "fair" agreement by using the guidelines described by Landis and Koch[38]. The Kappa coefficient for inter-observer agreement of judgments of positive or negative for the two examiners when using Lachman test was 0.23 with 72% agreement, when using pivot shift test was 0.23 with 76% agreement, and when using the Lelli test was 0.30 with 82% agreement. The inter-observer reliability with

Table 4. Examiner Hand Span Size

	Left (cm)	Right (cm)
Orthopaedic Surgeon	21.5	21.5
Experienced Physician Assistant	15.5	15.5

the patient under general anesthesia for the pivot shift test demonstrated "poor" agreement with the Kappa coefficient of 0.18 with 79% agreement. Unfortunately, the intra-observer value could not be computed for the Lachman test because there were no false negatives detected by the experienced surgeon, but there was 94% agreement. Similarly, the intra-observer value could not be calculated for the Lelli test because there were no false negatives for the experienced orthopaedic physician assistant but there was 97% agreement between the two observers (Table 2).

Intra-examiner reliability was calculated by comparing test results before and after the induction of anesthesia for each provider. Each of the three tests showed "poor" agreement except Lachman test for experienced physician assistant using the guidelines described by Landis and Koch[38]. For the experienced orthopaedic surgeon, the intra-observer Kappa value was 0.02 with 30% agreement for the pivot shift test, was 0.05 with 85% agreement for the Lelli test, and was not calculable for the Lachman test due to the lack of false negatives. For the experienced physician assistant, the Kappa coefficient for intra-observer agreement when using the Lachman test was 0.23 with 73% agreement, when using pivot shift test the Kappa value was 0.06 with 33% agreement, and when using Lelli test the Kappa value was not be able to computed as the physician assistant had no false negative results with the patient under anesthesia (Table 3).

The Lelli test seemed to be most favorable to both the surgeon and the physician assistant with at least 67% favorable, while the pivot shift was least often felt to be the most useful test (Figure 3). The experienced surgeon felt the Lachman test was the most beneficial to detect injury in 42% of patients, while the experienced physician assistant only thought it was most beneficial in 18% of patients.

The hand span for the experienced orthopaedic surgeon and the experienced physician assistant was measured 21.5cm and 15.5cm, respectively (Table 4). The physician assistant stated that hand size was likely a factor in 2 false negative results while performing the Lelli test. No relationship was found for either patients' thigh or patients' calf girths with the physical examination test results for both examiners for any of the three tests (p=0.110).

DISCUSSION

Despite the advent of MRI and its high sensitivity[39], physical examination continues to play a major role in ACL diagnosis. In our study, we observed that all three physical examination tests (Lachman test, Pivot Shift test, and Lelli test) to determine an ACL injury have at least a trend towards increased false negative test results prior to the induction of anesthesia. This is consistent with previous studies that demonstrated that physical examination tests are more accurate with the patient under anesthesia[25,30,40,41]. Despite the increased sensitivity of the Lachman test compared to the pivot shift test and anterior drawer test in the literature, no single test has been consistently shown to detect all ACL injuries[33,35,42]. Scholten et al[35] performed a meta-analysis of the physical diagnostic tests for ACL injuries and reported sensitivities of 62% and 86% for the anterior drawer test and Lachman test respectively, and between 18% and 48% for the pivot shift test. The sensitivity of the Lachman test, however, has been reported from other studies to range from 80% to 99%, with a specificity of 95%[25,29-32,36,43]. In meta-analyses, the sensitivity of the Lachman test is 0.85—0.871 with a specificity of 0.91—0.97, and the pivot shift had a sensitivity of 0.24—0.49 with a specificity of 0.98[33,35,42]. Wagemaker et al[37] assessed the diagnostic accuracy of a clinical history and physical examination in a primary care setting and found that a typical history for ACL injury combined with a positive anterior drawer test had a positive predictive value of between 36% and 80%.

To date, no physical exam maneuver has eliminated false negative test results. Guarding—the protective muscle action of the hamstrings secondary to joint pain—may be responsible for false negatives in some settings[36]. Others believe that some of these tests are not easily performed by examiners who have small hands or on patients with a large thigh girth or large calf girth[26,44]. In our study, even though the experienced physician assistant's hand span was considered small (15.5cm), only reported 2 false negatives (6%) out of the 33 patients that may be due to small hand size.

The findings from our study further demonstrate that the Lelli test may be another useful physical examination maneuver for both physicians and physician assistants. The sensitivity for the Lelli test in our patient population was not significantly different from the Lachman test, and had fewer overall false negatives when combining the data for the providers. However, this test hold little value in distinguishing between partial and complete tears as this test is a binary test (positive or negative result)[23]. Both the Lachman test and pivot shift test are based on a grading system that measures the amount of translation of the tibia relative to the femur, and these tests undoubtedly continue to hold an important role in diagnosis of ACL injuries[45].

Even though in our study both examiners preferred the Lelli test to diagnose ACL injuries in most patients, both examiners observed that soft cushions on the examination table can cause false negative results. Furthermore, if the examiner has a small fist size, or if the patient has a large, soft calf, this may have the potential to cause a false negative.

Several questions and limitations can be raised concerning the validity of our study and the applicability of these results to determine the examiner proficiency and accuracy in performing the different clinical diagnosis of ACL ruptures at clinic. We recognize that our study was performed with a relatively small number of patients, which decreased the chance of finding statistically significant results due to a low power. In addition, in this study we excluded patients who underwent examination within 72 hours of injury, which not only led to decreased enrollment but also prevents us from commenting on the usefulness of the Lelli test when guarding is likely most severe. The lack of blinding of the clinicians to the injury extremity was also another potential area of bias and may be responsible for the lack of any false positive test results in the study. Another weakness is the prevalence of male patients in the study, which may limit generalizability. Further expansion of the study to include more patients and more examiners is planned as future research.

CONCLUSION

A properly performed physical examination of the knee still holds a pivotal role in the diagnosis of ACL injury. The diagnostic accuracy and limitations of the various tests for ACL injury need to be understood. Clinically, in cases of suspicion of ACL injury, it is recommended performing at least two different physical examinations, as each test has its own specific limitations. The implementation of an acute ACL injury clinic may help minimize delays to surgery, which should result in better patient outcomes.

ACKNOWLEDGEMENT

The authors wish to thank Dr. George Lucas for his assistance, revision, and critical comments on the paper.

REFERENCES:

1. **Sanders TL, Maradit Kremers H, Bryan AJ, Larson DR, Dahm DL, Levy BA, Stuart MJ, Krych AJ.** Incidence of Anterior Cruciate Ligament Tears and Reconstruction: A 21-Year Population-Based Study. Am J Sports Med, 2016 Feb 26. PMID: 26920430
2. **Lee JK, Yao L, Phelps CT, Wirth CR, Czajka J, Lozman J.** Anterior cruciate ligament tears: MR imaging compared with arthroscopy and clinical tests. Radiology. 1988 Mar;166(3):861-4. PMID:3340785
3. **Mink JH, Levy T, Crues JV 3rd.** *T*ears of the anterior cruciate ligament and menisci of the knee: MR imaging evaluation. Radiology. 1988 Jun;167(3):769-74. PMID:3363138
4. **Bollen, SR, Scott BW.** Rupture of the anterior cruciate ligament–a quiet epidemic? Injury, 1996 Jul;27(6): 407-9. PMID: 8881137
5. **Noyes FR, Mooar PA, Matthews DS, Butler DL.** The symptomatic anterior cruciate-deficient knee. Part I: the long-term functional disability in athletically active individuals. J Bone Joint Surg Am, 1983 Feb;65(2): 154-62. PMID: 6687391
6. **Anderson AF, Anderson CN.** Correlation of meniscal and articular cartilage injuries in children and adolescents with timing of anterior cruciate ligament reconstruction. Am J Sports Med. 2015 Feb;43(2):275-81. PMID: 25497145
7. **Louboutin H, Debarge R, Richou J, Selmi TA, Donell ST, Neyret P, Dubrana F.** Osteoarthritis in patients with anterior cruciate ligament rupture: a review of risk factors. Knee. 2009 Aug;16(4):239-44. PMID: 19097796
8. **Lohmander LS, Englund PM, Dahl LL, Roos EM.** The long-term consequence of anterior cruciate ligament and meniscus injuries: osteoarthritis. Am J Sports Med. 2007 Oct;35(10):1756-69. PMID: 17761605
9. **Oiestad BE, Engebretsen L, Storheim K, Risberg MA.** Knee osteoarthritis after anterior cruciate ligament injury: a systematic review. Am J Sports Med. 2009 Jul;37(7):1434-43. PMID: 19567666
10. **Oiestad BE, Holm I, Aune AK, Gunderson R, Myklebust G, Engebretsen L, Fosdahl MA, Risberg MA.** Knee function and prevalence of knee osteoarthritis after anterior cruciate ligament reconstruction: a prospective study with 10 to 15 years of follow-up. Am J Sports Med. 2010 Nov;38(11):2201-10. PMID: 20713644
11. **Keays SL, Newcombe PA, Bullock-Saxton JE, Bullock MI, Keays AC.** Factors involved in the development of osteoarthritis after anterior cruciate ligament surgery. Am J Sports Med. 2010 Mar;38(3):455-63. PMID: 20051501
12. **Jomha NM, Borton DC, Clingeleffer AJ, Pinczewski LA.** Long-term osteoarthritic changes in anterior cruciate ligament reconstructed knees. Clin Orthop Relat Res. 1999 Jan;(358):188-93. PMID: 9973991

13. **Yüksel HY, Erkan S, Uzun M.** The evaluation of intraarticular lesions accompanying ACL ruptures in military personnel who elected not to restrict their daily activities: the effect of age and time from injury. Knee Surg Sports Traumatol Arthrosc. 2006 Nov;14(11):1139-47. PMID: 169270
14. **Church S, Keating JF.** Reconstruction of the anterior cruciate ligament: timing of surgery and the incidence of meniscal tears and degenerative change. J Bone Joint Surg Br. 2005 Dec;87(12):1639-42. PMID: 16326877
15. **Chhadia AM, Inacio MC, Maletis GB, Csintalan RP, Davis BR, Funahashi TT.** Are meniscus and cartilage injuries related to time to anterior cruciate ligament reconstruction? Am J Sports Med. 2011 Sep;39(9):1894-9. PMID: 21705649
16. **Granan LP, Bahr R, Lie SA, Engebretsen L.** Timing of anterior cruciate ligament reconstructive surgery and risk of cartilage lesions and meniscal tears: a cohort study based on the Norwegian National Knee Ligament Registry. Am J Sports Med. 2009 May;37(5):955-61. PMID: 19251674
17. **Millett PJ, Willis AA, Warren RF.** Associated injuries in pediatric and adolescent anterior cruciate ligament tears: does a delay in treatment increase the risk of meniscal tear? Arthroscopy. 2002 Nov-Dec;18(9):955-9. PMID: 12426537
18. **Arastu MH, Grange S, Twyman R.** Prevalence and consequences of delayed diagnosis of anterior cruciate ligament ruptures. Knee Surg Sports Traumatol Arthrosc. 2015 Apr;23(4):1201-5. PMID: 24671385
19. **Shelbourne KD.** The art of the knee examination: where has it gone? J Bone Joint Surg Am. 2010 Aug 4;92(9):e9. PMID: 20686055
20. **Solomon DH, Simel DL, Bates DW, Katz JN, Schaffer JL.** The rational clinical examination. Does this patient have a torn meniscus or ligament of the knee? Value of the physical examination. JAMA. 2001 Oct 3;286(13):1610-20. PMID: 11585485
21. **Makhmalbaf H, Moradi A, Ganji S, Omidi-Kashani F.** Accuracy of lachman and anterior drawer tests for anterior cruciate ligament injuries. Arch Bone Jt Surg. 2013 Dec;1(2):94-7. PMID: 25207297
22. **Thapa SS, Lamichhane AP, Mahara DP**. Accuracy of Lelli Test For Anterior Cruciate Ligament Tear. Journal of Institute of Medicine. 2015 Aug;37(2): 91-94.
23. **Lelli A, Di Turi RP, Spenciner DB, Dòmini M.** *The "Lever sign": a new clinical test for the diagnosis of anterior cruciate ligament rupture.* Knee Surg Sports Traumatol Arthrosc, 2014 Dec 25. PMID: 25536951
24. **Cooperman JM, Riddle DL, Rothstein JM.** Reliability and validity of judgments of the integrity of the anterior cruciate ligament of the knee using the Lachman's test. Phys Ther. 1990 Apr;70(4):225-33. PMID:2315385
25. **Donaldson WF 3rd, Warren RF, Wickiewicz T.** A comparison of acute anterior cruciate ligament examinations. Initial versus examination under anesthesia. Am J Sports Med. 1985 Jan-Feb;13(1):5-10. PMID:3976980
26. **Draper DO, Schulthies SS.** Examiner proficiency in performing the anterior drawer and Lachman tests. J Orthop Sports Phys Ther. 1995 Dec;22(6):263-6. PMID:8580954
27. **Galway HR, MacIntosh DL.** The lateral pivot shift: a symptom and sign of anterior cruciate ligament insufficiency. Clin Orthop Relat Res. 1980 Mar-Apr;(147):45-50. PMID:7371314
28. **Geraets SE, Meuffels DE, van Meer BL, Breedveldt Boer HP, Bierma-Zeinstra SM, Reijman M.** Diagnostic value of medical history and physical examination of anterior cruciate ligament injury: comparison between primary care physician and orthopaedic surgeon. Knee Surg Sports Traumatol Arthrosc. 2015 Apr;23(4):968-74. PMID: 25964958
29. **Jonsson T, Althoff B, Peterson L, Renström P.** Clinical diagnosis of ruptures of the anterior cruciate ligament: a comparative study of the Lachman test and the anterior drawer sign. Am J Sports Med. 1982 Mar-Apr;10(2):100-2. PMID:7081521
30. **Katz JW, Fingeroth RJ.** The diagnostic accuracy of ruptures of the anterior cruciate ligament comparing the Lachman test, the anterior drawer sign, and the pivot shift test in acute and chronic knee injuries. Am J Sports Med. 1986 Jan-Feb;14(1):88-91. PMID:3752353
31. **Kim SJ, Kim HK.** Reliability of the anterior drawer test, the pivot shift test, and the Lachman test. Clin Orthop Relat Res. 1995 Aug;(317):237-42. PMID:7671485
32. **Mitsou A, Vallianatos P.** Clinical diagnosis of ruptures of the anterior cruciate ligament: a comparison between the Lachman test and the anterior drawer sign. Injury. 1988 Nov;19(6):427-8. PMID:3267651
33. **Ostrowski, JA.** Accuracy of 3 diagnostic tests for anterior cruciate ligament tears. J Athl Train. 2006 Jan-Mar;41(1): 120-1. PMID: 16619105
34. **Parwaiz, H, Teo AQ, Servant C.** Anterior cruciate ligament injury: A persistently difficult diagnosis. Knee. 2016 Jan;23(1): 116-20. PMID: 26552783
35. **Scholten RJ, Opstelten W, van der Plas CG, Bijl D, Deville WL, Bouter LM.** Accuracy of physical diagnostic tests for assessing ruptures of the anterior cruciate ligament: a meta-analysis. J Fam Pract, 2003 Sep;52(9): 689-94. PMID: 12967539

36. **Torg JS, Conrad W, Kalen V.** Clinical diagnosis of anterior cruciate ligament instability in the athlete. Am J Sports Med. 1976 Mar-Apr;4(2):84-93. PMID:961972
37. **Wagemakers HP, Luijsterburg PA, Boks SS, Heintjes EM, Berger MY, Verhaar JA, Koes BW, Bierma-Zeinstra SM.** Diagnostic accuracy of history taking and physical examination for assessing anterior cruciate ligament lesions of the knee in primary care. Arch Phys Med Rehabil. 2010 Sep;91(9):1452-9. PMID: 20801267
38. **Landis JR, Koch GG.** The measurement of observer agreement for categorical data. Biometrics 1977; 33(1):159-174. PMID: 843571
39. **Fischer SP, Fox JM, Del Pizzo W, Friedman MJ, Snyder SJ, Ferkel RD.** Accuracy of diagnoses from magnetic resonance imaging of the knee. A multi-center analysis of one thousand and fourteen patients. J Bone Joint Surg Am, 1991 Jan;73(1): 2-10. PMID: 1985991
40. **Lucie RS, Wiedel JD, Messner DG.** The acute pivot shift: clinical correlation. Am J Sports Med. 1984 May-Jun;12(3):189-91. PMID:6742299
41. **Deveci A, Cankaya D, Yilmaz S, Özdemir G, Arslantaş E, Bozkurt M.** The arthroscopical and radiological corelation of lever sign test for the diagnosis of anterior cruciate ligament rupture. Springerplus, 2015 Dec 30;4: 830. PMID: 26753117
42. **Huang W, Zhang Y, Yao Z, Ma L.** Clinical examination of anterior cruciate ligament rupture: a systematic review and meta-analysis. Acta Orthop Traumatol Turc, 2016;50(1): 22-31. PMID: 26854045
43. **DeHaven KE.** Arthroscopy in the diagnosis and management of the anterior cruciate ligament deficient knee. Clin Orthop Relat Res. 1983 Jan-Feb;(172):52-6. PMID:6822005
44. **Draper DO, Schulthies S.** A test for eliminating false positive anterior cruciate ligament injury diagnoses. J Athl Train. 1993 Winter;28(4):355-7. PMID:16558252
45. **Dejour D, Ntagiopoulos PG, Saggin PR, Panisset JC.** The diagnostic value of clinical tests, magnetic resonance imaging, and instrumented laxity in the differentiation of complete versus partial anterior cruciate ligament tears. Arthroscopy. 2013 Mar;29(3): 491-9. PMID: 23343713

CASE REPORT: SNAPPING BICEPS FEMORIS TENDON DUE TO ABNORMAL FIBULAR MORPHOLOGY

Mia McNulty[1], Joseph Carreau, MD[2], Nathan Hendrickson, MD[2], Matthew Bollier, MD[2]

ABSTRACT

Background: Several cases of snapping biceps femoris tendons have been reported with anomalous insertions of the distal tendon insertion or in the context of trauma. There are only three published cases due to abnormal fibular head morphology.

Methods/Results: We present a case of unilateral snapping of the biceps femoris tendon in a 19 year old. We decided to proceed with surgery after the patient failed a trial of non-operative treatment and had significant functional limitations. Surgical exploration of the posterolateral knee showed a prominent ridge on the posterior aspect of the fibular head over which the biceps femoris tendon was snapping with deep knee flexion. The bony ridge was resected, leaving surrounding structures intact, including the insertion of the biceps femoris tendon. The patient experienced resolution of snapping symptoms and associated pain.

Conclusions: Although rare, snapping of the biceps femoris tendon can cause pain and functional limitation. In this case, resection of a prominent ridge on the fibular head resolved snapping and pain.

Level of evidence: Level five

Keywords: tendon snapping, biceps femoris tendon, fibular morphology

[1]University of Colorado School of Medicine

[2]University of Iowa Hospitals and Clinics

Corresponding Author:
Mia McNulty
University of Colorado School of Medicine
13001 E 17th Pl
Aurora, CO 80045
Email: mia.mcnulty@ucdenver.edu
Phone: (303)819-8938

No funding was obtained or utilized for this case report.

The authors have no disclosures that would pose potential conflicts of interest.

INTRODUCTION

Although rare, several cases of symptomatic snapping of biceps femoris tendon have been reported in the literature. Most commonly, previous cases have attributed the snapping to abnormalities with the distal insertion of tendon[1,2,3,4,5]. To the best of our knowledge, only three prior cases of snapping biceps femoris tendons have been, at least in part, attributed to abnormal fibular morphology: one due to fibular head exostosis[6], one case that caused snapping with knee flexion and internal rotation[7], and another case where both a prominent fibular head and an anomalous insertion of the biceps femoris tendon together caused snapping[8].

We report on a 19 year old with unilateral painful snapping of the biceps femoris tendon with knee flexion, found to be due to a prominent ridge on the fibular head, which was successfully treated with partial excision of the bony prominence.

CASE REPORT

History

A 19 year old male presented with a 2 year history of unilateral left lateral knee pain and snapping. There was no known trauma to the knee, but the patient did note the onset of symptoms after he began weight lifting 2 years prior, and that symptoms usually resolved with rest. He had experienced worsening of the pain associated with the snapping in recent months, and began having pain at rest. He did not wish to further explore conservative treatment options and was referred to our clinic for surgical evaluation.

Physical examination and imaging

Physical examination revealed no obvious deformity, swelling, or effusion. There was tenderness to palpation over the distal biceps femoris tendon approaching its insertion on the fibular head. There was no joint line tenderness, and both the ligamentous exam and extensor mechanism were normal. Notably, McMurray's exam was normal and did not reproduce snapping. With deep knee flexion while weight bearing, the biceps femoris tendon was noted to snap over a prominent fibular head (Figure 1), then snap back into place with subsequent knee extension. This snapping was observed with the tibia in neutral rotation relative to the femur.

Figure 1: Preoperative picture of prominent fibular head immediately before patient reproduces snapping with active knee flexion

Figure 2: Intra-operative photograph of the prominent ridge on the fibular head

X-rays showed no evidence of gross bony abnormality with normal joint alignment and spacing. Pre-operative knee MRI did not show any meniscus or ligament tearing. In addition, there was normal articular cartilage and no bony prominences or fibrous bands in fibular head region.

Surgical findings

An incision was made longitudinally over the posterior lateral aspect of the left knee. Careful dissection was carried out to isolate the tendinous insertion of the biceps femoris as well as the common peroneal nerve. The nerve was visible and protected throughout the case. The tendon was observed to have normal attachments, without abnormal or anomalous insertions on the fibula or tibia. A prominent ridge on the fibular head was observed, and intraoperative knee flexion and extension demonstrated visible snapping of the biceps femoris tendon over the ridge (Figure 2). This excess bone was resected, but the remainder of the fibular head and its ligamentous attachments, including the lateral collateral ligament, were left intact.

Knee arthroscopy showed a small frayed tear of the posterior root of the lateral meniscus that did not cause instability. The frayed portion of the meniscus was debrided, and a partial synovectomy of the anterior knee was carried out. No other abnormalities were noted on arthroscopic survey of the knee. The patient was instructed to weight bear as tolerated and had no restrictions on range of motion postoperatively.

CLINICAL OUTCOME

At a four week post-operative appointment, the patient had complete resolution of snapping symptoms. His range of motion at that time was 0-100 degrees of flexion. He planned to begin physical therapy for postoperative mobilization and return to sport. A phone interview with the patient at six months after surgery was conducted. The patient reported complete resolution of the snapping, full knee range of motion and return to all activities.

DISCUSSION

Anatomically, the long head of the biceps femoris originates from the ischial tuberosity and forms a tendon proximal to the knee joint. As Terry et al. described, proximal to the fibular head, the tendon bifurcates to yield a direct arm that inserts on the posterolateral fibular head and an anterior arm that inserts on the lateral fibular head with additional fibers inserting on the anterolateral tibia lateral to Gerdy's tubercle. The anterior arm also gives rise to an anterior aponeurosis, which continues distally to cover the anterior compartment of the leg, as well as a lateral aponeurotic component that attaches broadly over the lateral and posterior lateral collateral ligament. The complex insertion of the biceps femoris contributes to knee flexion, external rotation, while also acting as a dynamic stabilizer of the knee[4,9].

Snapping of the distal insertion of the biceps femoris tendon is a rare condition, but it has been documented in the literature. Most reported cases found anomalous insertions of the distal biceps upon surgical exploration[1,2,3,4,5]. Date et al. found three distinct tendinous components to the distal biceps femoris insertion, with one inserting at the posterolateral fibular head, one inserting on the lateral fibular head, and one inserting on the anterolateral proximal tibia. The anterolateral portion displaced over the fibular head and caused snapping when the knee was carried past 100 degrees of flexion, with worsening snapping with internal rotation. Resection of the anterolateral and the lateral tendinous insertion sites resolved the snapping.

Hernandez et al. and Kristensen both published cases where the biceps femoris tendon inserted entirely on the anterolateral tibia, without fibular insertions. In the case reported by Hernandez et al., the snapping occurred between 100-120 degrees of flexion with concurrent internal rotation. Reinsertion of the tendon onto the posterolateral fibula stopped the snapping over the fibular head. Similarly, the case reported by Kristensen et al. detailed snapping that occurred with flexion past 90 degrees, but was instead treated by resection of the lateral aspect of the fibular head without altering the tendon's insertion. Lokeic et al. reported a case where an abnormal anterior fibular insertion was found to cause snapping when the knee was extended from full flexion. Reinsertion of the tendon on the typical posterolateral aspect of the fibula prevented snapping from occurring. Kissenberth et al. reported on a case of symptomatic snapping with onset during rehabilitation for an uncomplicated anterior cruciate ligament repair of the contralateral knee. Upon surgical exploration, the authors noted that a more distal branching of the biceps femoris tendon into the direct and anterior arm, when combined with knee flexion, caused the anterior extension of the tendon's attachment to subluxate over the fibular head. Surgical transection of the anterior arm with reinsertion on the posterolateral fibula led to resolution of symptoms. Other authors have reported cases of trauma-induced snapping[10,11], and snapping in the context of seemingly normal anatomy[12,13].

Three prior publications found abnormal fibular head anatomy to cause snapping[6,7,8]. As with our patient, each of the cases treated the snapping with surgical resection of the abnormal aspects of the fibula. However, the abnormal fibular morphology was distinct in each of the three previously reported cases. In the case described by Fung et al., the bilateral presence of fibular head exostosis were found to cause the symptomatic snapping, which occurred when the knee was flexed past 90 degrees. This caused fraying of the distal biceps insertion, and the patient was treated with debridement of the frayed tissue and removal of the fibular exostosis, later undergoing the same procedure on the contralateral extremity. Bagchi et al. described a case where snapping occurred with 80 to 100 degrees of knee flexion secondary to an anomalous anterolateral proximal tibial insertion of the biceps femoris tendon and a prominent fibular head due to the presence of fibrocartilage, bone, fibrocollagenous tissue, and myxiod degeneration. Initial treatment included conservative resection of the prominent fibular head, but return of symptoms required a second, more extensive excision. A similar procedure was carried out on the contralateral knee after it too developed snapping symptoms.

Our case was most similar to the case reported by Bach et al., where the authors found tendon subluxation over a prominent fibular head between 80 and 100 degrees of knee flexion with concomitant internal rotation. However, in our case, knee flexion in the absence of internal rotation was sufficient to provoke tendon subluxation.

Similar to Bach et al., however, the fibular head abnormality was a prominent bony ridge, and symptom resolution resulted in resection of the bony prominence without disruption of the insertions of the biceps femoris or the lateral collateral ligament.

To our knowledge, this is the first reported case of unilateral snapping of the biceps femoris tendon due to abnormal fibular bony morphology that occurred with flexion of the knee in neutral rotation. In the absence of injury, most documented cases of snapping biceps femoris tendon have been bilateral, with symptoms occurring unilaterally or bilaterally[1,2,4,5,6,7,8]. This case is unique in that the patient had a unilateral onset of symptoms. Because the snapping occurred when the patient bent the knee in deep flexion, even in the absence of internal rotation, the symptoms were frequent and disruptive. In this case, our patient found the persistent symptoms to be intrusive enough to warrant surgery. Resection of the fibular head prominence led to complete resolution of symptoms.

Although several cases of snapping biceps femoris tendons have been reported in the literature, the phenomenon is most frequently attributed to anomalous insertions of the tendon. Rarely, abnormal bony morphology of the fibula can cause similar symptoms. We present a case, novel in that the snapping was unilaterally due to a prominent ridge on the fibular head, and that the symptoms occurred in the absence of internal rotation. We show that snapping due to abnormal morphology of the fibular head can be treated with bony resection, without disruption of the surrounding structures.

REFERENCES

1. **Date H, Hayakawa K, Nakagawa K, Yamada H.** Snapping knee due to the biceps femoris tendon treated with repositioning of the anomalous tibial insertion. 2010. Knee Surg Sports Traumatol Arthrosc. 20:1581-1583.
2. **Hernandez JA, Ruis M, Noonan KJ.** Snapping knee from anomalous biceps femoris tendon insertion: a case report. 1996. The Iowa Orthopaedic Journal. 16: 161-163.
3. **Lokiec F, Velkes S, Schindler A, Pritsch M.** the snapping biceps femoris syndrome. 1992. Clinical Orthopaedics and Related Research. 283: 205-206.
4. **Kissenberth MJ, Wilckens JH.** The snapping biceps femoris tendon. 2000. The American Journal of Knee Surgery. 13(1):25-28.
5. **Kristensen G, Nielsen K, Blyme PJH.** Snapping knee from biceps femoris tendon A case report. 1989. Acta Orthopaedica Scandinavica. 60(5): 621-621.
6. **Fung DA, Frey S, Markbreiter.** Bilateral symptomatic snapping biceps femoris tendon due to fibular exostosis. 2008. Journal of Knee Surgery. 21(1):55-57.
7. **Bach BR, Minihane K.** Subluxing biceps femoris tendon: an unusual case of lateral knee pain in a soccer athlete. 2001: The American Journal of Sports Medicine. 29(1): 93-95.
8. **Bagchi K, Grelsamer RP.** Partial fibular head resection for bilateral snapping biceps femoris tendon. 2003. Orthopedics. 26(11):1147-1149.
9. **Terry GC, LaPrade RF.** The biceps femoris muscle complex at the knee. 1996. The American Journal of Sports Medicine. 24(1): 1-8.
10. **Bansal R, Taylor C, Pimpalnerkar AL.** Snapping knee: an unusual biceps femoris tendon injury. 2005. The Knee. 12:458-460.
11. **Bernhardson AS, LaPrade RF.** Snapping biceps femoris tendon treated with an anatomic repair. 2010. Knee Surg sports Traumatol Arthrosc. 18:1110-1112.
12. **Crow SA, Quach T, McAllister D.** Partial tendon release for treatment of a symptomatic snapping biceps femoris tendon: a case report. 2009. Sports Health. 1(5): 435-437.
13. **Vavalle G, Capozzi M.** Symptomatic snapping knee from biceps femoris tendon subluxation: an unusual case of lateral pain in a marathon runner. 2010. J Orthopaed Traumatol. 11: 263-266.

THICKNESS OF THE ROTATOR CUFF TENDONS AT THE ARTICULAR MARGIN: AN ANATOMIC CADAVERIC STUDY

William C. Sessions[1], Rebekah L. Lawrence[2], J. Tyler Steubs[3], Paula M. Ludewig[2,4], Jonathan P. Braman[4]

ABSTRACT

Background: With a substantial portion of the population experiencing rotator cuff pathology, the importance of understanding mechanisms of rotator cuff disease remains critical. Current research aimed at understanding relationships between shoulder movement and cuff injuries has been hindered by our limited knowledge of the thickness of soft tissue structures within the shoulder. Therefore, the purpose of this study is to measure the thicknesses of all four rotator cuff tendons at the articular margin.

Methods: An anatomic study of 21 cadaveric shoulders was conducted. The thicknesses of the four rotator cuff tendon insertions were measured by caliper at the articular margin.

Results: The mean thickness of the supraspinatus at the articular margin was 4.9 mm ± 2.1 (median: 4.2 mm, range: 2.9-12.7 mm). The mean thickness of the infraspinatus tendon was 4.9 mm ± 1.3 (median: 4.8 mm, range: 3.0-7.2 mm). The mean thickness of the teres minor tendon was 3.20 mm ± 1.14 (median: 2.9 mm, range: 1.7-5.7 mm). Finally, the mean thickness of the subscapularis tendon at the articular margin was 5.5 mm ± 1.3 (median: 5.5 mm, range: 3.5-9.3 mm)

Conclusions: This current study provides needed objective data about the thickness of the rotator cuff tendons at the articular margin. Data regarding the infraspinatus, teres minor and teres major, which have been largely understudied, are particularly important. In addition, the current study demonstrates that rotator cuff thicknesses can vary substantially between individuals. There are likely natural age related changes as well as changes from etiologies that are not yet elucidated.

Clinical Relevance: Data from this study will allow for improved modelling accuracy of soft tissue structures specific to the shoulder. Eventually knowledge gained through study of shoulder mechanics can be used to pursue prevention of rotator cuff tears and improve targeted treatment planning.

Keywords: compression, rotator cuff, thickness, articular margin

INTRODUCTION

Shoulder pain is the third most common musculoskeletal problem with significant negative impact on quality of life.[1] Beyond those with shoulder pain are a significant number of the population living with asymptomatic shoulder injury. Among asymptomatic individuals the prevalence for rotator cuff tears is 23% in the general population increasing to 51% in individuals great than 80 years.[2] With a substantial portion of the population experiencing rotator cuff tears, the importance of understanding rotator cuff pathology has remained critical for both the researcher and clinician alike.

Historically, the pathophysiology of the rotator cuff has been extensively studied with numerous theories being suggested. Hypotheses proposed have included: variations in anatomy of the scapula[3-5], changes to tendon vascularity[6], degenerative changes secondary to

[1]Medical School,
University of Minnesota
Minneapolis, MN

[2]Department of Rehabilitation Medicine
Divisions of Physical Therapy & Rehabilitation Science
University of Minnesota
Minneapolis, MN

[3]Department of Emergency Medicine
Summa Akron City Hospital
Akron, OK

[4]Department of Orthopedics
University of Minnesota
Minneapolis, MN

Correspondence to:
Dr. Paula M. Ludewig, PhD, PT

Office: Divisions of Physical Therapy & Rehabilitation Science
366C Children's Rehab Center
426 Church Street SE
Minneapolis, MN 55455

Mailing: Cifision of Physical Therapy
MMC 388 Mayo
420 Delaware St SE
Minneapolis, MN 55455

Email: ludew001@umn.edu
Office Phone: 612-626-0420

Acknowledgements: The authors are grateful to both the individuals and families that chose to donate their bodies. One author receives research funding from Stryker Corporation. No funds received from Stryker were used for this project.

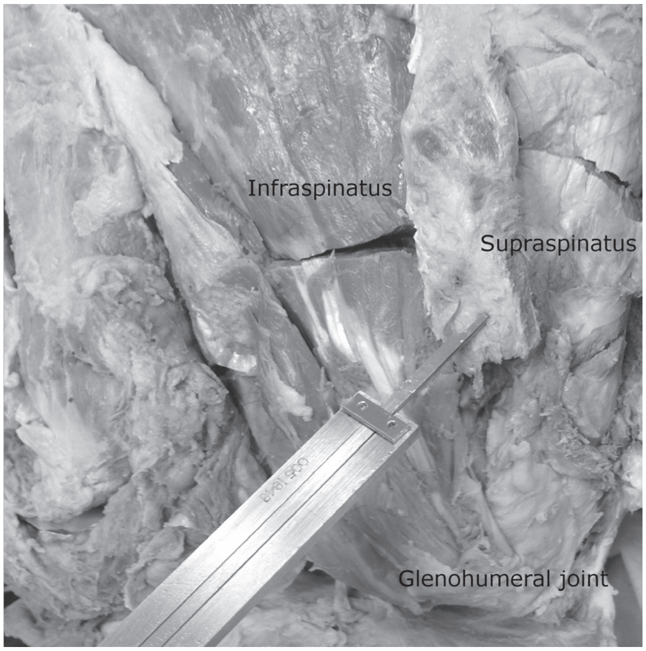


Figure 1: Example of dissection of shoulder with acromion process removed to expose the underlying supraspinatus muscle. Probe is located on the spine of scapula.

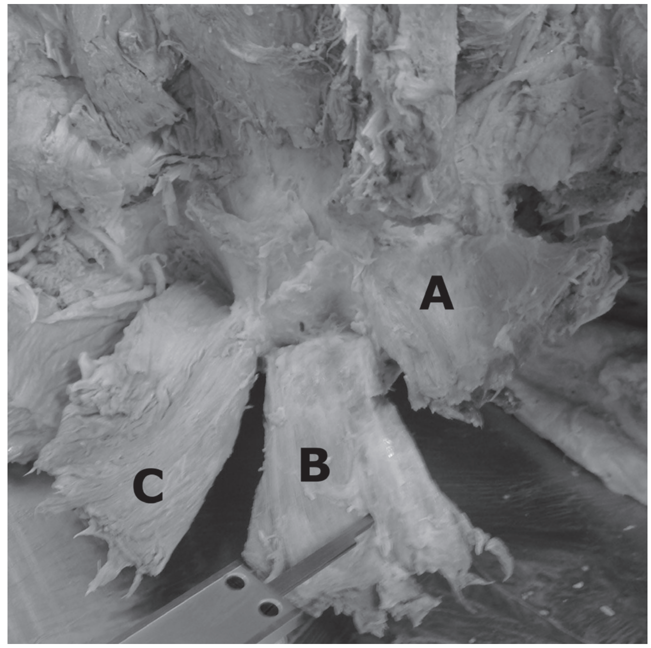


Figure 2: Example of shoulder dissection with rotator cuff tendons retracted to enable measurements of tendon thicknesses at the articular margin. A) Supraspinatus Muscle, B) Infraspinatus Muscle, C) Teres Minor Muscle

ageing[7], chronic tensile overload[8], and dynamic soft tissue compression[9,10]. To further distinguish the general contribution of the known possible mechanisms, studies have escalated in detail and subsequently complexity. Current research aimed at understanding the relationship between shoulder movement and dynamic rotator cuff compression have relied on methods like biplane fluoroscopy where the position of the bone structures can be precisely known during arm movements.[11,12] While these newer methods have given an enhanced understanding of dynamic shoulder mechanics; their utility in investigating possible rotator cuff compression is inherently limited by their reliance on bone-to-bone measurements like acromial humeral distance.

As research into the development of rotator cuff injury continues to advance, shoulder modelling is emerging as a method to provide previously inaccessible data. Although shoulder models have improved in both clinical applicability and accuracy, their continued reliance on deductions of rotator cuff anatomy derived from bone-to-bone measurements (i.e. acromial-humeral distance) limits further comprehension of the mechanisms behind rotator cuff injury.[11-16] Until the development of models that accurately account for the thickness of all soft tissue structures, we are limited in our understanding of mechanical rotator cuff compression, and other mechanisms of rotator cuff disease development.

Despite significant study into the anatomy and biomechanics of the shoulder, there is a limited amount of information regarding the thickness of the rotator cuff tendons near their insertions. Although some informative studies have been published describing the thickness of the more commonly torn supraspinatus, the other tendon insertions of the rotator cuff (infraspinatus, teres minor and subscapularis) have been largely overlooked.[17-20] In addition, many of the studies that have measured rotator cuff thickness have been minimally descriptive in the precise locations where tendon measurement occurred. Detailed representation of the rotator cuff is essential in creating accurate models that can further establish links between the biomechanics of the shoulder and pathophysiology of rotator cuff tendon disease. As there is an increased frequency for rotator cuff pathology to develop along the articular margin, this remains an area of higher interest. Therefore, the purpose of our study was to measure the insertion thickness of all four rotator cuff tendons at the articular margin.

METHODS

An anatomic study of 21 cadaveric shoulders (11 male and 10 female; average age at time of death: 78 years ± 14, range 59 – 101 years) was conducted. The cadavers were embalmed using a fluid concentrate that is 70% isopropyl alcohol, 13.25% phenol, 8% sorbitol, 7.5% formaldehyde USP-37, and 1.25% Barquat MB-50. Shoulders with direct rotator cuff pathology (partial or

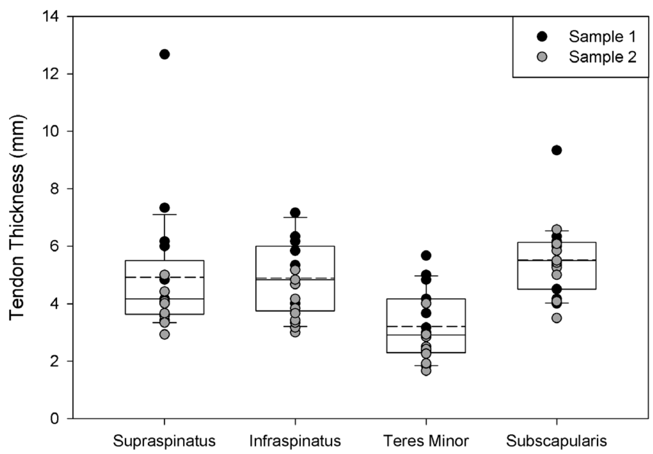


Figure 3. Box and vertical scatter plot of tendon thickness. Boundary box represents 25th- 75th percentile, the upper and lower error bar represent the 10th and 90th percentile, respectively, the solid line within the boundary box represents the median, and the dashed line within the boundary box represents the mean. Individual specimen values are presented, with the sample also identified.

full thickness tears) or diseases with probable effects on rotator cuff insertions (tendinitis, bursitis, rheumatoid arthritis, or glenohumeral osteoarthritis) were excluded from the study. Disease pathology was identified using included medical history for each cadaver as well as visual inspection of the shoulder at the time of dissection. Two individuals completed rotator cuff dissection and measurements from two subject samples following the same protocol with direct oversight from the same supervisor.

The skin and subcutaneous tissues were removed and the deltoid was released from its insertion at the deltoid tuberosity and reflected back to its origin. The acromion was cut and removed near its base to grant better access to the supraspinatus (Figure 1). The rotator cuff musculature (supraspinatus, infraspinatus, teres minor, and subscapularis) was dissected allowing visualization of the respective tendinous insertions (Figure 2).

The thickness of the four rotator cuff tendon insertions was measured with a caliper (Fowler Tools and Instruments, Vernier Model: Las Vegas, NV) by positioning the caliper as close to the insertion as anatomically possible without avulsing the tendon from its point of insertion. The muscle belly of each rotator cuff muscle was cut transversely and the distal half was retracted allowing the caliper to be positioned deep to the tendon without placing tension on the insertion. Each tendon was measured three times using within-subject measurements made by the same individual. Data was compiled and descriptive statistics (mean, standard deviation, median, range, percentiles) were calculated using SAS 9.4 (SAS Institute; Cary, NC).

RESULTS

The mean thickness of the supraspinatus at the articular margin was 4.9 mm ± 2.1 (median: 4.2 mm, range: 2.9-12.7 mm) (Figure 3). The mean thickness of the infraspinatus tendon at the articular margin was 4.9 mm ± 1.3 (median: 4.8 mm, range: 3.0-7.2 mm) (Figure 3). The teres minor tendon had a mean thickness of 3.2 mm ± 1.1 (median: 2.9 mm, range: 1.7-5.7 mm) at the articular margin (Figure 3). Finally, the mean thickness of the subscapularis tendon at the articular margin was 5.5 mm ± 1.3 (median: 5.5 mm, range: 3.5-9.3 mm) (Figure 3).

DISCUSSION

As orthopaedic research progresses and knowledge of the shoulder joint advances, the need for precise anatomical description is evident. Biomechanical studies relying on bone-to-bone measurements (i.e. acromial-humeral distance) have allowed for a preliminary knowledge of shoulder mechanics.[4,5,10-13] However, for improved understanding, shoulder models that account for the thickness of soft tissue structures will need to be used. The current study delivers relevant data about rotator cuff insertion thickness at the articular margin that will be useful in the on-going pursuit to more fully understand the mechanisms of shoulder injury.

Direct comparisons with existing literature are difficult given the limited number of related articles available and frequent lack of specification in describing precise anatomic locations where rotator cuff measurements where made. Roh et al.[19] described the supraspinatus insertion based on cadaveric dissection of embalmed shoulders. The study, which included a detailed dissection separating the anterior and posterior bellies of the supraspinatus tendon, found the thickness of the anterior supraspinatus tendon to be 3.1 mm and the thickness of posterior supraspinatus tendon to be 2.5 mm. However based on the authors' description of where the measurement was acquired, it appears their tendon measurements represent the thickness of the tendon as it inserts into the bone, which would account for the smaller values compared to the current study where measurements were made at the articular margin.

In addition to cadaveric studies, there have been multiple ultrasound studies evaluating the thickness of the supraspinatus tendon. Michener et al.[18] measured the supraspinatus thickness with ultrasound in 40 subjects (20 with "subacromial impingement syndrome" and 20 controls, average age 45 years). The authors reported the mean supraspinatus thickness in the asymptomatic group to be 6.0 mm and 6.6 mm in the symptomatic group. In a similar study, Cholewinski et al.[17] measured the thickness of the supraspinatus tendon to be 6.0 mm in 36 asymptomatic individuals (average age 57 years). Leong et al.[20] evaluated the thickness of the supraspinatus tendon in 37 college students (average age 21.4 years), including asymptomatic controls and symptomatic and asymptomatic volleyball players. Between these groups, the mean supraspinatus thickness ranged from 8.0 mm to 6.9 mm. These 2-D ultrasonographic measures are difficult to relate to specific 3D localization relative to the humeral anatomical structure.

Regardless of how measurements of tendon thickness are obtained, there are limitations inherent to the methods used. Studies utilizing cadaveric shoulders benefit from the opportunity to directly visualize and measure the tendon. However, there is little known about the effects of the embalming process on tendon thickness. Additionally, it is assumed that measurements completed with a caliper consistently obtain the largest measurement possible. This occurs since the caliper, which encompasses the tendon on both sides, must accommodate the thickest portion of the tendon. Conversely, ultrasound studies allow in vivo study of tendon thickness. However, they are subject to projection error that occurs when three-dimensional structures are projected as a two dimensional image. Additionally, ultrasound is prone to perception errors with transducer placement. If the transducer is not directly perpendicular to the structure measured, an oblique measurement is obtained. As imaging modalities improve, future studies will likely rely more on MRI to determine rotator cuff tendon thickness. However, conventional pulse sequences used with most clinical MRI's make both the tendons and entheses "invisible" and therefore unfit for obtaining accurate dimensional measurements.[24]

Although direct comparisons cannot be made between studies in which measurements varied in both the location and technique (ultrasound vs. cadaveric), a general trend can still be appreciated. As the mean age of subjects in a study increased the thickness of the tendon decreased. Leong et al.[20] (mean age 21.4 years) obtained an average supraspinatus thickness of 6.9 cm while Michener et al.[18] (mean age 45 years) obtained a mean thickness of 6.0 cm. The current study, with an average age of 78 years found an average supraspinatus thickness of 4.9 mm. Roh et al.[19] (mean age 82 years) found the average thickness to be 3.1 mm. When the full extent of current data available is evaluated with regards to age, there is evidence suggesting possible age related rotator cuff atrophy.[25] However, it is important to consider that none of the studies mentioned performed a histological or mechanical analysis of the tendon. Thickness of the tendon cannot be assumed to directly correlate with tendon strength as inflammation or fatty changes to the tendon may increase the thickness while subsequently decreasing tendon strength.

The current study identified one anomalous subject who demonstrated remarkably thick tendons. The supraspinatus tendon for this individual measured 12.7 mm compared to mean of 4.9 mm ± 2.1. Taking age and body mass index into consideration (age: 61 years, BMI: 26.4), the etiology of this anomaly remains unclear. Visually, the larger tendon was paired with a larger supraspinatus muscle belly. With a relatively small sample size for our study, the frequency of such anomalies also remains unclear.

Additionally, with regard to interpretation, the acromial humeral distance was not measured during the current study, as this varies with arm position. Therefore the percentage of the subacromial space occupied by the tendon cannot be determined from this analysis.

In the current study, the tendon thickness measured in the first sample was often larger than that measured in the second sample (Figure 3). Though different individuals completed the dissections and measurements, we believe the difference is primarily an artifact of age and not measurement difference. The average age for specimens in the first sample was 65.8 years versus the average age of specimens for the second sample was 89.1 years.

This current study provides needed objective data about the thickness of the rotator cuff tendons. Data regarding the infraspinatus, teres minor and teres major, which have been largely understudied, are particularly important as the accuracy of the data generated by shoulder models depends on the accuracy of the data on which the model is generated. As this data has previously been very limited, studies using modeling have been inherently limited by extrapolating data from other anatomic sites. The current study also demonstrates that rotator cuff thickness can vary substantially between individuals. Therefore it is essential that the generation of models take into consideration the possibility of significant variations in tendon thicknesses from etiologies that are not yet elucidated.

At a time when three dimensional shoulder modeling is increasingly important to the investigation of rotator cuff disease, the need for precise modeling is accelerating. This study provides accurate measurements of all four of the rotator cuff tendons at the articular margin, measurements that have been largely unavailable until this point. This data will allow for improved modeling accuracy of soft tissue structures specific to the shoulder. Musculoskeletal modeling, including finite element models, have the potential to begin to elucidate various etiologic mechanisms of rotator cuff disease, including compressive "impingement", and other tissue stress and biomechanical mechanisms. Eventually knowledge gained through models can be used to pursue prevention of rotator cuff tears and improve targeted treatment planning.

BIBLIOGRAPHY

1. **Whittle S, Buchbinder R.** In the clinic. rotator cuff disease. Ann Intern Med. 2015;162(1):ITC1-IT15.
2. **Tempelhof S, Rupp S, Seil R.** Age-related prevalence of rotator cuff tears in asymptomatic shoulders. J Shoulder Elbow Surg. 1999;8(4):296-299.
3. **Neer CS.** Anterior acromioplasty for the chronic impingement syndrome in the shoulder: A preliminary report. J Bone Joint Surg. 1972;54(1):41-50.
4. **Bigliani LU, Ticker JB, Flatow EL, Soslowsky LJ, Mow VC.** The relationship of acromial architecture to rotator cuff disease. Clin Sports Med. 1991;10(4):823-838.
5. **Spiegl UJ, Horan MP, Smith SW, Ho CP, Millett PJ.** The critical shoulder angle is associated with rotator cuff tears and shoulder osteoarthritis and is better assessed with radiographs over MRI. Knee Surg Sports Traumatol Arthrosc. 2016;24(7):2244-2251.
6. **Rathbun JB, Macnab I.** The microvascular pattern of the rotator cuff. J Bone Joint Surg Br. 1970;52(3):540-553.
7. **Neer CS, Craig EV, Fukuda H.** Cuff-tear arthropathy. J Bone Joint Surg. 1983;65(9):1232-1244.
8. **Soslowsky LJ, Thomopoulos S, Esmail A, et al.** Rotator cuff tendinosis in an animal model: Role of extrinsic and overuse factors. Ann Biomed Eng. 2002;30(8):1057-1063.
9. **Ludewig PM, Reynolds JF.** The association of scapular kinematics and glenohumeral joint pathologies. J Orthop Sports Phys Ther. 2009;39(2):90-104.
10. **Neer CS.** Impingement lesions. Clin Orthop Relat Res. 1983(173):70-77.
11. **Bey MJ, Brock SK, Beierwaltes WN, Zauel R, Kolowich PA, Lock TR.** In vivo measurement of subacromial space width during shoulder elevation: Technique and preliminary results in patients following unilateral rotator cuff repair. Clin Biomech (Bristol, Avon). 2007;22(7):767-773.
12. **Giphart JE, van der Meijden OA, Millett PJ.** The effects of arm elevation on the 3-dimensional acromiohumeral distance: A biplane fluoroscopy study with normative data. J Shoulder Elbow Surg. 2012;21(11):1593-1600.
13. **Cotton RE, Rideout DF.** Tears of the humeral rotator cuff; A radiological and pathological necropsy survey. J Bone Joint Surg. 1964;46:314-328.
14. **Graichen H, Bonel H, Stammberger T, et al.** Three-dimensional analysis of the width of the subacromial space in healthy subjects and patients with impingement syndrome. AJR Am J Roentgenol. 1999;172(4):1081-1086.
15. **Hébert L,J., Moffet H, Dufour M, Moisan C.** Acromiohumeral distance in a seated position in persons with impingement syndrome. J Magn Reson Imaging. 2003;18(1):72-79.
16. **Thompson MD, Landin D, Page PA.** Dynamic acromiohumeral interval changes in baseball players during scaption exercises. J Shoulder Elbow Surg. 2011;20(2):251-258.
17. **Cholewinski JJ, Kusz DJ, Wojciechowski P, Cielinski LS, Zoladz MP.** Ultrasound measurement of rotator cuff thickness and acromio-humeral distance in the diagnosis of subacromial impingement syndrome of the shoulder. Knee Surg Sports Traumatol Arthrosc. 2008;16(4):408-414.
18. **Michener LA, Subasi YSS, Seitz AL, Timmons MK, Walsworth MK.** Supraspinatus tendon and subacromial space parameters measured on ultrasonographic imaging in subacromial impingement syndrome. Knee Surg Sports Traumatol Arthrosc. 2015;23(2):363-369.
19. **Roh MS, Wang VM, April EW, Pollock RG, Bigliani LU, Flatow EL.** Anterior and posterior musculotendinous anatomy of the supraspinatus. J Shoulder Elbow Surg. 2000;9(5):436-440.
20. **Leong H, Tsui S, Ying M, Leung VY, Fu SN.** Ultrasound measurements on acromio-humeral distance and supraspinatus tendon thickness: Test-retest reliability and correlations with shoulder rotational strengths. J Sci Med Sport. 2012;15(4):284-291.
21. **Graichen H, Hinterwimmer S, von Eisenhart-Rothe R, Vogl T, Englmeier K, Eckstein F.** Effect of abducting and adducting muscle activity on glenohumeral translation, scapular kinematics and subacromial space width in vivo. J Biomech. 2005;38(4):755-760.
22. **Desmeules F, Minville L, Riederer B, Côté CH, Frémont P.** Acromio-humeral distance variation measured by ultrasonography and its association with the outcome of rehabilitation for shoulder impingement syndrome. Clin J Sport Med. 2004;14(4):197-205.
23. **Hinterwimmer S, Von Eisenhart-Rothe R, Siebert M, et al.** Influence of adducting and abducting muscle forces on the subacromial space width. Med Sci Sports Exerc. 2003;35(12):2055-2059.
24. **Du J, Chiang AJ, Chung CB, et al.** Orientational analysis of the achilles tendon and enthesis using an ultrashort echo time spectroscopic imaging sequence. Magn Reson Imaging. 2010;28(2):178-184.
25. **Melis B, DeFranco MJ, Chuinard C, Walch G.** Natural history of fatty infiltration and atrophy of the supraspinatus muscle in rotator cuff tears. Clin Orthop Relat Res. 2010;468(6):1498-1505.

AGE DIFFERENCES IN THE PREVALENCE OF ISOLATED MEDIAL AND LATERAL MENISCAL TEARS IN SURGICALLY TREATED PATIENTS

T.J. Ridley, MD[1]; Mark A. McCarthy, MD[2]; Matthew J. Bollier, MD[3];
Brian R. Wolf, MD[3]; Annunziato Amendola, MD[4]

ABSTRACT

Purpose: To compare the prevalence of isolated lateral and medial meniscal tears in different aged populations.

Methods: A five-year retrospective review for meniscal procedures performed on a total of 782 patients. Each chart was reviewed to document the prevalence of medial or lateral meniscal injuries. Inclusion criteria were patients found to have documented evidence of meniscal tear, either lateral or medial, without any concomitant injuries and/or any other procedures performed. Patients excluded from the study were those with concomitant pathologies, such as chondromalacia, malalignment or ligamentous injuries. Patients were classified by age into three groups: < 20 years, 20-30 years and > 30 years old.

Results: 68.7% of patients had medial meniscal tears, (average age 37.6 years), 17.1% of these were isolated medial meniscus injuries (average 31.9 years). 31.3% had lateral meniscal injuries (average 27.7 years). Of these, 18.8 % had isolated lateral meniscal injuries (average 22.8 years). All remaining patients had additional diagnoses/procedures. Isolated medial meniscal injuries were more common in older patients as 48 of the 92 isolated medial tears (52.2%) were found in patients > 30 years of age (p <0.001).

Isolated lateral meniscal injuries, on the other hand, were more common in younger patients. 29 of the 46 isolated lateral tears (63%) occurred in patients under 20 years (p = 0.002). Only seven (15.2%) isolated lateral tears were shown in patients older than 30 years.

Conclusion: Isolated lateral meniscal tears are more common in patients < 20 years, and decrease with age, while the prevalence of medial meniscal tears increase with age.

Keywords: meniscus; meniscal tears; meniscal lesions; medial; lateral; isolated meniscus tear

INTRODUCTION

Meniscal lesions are the most common intra-articular knee injury with arthroscopic partial meniscectomy the most frequent surgical procedures performed by orthopedists[1-4]. The mean annual prevalence of meniscal lesions has been reported to be 66 per 100,000 inhabitants, 61 of which result in meniscectomy[5,6], with a male to female prevalence ratio between 2.5:1 and 4:1, and overall prevalence peaking at 20-29 years of age for both sexes[5,7,8]. Meniscal lesions occur in all age groups, with the main etiological and pathophysiological factors varying and being highly dependent upon the patient's age[4,9,10].

The prevalence of lateral meniscal tears are thought to be higher in younger populations, with medial tears occurring in lower rates in younger people and increasing with age. To our knowledge, no study has evaluated the prevalence of isolated meniscal tears with respect to age. It was hypothesized that isolated medial meniscal tears are more common with increasing age, while lateral meniscal tears are more common in the younger population. This information will guide clinicians when developing differential diagnoses for patients with lateral and/or medial knee pain in different age groups.

[1]Department of Orthopaedic Surgery, University of Minnesota, Minneapolis, MN

[2]Department of Orthopaedic Surgery, Mayo Clinic, Eau Claire, WI

[3]Department of Orthopaedics and Rehabilitation, University of Iowa, Iowa City, IA

[4]Department of Orthopaedic Surgery, Duke University, Durham, NC

Corresponding author:
T.J. Ridley, MD
Department of Orthopaedic Surgery
University of Minnesota
2450 Riverside Avenue South
Suite R200
Minneapolis, MN 55454
+1-612-273-1177
ridle036@umn.edu

Subject informed consent: Waiver of informed consent for human study subjects was granted after review by our Institutional Review Board, as this retrospective study of observational data involved minimal risk to study participants.

Conflict of interest disclosure: The authors declare no conflicting interests of commercial, personal or intellectual nature in this study's design, interpretation of results, or presentation of its scientific content.

Source of funding: none

Table I

	< 20 years old	20-30 years old	> 30 years old
Medial	32/92 (34.8%)	12/92 (13%)	48/92 (52.2%)
Lateral	29/46 (63%)	10/46 (21.7%)	7/46 (15.2%)
p - value	0.002	0.19	< 0.001

Table 1. Isolated medial and lateral meniscal injuries by age group. Isolated medial meniscal injuries were more common in older patients (p < 0.001), while isolated lateral meniscal injuries were more common in younger patients (p = 0.002).

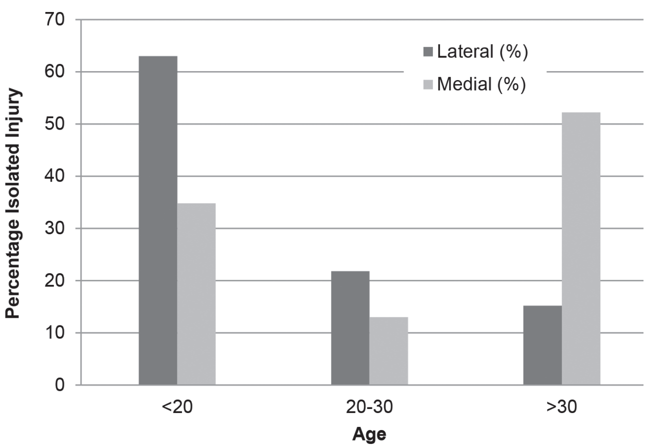


Figure 1. Percentage of Isolated Injuries vs Age. Isolated lateral meniscus injuries were more common in patients under 20 years of age. Isolated medial meniscus injuries were more common in patients greater than 30 years old.

METHODS

After obtaining institutional review board approval, a chart review was performed to identify patients who underwent arthroscopic meniscal procedures from July 1, 2007 – July 1, 2012 at a single institution, resulting in 782 patients who underwent an arthroscopic meniscal procedure. Each operative note was reviewed thoroughly to identify concomitant injuries such as cruciate or collateral ligament injuries, chrondromalacia, and any other pathology. We also documented procedural codes, such as microfracture, chondroplasty, OATS, HTO etc. Inclusion criteria were patients found to have documented evidence of meniscal tear, either lateral or medial, without any concomitant injuries and/or any other procedures performed. Patients excluded from the study were those with concomitant pathologies, such as chondromalacia, malalignment or ligamentous injuries.

Demographic data, structures injured, presence and grade of chondromalacia, and treatments were recorded. We reviewed each patient's chart for any other orthopedic injuries to the same joint.

Patient database was reviewed to document the prevalence of isolated medial or lateral meniscal injuries. Patients were further classified by age into three groups: less than 20 years, 20-30 years, and greater than 30 years old. The Chi-square test was performed by department statistician to evaluate for statistical difference in prevalence of isolated meniscal tears among these age groups. A value of $p < 0.05$ was considered significant.

RESULTS

782 total patients underwent meniscal procedures during the five-year period at our institution. 537 of these patients (68.7%) had medial meniscal tears at an average age of 37.6 years. Furthermore, 92 of these 537 (17.1%) were isolated medial meniscus injuries with an average age of 31.9 years (range 12-62). The remaining 445 patients had additional diagnoses and procedures performed (ligament surgery, chondroplasty).

245 of the 782 patients had lateral meniscal injuries at an average age of 27.7 years. Of these 245, 46 (18.8%) had isolated lateral meniscal injuries, average age 22.8 years (range 11-55). The remaining 199 patients had additional diagnoses/procedures.

When analyzed by age group, isolated medial meniscal injuries were more common in older patients. 48 of the 92 isolated medial tears (52.2%) were found in patients older than 30 years of age ($p < 0.001$) while only 32 (34.8%) and 12 (13.0%) of these injuries were found in patients younger than 20 years old and age 20-30, respectively (Table 1).

Isolated lateral meniscal injuries, on the other hand, were more common in younger patients. 29 of the 46 isolated lateral tears (63%) occurred in patients under 20 years ($p = 0.002$). Only seven (15.2%) isolated lateral tears were shown in patients older than 30 years (Figure 1). Ten isolated lateral tears (21.7%) were found in our 20-30 age group ($p = 0.19$).

DISCUSSION

The purpose of this study was to determine the prevalence of isolated meniscal injuries as it relates to patient age. Anecdotally, orthopedic surgeons have assumed that medial meniscal tears occur less frequently in younger patients, and more commonly in older patients, while lateral tears occur more often in a younger population. However, no prior studies were found that sought to prove this hypothesis. This study ultimately confirms this to be true. This information is valuable for providers in the clinical setting when developing differential diagnoses while evaluating patients of different ages with lateral and/or medial sided knee symptoms.

The medial meniscus covers approximately 50% of the medial tibial plateau and is more tightly adherent to the joint capsule than the lateral meniscus[11]. The lateral meniscus is smaller than the medial meniscus and covers approximately 70% of the lateral surface of the tibial plateau[11]. The lateral meniscus is loosely attached to the joint capsule, particularly in the posterolateral corner where the posterior third attaches to the capsule via the popliteomeniscal fascicles. Medial and lateral menisci have distinctly different dimensions: lateral menisci are approximately 32.4-35.7 mm in length and 26.6-29.3 mm wide, while medial menisci are 40.5-45.5 mm long and 27 mm wide[12,13]. Although both menisci are roughly wedge-shaped and semilunar, lateral menisci display greater variety in size, shape, thickness, and mobility than medial menisci[14,15]. Lateral menisci also cover a larger portion of the tibial plateau (75-93% laterally) in comparison to medial menisci (51%-74% medially)[2].

The propensity of lateral meniscal tears to occur in isolation in younger persons is likely due to its anatomic and biomechanical differences compared to the medial meniscus. The lateral meniscus is more mobile, has less staunch capsular attachments and covers a greater surface area of the lateral plateau than the medial meniscus. These characteristics make isolated tears of the lateral meniscus more likely in a traumatic setting in younger patients.

This study is not without limitations. In addition to the inherent weaknesses of a retrospective review, a further weakness of this study is that only meniscus injuries that underwent surgical intervention were included. Clinical outcomes and improvement post-meniscectomy is controversial in patients older than 50 years of age[4]. This has led many surgeons to refrain from arthroscopic treatment for meniscal tears in older patients. This likely leads to a gross underestimation of the prevalence of meniscal tears in the older population. However, this may not affect the results as it was found that microscopic degeneration was an almost invariable finding in patients over the age of forty and was as common in lateral as in medial menisci[10]. Furthermore, characteristics or tear patterns of the isolated tears, as well as treatment therein were not delineated, which could be interpreted as another weakness, or rather, may have provided further insight. However, the purpose of this study was to report on prevalence of medial and lateral meniscal tears. It was felt that, overall, this study accomplished the primary goal, supporting the proposed hypothesis that isolated medial meniscal tears are more common with increasing age, while lateral meniscal tears are more common in the younger population.

CONCLUSION

This study showed that isolated lateral meniscal tears occur more often in younger people. The prevalence of isolated lateral meniscal tears was more common in our defined young patient population of under 20 years of age, and in decreasing prevalence in our older patient groups (20-30, > 30 years of age). Additionally, the prevalence of isolated medial meniscal tears increases with age. This information is valuable in guiding clinicians when developing differential diagnoses upon evaluating patients of different ages with lateral and/or medial sided knee symptoms.

ACKNOWLEDGEMENTS

Department statistician Yubo Gao, PhD.

REFERENCES

1. **Englund M, Roos EM, Roos HP, Lohmander LS.** Patient-relevant outcomes fourteen years after meniscectomy: Influence of type of meniscal tear and size of resection. Rheumatology (Oxford) 2001;40(6):631-9. [PMID: 11426019] [DOI: 10.1093/rheumatology/40.6.631].
2. **Garrett WE, Jr., Swiontkowski MF, Weinstein JN, Callaghan J, Rosier RN, Berry DJ, Harrast J, Derosa GP.** American Board of Orthopaedic Surgery Practice of the Orthopaedic Surgeon: Part-II, certification examination case mix. J Bone Joint Surg Am 2006;88(3):660-7. [PMID: 16510834] [DOI: 10.2106/JBJS.E.01208].
3. **Morgan CD, Wojtys EM, Casscells CD, Casscells SW.** Arthroscopic meniscal repair evaluated by second-look arthroscopy. Am J Sports Med 1991;19(6):632-7; discussion 7-8. [PMID: 1781503] [DOI: 10.1177/036354659101900614].
4. **Salata MJ, Gibbs AE, Sekiya JK.** A systematic review of clinical outcomes in patients undergoing meniscectomy. Am J Sports Med 2010;38(9):1907-16. [PMID: 20587698] [DOI: 10.1177/0363546510370196].
5. **Baker BE, Peckham AC, Pupparo F, Sanborn JC.** Review of meniscal injury and associated sports. Am J Sports Med 1985;13(1):1-4. [PMID: 3838420] [DOI: 10.1177/036354658501300101].
6. **Hede A, Jensen DB, Blyme P, Sonne-Holm S.** Epidemiology of meniscal lesions in the knee. 1,215 open operations in Copenhagen 1982-84. Acta Orthop Scand 1990;61(5):435-7. [PMID: 2239168] [DOI: 10.3109/17453679008993557].
7. **Steinbruck K.** [Epidemiology of sports injuries. 25-year analysis of sports orthopedic-traumatologic ambulatory care]. Sportverletz Sportschaden 1999;13(2):38-52. [PMID: 10478388] [DOI: 10.1055/s-2007-993313].
8. **Steinbruck K.** [Epidemiology of sports injuries. A 15-year analysis of sports orthopedic ambulatory care]. Sportverletz Sportschaden 1987;1(1):2-12. [PMID: 3509867] [DOI: 10.1055/s-2007-993688].

9. **Makris EA, Hadidi P, Athanasiou KA.** The knee meniscus: Structure-function, pathophysiology, current repair techniques, and prospects for regeneration. Biomaterials 2011;32(30):7411-31. [PMID: 21764438] [DOI: 10.1016/j.biomaterials.2011.06.037].
10. **Noble J, Hamblen DL.** The pathology of the degenerate meniscus lesion. J Bone Joint Surg Br 1975;57(2):180-6. [PMID: 1173585]
11. **Rath E, Richmond JC.** The menisci: Basic science and advances in treatment. Br J Sports Med 2000;34(4):252-7. [PMID: 10953895] [DOI: 10.1136/bjsm.34.4.252].
12. **McDermott ID, Sharifi F, Bull AMJ, Gupte CM, Thomas RW, Amis AA.** An anatomical study of meniscal allograft sizing. Knee Surg Sports Traumatol Arthrosc 2004;12(2):130-5. [PMID: 12756521] [DOI: 10.1007/s00167-003-0366-7].
13. **Shaffer B, Kennedy S, Klimkiewicz J, Yao L.** Preoperative sizing of meniscal allografts in meniscus transplantation. Am J Sports Med 2000;28(4):524-33. [PMID: 10921644]
14. **Clark CR, Ogden JA.** Development of the menisci of the human knee joint. Morphological changes and their potential role in childhood meniscal injury. J Bone Joint Surg Am 1983;65(4):538-47. [PMID: 6833331]
15. **Greis PE, Bardana DD, Holmstrom MC, Burks RT.** Meniscal injury: I. Basic science and evaluation. J Am Acad Orthop Surg 2002;10(3):168-76. [PMID: 12041938]

STRENGTH OF RESISTANCE TO "FLIP" THE TIGHTENED HALF-HITCHES OF AN ARTHROSCOPIC KNOT

Alexander CM. Chong, MSAE, MSME[1,2], Pie Pichetsurnthorn, MS-1[3], Daniel J. Prohaska, MD[2,4]

ABSTRACT

PURPOSE: The purpose of this study was to biomechanically determine the minimum strength required to "flip" a seated and tightened half-hitch in a knot of different braided polyblend sutures.

METHODS: ForceFiber, FiberWire, Orthocord, and Ultrabraid were evaluated. All knot tying processes began by advancing an initial base knot down to a standardized rod. All half-hitches were tied using a single-hole knot pusher in a dry environment, and were tightened with 45N by using past-pointing maneuver. A tension was then deliberately applied to the wrapping suture limb until a "flip" occurred, and the amount of tension was measured by the load cell. Three trials for each half-hitch and 3 half-hitches for each arthroscopic knot with 12 knots of each material were tied. All respective tension loads were collected through the digital video recordings (knot closeup view and load cell reading).

RESULTS: Orthocord was the easiest to "flip" a seated and tightened half-hitch (average: 10±3N), whereas Ultrabraid was hardest to "flip" (average: 23±7N). ForceFiber and FiberWire were about 49% and 15% more resistance to "flip" when compared to Orthocord. After each trial of flipping the half-hitch back and re-tightened, there was a significant reduction in strength required to "flip" the tightened half-hitch.

CONCLUSION: 1) The unintentional minimum tensile strength greater than 10N applied to the wrapping suture limb on the seated and tightened half-hitch could potentially "flip" the half-hitch in a knot during arthroscopic procedures, and 2) different braided suture material has an affect on the tensile strength to "flip" a seated and tightened half-hitch in an arthroscopic knot.

CLINICAL RELEVANCE: The findings of this study indicated that even a seated and tightened half-hitch in an arthroscopic knot could easily be "flipped" if an unintentional tension was applied to the wrapping suture limb, and thereby reduced the knot security strength. In addition different suture materials could have an effect on the strength needed to "flip" the tightened half-hitch.

KEYWORDS: Half-hitch; Arthroscopy; Flip strength; Braided polyblend suture; Reversing half-hitches on alternating posts.

INTRODUCTION

Arthroscopic suturing and knot tying is an essential skill for most orthopaedic surgeons to master in order to re-approximate tissues arthroscopically utilizing suturing techniques.[1-5] It has been shown that at least 3 reversing half-hitches on alternating posts (RHAPs) after placement of most types of sliding or nonsliding knots are necessary for optimal knot integrity.[6-9] The half-hitch consisted of a single turn around the post limb. Chan et al[10] described a technique for switching posts simply by alternating tension on the suture limbs, this "flips" the knot, and the wrapping limb (or the loop

[1]Department of Graduate Medical Education – Orthopaedics Surgery, Via Christi Health, 929 N. Saint Francis, Wichita, KS 67214

[2]Department of Orthopaedics Surgery, The University of Kansas School of Medicine-Wichita, 929 N. Saint Francis, Wichita, KS 67214

[3]KU School of Medicine–Wichita, 1010 North Kansas, Wichita, KS 67214

[4]Advanced Orthopaedics Associates, 2778 N. Webb Road, Wichita, KS 67226

Investigation performed at the Department of Orthopaedic Surgery, The University of Kansas School of Medicine-Wichita at Wichita, KS, USA

Corresponding Author:
Alexander Chong, Research Engineer, Department of Graduate Medical Education – Orthopaedics Surgery, Via Christi Health, 929 N. Saint Francis, Wichita, KS 67214 USA [alex.chong.ortho@gmail.com], 316-832-8923, Fax: 316-291-4998

Acknowledgements and Disclosure:
The authors wish to thank Via Christi Health, The University of Kansas School of Medicine-Wichita, DePuy-Mitek, Smith-Nephew, and Stryker for providing the materials and instrument used in this study. The authors report no actual or potential conflict of interest in relation to this article.

Conflict of Interest Statement:
This study received material support from DePuy-Mitek (Warsaw, IN), Smith-Nephew (Memphis, TN), and Stryker (San Jose, CA) in support of this research for or in preparation of this study, but had no role in the collection, analysis, and interpretation of data, in the writing of the manuscript, or in the decision of submit the manuscript for publication. This study also did not receive any funding support, payments, or other personal benefit, or a commitment or agreements that were related in any way to the subject of the research that we conducted in connection with the research.

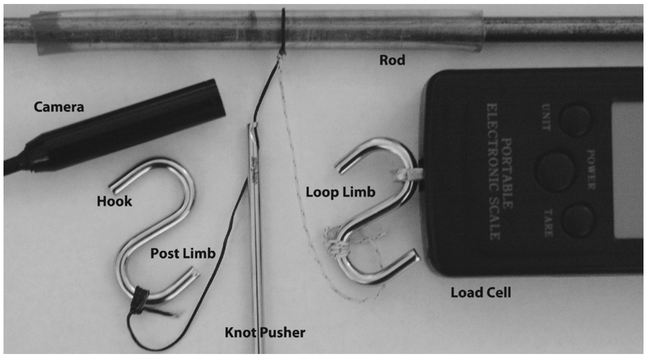


Figure 1. Experimental Setup

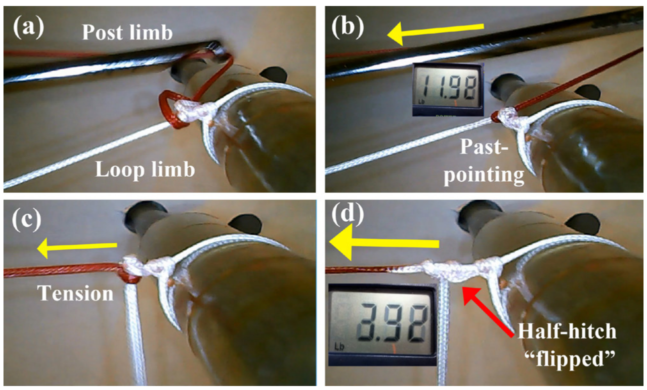


Figure 2. Half-Hitch Flipping Process

limb) effectively becomes the post. However, Meier et al[11] noted that there is a potential flaw when a "flipped" knot is tensioned, past-pointed or pulled back by the knot pusher which may inadvertently revert the knot to its original configuration. This converts a series of RHAPs into a series of identical half-hitches on the same post, a configuration that has inferior knot security. To date, there has not been a study documenting the amount of tension that inadvertently "flips" the seated and tightened half-hitch to the direction that was not intended. The purpose of this study was to biomechanically determine the minimum strength required to "flip" a seated and tightened half-hitch in an arthroscopic knot of different braided polyblend sutures. The hypothesis of this study was that different braided suture materials used in arthroscopic procedures required different minimum tensile strength to revert a seated and tightened half-hitch in an arthroscopic knot.

MATERIALS AND METHODS

Four different types of #2 braided polyblend polyethylene arthroscopy sutures were evaluated for comparison: ForceFiber (Stryker, San Jose, CA), FiberWire (Arthrex, Naples, FL), Orthocord (DePuy-Mitek, Warsaw, IN), and Ultrabraid (Smith-Nephew, Memphis, TN). All knot tying processes in this study began by advancing three identical half-hitches on the same post (initial base knot) down to a standardized 30 mm circumference rod of which is intended to provide a consistent starting circumference for each knot. All half-hitches were tied using standard arthroscopic techniques with a standard single-hole knot pusher in a dry environment (Figure 1), and the half-hitch consisted of a single turn around the post limb. The knot pusher was kept on the post suture limb for the entire knot-tying process, and each half-hitch was tightened manually with at least 45 N by using past-pointing maneuver. The past-pointing maneuver essentially creates an opposing force on the knot by tensioning both suture limbs simultaneously in diverging directions, by use of a knot pusher, much in the way one would tie the knot by hand.[12,13] The 45 N loads was conformed with a load cell (Protable Electronic Scale, China).

The first half-hitch after the initial base knot is placed over the post suture limb, but then the post was switched by increasing minor tension on the loop suture limb, by using the knot pusher lead the half-hitch down onto the base knot (Figure 2a) and tightened manually with at least 45 N loading by using the past-pointing technique (Figure 2b). A tension, which was in the direction away from the knot, was then deliberately applied to the post suture limb until a "flip" occurred (Figures 2c and 2d). The amount of tension was measured by the load cell, while slack was given to the loop suture limb. Two digital cameras were used to create the digital video recording of each individual tightened half-hitch "flip" simultaneously; one recorded the closeup view of the knot and the other recorded the load cell reading.

The half-hitch was then "flipped" back again by applying minor tension on the loop suture limb, and was retightened to the half-hitch again with at least 45 N loads by using the past-pointing technique. This procedure was repeated 3 trials for each half-hitch, and 3 half-hitches for each arthroscopic knot. All the respective tension loads were collected through the digital video recordings. A total of 12 knots of each material were tied, resulting in a total of 108 half-hitches flipped, measured, and recorded.

Statistical analysis

Means and standard deviations were calculated for each trial and each material, and these values were used to determine the statistical relevance of the difference in ultimate "flip" post strength. A one-way analysis of variance (ANOVA) of SPSS software (Version 19.0; SPSS Inc, Chicago, IL) with the Least Significant Difference (LSD) multiple comparisons post hoc analysis was performed to determine the statistical relevance of the difference in the performance of each suture material. The level of significant difference was defined as $p < 0.05$.

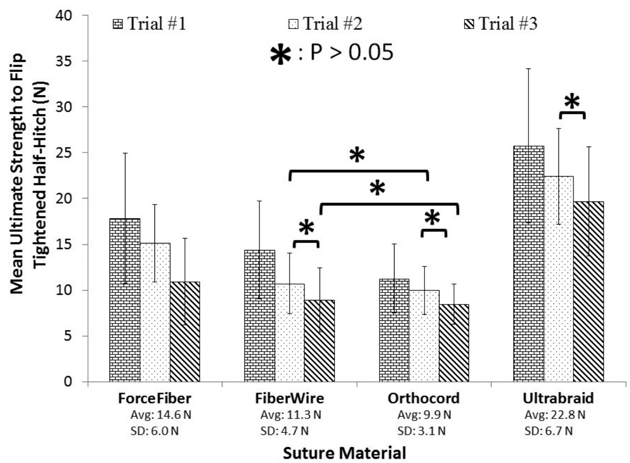


Figure 3. Flip Post Strength Test Summary Results

RESULTS

Figure 3 shows the mean ultimate strength to "flip" a tightened half-hitch of 4 different braided polyblend polyethylene arthroscopy suture materials of each trial. Overall, the Orthocord was the easiest to "flip" compared to the other test materials (average: 10 ± 3 N, range: 4 – 20 N, $p<0.05$), whereas Ultrabraid was found to have highest resistance to "flip" in a tightened half-hitch (average: 23 ± 7 N, range: 9 – 40 N, $p<0.05$). When compared to the Orthocord, ForceFiber and FiberWire were about 49% and 15% more resistance to "flip" in a tightened half-hitch. Across all the suture materials, there was a statistical difference detected among the suture in the mean ultimate strength to flip a tightened half-hitch in a knot ($p<0.05$).

The results also showed an interesting trend that after each trial of flipping the half-hitch back and re-tightened, there was a significant reduction in strength that required to "flip" the tightened half-hitch. However, statistically for FiberWire, Orthocord and Ultrabraid, the strength to revert a tightened half-hitch was not significantly different after the second trial. There were no significant difference detected between FiberWire and Orthocord for the second and third trials in term of flipping strength.

DISCUSSION

The results of this study supported our hypothesis that different braided suture materials used in arthroscopic procedures required different minimum tensile strength to revert a tightened half-hitch in an arthroscopic knot. Switching the post limb between throws in a series of half-hitches has been demonstrated to increase the knot security by increasing the friction and the internal interference.[6,8] Chan and Burkhart[10] developed an easy technique to switch post by increasing tension on the suture limbs. However, slightly over tensioning the wrapping suture limb on a tightened half hitch will cause the knot to flip back. The goal of this study was set out to provide basic data that the unintentional minimum strength on the loop suture limb that could potential "flip" a tightened half-hitch during knot tying process on different suture materials, and that may help guide the surgeons to prevent the discrepancies of maximum clinical failure loads observed between orthopaedic surgeons, and thereby achieve a better outcome in arthroscopic surgeries that required knot tying. Our results revealed that a tensional strength as low as 4 N (range: 4 – 40 N depending on suture material) on the loop suture limb could potential "flip" the 45 N tightened half-hitches down at the base knot. Therefore, caution should be used when tying the 3 RHAPs in a knot, such as pulling back the knot pusher while tying the next half hitch thraw or turning the suture around the post limb resulting in an unintentional tension applied to the wrapping limb.

Several studies have determined that braided polyblend sutures now commonly used for arthroscopic knots have better strength profiles,[4,6,14-16] with each company having their own design in material selection, weaver patterns, and coating. For example, even though both Ultrabraid and ForceFiber are made with braided nonabsorbable ultra-high molecular weight polyethylene (UHMWPE) with some variations in weaver patterns, there was an approximately 35% difference in strength needed to "flip" the tightened half-hitch. Orthocord is made with dyed absorbable polydioxanone core (polydioxanone 68%) with a combination of the undyed nonabsorbable UHMWPE (32%) as a sleeve and coated with polyglactin.[2,4] We suspected that the coating on Orthocord could possibly cause the tightened half- hitch to be "flipped" much easier than the other suture materials. Indeed, the results of this study indicated that Orthocord had the lowest UTS (average: 10 ± 3 N). In comparison, FiberWire, which is known to be the roughest suture material compared to the other suture materials, manufactured with a multifiber core of UHMWPE covered with braided polyester suture material, only required an average of 11 ± 5 N to "flip" a tightened half-hitch. Our findings are in agreement with those of Abbi and colleagues[14], Lieurance and colleagues[17], and Mahar and colleagues[18] with respect to suture materials having a major effect on knot security even with a series of 3 RHAPs.

While tying the 3 RHAPs in a knot, mistakes can occur, such as pulling back the knot pusher while tying the knot or turning the suture around the post limb resulting in an unintentional tension applied to the wrapping limb, thus easily "flipped" the half-hitch and thereby reversing the kinking effect created by alternating posts, and that produce insecure knots or suture loops[11]. In addition, we observed that during our experiment, over tensioning (> 50N) during past-pointing or over-pointing could also potentially "flip" the previously seated half-hitch in the base knot that has already been tightened without noticing. Unfortunately, there is no a convenient tool, such as a protable and small load cell, that can be use during surgery for a surgeon to indicate he/she has unintentionally "flipped" the tightened half-hitch down at the base knot. There is, however, a technique describe as "Reverse Flipping Technique" by Chong and colleagues[19], which can be absolutely sure that the half-hitch is tightened in the direction that was intended to be placed, by purposely "flips" the half-hitch down at the main knot, and once comfirm the half-hitch is in the direction that was intended to be placed, then the half-hitch can be retightened using either a past-pointing or over-pointing technique.

There are certain limitations to our experimental design. All arthroscopic knots were tied similar to clinical technique with only using knot pusher, but in the laboratory setting, this may have resulted in knots that were not exactly like clinical knots. Our model used metal hooks and a metal rod which are incompressible and do not interpose on the knot as soft tissue does in the clinical setting. Furthermore, knots were tied without tension against the sutures, whereas clinically knots are tied under tension as tissues are pulled together in reconstructions. Another inherent limitation is having only used a static Surgeon's knot as the initial sliding knot and no other knot type. The authors also recognize that the experimental setup lacked randomization in the order the suture material was performed. There is also the possibility of participant fatigue with knot tying that could be a potential limitation of this study. An additional limitation in our model is the relatively small number of samples, a larger study may more clearly demonstrate the consistency and efficiency of tying 3 RHAPs in a knot. This study only used Four different types of #2 braided polyblend polyethylene arthroscopy sutures (ForceFiber, FiberWire, Orthocord, and Ultrabraid); therefore, we cannot generalize our results to other types of suture materials or knots. Another weakness of this study is all half-hitches were tied in dry environment, whereas, in the clinical setting, where there is fluid environment and the body temperature, could potentially affect the effectiveness of half-hitches in a knot, as knot security depends on friction, internal interference, and slack between throws.[20]

CONCLUSIONS

Overall, we can conclude that the unintentional minimum tensile strength greater than 10 N applied to the wrapping suture limb on the seated and tightened half-hitch could potentially "flip" the half-hitch in a knot during arthroscopic procedures. Caution should be use when tying the 3 RHAPs in a knot using standard arthroscopic techniques with a standard knot pusher and a arthroscopic cannula. In addition, this study also demonstrated that different braided suture material has an effect on the tensile strength to "flip" a seated and tightened half-hitch in an arthroscopic knot. We believe that this may prevent the discrepancies of maximum clinical failure loads observed between orthopaedic surgeons, and thereby achieve a better outcome.

REFERENCES

1. **Baumgarten KM, Wright RW.** Ease of tying arthroscopic knots. J Shoulder Elbow Surg. 2007 Jul-Aug;16(4):438-42. Epub 2007 May 15. PMID:17507243
2. **Kim SH, Ha KI, Kim SH, Kim JS.** Significance of the internal locking mechanism for loop security enhancement in the arthroscopic knot. Arthroscopy. 2001 Oct;17(8):850-5. PMID: 11600983
3. **Leedle BP, Miller MD.** Pullout strength of knotless suture anchors. Arthroscopy. 2005 Jan;21(1):81-5. PMID: 15650671
4. **Mishra DK, Cannon WD Jr, Lucas DJ, Belzer JP.** Elongation of arthroscopically tied knots. Am J Sports Med. 1997 Jan-Feb;25(1):113-7. PMID: 9006704
5. **Tidwell JE, Kish VL, Samora JB, Prud'homme J.** Knot security: how many throws does it really take? Orthopedics. 2012 Apr;35(4):e532-7. doi: 10.3928/01477447-20120327-16. PMID: 22495855
6. **Lo IK, Burkhart SS, Chan KC, Athanasiou K.** Arthroscopic knots: determining the optimal balance of loop security and knot security. Arthroscopy. 2004 May;20(5):489-502. PMID: 15122139
7. **Loutzenheiser TD, Harryman DT 2nd, Yung SW, France MP, Sidles JA.** Optimizing arthroscopic knots. Arthroscopy. 1995 Apr;11(2):199-206. PMID: 7794433
8. **Chan KC, Burkhart SS, Thiagarajan P, Goh JC.** Optimization of stacked half-hitch knots for arthroscopic surgery. Arthroscopy 2001 Sep;17(7):752-9. PMID: 11536096
9. **Kim SH, Yoo JC, Wang JH, Choi KW, Bae TS, Lee CY.** Arthroscopic sliding knot: how many additional half-hitches are really needed? Arthroscopy. 2005 Apr;21(4):405-11. PMID: 15800519
10. **Chan KC, Burkhart SS.** How to switch posts without rethreading when tying half-hitches. Arthroscopy. 1999 May;15(4):444-50. PMID: 10355722
11. **Meier JD, Meier SW.** Over-pointing technique: an approach to past-pointing arthroscopic knots on alternating suture posts without alternating the knot pusher. Arthroscopy. 2007 Dec;23(12):1358.e1-3. Epub 2007 Jun 18. PMID: 18063184

12. **Nottage WM, Lieurance RK.** Arthroscopic knot typing techniques. Arthroscopy. 1999 Jul-Aug;15(5):515-21. PMID: 10424555
13. **Milia MJ, Peindl RD, Connor PM.** Arthroscopic knot tying: the role of instrumentation in achieving knot security. Arthroscopy. 2005 Jan;21(1):69-76. PMID: 15650669
14. **Abbi G, Espinoza L, Odell T, Mahar A, Pedowitz R.** Evaluation of 5 knots and 2 suture materials for arthroscopic rotator cuff repair: very strong sutures can still slip. Arthroscopy. 2006;22(1):38-43. PMID: 16399459
15. **Wüst DM, Meyer DC, Favre P, Gerber C.** Mechanical and handling properties of braided polyblend polyethylene sutures in comparison to braided polyester and monofilament polydioxanone sutures. Arthroscopy. 2006 Nov;22(11):1146-53. PMID: 17084288
16. **Livermore RW, Chong AC, Prohaska DJ, Cooke FW, Jones TL.** "Knot Security, Loop Security and Elongation of Braided Polyblend Sutures used for Arthroscopic Knots", AM J Orthop (Belle Mead NJ). 2010 Dec;39(12):569-76. PMID: 21720573
17. **Lieurance RK, Pflaster DS, Abbott D, Nottage WM.** Failure characteristics of various arthroscopically tied knots. Clin Orthop Relat Res. 2003 Mar;(408):311-8. PMID: 12616076
18. **Mahar AT, Moezzi DM, Serra-Hsu F, Pedowitz RA.** Comparison and performance characteristics of 3 different knots when tied with 2 suture materials used for shoulder arthroscopy. Arthroscopy. 2006 Jun;22(6):614.e1-2. PMID: 16762698
19. **Chong AC, Prohaska DJ, Pate RC.** "Reverse Flipping Technique: An Alternate Approach to Tie Reversing Half-Hitches on Alternating Posts". Arthroscopy Technique, 2016 Apr 25; 5(2): e403-5. PMID: 27462541
20. **Burkhart SS, Wirth MA, Simonich M, Salem D, Lanctot D, Athanasiou K.** Knot security in simple sliding knots and its relationship to rotator cuff repair: how secure must the knot be? Arthroscopy. 2000 Mar;16(2):202-7. PMID: 10705334

FINITE ELEMENT ANALYSIS OF PATELLA ALTA: A PATELLOFEMORAL INSTABILITY MODEL

Nicole A. Watson PhD[1]*, Kyle R. Duchman MD[2], Nicole M. Grosland PhD[1], Matthew J. Bollier MD[2]

ABSTRACT

Background: This study aims to provide biomechanical data on the effect of patella height in the setting of medial patellofemoral ligament (MPFL) reconstruction using finite element analysis. The study will also examine patellofemoral joint biomechanics using variable femoral insertion sites for MPFL reconstruction.

Methods: A previously validated finite element knee model was modified to study patella alta and baja by translating the patella a given distance to achieve each patella height ratio. Additionally, the models were modified to study various femoral insertion sites of the MPFL (anatomic, anterior, proximal, and distal) for each patella height model, resulting in 32 unique scenarios available for investigation.

Results: In the setting of patella alta, the patellofemoral contact area decreased, resulting in a subsequent increase in maximum patellofemoral contact pressures as compared to the scenarios with normal patellar height. Additionally, patella alta resulted in decreased lateral restraining forces in the native knee scenario as well as following MPFL reconstruction. Changing femoral insertion sites had a variable effect on patellofemoral contact pressures; however, distal and anterior femoral tunnel malpositioning in the setting of patella alta resulted in grossly elevated maximum patellofemoral contact pressures as compared to other scenarios.

Conclusions: Patella alta after MPFL reconstruction results in decreased lateral restraining forces and patellofemoral contact area and increased maximum patellofemoral contact pressures. When the femoral MPFL tunnel is malpositioned anteriorly or distally on the femur, the maximum patellofemoral contact pressures increase with severity of patella alta.

Clinical Relevance: When evaluating patients with patellofemoral instability, it is important to recognize patella alta as a potential aggravating factor. Failure to address patella alta in the setting of MPFL femoral tunnel malposition may result in even further increases in patellofemoral contact pressures, making it essential to optimize intraoperative techniques to confirm anatomic MPFL femoral tunnel positioning.

INTRODUCTION

The stability of the patellofemoral joint is maintained by a complex interaction between static soft tissue restraints, the dynamic action of the quadriceps, and bony anatomy about the knee. Patella alta, or high riding patella, is frequently associated with patellar instability[1,2] as the patella only engages the bony constraints of the trochlear groove in higher degrees of knee flexion[3]. Several studies[2,4-7] have provided radiographic methods to quantify patellar height with associated values defining patella alta and patella baja, or low riding patella. While several studies[8-10] have described increased contact pressures in patients with patella alta, the biomechanical effects of treatments aimed at patellar instabilty, including medial patellofemoral ligament (MPFL) reconstruction, have yet to be determined.

While patella alta frequently plays a role in patients with patellar instability, it often does so in combination with other pathology. Soft tissue restraints play a critical role in patellar stability. The medial patellofemoral ligament (MPFL) is the primary soft tissue restraint to lateral translation of the patella[11-13], acting as a check-rein during the first 30° of knee flexion prior to the patella engaging the trochlear groove[14,15]. Following acute lateral patellar dislocation, the MPFL is the most consistently injured ligamentous structure[16-18]. With nonoperative management of acute lateral patellar dislocations, recurrent dislocation is not uncommon, with resultant episodic dislocation more common in patients with multiple instability events[19,20]. MPFL reconstruction aims to restore the form and function of the native MPFL. However,

[1]Center for Computer Aided Design, University of Iowa, Iowa City, IA 52242

[2]Department of Orthopaedics and Rehabilitation, University of Iowa, Iowa City, IA 52242

*Corresponding Author:
Nicole A. Watson, Center for Computer Aided Design, 1420 Seamans Center, University of Iowa, Iowa City, IA 52242
Tel: (319)335-6425
Fax: (319)335-5631

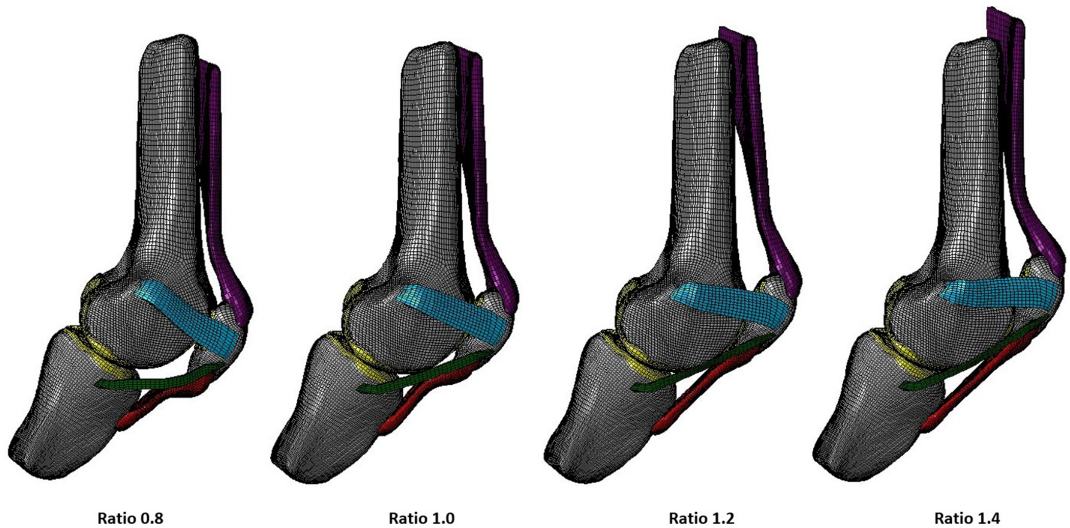


Figure 1. The patella baja (Caton-Deschamps 0.8), "normal" (Caton-Deschamps 1.0), and patella alta (Caton-Deschamps 1.2 and 1.4) finite element models. Each model includes the quadriceps tendon (purple), patellar tendon (red), cartilage (yellow), medial patellofemoral ligament (blue), and medial patellotibial ligament (green).

experimental studies have shown that even anatomic MPFL reconstruction may alter contact pressures within the patellofemoral joint[21], while non-anatomic reconstruction and excessive graft tension may lead to increased medial patellofemoral contact pressures, resultant medial instability, or even catastrophic failure[15,22,23].

More frequently than not, several factors play a role in patellar instability. Patella alta and MPFL insufficiency are often concomitantly identified in this patient population1, and failure to address both pathologies can lead to treatment failure[24]. To our knowledge, no studies have examined patellofemoral biomechanics after MPFL reconstruction in the setting of patella alta or patella baja. Therefore, the purpose of this study was to use finite element (FE) analysis in order to better define patellofemoral biomechanics and patellofemoral contact pressures before and after MPFL reconstruction in the setting of patella alta and baja while also analyzing the effects of the MPFL insertion site. We hypothesize that patella alta will increase the magnitude of contact pressures within the patellofemoral joint. Additionally, we hypothesize that changes in the femoral MPFL insertion site will further alter patellofemoral mechanics and contact pressures in knees with concomitant pathology.

METHODS

A previously validated patellofemoral finite element (FE) model[25] was modified to meet the aims of this study. Briefly, the patellofemoral model was generated using surfaces obtained from a magnetic resonance (MR) image of a cadaveric knee specimen. Bones were modeled using three-dimensional rigid elements since bone is significantly stiffer than the soft tissues, which were the structures of interest for the purposes of this study. Similar to previous computational models of patellofemoral biomechanics[26-29], the model did not include the fibula. The cartilage, patellar tendon (PT), and quadriceps tendon (QT) were modeled using 8-noded hexahedral elements. The MPFL and the medial patellotibial ligament (MPTL) were also modeled using hexahedral elements. The meniscus was not included since the study focused on the patellofemoral interaction with the knee fixed in 30° of flexion. The model included 39,515 elements.

The viscoelastic nature of the cartilage was simplified to linear elastic material properties ($E=12$ MPa, $\nu=0.45$) based on previous literature[28-30]. The tendon and ligaments were modeled as hyperelastic with the material properties adapted from stress-strain and force-displacement curves reported previously[31-33]. The reconstructed MPFL assumed material property characteristics of the split anterior tibialis tendon[34]. The anterior tibialis tendon was used to mirror the allograft used in previous corresponding experimental study[35]. The anatomic reconstruction insertion site and dimensions were considered to be the same as the native MPFL ligament model. The model was validated against a corresponding experimental study[35].

Patella Height

A validated finite element patellofemoral knee model was modified to account for four different patella heights. The validated model depicts a 'normal' knee with a Caton-Deschamps Index ratio of 1.036. The patella height was adjusted to study patella alta and baja ratios of 1.4, 1.2, and 0.8 (Figure 1). To create various patellar heights, the patella in the 'normal' model was translated a given

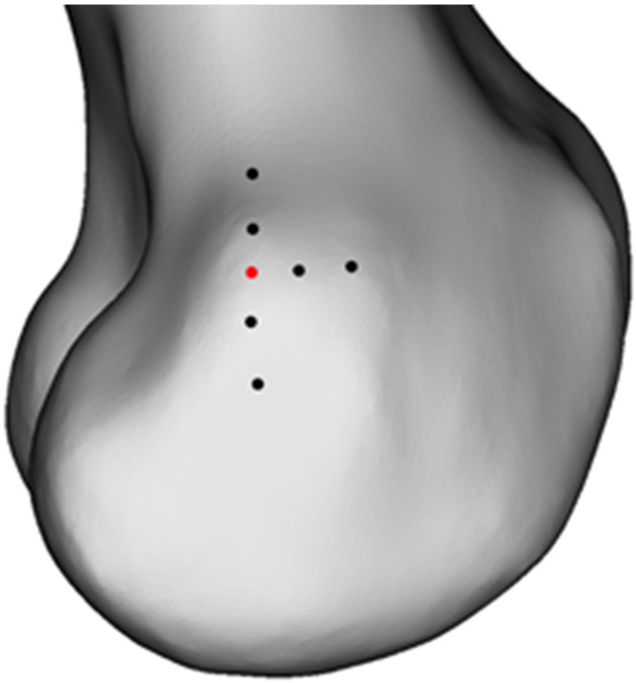


Figure 2. Various femoral insetion sites for the reconstructed medial patellofemoral ligament. The red dot represents the anatomical insertion site. The black dots show locations 5mm and 10mm anterior, proximal, and distal to the anatomic insertion site.

distance to achieve each patella height ratio. The new nodal coordinates for the entire model were output and used as the starting coordinates for the patella alta and patealla baja models.

MPFL Insertion Site

Each patella height model was also modified to study multiple MPFL reconstruction insertion sites. Specifically, the insertion sites were repositioned in increments of 5 mm from the anatomic position on the femur[13,37]. The femoral insertion was modeled at 5 mm and 10 mm anterior, proximal, and distal to the anatomic position with the patellar insertion remaining at the anatomic location, thus creating seven unique insertion scenarios (Figure 2). The different insertion sites were modeled for each patellar height, resulting in 28 unique MPFL reconstruction scenarios and four native MPFL model variants.

Boundary conditions

For each patellar height and MPFL insertion site, the knee was positioned at 30° of flexion with the femur fixed in all directions. The tibia was free to translate and rotate about the anterior-posterior axis (*z*-axis), allowing anterior-posterior translation and varus-valgus rotation. The patella was free to rotate and displace in all directions. The quadriceps was physiologically loaded to 178 N, with separate forces through each individual component of the quadriceps as previously described[38-40]. With the quadriceps loaded, the tibia and femur were fixed in all directions and the patella was displaced laterally 10 mm. The resultant patellar restraining force, contact pressure, and contact area were compared for the different scenarios described above. Analyses were completed using Abaqus/Standard (Version 6.12-1; Dassault Systèmes Simulia, Providence, RI).

RESULTS

A total of 32 scenarios were available for finite element analysis using variable femoral insertion sites for MPFL reconstruction in the setting of normal patellar height, patella baja, and patella alta. Lateral restraining force was smallest for the native MPFL scenario regardless of patellar height. MPFL reconstruction increased the lateral restraining force in all scenarios as compared to the native MPFL, with anterior translation of the femoral MPFL insertion site resulting in the largest lateral restraining forces. Patella alta, with separate scenarios created for Caton-Deschamps ratios of 1.2 and 1.4, consistently decreased the lateral restraining force (Table 1).

Table I. Restraining Force (N)

	Ratio 0.8	Ratio 1.0	Ratio 1.2	Ratio 1.4
Anatomical - Native	78.6	80.0	90.3	70.0
Anatomical - Reconstruction	136.2	148.9	147.6	103.5
Anterior 5mm	145.4	163.1	160.1	113.6
Anterior 10mm	157.6	176.9	166.5	119.7
Distal 5mm	142.8	159.4	154.0	109.7
Distal 10mm	138.3	154.5	156.2	112.2
Proximal 5mm	115.1	125.1	127.5	90.7
Proximal 10mm	102.9	114.1	113.1	79.8

The lateral restraining force (N) of the patella after 10mm lateral displacement for each patella height and corresponding femoral insertion site.

Table II. Contact Force (N)

	Ratio 0.8	Ratio 1.0	Ratio 1.2	Ratio 1.4
Anatomical - Native	183.9	190.6	184.3	118.2
Anatomical - Reconstruction	220.4	226.9	231.2	141.3
Anterior 5mm	224.3	232.4	233.3	147.7
Anterior 10mm	229.5	236.5	226.7	152.4
Distal 5mm	222.8	230.0	232.7	146.1
Distal 10mm	217.1	222.1	226.0	148.9
Proximal 5mm	208.6	215.4	215.3	131.5
Proximal 10mm	201.3	211.7	204.2	124.3

The patellofemoral contact force (N) after 10mm lateral patella displacement for each patella height and corresponding femur insertion site.

Table III. Contact Area (mm^2)

	Ratio 0.8	Ratio 1.0	Ratio 1.2	Ratio 1.4
Anatomical - Native	117.0	67.6	59.9	30.8
Anatomical - Reconstruction	139.3	71.8	54.4	48.0
Anterior 5mm	143.7	86.7	55.5	49.7
Anterior 10mm	143.2	95.2	59.3	49.3
Distal 5mm	137.8	83.8	54.4	48.8
Distal 10mm	140.2	89.1	65.2	45.4
Proximal 5mm	132.6	67.2	63.0	42.9
Proximal 10mm	131.3	60.1	59.4	35.4

The patellofemoral contact area (mm2) after 10mm lateral patella displacement for each patella height and corresponding femur insertion site.

The patellofemoral joint contact force increased following MPFL reconstruction regardless of femoral insertion site as compared to the native MPFL scenario. Contact forces were similar in the setting of normal patella height (Caton-Deschamps 1.0), patella baja (Caton-Deschamps 0.8), and mild patella alta (Caton-Deschamps 1.2); there was a noted decrease in contact forces in the setting of severe patella alta (Caton-Deschamps 1.4) (Table 2).

Patellofemoral contact area was greatest in the setting of patella baja and gradually decreased with interval increases in patellar height (Table 3). The differences in contact area based on patellar height drove subsequent changes in maximum patellofemoral contact pressures, which were decreased in patella baja and increased for patella alta after anatomic MPFL reconstruction. Particularly large maximum patellofemoral contact pressures were noted with anterior and distal femoral insertion sites in the setting of severe patella alta (Caton-Deschamps 1.4) (Figure 3).

DISCUSSION

Patellar stability is maintained by a complex interplay between static soft tissue restraints, dynamic muscle action, and osseous anatomy about the knee. MPFL reconstruction has become a popular and effective method for treatment of MPFL pathology, either from acute injury or chronic insufficiency[18,41,42]. The present study provides biomechanical data using an established finite element knee model following MPFL reconstruction while taking into consideration the effect of patellar heightas well as the effect of the femoral insertion point during MPFL reconstruction. We found that MPFL reconstruction increased the lateral restraining force of the patella as compared to the native knee, with decreasing lateral restraining force noted with increasing patellar height. Additionally, we noted increased maximum patellofemoral contact pressures following MPFL reconstruction in the setting of patella alta, with notably large increases in maximum contact pressures when the femoral insertion site was placed anterior or distal to the anatomic insertion. Several of these findings warrant further discussion.

The femoral insertion of the MPFL and its subsequent effect on patellofemoral biomechanics has been studied extensively throughout the literature[12,18,22]. Stephen et

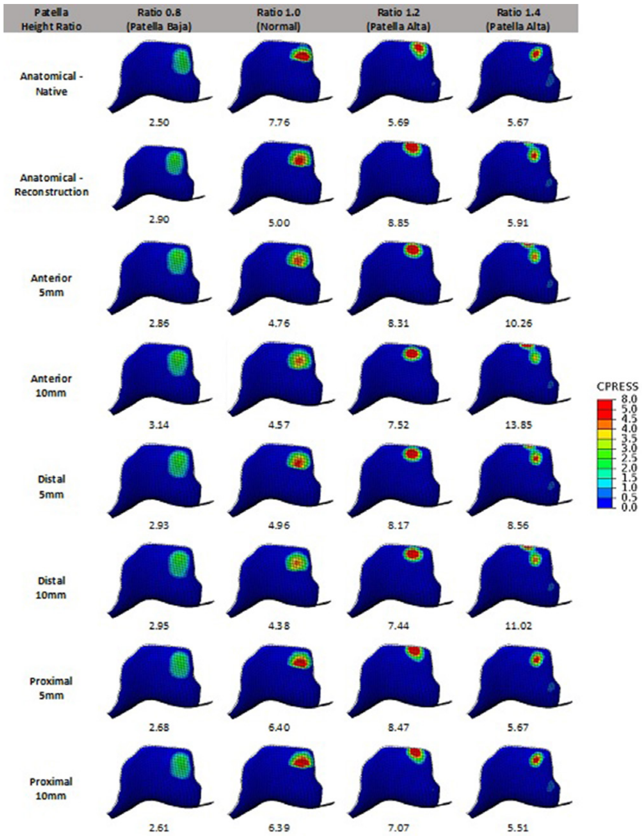


Figure 3. The contact pressure and area for each loading scenario after 10mm lateral patella displacement. The value below each image is the maximum contact pressure (MPa).

al.[23] found that MPFL femoral tunnel placement that was proximal or distal to the anatomic insertion point significantly increased contact pressures within the patellofemoral joint. The present study found that the femoral insertion site studied in isolation had variable effects on maximum patellofemoral contact pressures, but in the setting of patella alta (Caton-Deschamps 1.4), misplaced femoral tunnels dramatically increased maximum contact pressures within the patellofemoral joint. We find this particularly important given the general difficulty in consistently identifying the anatomic femoral insertion of the MPFL[18,43], as well as the high frequency of patella alta in this patient population1. Clinically, both femoral tunnel malpositioning and untreated patella alta have been identified as potential causes of failure following MPFL reconstruction[15,24]. Our findings echo these clinical concerns, as femoral tunnel malpositioning in the setting of patella alta increases maximum contact pressures within the patellofemoral joint.

Even prior to concerns regarding MPFL femoral tunnel positioning, Dejour and colleagues identified patella alta as one of the contributing factors to patellar instability, suggesting tibial tubercle distalization in patients with patellar instability that exhibited this radiographic finding1. Since that time, several studies have investigated the biomechanical effects of patellar height[8-10]. Luyckx et al.[8] investigated the influence of patellar height on patellofemoral joint biomechanics and found that patella alta decreased contact area. Similarly, we found that patella alta caused a decrease in contact area. Although this study does not compare directly to the previous studies that looked at the patellofemoral biomechanics throughout flexion[8-10], the current study allowed us to determine the role patella height had on lateral restraining force. We found that patella alta decreased lateral restraining force even after MPFL reconstruction, suggesting that unaddressed patella alta may biomechanically serve as risk factor for recurrent episodic patellar dislocation. Our findings provide a biomechanical basis for addressing patella alta at the time of surgery in this patient population.

Inherent limitations of finite element models, including boundary conditions and simplified material properties, exist for the present study. In this model, the MPFL and medial patellotibial ligament were modeled based on anatomic data reported in the literature[44-47] and were not specimen-specific. Although defining these ligaments from medical images would be ideal, it presents a challenge due to the thin anatomy and complex nature of the attachment site. With advances in medical imaging, future models may be able to define all soft tissues on a specimen-/subject- specific basis. Additionally, this model did not incorporate the meniscus since static loading options were considered. To study various loading conditions and angles of flexion, the meniscus should be included. Also, the model boundary conditions do not capture in vivo scenarios; however, the biomechanics do mimic in vitro loading conditions. The model boundary constraints should be considered when applying these predicted trends to clinical situations. Lastly, this study was limited to one angle of flexion, 30 degrees, and no graft pretension. Future work should continue to investigate various tibiofemoral flexion angles and different MPFL graft pretensions to gain a better understanding of patellar height and MPFL insertion location on the patellofemoral biomechanics.

In conclusion, treatment of patellar instability requires recognition and understanding of the multiple factors that affect patellar stability, often leading to an algorithmic-based treatment approach. The present study provides the first data on patellofemoral biomechanics following MPFL reconstruction in the setting of variable patellar height and femoral insertion sites. We found that persistent patella alta after MPFL reconstruction decreases lateral restraining force, potentially providing a biomechanical explanation for clinical failures of isolated MPFL reconstruction in the setting of patella alta. Additionally, we found that patella alta increased maximum patellofemoral contact pressures, particularly with anterior and distal femoral tunnel malpositioning. We feel these findings are important, as patellar instability is often caused by a constellation of pathologies, and failure to address all of these factors at the time of surgery may result in treatment failure.

REFERENCES

1. **Dejour H, Walch G, Nove-Josserand L, Guier CH.** Factors of patellar instability: an anatomic radiographic study. Knee Surg Sports Traumatol Arthrosc. 1994;2:19-26.
2. **Lancourt JE, Cristini JA.** Patella Alta and Patella Infera: Their Etiological Role in Patellar Dislocation, Chondromalacia, and Apophysitis of the Tibial Tubercle. J Bone Joint Surg Am. 1975;57A:1112-1115.
3. **Greiwe RM, Saifi C, Ahmad CS, Gardner TR.** Anatomy and Biomechanics of Patellar Instability. Oper Tech Sports Med. 2010;18:62-67.
4. **Berg EE, Mason SL, Lucas MJ.** Patellar height ratios. Am J Sports Med. 1996;24:218-221.
5. **Blackburne JS, Peel TE.** A new method of measuring patellar height. J Bone Joint Surg Br. 1977;59:241-242.
6. **Caton J, Deschamps G, Chambat P, Lerat J, Dejour H.** Patella infera. Apropos of 128 cases. Rev Chir Orthop Reparatrice Appar Mot. 1982;68:317-325.
7. **Insall J, Salvati E.** Patella position in the normal knee joint. Radiology. 1971;101:101-104.
8. **Luyckx T, Didden K, Vandenneucker H, Labey L, Innocenti B, Bellemans J.** Is there a biomechanical explanation for anterior knee pain in patients with patella alta? Influence of patellar height on patellofemoral contact force, contact area and contact pressure. J Bone Joint Surg Br. 2009;91:344-350.
9. **Singerman R, Davy DT, Goldberg VM.** Effects of patella alta and patella infera on patellofemoral contact forces. J Biomech. 1994;27:1059-1065.
10. **Ward SR, Powers CM.** The influence of patella alta on patellofemoral joint stress during normal and fast walking. Clin Biomech (Bristol, Avon). 2004;19:1040-1047.
11. **Desio SM, Burks RT, Bachus KN.** Soft tissue restraints to lateral patellar translation in the human knee. Am J Sports Med. 1998;26:59-65.
12. **Melegari TM, Parks BG, Matthews LS.** Patellofemoral contact area and pressure after medial patellofemoral ligament reconstruction. Am J Sports Med. 2008;36:747-752.
13. **Schöttle PB, Fucentese SF, Romero J.** Clinical and radiological outcome of medial patellofemoral ligament reconstruction with a semitendinosus autograft for patella instability. Knee Surgery, Sports Traumatology, Arthroscopy. 2005;13:516-521.
14. **Bicos J, Fulkerson JP, Amis A.** Current Concepts Review : The Medial Patellofemoral Ligament. Am J Sports Med. 2007;35:484-492.
15. **Bollier M, Fulkerson J, Cosgarea A, Tanaka M.** Technical Failure of Medial Patellofemoral Ligament Reconstruction. Arthroscopy. 2011;27:1153-1159.
16. **Amis AA, Firer P, Mountney J, Senavongse W, Thomas NP.** Anatomy and biomechanics of the medial patellofemoral ligament. Knee. 2003;10:215-220.
17. **Farr J, Schepsis AA.** Reconstruction of the medial patellofemoral ligament for recurrent patellar instability. J Knee Surg. 2006;19:307-316.
18. **Servien E, Fritsch B, Lustig S, et al.** In vivo positioning analysis of medial patellofemoral ligament reconstruction. Am J Sports Med. 2011;39:134-139.
19. **Fithian DC, Paxton EW, Stone ML, et al.** Epidemiology and natural history of acute patellar dislocation. Am J Sports Med. 2004;32:1114-1121.
20. **Hawkins RJ, Bell RH, Anisette G.** Acute patellar dislocations. Am J Sports Med. 1986;14:117-120.
21. **Beck P, Brown NAT, Greis PE, Burks RT.** Patellofemoral contact pressures and lateral patellar translation after medial patellofemoral ligament reconstruction. Am J Sports Med. 2007;35:1557-1563.
22. **Elias JJ, Cosgarea AJ.** Technical errors during medial patellofemoral ligament reconstruction could overload medial patellofemoral cartilage. Am J Sports Med. 2006;34:1478-1485.
23. **Stephen JM, Kaider D, Lumpaopong P, Deehan DJ, Amis AA.** The effect of femoral tunnel position and graft tension on patellar contact mechanics and kinematics after medial patellofemoral ligament reconstruction. Am J Sports Med. 2014;42:364-372.
24. **Thaunat M, Erasmus PJ.** Recurrent patellar dislocation after medial patellofemoral ligament reconstruction. Knee Surg Sports Traumatol Arthrosc. 2008;16:40-43.
25. **DeVries Watson NA, Duchman KR, Bollier MJ, Grosland NM.** A Finite Element Analysis of Medial Patellofemoral Ligament Reconstruction. Iowa Orthop J. 2015;35:13-19.
26. **Besier TF, Gold GE, Delp SL, Fredericson M, Beaupré GS.** The influence of femoral internal and external rotation on cartilage stresses within the patellofemoral joint. J Orthop Res 2008;26:1627-1635.
27. **Besier TF, Draper C, Pal S, et al.** Imaging and musculoskeletal modeling to investigate the mechanical etiology of patellofemoral pain. In: Sanchis-Alfonso V, ed. Anterior Knee Pain and Patellar Instability: Springer-Verlag; 2011:269-284.
28. **Fitzpatrick CK, Baldwin MA, Rullkoetter PJ.** Computationally Efficient Finite Element Evaluation of Natural Patellofemoral Mechanics. J Biomech Eng. 2010;132.

29. **Shirazi-Adl A, Mesfar W.** Effect of tibial tubercle elevation on biomechanics of the entire knee joint under muscle loads. Clin Biomec (Briston, Avon). 2007;22:344-351.
30. **Mesfar W, Shirazi-Adl A.** Biomechanics of changes in ACL and PCL material properties or prestrains in flexion under muscle force-implications in ligament reconstruction. Comput Methods Biomech Biomed Engin. 2006;9:201-209.
31. **Atkinson P, Atkinson T, Huang C, Doane R.** A comparison of the mechanical and dimensional properties of the human medial and lateral patellofemoral ligaments. Orthopaedic Research Society; 2000 March 12-15, 2000; Orlando, Florida.
32. **Mesfar W, Shirazi-Adl A.** Biomechanics of the knee joint in flexion under various quadriceps forces. Knee. 2005;12:424-434.
33. **Stäubli HU, Schatzmann L, Brunner P, Rincón L, Nolte LP.** Mechanical tensile properties of the quadriceps tendon and patellar ligament in young adults. Am J Sports Med. 1999;27:27-34.
34. **Donahue TLH, Howell SM, Hull ML, Gregersen C.** A biomechanical evaluation of anterior and posterior tibialis tendons as suitable single-loop anterior cruciate ligament grafts. Arthroscopy. 2002;18:589-597.
35. **Duchman KR, A. DeVries NA, McCarthy MA, Kuiper JJ, Grosland NM, Bollier MJ.** Biomechanical Evaluation of Medial Patellofemoral Ligament Reconstruction. Iowa Orthop J 2013;33:64-69.
36. **Caton J, Deschamps G, Chambat P, Lerat JL, Dejour H.** Les rotules basses: A propos de 128 observations. Rev Chir Orthop Reparatrice Appar Mot. 1982;68:317-325.
37. **Smirk C, Morris H.** The anatomy and reconstruction of the medial patellofemoral ligament. Knee. 2003;10:221-227.
38. **Amis AA, Senavongse W, Bull AMJ.** Patellofemoral kinematics during knee flexion\extension: An in vitro study. J Orthop Res. 2006;24:2201-2211.
39. **Farahmand F, Tahmasbi MN, Amis AA.** Lateral force-displacement behaviour of the human patella and its variation with knee flexion–a biomechanical study in vitro. J Biomech. 1998;31:1147-1152.
40. **Senavongse W, Amis AA.** The effects of articular, retinacular, or muscular deficiencies on patellofemoral joint stability: a biomechanical study in vitro. J Bone Joint Surg Br. 2005;87:577-582.
41. **Enderlein D, Nielsen T, Christiansen SE, Faunø P, Lind M.** Clinical outcome after reconstruction of the medial patellofemoral ligament in patients with recurrent patella instability. Knee Surg Sports Traumatol Arthrosc. 2014;22:2458-2464.
42. **Howells N, Barnett A, Ahearn N, Ansari A, Eldridge J.** Medial patellofemoral ligament reconstruction A prospective outcome assessment of a large single centre series. J Bone Joint Surg Br. 2012;94:1202-1208.
43. **McCarthy M, Ridley TJ, Bollier M, Wolf B, Albright J, Amendola A.** Femoral Tunnel Placement in Medial Patellofemoral Ligament Reconstruction. Iowa Orthop J. 2013;33:58-63.
44. **Baldwin JL.** The anatomy of the medial patellofemoral ligament. Am J Sports Med. 2009;37:2355-2361.
45. **LaPrade RF, Engebretsen AH, Ly TV, Johansen S, Wentorf FA, Engebretsen L.** The anatomy of the medial part of the knee. J Bone Joint Surg Am. 2007;89:2000-2010.
46. **Panagiotopoulos E, Strzelczyk P, Herrmann M, Scuderi G.** Cadaveric study on static medial patellar stabilizers: the dynamizing role of the vastus medialis obliquus on medial patellofemoral ligament. Knee Surg Sports Traumatol Arthrosc. 2006;14:7-12.
47. **Philippot R, Chouteau J, Wegrzyn J, Testa R, Fessy MH, Moyen B.** Medial patellofemoral ligament anatomy: implications for its surgical reconstruction. Knee Surg Sports Traumatol Arthrosc. 2009;17:475-479.

TOTAL SHOULDER ARTHROPLASTY: IS LESS TIME IN THE HOSPITAL BETTER?

Kyle R. Duchman MD,[1] Chris A. Anthony MD,[1] Robert W. Westermann MD,[1]
Andrew J. Pugely MD,[1] Yubo Gao PhD,[1] Carolyn M. Hettrich MD, MPH[1]

ABSTRACT

Background: The incidence of total shoulder arthroplasty (TSA) has increased significantly over the last decade. Short-stay protocols for other high-volume procedures have been shown to be safe and effective but have yet to be fully explored for TSA. Our purpose in comparing short-stay and inpatient TSA was to determine: (1) patient demographics and comorbidities, (2) 30-day morbidity, mortality, and readmissions using a matched analysis, and (3) independent predictors of 30-day complications.

Methods: The American College of Surgeons National Surgical Quality Improvement (ACS NSQIP) database was queried and all patients undergoing elective, primary TSA between 2006 and 2013 were identified. Patients were categorized as short-stay or inpatient based on day of discharge. Propensity score matching was used to adjust for selection bias. Univariate and multivariate statistical analysis was used to compare 30-day morbidity and mortality between the two cohorts.

Results: Overall, 4,619 cases were available, with inpatient admission occurring in 65.7% of patients. Prior to propensity score matching, short-stay patients were significantly younger, more frequently male, with fewer comorbid conditions. After matching, inpatient admission was associated with increased rates of urinary tract infection (1.1% vs. 0.1%; $p = 0.001$), blood transfusion (5.3% vs. 0.8%; $p < 0.001$), and total complications (4.7% vs. 1.8%; $p < 0.001$). Multivariate analysis identified inpatient admission as an independent risk factor for 30-day complication following TSA.

Conclusions: Short-stay TSA is a safe option for the appropriately selected patient. Inpatient admission was an independent risk factor for complication following TSA.

Level of Evidence: III

INTRODUCTION

The general success of total shoulder arthroplasty (TSA)[1-3], along with more widespread adoption reverse total shoulder arthroplasty, has resulted in a significant increase in TSA utilization in the United States over the last decade[4,5]. In order to meet future demands, maximizing the quality and efficiency of care for total shoulder arthroplasty patients is essential. While outpatient or short-stay protocols have been shown to be safe and effective for several high-volume orthopaedic procedures, including lower extremity arthroplasty[6-9], TSA continues to be performed primarily as an inpatient procedure, with the average length of stay typically exceeding two days[10].

Historically, TSA required an inpatient admission to achieve adequate pain control prior to hospital discharge. However, with the expansion of regional anesthetic techniques, outpatient and short-stay discharge following TSA has become possible[11-13]. Total shoulder arthroplasty has been shown to have lower postoperative complications as compared to total hip and knee arthroplasty[14,15]. Nonetheless, outpatient and short-stay protocols for TSA have yet to become as widespread as those for total hip and knee arthroplasty where these protocols have resulted in decreased length of stay, hospital costs, complications, and readmissions postoperatively[16-18]. Given the anticipated future demand for TSA, it will be important to determine the safety and efficacy of similar programs for TSA moving forward.

The purpose of the present study is to compare 30-day morbidity, mortality, and readmission rates among patients who underwent primary, elective TSA as an outpatient or short-stay procedure versus those who

[1]Department of Orthopaedics & Rehabilitation,
University of Iowa Hospitals and Clinics
Iowa City, Iowa

Corresponding Author:
Chris A. Anthony, MD
Department of Orthopaedic Surgery and Rehabilitation
University of Iowa Hospitals and Clinics
200 Hawkins Drive, 01008 JPP, Iowa City, IA 52242, USA
Tel: (319)356-1616
Fax: (319)353-6754
e-mail: chris-anthony@uiowa.edu

Each author certifies that he or she has no commercial associations (eg, consultancies, stock ownership, equity interest, patent/licensing arrangements, etc) that might pose a conflict of interest in connection with the submitted article.

Each author certifies that his or her institution approved or waived approval for the human protocol for this investigation and that all investigations were conducted in conformity with ethical principles of research.

required a formal inpatient admission postoperatively. We utilized a large, prospectively maintained, multi-center national database to better explore the safety of outpatient or short-stay disposition following TSA. In comparing short-stay and inpatient admissions following TSA, we sought to determine: (1) patient demographics and comorbidities, (2) 30-day morbidity, mortality, and readmissions using a matched analysis, and (3) independent predictors of 30-day complications.

METHODS

This study received an exemption from the institutional review board at the University of Iowa and was internally funded.

The American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP) database collects data from nearly 500 hospitals across the United States, including both academic and private institutions, with collection methods previously described[19,20]. In brief, trained clinical reviewers, termed surgical clinical reviewers, collect patient demographic, laboratory, operative, and 30-day morbidity and mortality data using strict definitions regardless of admission status. Frequent internal auditing mechanisms, including thorough chart review, direct surgeon communication, and telephone communication, maintains high data fidelity with overall disagreement rates reported at <1.8%[21]. The database has recently been utilized extensively for orthopaedic research[9,10,14,22,23].

We queried the ACS NSQIP database for all TSA procedures performed between 2006 and 2013 using the Current Procedural Terminology (CPT) code 23472. Cases involving emergent surgery, preoperative wound infection, preoperative sepsis, and contaminated wounds were excluded. Using these initial criteria, 4,619 elective, primary TSA cases were identified. Due to CPT coding limitations in the early period of the study, reverse shoulder arthroplasty could not be distinguished from traditional TSA. Preoperative data provided by the ACS NSQIP database are broadly categorized into patient demographic characteristics, preoperative comorbidities, laboratory values, and operative variables[20]. Outcome data provided by the ACS NSQIP includes postoperative 30-day morbidity and mortality data. Individual morbidity and mortality data includes wound infections, categorized as deep, superficial, and organ space infection, based on modified Centers for Disease Control criteria[24], wound dehiscence, pneumonia, unplanned intubation, deep venous thrombosis, pulmonary embolism, renal insufficiency, acute renal failure, urinary tract infection, stroke, coma (exceeding twenty-four hours), peripheral nerve injury, cardiac arrest, myocardial infarction, blood transfusion (administration of blood-cell products up to seventy-two hours postoperatively), graft/implant failure, sepsis, septic shock, unplanned readmission, and mortality. Individual outcome data was available for all included years with the exception of unplanned readmission, which was only available for the included years 2012 and 2013. The composite category, “total complications,” included all individual complications listed with the exception of unplanned readmissions given its limited timeframe in the study. While a single patient could potentially suffer multiple individual complications within the composite category, only a single complication was considered for the total complications calculation.

For the purpose of this study, patients were stratified into two groups based on day of hospital discharge. Those discharged on postoperative day 0 or 1 were defined as short-stay, while those discharged on postoperative day 2 or greater were defined as inpatients. Differences in patient demographic characteristics, preoperative comorbidities, laboratory values, and operative variables were compared between short-stay patients and inpatients. In order to account for selection bias between short-stay patients and inpatients, propensity score matching was implemented as previously described[23,25]. This method allowed for creation of a propensity score based on demographic characteristics and comorbidities with subsequent 1:1 matching of each patient within the short-stay group to a patient with the most similar propensity score within the inpatient group. Using this method, it was possible to perform an adjusted comparison of postoperative complications for the two cohorts.

After unadjusted and adjusted comparison of preoperative variables, complication rates for each individual and composite outcome were calculated and compared between the two cohorts. Multivariate models were created to account for confounding and mediating preoperative demographic characteristics, comorbidities, and operative variables. Any variable with <80% chart completion was excluded from the multivariate analysis, and only demographic characteristics, preoperative comorbidities, and operative variables with univariate p values <0.1 were included in the final multivariate model. The variables ultimately included in the multivariate model were age, history of chronic obstructive pulmonary disease (COPD), functional status, American Society of Anesthesiologists (ASA) classification, and short-stay versus inpatient admission. The dependent outcome for the multivariate logistic regression model was the composite category total complications (yes or no). The multivariate model required complete data for each included variable, and a total of 42 patients were missing either ASA classification or functional status data, allowing for 99.1% (4577) of patients to be included in the final model.

Standard statistical tests, including chi-square for categorical variables and Student's t-test for continuous variables, were used for univariate analysis. All statistical analyses were performed using SAS software (version 9.3; SAS Institute, Cary, NC) and performed by a clinical statistician. The level of significance for all portions of the analysis was set at $p < 0.05$.

RESULTS

Overall, 4,619 patients undergoing primary, elective TSA were identified between 2006 and 2013. Of these, 34.3% (1584) of patients were categorized as short-stay and 65.7% (3035) as inpatients. The short-stay patient cohort was significantly younger (67.6 vs. 71.0 years; $p < 0.001$), less frequently female (46.5% vs. 62.1%; $p < 0.001$), more frequently white (89.5% vs. 84.2%; $p < 0.001$), with a lower incidence of diabetes (13.0% vs. 18.6%; $p < 0.001$), COPD (3.0% vs. 7.1%; $p < 0.001$), coronary artery disease (0.1% vs. 0.6%; $p = 0.030$), dialysis (0.1% vs. 0.6%; $p = 0.006$), and more frequently ASA classification 3 or 4 (40.2% vs. 55.4%; $p < 0.001$) compared to the inpatient TSA cohort (Table 1).

After propensity score matching, both cohorts contained 1,584 patients, and only race, incidence of diabetes, and incidence of COPD remained significantly different between the two cohorts. Total complications following TSA for the unadjusted cohorts were 5.0% for inpatient admission and 1.8% for short-stay ($p < 0.001$) (Table 2). The incidence of pneumonia (0.72% vs. 0.19%, $p = 0.019$), urinary tract infection (1.4% vs. 0.13%; $p < 0.001$), and postoperative blood transfusion (6.7% vs. 0.8%; $p < 0.001$) were all increased in the inpatient cohort as well. The 30-day mortality was 0% for short-stay patients compared with 0.3% for inpatients. After propensity score matching, total complications (4.7% vs. 1.8%; $p < 0.001$), the incidence of urinary tract infection (1.1% vs. 0.13%; $p < 0.001$), and postoperative blood transfusion (5.3% vs. 0.8%; $p < 0.001$) remained increased in the inpatient cohort. There was no difference in unplanned readmission rates between the two cohorts for both the unadjusted and adjusted analysis.

In order to determine significant predictors of total complications, multivariate logistic regression was utilized. Out of all included variables, only inpatient admission (Odds Ratio [OR] = 2.49; 95% Confidence Interval [CI] 1.653-3.741) was identified as a significant independent risk factor for complication following elective, primary TSA (Table 3).

DISCUSSION

While several orthopaedic procedures have been shown to be safe and effective when performed as outpatient or short-stay procedures[7-9,17,18], TSA remains a primarily inpatient procedure. The current study identified an unadjusted 1.8% incidence of complications for short-stay TSA patients as compared with a 5.0% complication rate for inpatients. Significant differences in patient demographic characteristics and comorbidities were noted between the two cohorts, yet complications remained significantly increased following inpatient admission after implementation of an established propensity score matching algorithm. Additionally, we found that inpatient hospital admission was the only independent risk factor for complication during the 30-day postoperative period using a large, national database. Several of these findings warrant further discussion.

The present study does have several limitations. The ACS NSQIP only collects data for 30-day morbidity, mortality, and readmissions, and as such, fails to capture complications that occur beyond that time point. Additionally, 30-day readmission data, an important healthcare quality metric, was only available for 57.0% of the cohort as this data has only recently been collected by ACS NSQIP. While the ACS NSQIP obtains data from a combination of academic and private hospitals, it has been suggested that participating institutions may be biased toward larger hospitals with an interest in quality improvement[26], which may affect perioperative outcomes following TSA[27]. The ACS NSQIP does not provide data on orthopaedic-specific outcomes of interest nor does it provide orthopaedic-specific definitions for perioperative infection, specifically periprosthetic joint infection, which limits reporting of orthopaedic outcomes. We elected to categorize patients into short-stay or inpatient admission based on previously defined protocols for short-stay or rapid recovery total hip and knee arthroplasty[8,18,28] while also considering the mean 2.2 day length of stay for TSA that has been previously reported[10]. Despite these limitations, we believe that the large sample size, accurate data recording, and overall generalizability of the ACS NSQIP database outweigh the limitations outlined above.

The first aim of the present study was to compare demographic characteristics and preoperative comorbidities between short-stay patients and patients requiring inpatient admission following TSA. Previous studies have identified risk factors for increased length of stay following TSA including increased patient age, female sex, insurance status, and medical comorbidities, specifically renal failure and congestive heart failure[10,29,30]. Similarly, we identified differences in the demographic characteristics and preoperative comorbidities between short-stay and inpatient TSA patients. Short-stay patients in the present study were significantly younger with a mean age of 67.6 years, less frequently female, and less likely to have major comorbidities including diabetes, COPD, coronary artery disease, or ASA classification of

Table I. Demographic Characteristics, Preoperative Comorbidities, and Preoperative Laboratory Values

			p Value	
	Inpatient (n = 3035)	**Short-Stay (n = 1584)**	**Unadjusted**	**Propensity Score-Adjusted**
Demographic Characteristics				
Age*	71.0 ± 9.9	67.6 ± 10.46	<0.001	0.114
Female sex (%)	62.1	46.5	<0.001	0.829
Race/ethnicity (%)			<0.001	<0.001
White	84.2	89.5		
Black	4.3	2.7		
Other	7.9	11.5		
Pre-operative health and comorbidities				
Dependent functional status (%)	3.6	3.2	0.464	0.119
BMI (kg/m2)*	30.7 ± 6.9	30.6 ± 6.1	0.503	0.942
Recent weight loss (%)	0.1	0.1	1.00	1.00
Diabetes mellitus (%)	18.6	13.0	<0.001	0.006
Smoking (%)	8.3	10.7	0.009	0.289
Alcohol (%)	2.0	3.1	0.087	0.158
Chronic obstructive pulmonary disease (%)	7.1	3.0	<0.001	0.002
Coronary artery disease (%)	0.6	0.1	0.030	0.288
Peripheral vascular disease (%)	0.5	0.5	1.00	0.209
History of transient ischemic attack (%)	4.1	3.1	0.263	0.660
Dialysis (%)	0.6	0.1	0.006	0.070
Steroids (%)	5.0	4.4	0.374	1.00
Bleeding disorder (%)	3.4	2.3	0.053	0.812
Preoperative blood transfusion (%)	0.1	0.1	1.00	1.00
Radiation therapy (%)	0	0	1.00	1.00
Chemotherapy (%)	0.3	0	0.306	1.00
Other recent operation (%)	0.5	0.5	1.00	1.00
Pre-operative laboratory values				
WBC* (10^3 cells/µL)	7.2 ± 2.3	7.0 ± 2.7	0.100	0.625
Hematocrit* (%)	39.9 ± 4.5	40.8 ± 4.1	<0.001	0.247
Platelets* (per/µL)	243.5 ± 71.1	239.5 ± 66.7	0.080	0.547
Creatinine* (mg/dL)	1.0 ± 0.6	0.94 ± 0.5	0.080	0.526
Serum Albumin* (g/dL)	4.0 ± 0.5	4.1 ± 0.4	0.001	0.137
International normalized ratio*	1.1 ± 0.4	1.0 ± 0.2	0.034	0.127
Operative Variables				
ASA class (%)			<0.001	0.122
1 (no disturbance)	1.5	3.2		
2 (mild disturbance)	43.2	56.6		
3 (severe disturbance)	52.3	38.9		
4 (life-threatening disturbance)	3.1	1.3		

*Values are given as the mean ± standard deviation.

Table II. Unadjusted and Adjusted 30-day complications between Short-Stay and Inpatient TSA

	Inpatient		Short-Stay	p Value	
	Unadjusted	Matched		Unadjusted	Matched
Complications (%)	n = 3035	n =1588	n = 1584		
Total Complications	5.0	4.7	1.8	<0.001	<0.001
Superficial Wound Infection	0.3	0.3	0.1	0.178	0.218
Deep Wound Infection	0.1	0.2	0.25	0.241	1.00
Organ Space Infection	0.1	0.2	0	0.306	0.250
Wound Dehiscence	0.1	0.3	0.1	0.666	0.375
Pneumonia	0.7	0.7	0.2	0.019	0.057
Urinary Tract Infection	1.4	1.1	0.1	<0.001	<0.001
Sepsis	0.4	0.3	0.1	0.069	0.218
Septic Shock	0.1	0	0	0.556	1.00
Deep Venous Thrombosis	0.3	0.2	0.5	0.267	0.226
Pulmonary Embolism	0.3	0.4	0.4	0.787	1.00
Postoperative Transfusion	6.7	5.3	0.8	<0.001	<0.001
Renal Insufficiency	0.1	0.1	0.1	1.00	1.00
Acute Renal Failure	0	0	0	1.00	1.00
Stroke	0.2	0.1	0	0.172	0.500
Coma >24 hours	0	0	0	1.00	1.00
Peripheral Nerve Injury	0.3	0.3	0.1	0.178	0.218
Cardiac Arrest	0.10	0	0	0.556	1.00
Myocardial Infarction	0.3	0.3	0.1	0.351	0.453
Unplanned Intubation	0.2	0.1	0	0.172	1.00
Graft/Implant Failure	0	0.1	0	1.00	1.00
Unplanned Readmission*	2.8	2.4	2.3	0.401	0.827
Reoperation	1.0	1.1	0.8	0.496	0.271
Mortality	0.3	0.1	0	0.057	1.00

*Data available for 2012-2013 only

3 or 4. Recognizing the differences in these two cohorts, while also noting the low complication rate for short-stay patients with the demographic and health characteristics of the patients in this study, will be important for clinicians and hospitals looking to implement safe and effective short-stay protocols for TSA patients.

The second aim of this study was to examine perioperative morbidity and mortality following TSA while comparing short-stay and inpatient cohorts using propensity score matching. Previous studies have reported 30-day composite complication rates between 2 and 4%[15,31], with a high degree of variability in reporting of postoperative blood transfusion as a complication[32-34]. Using the same database as the present study, Anthony et al. reported a composite complication rate of 8%, with postoperative blood transfusion identified as the most common individual complication following TSA at a rate of 4.3%[14]. In the present study, which extended analysis to 2013, the unadjusted total complication rate for inpatients was 5.0% compared with 1.8% for short-stay patients. This statistically significant difference in total complications remained even after propensity score matching to account for the difference in preoperative demographic characteristics and comorbidities between the two cohorts. Additionally, there was no difference in unplanned readmission between the two cohorts in both the unadjusted and adjusted analysis. While previous studies investigating outpatient and short-stay elective surgery in the shoulder and knee have noted increased complications with inpatient admission[8,35], the present study is the first to specifically comment on this finding in TSA patients.

Table III. Multivariate Analysis of Demographic, Comorbidities, and Operativ Variables Associated with Thirty-Day Complications Following TSA

	p Value	Adjusted Odds Ratio*
Demographic Characteristics		
Age (years)		
<50	**Ref**	**Ref**
50-59	0.278	0.582 (0.218-1.550)
60-69	0.202	0.563 (0.232-1.362)
70-79	0.638	0.813 (0.343-1.927)
>80	0.726	1.170 (0.486-2.816)
Preoperative health and comorbidities		
COPD		
No	**Ref**	**Ref**
Yes	0.293	1.338 (0.778-2.299)
Functional Status		
Independent	**Ref**	**Ref**
Dependent	0.153	1.595 (0.840-3.029)
Operative Variables		
ASA Class		
1 & 2	**Ref**	**Ref**
3 & 4	0.198	1.233 (0.896-1.697)
Discharge Status		
Short-Stay	**Ref**	**Ref**
Inpatient	<0.001	2.486 (1.653-3.741)

*Odds ratio and associated 95% Confidence Intervals.

Lastly, we aimed to identify independent risk factors for complications following TSA using a multivariate logistic regression model. Previous studies have identified increasing patient age, cardiac conditions, elevated ASA class, increasing number of comorbid conditions, and prolonged operative time as independent risk factors for complication following TSA[14,31,36,37]. In the present study, only postoperative hospital admission was identified as an independent risk factor for complications, with over twice the risk of complication in this cohort as compared to short-stay patients. Given these findings, optimizing short-stay or fast-track protocols, as has been done for total hip and knee arthroplasty[6,18], may help accommodate the anticipated increase in TSA utilization. Most importantly, the findings from the present study suggest that short-stay TSA, as defined by this study, is safe, with infrequent short-term morbidity reported in appropriately selected TSA candidates.

In conclusion, the present study identified short-stay TSA as a safe alternative to traditional inpatient admission when considering short-term morbidity. While careful patient selection and improved institutional protocols specific to reducing TSA complications and improving postoperative pain control need to be optimized, the current study provides data to support implementation of these protocols at hospitals with appropriate resources and experience. In addition to the low postoperative morbidity associated with short-stay TSA reported in this study, expedited discharge may help accommodate the predicted increase in TSA utilization.

REFERENCES

1. **Boorman, R.S., et al.**, The effect of total shoulder arthroplasty on self-assessed health status is comparable to that of total hip arthroplasty and coronary artery bypassgrafting. Journal of shoulder and elbow surgery, 2003. 12(2): p. 158-163.
2. **Carter, M.J., et al.**, Impact of total shoulder arthroplasty on generic and shoulder-specific health-related quality-of-life measures. The Journal of Bone & Joint Surgery, 2012. 94(17): p. e127.

3. **Deshmukh, A.V., et al.**, Total shoulder arthroplasty: long-term survivorship, functional outcome, and quality of life. Journal of shoulder and elbow surgery, 2005. 14(5): p. 471-479.
4. **Kim, S.H., et al.**, Increasing incidence of shoulder arthroplasty in the United States. The Journal of Bone & Joint Surgery, 2011. 93(24): p. 2249-2254.
5. **Padegimas, E.M., et al.**, Future Patient Demand for Shoulder Arthroplasty by Younger Patients: National Projections. Clinical Orthopaedics and Related Research®, 2015. 473(6): p. 1860-1867.
6. **Gondusky, J.S., et al.**, Day of surgery discharge after unicompartmental knee arthroplasty: an effective perioperative pathway. The Journal of arthroplasty, 2014. 29(3): p. 516-519.
7. **Iyengar, J.J., et al.**, Current trends in rotator cuff repair: surgical technique, setting, and cost. Arthroscopy: The Journal of Arthroscopic & Related Surgery, 2014. 30(3): p. 284-288.
8. **Lovald, S.T., et al.**, Complications, mortality, and costs for outpatient and short-stay total knee arthroplasty patients in comparison to standard-stay patients. The Journal of arthroplasty, 2014. 29(3): p. 510-515.
9. **Martin, C.T., et al.**, Thirty-Day Morbidity After Single-Level Anterior Cervical Discectomy and Fusion: Identification of Risk Factors and Emphasis on the Safety of Outpatient Procedures. The Journal of Bone & Joint Surgery, 2014. 96(15): p. 1288-1294.
10. **Dunn, J.C., et al.**, Predictors of length of stay after elective total shoulder arthroplasty in the United States. Journal of Shoulder and Elbow Surgery, 2015. 24(5): p. 754-759.
11. **Gallay, S., et al.**, Development of a regional model of care for ambulatory total shoulder arthroplasty. Clinical orthopaedics and related research, 2008. 466(3): p. 563-572.
12. **Ilfeld, B.M., et al.**, Ambulatory continuous interscalene nerve blocks decrease the time to discharge readiness after total shoulder arthroplasty: a randomized, triple-masked, placebo-controlled study. ANESTHESIOLOGY-PHILADELPHIA THEN HAGERSTOWN-, 2006. 105(5): p. 999.
13. **Ilfeld, B.M., et al.**, Total shoulder arthroplasty as an outpatient procedure using ambulatory perineural local anesthetic infusion: a pilot feasibility study. Anesthesia & Analgesia, 2005. 101(5): p. 1319-1322.
14. **Anthony, C.A., et al.**, What Are Risk Factors for 30-day Morbidity and Transfusion in Total Shoulder Arthroplasty? A Review of 1922 Cases. Clinical Orthopaedics and Related Research®, 2015. 473(6): p. 2099-2105.
15. **Fehringer, E.V., et al.**, Shoulder arthroplasties have fewer complications than hip or knee arthroplasties in US veterans. Clinical Orthopaedics and Related Research®, 2010. 468(3): p. 717-722.
16. **Healy, W.L., et al.**, Impact of cost reduction programs on short-term patient outcome and hospital cost of total knee arthroplasty. The Journal of Bone & Joint Surgery, 2002. 84(3): p. 348-353.
17. **Raphael, M., M. Jaeger, and J. van Vlymen**, Easily adoptable total joint arthroplasty program allows discharge home in two days. Canadian Journal of Anesthesia/Journal canadien d'anesthésie, 2011. 58(10): p. 902-910.
18. **Stambough, J.B., et al.**, Rapid Recovery Protocols for Primary Total Hip Arthroplasty Can Safely Reduce Length of Stay Without Increasing Readmissions. The Journal of arthroplasty, 2015. 30(4): p. 521-526.
19. **Ingraham, A.M., et al.**, Quality improvement in surgery: the American College of Surgeons national surgical quality improvement program approach. Advances in surgery, 2010. 44(1): p. 251-267.
20. American College of Surgeons National Surgical Quality Improvement Program. User Guide for the 2013 ACS NSQIP Participant Use Data File (PUF). 2015 August 8]; Available from: https://www.facs.org/~/media/files/quality%20programs/nsqip/acs_nsqip_puf_user_guide_2013.ashx.
21. **Shiloach, M., et al.**, Toward robust information: data quality and inter-rater reliability in the American College of Surgeons National Surgical Quality Improvement Program. Journal of the American College of Surgeons, 2010. 210(1): p. 6-16.
22. **Duchman, K.R., et al.**, The Effect of Smoking on Short-Term Complications Following Total Hip and Knee Arthroplasty. J Bone Joint Surg Am, 2015. 97(13): p. 1049-1058.
23. **Pugely, A.J., et al.**, Differences in short-term complications between spinal and general anesthesia for primary total knee arthroplasty. The Journal of Bone & Joint Surgery, 2013. 95(3): p. 193-199.
24. **Horan, T.C., et al.**, CDC definitions of nosocomial surgical site infections, 1992: a modification of CDC definitions of surgical wound infections. Infection Control, 1992. 13(10): p. 606-608.
25. **Duchman, K.R., et al.**, Differences in Short-Term Complications Between Unicompartmental and Total Knee Arthroplasty. The Journal of Bone & Joint Surgery, 2014. 96(16): p. 1387-1394.
26. **Huffman, K.M., et al.**, A comprehensive evaluation of statistical reliability in ACS NSQIP profiling models. Annals of surgery, 2015. 261(6): p. 1108-1113.

27. **Singh, A., et al.**, The effect of surgeon and hospital volume on shoulder arthroplasty perioperative quality metrics. Journal of Shoulder and Elbow Surgery, 2014. 23(8): p. 1187-1194.
28. **den Hartog, Y.M., et al.**, Which patient characteristics influence length of hospital stay after primary total hip arthroplasty in a 'fast-track' setting? Bone Joint J, 2015. 97-B(1): p. 19-23.
29. **Matsen, F.A., et al.**, Factors Affecting Length of Stay, Readmission, and Revision After Shoulder Arthroplasty: A Population-Based Study. J Bone Joint Surg Am, 2015. 97: p. 9.
30. **Menendez, M.E., et al.**, Predictors of extended length of stay after elective shoulder arthroplasty. Journal of Shoulder and Elbow Surgery, 2015.
31. **Waterman, B.R., et al.**, Thirty-day morbidity and mortality after elective total shoulder arthroplasty: patient-based and surgical risk factors. Journal of Shoulder and Elbow Surgery, 2015. 24(1): p. 24-30.
32. **Gruson, K.I., et al.**, Transfusion after shoulder arthroplasty: an analysis of rates and risk factors. Journal of Shoulder and Elbow Surgery, 2009. 18(2): p. 225-230.
33. **Hardy, J.C., et al.**, Blood transfusion associated with shoulder arthroplasty. Journal of Shoulder and Elbow Surgery, 2013. 22(2): p. 233-239.
34. **Millett, P.J., et al.**, Analysis of transfusion predictors in shoulder arthroplasty. The Journal of Bone & Joint Surgery, 2006. 88(6): p. 1223-1230.
35. **Waterman, B.R., et al.**, Outcomes after Bankart repair in a military population: predictors for surgical revision and long-term disability. Arthroscopy: The Journal of Arthroscopic & Related Surgery, 2014. 30(2): p. 172-177.
36. **Chalmers, P.N., et al.**, Predictors of early complications of total shoulder arthroplasty. The Journal of arthroplasty, 2014. 29(4): p. 856-860.
37. **Johnson, C.C., et al.**, Does preoperative American Society of Anesthesiologists score relate to complications after total shoulder arthroplasty? Clinical Orthopaedics and Related Research®, 2014. 472(5): p. 1589-1596.

OUTSIDE-IN VS. ANTEROMEDIAL PORTAL DRILLING DURING PRIMARY ACL RECONSTRUCTION: COMPARISON AT TWO YEARS

Tyler CarlLee, MD , Zach Ries, MD, Kyle Duchman, MD, Yubo Gao, PhD , Brian Wolf, MD,
Annunziato Amendola, MD, Carolyn Hettrich, MD, Matthew Bollier, MD

ABSTRACT

Background: Anteromedial (AM) and outside-in (OI) are two commonly used techniques for drilling the femoral tunnel during anterior cruciate ligament reconstruction (ACLR). The purpose of this study was to compare clinical and radiographic outcomes of patients undergoing primary ACLR using either AM or OI femoral drilling with minimum two year follow-up.

Methods: Overall, 138 prospectively enrolled patients undergoing primary ACLR underwent AM or OI femoral drilling. Patients were categorized by femoral drilling technique and were evaluated pre-operatively as well as at six weeks and two years post-operatively. Outcomes scores were collected at each visit using SF-36 PCS and MCS components, KOOS, and the Knee Activity Rating Scale. Complications, including graft failure, stiffness requiring manipulation under anesthesia, and revision surgery were also collected.

Results: Overall, 47 (34.1%) patients underwent AM femoral drilling and 91 (65.9%) patients underwent OI femoral drilling. Univariate analysis revealed no difference in pre-operative outcomes with the exception of the AM group having higher KOOS Knee Pain ($p=0.023$) and WOMAC Pain ($p=0.036$) scores. Postoperatively, OI femoral tunnels had a higher radiographic coronal angle (68.8°±8.6° vs 51.4°±11.3°; $p<0.001$) and knee extension (1.2°±2.7 vs 2.9°±4.0°; $p=0.010$). There were no differences in knee flexion, complications, or graft failure. Postoperatively, the AM group had higher KOOS ADL and WOMAC Functional (85 vs. 79 ,$p=0.030$) scores at the six week mark, although these differences did not meet the minimal clinically importance difference1. Graft failure at two years were similar in the AM and OI groups (8.5% vs. 6.6%, $p=0.735$). Multivariate analysis showed no clinical outcome differences between AM and OI techniques.

Conclusions: ACL reconstruction using the AM technique yielded lower radiographic coronal tunnel angle and slightly decreased knee extension. The theoretical risk of graft failure secondary to higher coronal angle of the graft as it passes around a sharper femoral tunnel aperture was not observed. Additionally, differences in pre-operative KOOS Knee pain existed but these differences were not significant postoperatively. We conclude no clinically relevant differences by two years in patients undergoing primary ACL reconstruction using either AM or OI femoral drilling techniques.

Level of Evidence: Level II Prospective Comparative Study

INTRODUCTION

Nearly 200,000 ACL reconstructions are performed in the United States annually[2]. The most frequently cited reason for revision ACL reconstruction reported in the literature is surgical technique, with the vast majority related to malposition of the bony tunnels[3,4,5,6,7]. Although surgeons were able to define the femoral origin of the ACL almost half a century ago[8], it has been difficult to place grafts in this position with the historically popular transtibial (TT) technique[9,10,11,12]. For this reason, a variety of arthroscopic techniques have evolved in order to provide more anatomic femoral tunnel positioning.

There have been multiple studies that link a TT approach with a higher likelihood of producing a vertical graft. Verticality of the graft may lead to knee instability and a higher chance of poor clinical outcomes[7,13]. Other authors have studied the accuracy of femoral tunnel placement using anteromedial portal, outside-in, and transtibial techniques[14]. A 2013 survey identified that the majority of surgeons in North America and internation-

---

All authors are members of University of Iowa Hospitals and Clinics Department of Orthopaedic Surgery and Rehabilitation

Corresponding Author:
Tyler CarlLee
University of Iowa Hospitals and Clinics
Department of Orthopaedic Surgery and Rehabilitation
200 Hawkins Drive
Iowa City, IA 52242
Email: tyler-carllee@uiowa.edu
Phone: 319-356-2223

Source of Funding: There was no funding for this project.

Conflict of Interest Statement: None of the authors or any of their immediate family member has received anything of value from, or has financial securities held in a commercial company or institution related directly or indirectly to the subject of this study.

ally prefer anteromedial approaches for placement of the femoral tunnel[15]. There are many studies comparing the biomechanical and radiographic outcomes associated with these various femoral tunnel techniques,[16,17] but the literature is lacking in comparing the clinical outcomes. There are several methods to assess tunnel placement including intra-operative fluoroscopy, post operative computed tomography (CT) scan, post-operative radiographs and post-operative MRI. Radiographs of the knee are useful and cost effective in determining the anatomic placement of a graft and have been shown to accurately predict graft placement when validated with three dimensional CT scans[18]. Recently it has been shown that kinematics, relative position of the tibia, and cartilage loading patterns may be different in AM placed grafts versus OI grafts[16].

Given the lack of short and mid-term follow-up investigations comparing patients with AM or OI placed grafts, the purpose of this study was to prospectively compare clinical and radiographic outcomes of patients undergoing primary ACL reconstruction using either AM or OI technique with minimum two-year follow-up.

METHODOLOGY

Following institutional review board approval, patients who underwent primary ACLR were identified from a prospectively maintained, single institution ACLR registry. Patients who underwent ACL reconstruction from 2011 to 2014 were included in the registry. There were a total of 138 patients who underwent primary ACLR by four surgeons. Patient information including age, sex, and preoperative patient reported outcome scores were obtained. Other data collected include operative information (graft type, concomitant injuries, fixation device) and post operative clinical information (patient reported outcome scores, radiographic measurements, and clinical exam measurements). Range of motion was defined in terms of flexion and extension at the knee. Extension was reported in the number of degrees short of full extension.

Patients were divided into two groups according to the technique used to place the femoral tunnel, which was based on surgeon preference. The AM technique utilized a low anteromedial portal that was localized with a spinal needle. A flexible reaming system allowed for subsequent drilling of the tunnel over a guidepin with the knee in hyperflexion while visualizing through the anterolateral portal. The graft was fixed with either suspensory or screw fixation. The OI technique utilized a Flipcutter (Arthrex) and a separate incision on the lateral aspect of the distal femur. A drill guide was placed against the lateral femoral cortex with a targeting guide centered over the femoral footprint of the ACL. An all-in-one guide pin and reamer is introduced from outside-in into the notch, followed by reaming in the reverse direction. This technique utilizes the camera in an anteromedial portal. The graft was fixed with suspensory fixation in all but one patient in the OI group.

There were 47 patients in the anteromedial group and 91 patients in the OI group. Complete data was available for 31 and 64 patients from each group for a follow-up rate of 66% and 70% respectively. Patients were evaluated clinically at baseline, six weeks and two years post-operatively and radiographically at six weeks postoperatively. Outcomes scores were collected at each visit using SF-36 PCS and MCS components, KOOS, and the Knee Activity Rating Scale. Two authors (TC and ZR) made radiographic measurements to assess the placement of the femoral tunnel using AP and lateral knee radiographs recorded at the patient's six week follow up visit. The site of the femoral tunnel was measured in the AP direction on a lateral radiograph of the knee using the quadrant technique proposed in a previously validated study by Sommer et al[19]. The coronal obliquity with relation to the femur's anatomic axis was measured using a technique relying on the head of an interference screw described by Shah[20]. In patients that had a tight rope device used instead of an interference screw, this measurement was made using a technique described by Illingsworth18 in which a line drawn down the femoral tunnel forms the angle with the femur's anatomic axis.

Univariate analysis allowed comparison of demographic and operative characteristics for patients who undergoing ACLR with AM or OI drilling. Select variables ($p < 0.1$) were subsequently used to create a multivariate logistic regression model to identify independent risk factors for graft failure, complications, and outcome scores. Significance was defined as $p < 0.05$ and results were reported as odds ratios (ORs) and 95% confidence intervals (95% CIs). Model performance was assessed through the c-statistic and model calibration, with Hosmer-Lemeshow chi-square statistics. All data and statistical analysis was performed with use of SAS (version 9.3; SAS Institute).

RESULTS

Overall 138 patients were followed for a minimum of two years after primary ACLR. The anteromedial group (AM) consisted of 47 patients while the outside-in (OI) consisted of 91 patients. Complete data was available (Table 1) for 31 and 64 patients from each group for a follow up rate of 66% and 70% respectively.

The two groups did not significantly differ with respect to the average patient age, male/female ratio, concomitant injury or pathology diagnosed at the time of surgery, and the majority of the baseline patient reported outcome scores (Tables 1 and 4). There was a significant difference in pre-operative KOOS Pain and

Table I. Patient Demographics

	Anteromedial	Outside-In	P-value
Number of Patients	47	91	
Male/Female	21/26	46/45	0.5133
Mean Age (years)	25.04	25.4	0.8496
Pre Op KOOS	62.16	58.28	0.245
Pre Op KOOS Pain	68.96	60.23	**0.0232**
Pre OP Womac Pain	78.86	70.58	**0.0361**
Pre OP SF36 Mental	56.48	54.48	0.2435
Pre OP SF36 Physical	40.76	37.40	0.0800
Pre OP KOOS ADL	72.86	69.42	0.3531
Pre OP Womac Functional	72.86	69.41	0.3531
Pre OP Knee Activity Score	12.6	11.4	0.2228
Associated Injury			
Lateral Meniscus Tear	19	41	0.6031
Medial Meniscus Tear	17	30	0.7067
Meniscus Repaired	7	22	0.2047
MCL Injury	9	17	0.9469
LCL Injury	7	7	0.1842
PCL Injury	1	3	1

Table II. Operative Values

	Anteromedial	Outside-In	P-value
Graft Choice			
Hamstring	34	53	0.1039
Bone-tendon-bone	13	16	0.1685
Tibialis Anterior	0	22	**<0.0001**
Autograft/Allograft	43/4	61/30	**0.0015**
Femoral Fixation			
Suspensory	34	90	**<0.0001**
Screw	13	1	**<0.0001**
Tibial Fixation			
Suspensory	0	14	**0.0025**
Screw	47	77	**0.0025**

Table III. Post-Operative Outcomes

	Anteromedial	Outside-In	P-value
Mean Coronal Angle (degrees)	51.37	68.78	**<0.0001**
Lateral Quadrant	1.044	1.092	0.2677
Flexion (degrees)	117.7	119.2	0.6042
Extension (degrees)	2.87	1.16	**0.0105**
Post Op 6 Week Knee Activity Score	12.9	12	0.372
Post Op 2 Year Knee Activity Score	12.6	10.5	0.075
Post Op 6 Week KOOS	72.28	68.09	0.1063
Post Op 2 Year KOOS	84.65	81.11	0.2317
Post Op 6 Week WOMAC Pain	87.91	83.03	0.0836
Post Op 2 Year WOMAC Pain	93.43	89.63	0.1154
Complications at 6 weeks	1	2	0.062
Complications at any time	8	8	0.1544
Re-rupture	4(8.5%)	6(6.6%)	0.7345

WOMAC Pain scores between the two groups. The majority of patients were injured with a rotational force at the knee in a non-contact sporting event (58%). The most common graft choice overall was hamstring autograft (n=83, 60%). However, a significantly larger number of tibialis anterior allograft was used in the OI group (n=22 vs n=0, p<0.0001). Allograft was more commonly used in the OI group (n=30 vs n=4; 33% vs 8.5%, p=0.0015). The majority of the femoral fixation was suspensory in both groups, and tibial fixation was most often an interference screw (n=122, 124; 88% and 90%, respectively (Table 2).

Extension (2.9°±4.0° vs 1.2°±2.7; p=0.010) and mean coronal angle (51.4°±11.3° vs 68.8°±8.6°; p<0.001) were significantly different between the two groups (Tables 3 & 4). There were no differences clinical outcome scores with the exception of AM group having a higher six week and two year post-op KOOS ADL and WOMAC Functional scores(85 vs. 79 ,p=0.030). The remainder of the measured variables including complication and re-rupture rates showed no significant difference at six weeks or two years. Multivariate analysis showed no difference between groups in any of the clinical, radiographic or patient reported outcomes.

Complications were similar between the two groups at six weeks and two years. These were defined as reasons to return to the operating room within two years. At two year follow-up there were eight complications in the AM group and eight complications in the OI group. Graft failure (one from MRSA infection in the OI group) accounted for all but four of the complications in the AM group and all but two of the complications in the OI group. There were two cases of hardware removal for

Table IV. Post-Operative Clinical Scores			
Outcome	**Anteromedial**	**Outside-In**	**P-value**
Post Op 6 Week Knee Activity Score	12.9	12	0.372
Post Op 2 Year Knee Activity Score	12.6	10.5	0.075
Post Op 6 Week Physical Score	44.24	43.0	0.3994
Post Op 6 Week Mental Score	53.77	53.01	0.6404
Post Op 2 Year Physical Score	50.84	49.10	0.3367
Post OP 2 Year Mental Score	54.97	53.82	0.5254
Post Op 6 Week KOOS Knee Pain	78.39	73.24	0.0955
Post Op 2 Year KOOS Knee Pain	87.93	83.25	0.1250
Post Op 6 Week KOOS ADL	85.28	79.41	**0.0296**
Post OP 2 Year KOOS ADL	94.95	91.10	0.0593
Post OP 6 Week WOMAC Functional	85.28	79.41	**0.0296**
Post OP 2 Year WOMAC Functional	94.95	91.10	0.0593
Post Op 6 Week KOOS	72.28	68.09	0.1063
Post Op 2 Year KOOS	84.65	81.11	0.2317
Post Op 6 Week WOMAC Pain	87.91	83.03	0.0836
Post Op 2 Year WOMAC Pain	93.43	89.63	0.1154
Post Op 6 Week WOMAC Stiffness	67.44	68.25	0.8319
Post Op 2 Year WOMAC Stiffness	77.86	78.31	0.9190

prominent hardware, one case of a loose body removal, and one case of a cyclops lesion in the AM group. In the OI group there were two cases of arthrofibrosis requiring manipulation under anesthesia.

DISCUSSION

While many aspects of ACL reconstruction have been studied, it is clear that the location of the femoral tunnel affects knee kinematics as well as patient functional outcomes[19,21]. There is still controversy regarding the best technique to achieve an anatomic location of the femoral origin of the ACL. There is reproducible evidence that supports improved knee mechanics, more anatomic graft placement on the femur, and improved knee stability using an independent drilling method over a transtibial method[22,23,24]. However, current evidence fails to reveal clinically significant differences between techniques[24]. In this study, we showed no difference in clinical outcomes at two years post-operatively for patients undergoing AM or OI femoral drilling during primary ACLR using a prospectively maintained, single institution ACLR database.

Although clinical outcomes between groups were similar at the two year time point, the coronal oblique angle was significantly higher for femoral tunnels drilled using the OI technique. In a previous study, Chang[25] reported no difference in coronal obliquity when comparing AM and OI techniques. In the present study, patients in the OI group had a higher angle of obliquity, consistent with a more vertically oriented graft. Previous studies have identified more obliquity in tunnels placed through an AM and OI compared to a TT approach[26]. Increased verticality has corresponded to more laxity with anterior tibial translation and increased rotational instability[26]. However, we did not observe higher graft failure rates at two year follow-up.

When assessing range of motion following ACL reconstruction, the OI group had better extension than those in the AM group but the clinical significance of this difference (1.5 degrees) is likely inconsequential[27]. Clinically it appears the minimum amount of a flexion contracture that leads to anterior knee pain is approximately five degrees[27]. Therefore, this observation represents a statistical difference that has poor clinical relevance.

While our reported complication rate may seem high for primary ACL reconstruction in the AM group, the majority of complications listed were sensitivity from prominent hardware and arthrofibrosis. Other surgeons with higher thresholds for returning to the operating room may not consider these as complications. Our six week complication rates were similar to others reported in the literature[28] at around 2%. However, our early complications were all re-ruptures related to new trauma or infection. Compared to the MOON data which reported 4.4% re-rupture at two year follow up in primary ACL reconstruction, our re-rupture rate was 7.2% in all comers. However, our mean patient age was younger at 25 years compared to 27.4 years, a risk factor that has been associated with higher increases in re-ruptures[29].

Our clinical results compare favorably with other reported clinical results in the literature. In a systematic review with meta-analysis, Riboh et al[24] found no significant difference in patient reported outcome measures at short to mid-term follow up between independent drilling groups. In a study by Lansdown[16], at one year postoperatively patients in the OI group had similar KOOS scores to those in the AM group with improved scores in the KOOS-symptoms category. This was a small study with only 10 patients per cohort.

Major strengths of our study include prospectively gathered data in a group of patients treated by multiple surgeons, at minimum two year follow-up. The present study has several limitations. Follow-up was limited to two years and included<80% of patients within the database. Additionally, the majority of AM ACLR procedures were performed by a single surgeon, and there was limited crossover between techniques for the four surgeons contributing to the database. Furthermore, we did not report an activity level measure, which in combination with patient age, is the most predictive of subsequent graft rupture[29]. Finally, the influence of concomitant injuries and post operative protocols on patient reported outcomes was not addressed specifically.

In conclusion, we found no clinically relevant differences by two years in patients undergoing primary ACL reconstruction using either the AM or outside in femoral drilling techniques.

BIBLIOGRAPHY

1. **Collins NJ, Misra D, Felson DT, Crossley KM, Roos EM.** Measures of knee function: International Knee Documentation Committee (IKDC) Subjective Knee Evaluation Form, Knee Injury and Osteoarthritis Outcome Score (KOOS), Knee Injury and Osteoarthritis Outcome Score Physical Function Short Form (KOOS-PS), Knee Outcome Survey Activities of Daily Living Scale (KOS-ADL), Lysholm Knee Scoring Scale, Oxford Knee Score (OKS), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), Activity Rating Scale (ARS), and Tegner Activity Score (TAS). Arthritis care & research 2011;63 Suppl 11:S208-28.
2. **Lynch TS, Parker RD, Patel RM, et al.** The Impact of the Multicenter Orthopaedic Outcomes Network (MOON) Research on Anterior Cruciate Ligament Reconstruction and Orthopaedic Practice. The Journal of the American Academy of Orthopaedic Surgeons 2015;23:154-63.
3. **Greis PE, Johnson DL, Fu FH.** Revision anterior cruciate ligament surgery: causes of graft failure and technical considerations of revision surgery. Clinics in sports medicine 1993;12:839-52.
4. **Johnson CC, Garcia GH, Garner MR, Marx RG.** Quality of Life Following ACL Reconstruction: Baseline Predictors of Patient-Reported Outcomes. HSS journal : the musculoskeletal journal of Hospital for Special Surgery 2016;12:94-7.
5. **Getelman MH, Friedman MJ.** Revision anterior cruciate ligament reconstruction surgery. The Journal of the American Academy of Orthopaedic Surgeons 1999;7:189-98.
6. **Battaglia TC, Miller MD.** Management of bony deficiency in revision anterior cruciate ligament reconstruction using allograft bone dowels: surgical technique. Arthroscopy : the journal of arthroscopic & related surgery : official publication of the Arthroscopy Association of North America and the International Arthroscopy Association 2005;21:767.
7. **Marchant BG, Noyes FR, Barber-Westin SD, Fleckenstein C.** Prevalence of nonanatomical graft placement in a series of failed anterior cruciate ligament reconstructions. The American journal of sports medicine 2010;38:1987-96.
8. **Girgis FG, Marshall JL, Monajem A.** The cruciate ligaments of the knee joint. Anatomical, functional and experimental analysis. Clinical orthopaedics and related research 1975:216-31.
9. **Arnold MP, Kooloos J, van Kampen A.** Single-incision technique misses the anatomical femoral anterior cruciate ligament insertion: a cadaver study. Knee surgery, sports traumatology, arthroscopy : official journal of the ESSKA 2001;9:194-9.
10. **Harner CD, Fu FH, Irrgang JJ, Vogrin TM.** Anterior and posterior cruciate ligament reconstruction in the new millennium: a global perspective. Knee surgery, sports traumatology, arthroscopy : official journal of the ESSKA 2001;9:330-6.
11. **Abebe ES, Moorman CT, 3rd, Dziedzic TS, et al.** Femoral tunnel placement during anterior cruciate ligament reconstruction: an in vivo imaging analysis comparing transtibial and 2-incision tibial tunnel-independent techniques. The American journal of sports medicine 2009;37:1904-11.
12. **Chalmers PN, Mall NA, Cole BJ, Verma NN, Bush-Joseph CA, Bach BR, Jr.** Anteromedial versus transtibial tunnel drilling in anterior cruciate ligament reconstructions: a systematic review. Arthroscopy : the journal of arthroscopic & related surgery : official publication of the Arthroscopy Association of North America and the International Arthroscopy Association 2013;29:1235-42.
13. **Zantop T, Wellmann M, Fu FH, Petersen W.** Tunnel positioning of anteromedial and posterolateral bundles in anatomic anterior cruciate ligament reconstruction: anatomic and radiographic findings. The American journal of sports medicine 2008;36:65-72.
14. **Osti M, Krawinkel A, Ostermann M, Hoffelner T, Benedetto KP.** Femoral and tibial graft tunnel parameters after transtibial, anteromedial portal, and outside-in single-bundle anterior cruciate ligament reconstruction. The American journal of sports medicine 2015;43:2250-8.

15. **Chechik O, Amar E, Khashan M, Lador R, Eyal G, Gold A.** An international survey on anterior cruciate ligament reconstruction practices. International orthopaedics 2013;37:201-6.
16. **Lansdown DA, Allen C, Zaid M, et al.** A comprehensive in vivo kinematic, quantitative MRI and functional evaluation following ACL reconstruction - A comparison between mini-two incision and anteromedial portal femoral tunnel drilling. The Knee 2015;22:547-53.
17. **Erdem M, Gulabi D, Asil K, Erdem AC.** Farmedial versus anteromedial portal drilling of the femoral tunnel in ACL reconstruction: a computed tomography analysis. Archives of orthopaedic and trauma surgery 2015;135:539-47.
18. **Illingworth KD, Hensler D, Working ZM, Macalena JA, Tashman S, Fu FH.** A simple evaluation of anterior cruciate ligament femoral tunnel position: the inclination angle and femoral tunnel angle. The American journal of sports medicine 2011;39:2611-8.
19. **Sommer C, Friederich NF, Muller W.** Improperly placed anterior cruciate ligament grafts: correlation between radiological parameters and clinical results. Knee surgery, sports traumatology, arthroscopy : official journal of the ESSKA 2000;8:207-13.
20. **Shah AA, Brien A, Lowe WR.** Radiographic results of femoral tunnel drilling through the anteromedial portal in anterior cruciate ligament reconstruction. Arthroscopy : the journal of arthroscopic & related surgery : official publication of the Arthroscopy Association of North America and the International Arthroscopy Association 2010;26:1586-92.
21. **Khalfayan EE, Sharkey PF, Alexander AH, Bruckner JD, Bynum EB.** The relationship between tunnel placement and clinical results after anterior cruciate ligament reconstruction. The American journal of sports medicine 1996;24:335-41.
22. **Steiner ME, Battaglia TC, Heming JF, Rand JD, Festa A, Baria M.** Independent drilling outperforms conventional transtibial drilling in anterior cruciate ligament reconstruction. The American journal of sports medicine 2009;37:1912-9.
23. **Tompkins M, Milewski MD, Brockmeier SF, Gaskin CM, Hart JM, Miller MD.** Anatomic femoral tunnel drilling in anterior cruciate ligament reconstruction: use of an accessory medial portal versus traditional transtibial drilling. The American journal of sports medicine 2012;40:1313-21.
24. **Riboh JC, Hasselblad V, Godin JA, Mather RC, 3rd.** Transtibial versus independent drilling techniques for anterior cruciate ligament reconstruction: a systematic review, meta-analysis, and meta-regression. The American journal of sports medicine 2013;41:2693-702.
25. **Chang MJ, Chang CB, Won HH, Je MS, Kim TK.** Anteromedial portal versus outside-in technique for creating femoral tunnels in anatomic anterior cruciate ligament reconstructions. Arthroscopy : the journal of arthroscopic & related surgery : official publication of the Arthroscopy Association of North America and the International Arthroscopy Association 2013;29:1533-9.
26. **Lee MC, Seong SC, Lee S, et al.** Vertical femoral tunnel placement results in rotational knee laxity after anterior cruciate ligament reconstruction. Arthroscopy: the journal of arthroscopic & related surgery: official publication of the Arthroscopy Association of North America and the International Arthroscopy Association 2007;23:771-8.
27. **Irrgang JJ, Harner CD.** Loss of motion following knee ligament reconstruction. Sports medicine (Auckland, NZ) 1995;19:150-9.
28. **Jameson SS, Dowen D, James P, Serrano-Pedraza I, Reed MR, Deehan D.** Complications following anterior cruciate ligament reconstruction in the English NHS. The Knee 2012;19:14-9.
29. **Kaeding CC, Pedroza AD, Reinke EK, Huston LJ, Spindler KP.** Risk Factors and Predictors of Subsequent ACL Injury in Either Knee After ACL Reconstruction: Prospective Analysis of 2488 Primary ACL Reconstructions From the MOON Cohort. The American journal of sports medicine 2015;43:1583-90.

MEDIAL MENISCUS ROOT TEAR IN THE MIDDLE AGED PATIENT: A CASE BASED REVIEW

Joseph H. Carreau, MD, Sean E. Sitton, MD, Matthew Bollier, MD

ABSTRACT

Biomechanical studies have shown that medial meniscal root tears result in meniscal extrusion and increased tibiofemoral joint contact pressures, which can accelerate the progression of arthritis. Repair is generally recommended for acute injuries in the young, active patient population. The far more common presentation however, is a subacute root tear with medial meniscal extrusion in a middle aged patient. Coexisting arthritis is common in this population and complicates decision making. Treatment should be based on the severity of the underlying arthritis. In cases of early or minimal arthritis, root repair is ideal to improve symptoms and restore meniscal function. In patients with moderate or severe medial compartment arthritis, medial unloader bracing or injections can be tried initially. When non-operative treatment fails, high tibial osteotomy or arthroplasty is recommended. Long term clinical studies are needed to determine the natural history of medial meniscal root tears in middle aged patients and the best surgical option.

Key Words: Meniscus root tear; meniscus repair; medial meniscus; middle age; MMRT; arthritis

INTRODUCTION

There remains little doubt that the meniscus plays a crucial role for maintaining homeostasis of the knee joint. In addition to lubricating properties and providing secondary stability, the meniscus distributes significant load across the tibiofemoral joint.[1,2] Current evidence suggests that tears of the meniscus disrupt normal homeostasis and increase contact force which can lead to premature arthritis.[3-5]

Injury to the root of the medial meniscus is a subtype of tear that may have profound impact on the health of the knee. Tears of the meniscus root insertion lead to meniscal extrusion, and subsequent loss of hoop stresses- an inherently critical structural property of the meniscus.[6] Meniscus root tears creates profound changes in load transmission, and is biomechanical similar that of total meniscectomy.[7] Although the true incidence is not known, medial meniscus root tears (MMRT) may occur in up to 10% of knees undergoing arthroscopy,[8] with even higher rates in the Asian population. The average age of presentation nears 58 years old with risk factors being age, elevated body mass index (BMI), female sex and decreased activity level.[9]

Surgical techniques for root tears have evolved in recent times, with most techniques aimed at arthroscopic anatomic restoration of the root avulsion.[10] While the biomechanical implications of a root tear seem to be clear, the clinical corollary of repair is less clear as outcomes haven't been well substantiated; specifically in the middle aged population. Nevertheless, recognition of the tear, and a thorough understanding of the implications and coexisting joint pathology can help guide the treating physician in providing appropriate recommendations to patients.

In this review, we illustrate the clinical presentation, imaging findings, and discuss surgical decision making via a case based review to help expand the general knowledge base and facilitate treatment decision making for clinicians facing this challenging problem.

BACKGROUND

Although medial meniscal root tears can occur in the setting of trauma or in association with acute ligamentous injury, they are much more commonly the result of a chronic process that occurs in middle-aged patients with a degenerative knee. Lateral root tears on the other hand, are more commonly associated with acute knee trauma and ligamentous injuries. Recent studies have also shown tears of the posterior root of the medial meniscus to be more common in patients with the following risk factors: increased age, female sex, sedentary lifestyle, obesity and overall varus mechanical alignment of the knee.[9,11] MMRT's can often be missed in these patients as there is usually not a history of trauma and often present with a subacute pain history.

Department of Orthopedics and Rehabilitation
University of Iowa Hospitals and Clinics

Corresponding Author:
Sean E. Sitton, MD
Department of Orthopedics and Rehabilitation
University of Iowa Hospitals and Clinics
200 Hawkins Dr.
Iowa City, IA 52242
Sean-sitton@uiowa.edu
Phone: (801) 400-4745

The authors declare no conflicts of interest.

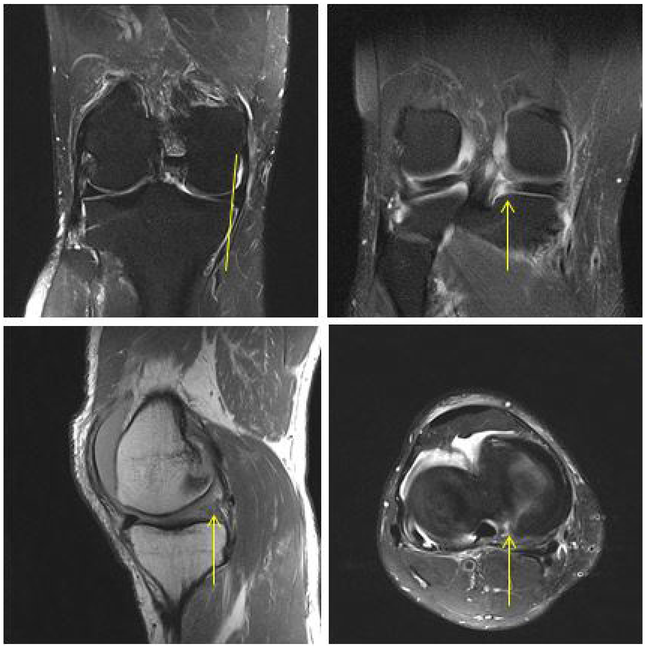


Figure 1: Coronal T2 weighted image showing extrusion of the medial meniscus beyond the dimensions of the medial tibial plateau (upper left), while upper right image confirms avulsion of the root of the medial meniscus. A pathognomonic "ghost sign", or segmental defect of the posterior root on T1 weighted sagittal MRI image (lower left), and a radial tear of the posterior root as seen on axial T2 weighted image (lower right).

Etiology

The relationship of chronic MMRT in the arthritic knee isn't well understood as it remains unclear whether meniscus root tear and extrusion is a cause or effect. Lerer reported that 20% of patients with extrusion of the medial meniscus had no or minimal evidence of degenerative joint disease, thus concluding that perhaps root tears precede arthritis.[12] Still, others have found a significant correlation of advanced arthritis to MMRT, suggesting perhaps extrusion and tearing may be an effect of joint space narrowing, rather than cause. In a total knee arthroplasty study, Choi, et al found 78% of patients to have tears involving the root or posterior horn at the time of knee replacement surgery.[13] Regardless of cause or effect of MMRT's, there appears to be a correlation with medial arthritis of the knee, of which the relationship is important to appreciate.

Anatomy: Medial Meniscus

The medial meniscus is semicircular in shape, with a slightly broader region posteriorly. The anterior horn insertion is somewhat variable, and has an attachment to the anterior horn of the lateral meniscus, via the intermeniscal ligament and was seen in 50% of cadaveric knees, in at least one study.[14] While the anterior horn only has inferior attachments to the tibia, the body of the meniscus has direct superior and inferior peripheral attachments to the capsule, which blends into the deep medial collateral ligament. The posterior horn of the meniscus loses its superior capsular attachments but inserts on the posterior tibia via the posterior root. According to recent anatomic studies, the root can reproducibly be located 9.6 mm posterior and 0.7 mm lateral from the medial tibial eminence. Alternatively, it can be found 3.5 mm lateral from the medial tibial plateau articular cartilage inflection point,[15,16] which may serve as reliable arthroscopic location for fixation.

Biomechanics/Pathology

The menisci are fibrocartilaginous wedge-shaped discs that act as shock absorbers by distributing the force through circumferential hoop stresses. The menisci typically bear somewhere between 40-70% of the mechanical force that is transmitted through the knee joint.[17-19] The meniscus also serves as an important secondary stabilizer of the knee, which helps to maintain normal knee kinematics and prevent degeneration of the cartilage.

A significantly greater mechanical load is seen by the posterior horn of the medial meniscus compared to the anterior, especially with the knee in flexion. This greater load leads to more frequent tears of the posterior root than anterior tears. Posterior root tears are also more biomechanically significant, as they can disrupt the essential shock-absorbing ability of the meniscus and render it unable to adequately transfer axial load into hoop stresses. The secondary stabilizing effects are also lost in the setting of a root tear. This inability to transfer load into hoop stresses and loss of stabilization in turn leads to abnormal knee kinematics.[20] As a result, the meniscus can become extruded and the medial compartment of the joint is subjected to increased contact pressures over decreased contact surfaces, which can greatly accelerate the arthritic process. In recent biomechanical studies, the effect of a posterior root tear of the medial meniscus has even been compared to that of a total meniscectomy.[21,22] Since meniscal root tears were first described in the literature by Pagnani et al. in 1991,[23] there has been much effort and research focused on properly identifying and repairing these lesions if possible, with the purpose of preserving the articular surface of the medial compartment.

Imaging

Weight bearing radiographs are a standard in a painful knee workup and should include anteroposterior (AP), lateral (LAT), standing AP with 45° of knee flexion (Rosenberg view) and Merchant views. Long leg alignment films should also be considered to gain a better understanding of the mechanical axis if malalignment is suspected.

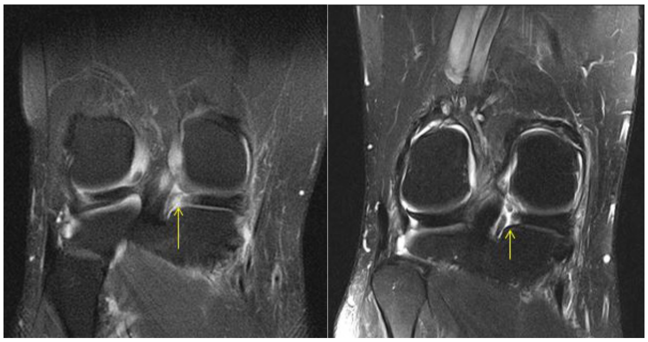


Figure 2: Note true avulsion of the root (left), while the image on the right demonstrates a complete radial avulsion of the posterior horn, with remnant root still attached.

When radiographs rule out moderate to severe medial compartment arthritis, magnetic resonance imaging (MRI) should be considered as the clinical diagnosis of a root tear can be challenging. Extrusion of the meniscus, as seen on a coronal image, is often, but not always associated with meniscus root tear. If the peripheral meniscus edge is greater than 3 mm beyond the outer margin of the tibial surface it is said to be extruded and should tip the clinician off to a possible root injury (Figure 1). In a recent, large multicentered osteoarthritis study, Crema et al, found that MMRT was strongly associated with meniscus extrusion. In this study, they determined the presence of meniscus extrusion increased odds of root tear by a factor of 10.2.[24]

The posterior horn of the medial meniscus can generally be visualized on MRI. Coronal T2 weighted images, which some have argued has the highest accuracy for diagnosing a tear.[25] T1 sagittal images may be used to look for a "ghost sign", which represents either increased signal or absence of the typically dark signal found in the posterior meniscus root.[18,19,26] Axial images are of value as well, and can be used to help visualize a tear (Figure 1). Choi et al reported very high diagnostic accuracy of MRI for detection of MMRT. Positive predictive values, negative predictive values, sensitivity and specificity of axial, coronal and sagittal were all >90%.[27]

Differentiation of a true root tear from paracentral radial tear should also be accomplished. While the blood supply to the root is abundant, the paracentral meniscus blood supply is more limited, and may not be as amenable to repair.[28,29] (Figure 2) represents a comparison of a true root avulsion and a paracentral root tear. Although paracentral root tear may represent a different tear pattern, Laprade et al showed significantly increased mean contact pressures after radial tear 3, 6 and 9 mm from the root, making them essentially biomechanically equivalent to root tears.[10]

Associated MRI findings are commonly found in with MMRT. One study showed 97% of MRI's obtained with a MMRT also had some evidence of degenerative joint disease. As expected, medial femoral condyle lesions were commonly observed.[30] Increased femoral condyle stress related edema and subchondral collapse has also been observed and seems to have an association with MMRT's.[31] Furthermore, well defined bony ossicles within the meniscus substance have been reported in association with MMRT. In a retrospective imaging study of meniscal ossicles, Mohankumar et al reported 66% were found within the posterior root, and when an ossicle was present in the meniscus, a root tear was visualized in 74% of cases. It's not clear however, whether ossicles are post traumatic, congenital or related to mucoid degeneration.[32]

In sum, associated pathology is frequent in this setting of MMRT, thus the overall cartilage health should be critically evaluated and considered by the clinician when considering treatment options.

CASES

Case 1: Non-operative management

A 55 year old farmer presented with chronic, posteromedial pain in his left knee pain without clear injury history. His exam was notable for mild posteromedial joint line tenderness. Ligamentous exam was normal. Radiographs demonstrated mild medial joint line narrowing, worse on Rosenberg views. MRI of his left knee demonstrated meniscus root tear with significant extrusion and full thickness medial femoral cartilage loss. Given the degree of arthrosis, he was counseled about treatment options and elected for non-operative management. He ultimately underwent a series of steroid injections and was able to return to activities and work without limitation. Interestingly, he presented 7 years later after an acute injury to the contralateral, right knee and was found to have an acute, extruded menisus root tear. A screening xray of his left knee was acquired, and as seen in the serial radiograph, his arthritis has progressed significantly over time. Nevertheless, his left knee remains asymptomatic (Figure 3).

Non operative management of a MMRT should be considered in the setting of advanced arthritis, those unable or unwilling to comply with postoperative rehab or those that are poor surgical candidates. Non surgical measures to consider include non steroidal anti-inflammatory medication (NSAIDs), corticosteroid injection therapy, activity modifications, medial unloader bracing, physical therapy (PT) and weight loss management.

Non operative treatment with NSAIDs and supervised PT has been shown to be effective at controlling symptoms in at least two, retrospective level IV studies. Kim, et al treated 30 patients with MMRT (mean age of

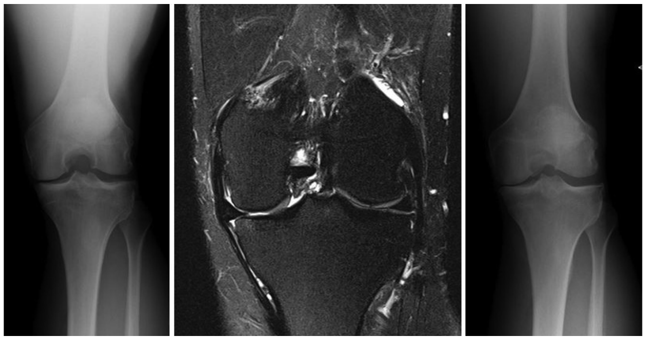


Figure 3: Rosenberg x-ray (left) demonstrating mild joint line narrowing. T2 weighted coronal MRI (middle) shows meniscus extrusion with medial femoral condyle defect and was thus treated non-operatively. The patient was seen 7 years later for increasing contralateral knee pain and underwent screening x-rays showing progression of medial arthritis (right). It should be noted that he remains asymptomatic despite radiographic progression of arthritis.

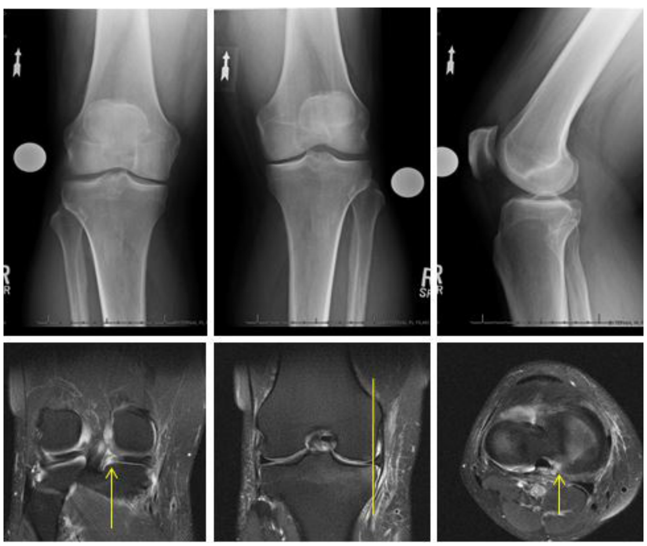


Figure 4: AP, Rosenberg and lateral radiographs (top) demonstrating mild medial joint line narrowing. MRI demonstrating root tear and extrusion with diffuse cartilage thinning medially.

59) with PT and NSAIDs for 8- 12 weeks and showed improved symptoms up to 12 months.[33] The authors reported a slight decline in clinical scores thereafter. Neogi, et al reported their experience with NSAIDs and PT treatment of MMRT's in 33 patients with an average age of 55.8 years old. The authors noted clinical improvements for 6 months, however a gradual clinical decline and advancement of arthritis by x-ray was observed at 35 months. Nevertheless, final follow up was still significantly improved from pre-treatment status.[34] A recent study by Krych, et al showed non operative management of MMRT to have a very high failure rate, with 31% of patients undergoing arthroplasty by 30 months after and an overall failure rate of 87%[36].

In sum, non-surgical management should be initiated in patients with moderate to severe arthritis, or those who are not surgical candidates, however as progression of arthritis is common, counseling about arthritis progression should be undertaken.

Case 2: partial menisectomy

A 46 yo M pipeline welder presented with 3 months of worsening knee pain that initially began while running on a treadmill. He experienced medial sided pain and swelling since, which was made worse with stairs and deep squatting. He received physical therapy and a steroid injection with limited pain relief through his primary care provider. Upon referral, the exam was notable for medial joint line tenderness and ligamentous stability. Radiographs showed Kellegren-Lawrence grade II medial arthritis. MRI demonstrated a MMRT with extrusion of 4 mm. Tibiofemoral cartilage was diffusely thinned medially (Figure 4). Preoperatively he was counseled about meniscectomy versus repair, pending the status of his cartilage. At arthroscopy, diffuse Grade II/III Outerbridge chondromalacia was noted, thus partial meniscectomy was performed (Figure 5). Postoperatively, he was advanced to weight bearing as tolerated and returned to activities gradually. By 12 weeks post op he was largely pain free and had returned to work without difficulty. At 6 mo post op he continued to be asymptomatic and was counseled about the long term status of his knee. He returned at 1 year post op with increased medial sided knee pain and was found to have advanced arthritis of the knee. He ultimately underwent steroid injection therapy, but was referred on for consideration of unicompartmental arthroplasty.

Arthroscopic partial meniscectomy can be considered for symptomatic relief, when repair cannot be achieved or the arthritis is too advanced. Ozcok et al reported modest improvements in symptoms out to 56 months in a study of 67 patients undergoing meniscectomy for MMRT (average age 55.8 yrs). While Lysholm knee scores improved from 53 to 67 at follow up, the authors did observe advancement of Kellgren-Lawrence (KL) grade arthritis from an average of 2 to 3 at final follow up.[8]

In another level IV study, Han et al reported longer term data on 46 patients with MMRT that underwent meniscectomy. Unfortunately, at an average of 77 months post op, only 56% of patient reported improvement in pain, while 67% were satisfied and 19% required re-operation. 35% of patients showed progression of arthritis by KL grade[35].

Kim et al, reported a level III comparative study of 58 patients that underwent either partial meniscectomy or root repair. Although meniscectomy and repair were both improved from preoperative state at close to 4 year

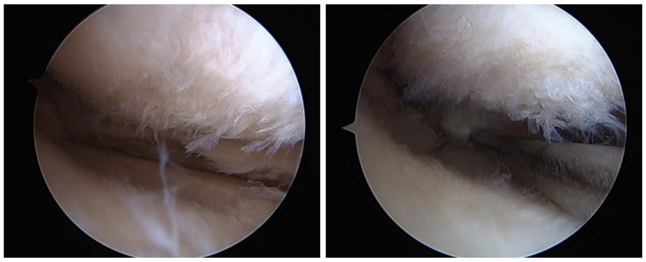


Figure 5: Arthroscopic images at time of surgery demonstrate diffuse, Outerbridge Grade II/III chondromalacia, with meniscus root avulsion noted (left). Given the state of the cartilage, meniscus debridement was performed.

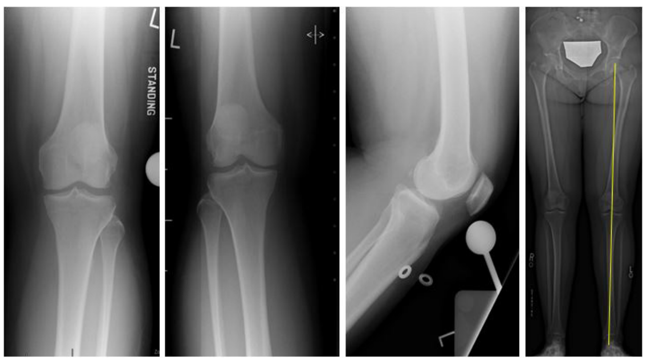


Figure 6: Standing AP, Rosenberg and lateral radiographs demonstrating minimal medial joint line narrowing. Mechanical axis is neutral on AP long-leg x-ray.

follow up, the meniscectomy group had more radiographic progression of arthritis compared to the repair group (30% vs 75%, p<.05)[36].

In sum, meniscectomy can be considered for symptomatic relief when MMRT is present in the setting of mild to moderate arthritis. Patient counseling about the likely early clinical benefits, but probable mid to late term arthritic changes should be performed.

Case 3: Root Repair

46 year old female homemaker presents with 10 months of significant left knee pain, located in the posteromedial knee after stepping into a pothole. She received one prior steroid injection from her primary care provider that provided limited pain relief. The exam was notable for posteromedial joint line tenderness and significant pain with deep knee flexion. Thessaly test for meniscus tear was positive. Ligamentous exam was reassuring. Radiographs revealed preserved joint line and no malalignment (Figure 6). MRI showed tear of the posterior horn of the medial meniscus (Figure 7). She underwent arthroscopic repair of the meniscus root with transtibial pullout repair technique (Figure 8). She was made non weight bearing for 6 weeks, with restrictions in motion to 90 degrees. Weight bearing and range of motion were progressed thereafter and she returned to all activities by 6 months post op.

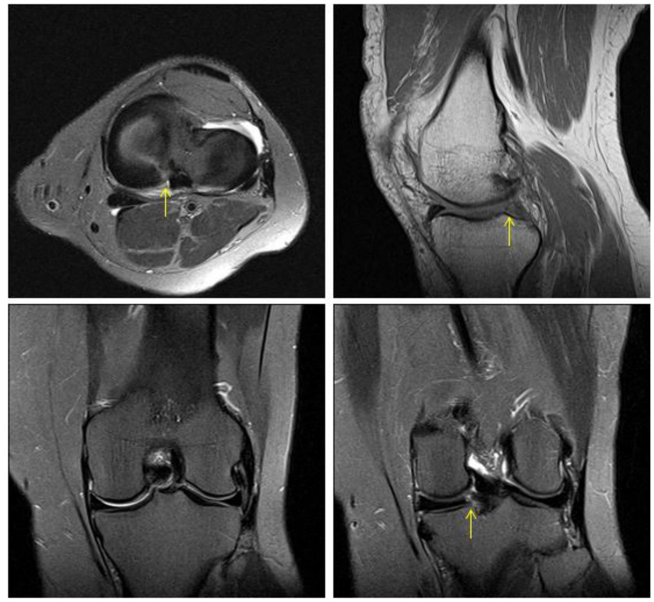


Figure 7: Axial T2, sagittal T1, and coronal T2 weighted images demonstrating complete root avulsion with no significant cartilage loss.

Clinical data after surgical root repair is sparse and largely limited to retrospective series. In a level IV study, Lee, at al reported data on 20 patients with MMRT that underwent repair with a minimum 2 year follow up. At almost 32 month average follow up, they showed significant clinical improvement with only one patient showing radiographic progression of arthritis and 1 patient re-tearing at 6 mo post op. Additionally, second-look arthroscopy was performed on 10 patients and complete healing of the root was noted in all [37]. In contrast, Seo et al reported 21 patients that underwent medial meniscus root repair but in their study, found no cases of complete healing during second-look arthroscopies at 13 mo average follow up. It should be recognized that his study did include patients with varus alignment and grade III/IV Outerbridge chondromalacia that required osteotomy. Despite high rates of incomplete healing, average clinical scores showed significant improvement at follow up[38].

Surgical Technique

Several modifications in surgical repair of MMRT have occurred in recent years, but most treatment is aimed at restoring the root attachment via a suture anchor or through transtibial bone tunnels. Transosseus repair techniques, such as the transtibial pullout repair have gained popularity, and has been our preferred practice

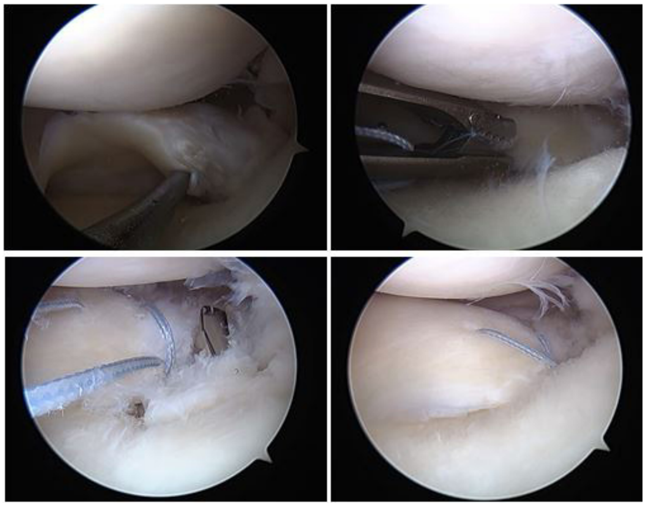


Figure 8: Arthroscopic images of the right knee revealing displaced, avulsion of the posterior horn of the medial meniscus (upper left). Note the preserved cartilage. Figure-of-eight stitch passed through the meniscus root (upper right). A 5 mm tunnel drilled inside out from the medial tibia in the root anatomic footprint (lower left). Sutures then retrieved through the tunnel and secured over a cortical button on the medial tibia, thus repairing root tear to its footprint.

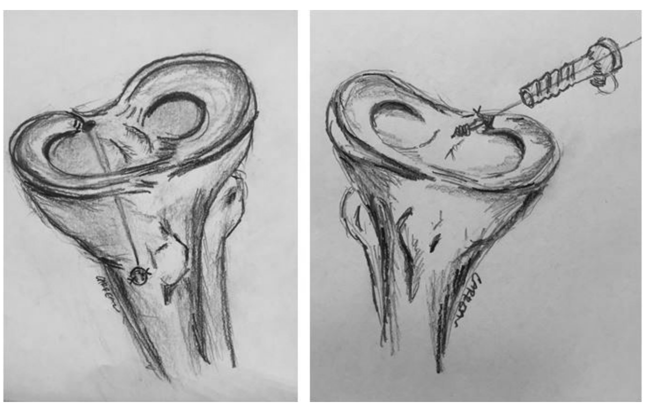


Figure 9: Trans-tibial pullout technique (left) and suture anchor technique (right).

(Figure 9). Standard medial and lateral parapatellar arthroscopic portals are created and the torn meniscus stump is debrided down to a bleeding bone trough with an arthroscopic shaver. If access into the medial joint space is limited, pie crusting the femoral side of the MCL from outside-in with a spinal needle can help to enhance the working space. No. 2 non-absorbable suture is then passed through the meniscus root using a suture passing device. We prefer to use a Knee Scorpion (Arthrex, Naples, FL) for suture passage. Various stitch configurations have been described, but we prefer a figure-of-8 pattern. Sutures are thereafter retrieved from the lateral portal. An anterior cruciate ligament (ACL) guide is introduced from the medial portal, and centered on the root footprint. A guide pin is advanced from the proximal medial or lateral tibia to the ACL guide tip. A 5 mm tunnel is drilled over the guide pin, carefully breaching the tibial surface. Alternatively, a retrograde reaming device may be used to drill a socket for which the root may be dunked within. Sutures are then retrieved through the tunnel (we prefer a Hewson suture passer) and shuttled exteriorly where they are secured over a plate, screw or cortical button.

Suture anchor techniques on the other hand, involve establishing an accessory posteromedial portal to gain access to the posterior root (Figure 9). A suture anchor can be placed at the anatomic root location through the accessory posteromedial portal. Similar to the transtibial technique, sutures may then be passed through the root, shuttled between portals, and tied all inside using a knot pusher.

Several biomechanical studies investigating these techniques have been performed. Allaire et al showed peak contact pressures within the tibiofemoral joint were restored to normal after transtibial pullout root repair at 0, 30, 60 and 90 of knee flexion[7]. Marzo and Gurske-DePerio showed similar findings with significant increases in mean peak contact pressures after tear and restoration of loading profiles equal to that of the control knee after repair[6]. At least one biomechanical study has compared transtibial pullout to suture anchor fixation. Feucht et al performed a cadaveric study which revealed suture anchor repair to have lower displacement and higher stiffness after 100, 500 and 1000 cyles then transtibial pullout repair. Neither technique was effective at reaching native strength of the intact medial meniscus root, however[39].

There remains little clinical data comparing different surgical techniques. One recent prospective study however, has been performed comparing the two techniques. Kim at al compared 22 patients that underwent transtibial pullout to 23 patients that underwent suture anchor repair of MMRT. At 2 years follow up, there didn't appear to be statistically significant differences in the repair techniques when evaluating functional improvement or healing rates. Both techniques resulted in significant improvements from preoperative state ($p<.05$)[40].

Case 4: High Tibial Osteotomy

A 44 year old female teacher presented to our clinic with 8 weeks of medial sided knee pain without a clear injury. She was quite active, and prior to this was able to run 6-8 miles per week. She received one previous steroid injection by her primary care provider, which provided limited pain relief. Examination was notable for medial joint line tenderness and ligamentous stability. Radiographs revealed mild medial joint line narrowing,

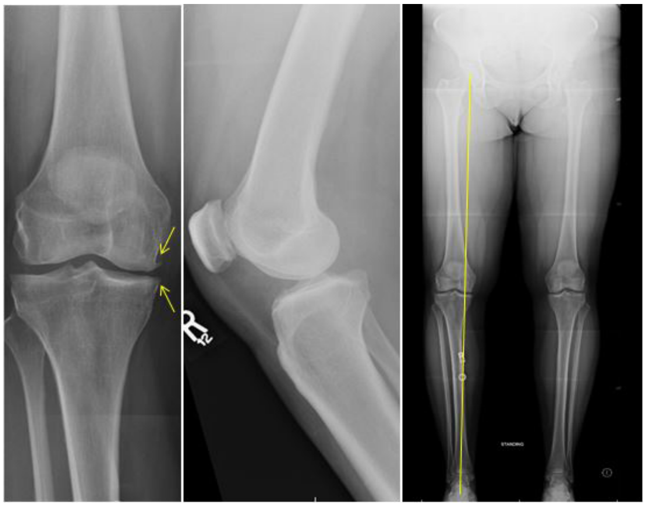


Figure 10: AP and lateral radiographs demonstrate mild medial joint line narrowing with early osteophytes. Mechanical axis passes medial to the center of the knee, which measured 5 degrees of varus (right).

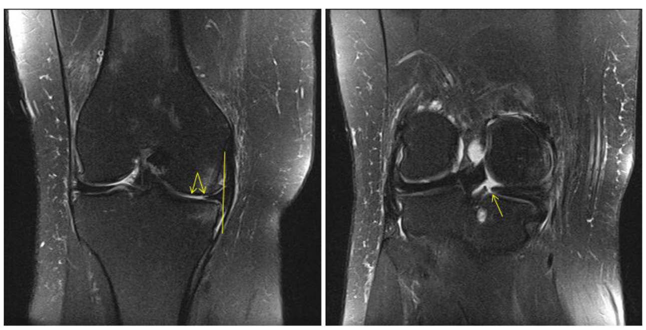


Figure 11: T2-weighted coronal images demonstrating near full thickness cartilage loss from both the medial femoral condyle and medial plateau with 3.8 mm of extrusion of the medial meniscus (left). Note the radial tear is seen at the junction of the posterior body and root (right).

and varus alignment (Figure 10). MRI revealed paracentral medial meniscus root tear with extrusion and diffuse changes of the medial tibiofemoral joint, with preserved lateral cartilage (Figure 11). Given the varus alignment, moderate cartilage loss, and paracentral nature of the tear, she was offered an arthroscopic meniscectomy with high tibial osteotomy to unload her medial knee joint. At the time of arthroscopy, Outerbridge grade III/IV arthritis was evident within the medial compartment but her lateral joint space was preserved. She underwent debridement of the meniscus tear and high tibial osteotomy for correction of her varus. By 6 months post op, she was back to swimming, biking and ice skating without any knee pain (Figure 12).

In this case, the patient had far too advanced arthritis and an unfavorable tear pattern to consider meniscus repair. Furthermore, her desired activity level was not

Figure 12: AP and lateral radiographs taken 6 months post-op, after high tibial osteotomy (iBalance, Arthrex, Naples, Fl)

amenable to arthroplasty, thus an osteotomy was offered for treatment.

In a level IV study, Moon et al reported 51 patients that underwent MMRT repair. At mean follow up of 33 months, those with Outerbridge grade 3 or 4 chondral changes and those with genu varum > 5° were associated with poorer outcome after root repair. These were both independent risk factors for inferior clinical outcome ($p < .05$)[41].

In a noteworthy level IV study, Nha et al performed second look arthroscopies on 20 patients that underwent high tibial osteotomy for medial arthritis and MMRT. At arthroscopy, 50% of the root tears were completely healed despite no previous attempt at direct repair at the time of HTO. Interestingly, there was no correlation between healing rate and clinical outcome[42].

In sum, in the setting of KL grade III/IV arthritis or significant varus alignment, salvage operations such as HTO or arthroplasty should be considered if conservative measures fail.

SUMMARY

Tears of the posterior horn of the medial meniscus in the middle aged patient present a challenging clinical problem. As highlighted in the cases presented, clinical decision making in the middle aged individual should be based on degree of associated pathology and patient activity level and goals. Biomechanical studies clearly show that these tears lead to loss of hoop stress and extrusion, which profoundly impact the contact pressures within the knee. It's postulated that this may advance joint degeneration, however long term studies about the natural history of these tears are needed. Clinical outcomes for both non operative treatment and meniscectomy are largely limited to retrospective case series. These methods do seem to offer short term clinical benefit, but progression of arthritis seems probable. The biomechanical evidence for repair on the other hand is strong, however long term clinical data supporting repair is quite limited and what role if any repair plays in slowing or reversal of arthritis of the knee is not understood. Regardless of the treatment rendered, the patient should be educated on the consequence of a MMRT, as progression of arthritis is common.

In summary, patients with a MMRT should undergo careful and critical evaluation of the cartilage within the knee. If moderate chondral loss is present, salvage options such as osteotomy or arthroplasty should be considered in conjunction with the patient's activities and goals in mind. Future studies aimed at improving our understanding of what role surgery plays in the treatment of medial meniscus root tears in the middle aged patient is warranted.

REFERENCES

1. **Walker PS, and Margaret J. Erkiuan.** "The role of the menisci in force transmission across the knee." Clinical orthopaedics and related research 109 (1975): 184-192.
2. **Makris EA, Pasha Hadidi, and Kyriacos A.** Athanasiou. "The knee meniscus: structure–function, pathophysiology, current repair techniques, and prospects for regeneration." Biomaterials 32.30 (2011): 7411-7431.
3. **Alford JW, Paul Lewis, Richard W. Kang, and Brian J. Cole.** "Rapid progression of chondral disease in the lateral compartment of the knee following meniscectomy." Arthroscopy: The Journal of Arthroscopic & Related Surgery 21, no. 12 (2005): 1505-1509.
4. **Tapper EM, and NORMAN W. HOOVER.** "Late results after meniscectomy." J Bone Joint Surg Am 51.3 (1969): 517-603.
5. Fairbank TJKjcamJoBJS, British Volume 30, no. 4 (1948): 664-670.
6. **Marzo JM, and Jennifer Gurske-DePerio.** "Effects of medial meniscus posterior horn avulsion and repair on tibiofemoral contact area and peak contact pressure with clinical implications." The American journal of sports medicine 37.1 (2009): 124-129.
7. **Allaire R, Muturi Muriuki, Lars Gilbertson, and Christopher D. Harner.** "Biomechanical consequences of a tear of the posterior root of the medial meniscus." The Journal of Bone & Joint Surgery 90, no. 9 (2008): 1922-1931.
8. **Ozkoc G, Esra Circi, Ugur Gonc, Kaan Irgit, Aysin Pourbagher, and Reha N. Tandogan.** "Radial tears in the root of the posterior horn of the medial meniscus." Knee Surgery, Sports Traumatology, Arthroscopy 16, no. 9 (2008): 849-854.
9. **Hwang B-Y, Sung-Jae Kim, Sang-Won Lee, Ha-Eun Lee, Choon-Key Lee, David J. Hunter, and Kwang-Am Jung.** "Risk factors for medial meniscus posterior root tear." The American journal of sports medicine 40, no. 7 (2012): 1606-1610.
10. **LaPrade RF, Christopher M. LaPrade, and Evan W. James.** "Recent advances in posterior meniscal root repair techniques." Journal of the American Academy of Orthopaedic Surgeons 23.2 (2015): 71-76.
11. **Doherty DB, Lowe WR.** Meniscal Root Tears: Identification and Repair. American journal of orthopedics (Belle Mead, N.J.). Mar-Apr 2016;45(3):183-187.
12. **Lerer DB, Umans HR, Hu MX, Jones MH.** The role of meniscal root pathology and radial meniscal tear in medial meniscal extrusion. Skeletal radiology. Oct 2004;33(10):569-574.
13. **Choi E-S, and Sang-Jun Park.** "Clinical evaluation of the root tear of the posterior horn of the medial meniscus in total knee arthroplasty for osteoarthritis." Knee surgery & related research 27, no. 2 (2015): 90-94.
14. **LaPrade CM, Michael B. Ellman, Matthew T. Rasmussen, Evan W. James, Coen A. Wijdicks, Lars Engebretsen, and Robert F. LaPrade.** "Anatomy of the Anterior Root Attachments of the Medial and Lateral Menisci A Quantitative Analysis." The American journal of sports medicine 42, no. 10 (2014): 2386-2392.
15. **Johannsen AM, David M. Civitarese, Jeffrey R. Padalecki, Mary T. Goldsmith, Coen A. Wijdicks, and Robert F. LaPrade.** "Qualitative and quantitative anatomic analysis of the posterior root attachments of the medial and lateral menisci." The American journal of sports medicine 40, no. 10 (2012): 2342-2347.
16. **Śmigielski R, Roland Becker, Urszula Zdanowicz, and Bogdan Ciszek.** "Medial meniscus anatomy—from basic science to treatment." Knee Surgery, Sports Traumatology, Arthroscopy 23, no. 1 (2015): 8-14.
17. **Shrive NG, O'Connor JJ, Goodfellow JW.** Loadbearing in the knee joint. Clinical orthopaedics and related research. Mar-Apr 1978(131):279-287.

18. **Seedhom BB.** Transmission of the Load in the Knee Joint with Special Reference to the Role of the Menisci: Part I: Anatomy, Analysis and Apparatus. Engineering in Medicine. October 1, 1979 1979;8(4):207-219.
19. **Ahmed AM, Burke DL.** In-Vitro of Measurement of Static Pressure Distribution in Synovial Joints—Part I: Tibial Surface of the Knee. Journal of Biomechanical Engineering. 1983;105(3):216-225.
20. **LaPrade RF, LaPrade CM, Ellman MB, Turnbull TL, Cerminara AJ, Wijdicks CA.** Cyclic displacement after meniscal root repair fixation: a human biomechanical evaluation. The American journal of sports medicine. Apr 2015;43(4):892-898.
21. **Kim SB, Ha JK, Lee SW, et al.** Medial meniscus root tear refixation: comparison of clinical, radiologic, and arthroscopic findings with medial meniscectomy. Arthroscopy : the journal of arthroscopic & related surgery : official publication of the Arthroscopy Association of North America and the International Arthroscopy Association. Mar 2011;27(3):346-354.
22. **Allaire R, Muriuki M, Gilbertson L, Harner CD.** Biomechanical consequences of a tear of the posterior root of the medial meniscus. Similar to total meniscectomy. The Journal of bone and joint surgery. American volume. Sep 2008;90(9):1922-1931.
23. **Pagnani MJ, Cooper DE, Warren RF.** Extrusion of the medial meniscus. Arthroscopy : the journal of arthroscopic & related surgery : official publication of the Arthroscopy Association of North America and the International Arthroscopy Association. 1991;7(3):297-300.
24. **Crema MD, Frank W. Roemer, David T. Felson, Martin Englund, Ke Wang, Mohamed Jarraya, Michael C. Nevitt et al.** "Factors associated with meniscal extrusion in knees with or at risk for osteoarthritis: the Multicenter Osteoarthritis study." Radiology 264, no. 2 (2012): 494-503.
25. **Lee SY, Won-Hee Jee, and Jung-Man Kim.** "Radial tear of the medial meniscal root: reliability and accuracy of MRI for diagnosis." American Journal of Roentgenology 191, no. 1 (2008): 81-85.
26. <283.full.pdf>.
27. **Choi S-H, Sooho Bae, Suk Kyeong Ji, and Moon Jong Chang.** "The MRI findings of meniscal root tear of the medial meniscus: emphasis on coronal, sagittal and axial images." Knee Surgery, Sports Traumatology, Arthroscopy 20, no. 10 (2012): 2098-2103.
28. **Koenig JH, Anil S. Ranawat, Hilary R. Umans, and Gregory S. DiFelice.** "Meniscal root tears: diagnosis and treatment." Arthroscopy: The Journal of Arthroscopic & Related Surgery 25, no. 9 (2009): 1025-1032.
29. **Arnoczky SP, and Russell F. Warren.** "Microvasculature of the human meniscus." The American journal of sports medicine 10, no. 2 (1982): 90-95.
30. **Lee YG, Jae-Chan Shim, Yun Sun Choi, Jin Goo Kim, Ghi Jai Lee, and Ho Kyun Kim.** "Magnetic resonance imaging findings of surgically proven medial meniscus root tear: tear configuration and associated knee abnormalities." Journal of computer assisted tomography 32, no. 3 (2008): 452-457.
31. **Sung JH, Jeong Ku Ha, Dhong Won Lee, Won Yeong Seo, and Jin Goo Kim.** "Meniscal extrusion and spontaneous osteonecrosis with root tear of medial meniscus: comparison with horizontal tear." Arthroscopy: The Journal of Arthroscopic & Related Surgery 29, no. 4 (2013): 726-732.
32. **Mohankumar R, Andrew Palisch, Waseem Khan, Lawrence M. White, and William B. Morrison.** "Meniscal ossicle: posttraumatic origin and association with posterior meniscal root tears." American Journal of Roentgenology 203, no. 5 (2014): 1040-1046.
33. **Lim HC, Ji Hoon Bae, Joon Ho Wang, Chang Woo Seok, and Min Keun Kim.** "Non-operative treatment of degenerative posterior root tear of the medial meniscus." Knee Surgery, Sports Traumatology, Arthroscopy 18, no. 4 (2010): 535-539.
34. **Neogi DS, Ashok Kumar, Laxman Rijal, Chandra Shekhar Yadav, Ashish Jaiman, and Hira Lal Nag.** "Role of nonoperative treatment in managing degenerative tears of the medial meniscus posterior root." Journal of Orthopaedics and Traumatology 14, no. 3 (2013): 193-199.
35. **Han SB, Gautam M. Shetty, Dae Hee Lee, Dong Ju Chae, Seung Suk Seo, Kook Hyun Wang, Si Hoon Yoo, and Kyung Wook Nha.** "Unfavorable results of partial meniscectomy for complete posterior medial meniscus root tear with early osteoarthritis: a 5-to 8-year follow-up study." Arthroscopy: The Journal of Arthroscopic & Related Surgery 26, no. 10 (2010): 1326-1332.
36. **Kim SB, Jeong Ku Ha, Soo Won Lee, Deok Won Kim, Jae Chan Shim, Jin Goo Kim, and Mi Young Lee.** "Medial meniscus root tear refixation: comparison of clinical, radiologic, and arthroscopic findings with medial meniscectomy." Arthroscopy: The Journal of Arthroscopic & Related Surgery 27, no. 3 (2011): 346-354.
37. **Lee JH, Young Jin Lim, Ki Bum Kim, Kyu Hyung Kim, and Ji Hun Song.** "Arthroscopic pullout suture repair of posterior root tear of the medial meniscus: radiographic and clinical results with a 2-year follow-up." Arthroscopy: The Journal of Arthroscopic & Related Surgery 25, no. 9 (2009): 951-958.

38. **Seo H-S, Su-Chan Lee, and Kwang-Am Jung.** "Second-look arthroscopic findings after repairs of posterior root tears of the medial meniscus." The American journal of sports medicine 39, no. 1 (2011): 99-107.
39. **Feucht MJ, Eduardo Grande, Johannes Brunhuber, Nikolaus Rosenstiel, Rainer Burgkart, Andreas B. Imhoff, and Sepp Braun.** "Biomechanical comparison between suture anchor and transtibial pull-out repair for posterior medial meniscus root tears." The American journal of sports medicine 42, no. 1 (2014): 187-193.
40. **Kim J-H, Ju-Hwan Chung, Dong-Hoon Lee, Yoon-Seok Lee, Jung-Ryul Kim, and Keun-Jung Ryu.** "Arthroscopic suture anchor repair versus pullout suture repair in posterior root tear of the medial meniscus: a prospective comparison study." Arthroscopy: The Journal of Arthroscopic & Related Surgery 27, no. 12 (2011): 1644-1653.
41. **Moon H-K, Yong-Gon Koh, Yong-Chan Kim, Young-Sik Park, Seung-Bae Jo, and Sae-Kwang Kwon.** "Prognostic factors of arthroscopic pull-out repair for a posterior root tear of the medial meniscus." The American journal of sports medicine 40, no. 5 (2012): 1138-1143.
42. **Nha K-W, Yong Seuk Lee, Dae-Hee Hwang, Jae Ho Kwon, Dong Ju Chae, Young Jee Park, and Jong In Kim.** "Second-look arthroscopic findings after open-wedge high tibia osteotomy focusing on the posterior root tears of the medial meniscus." Arthroscopy: The Journal of Arthroscopic & Related Surgery 29, no. 2 (2013): 226-231.

MARJOLIN'S ULCER OF THE TIBIA WITH PELVIC LYMPH NODE METASTASIS

Craig C. Akoh, MD*, Justin Chang, BS, Joseph Buckwalter, MD

ABSTRACT

Marjolin's ulcer, a form of squamous cell carcinoma, is a rare complication of a chronic wound infection. To date, there have not been any detailed reports of lymphatic spread of Marjolin's ulcer from an extremity. This report describes a 44-year old male with a history of an open tibia fracture at age 15, who presented with chronic osteomyelitis, increasing bloody wound drainage, and an enlarging vascular exophytic masses in the region of drainage. Biopsy of the mass showed squamous cell carcinoma. Initial staging with computed tomography (CT) was negative for metastatic disease. Six months after undergoing a below-knee amputation (BKA), the patient developed an enlarged lymph node in the left inguinal area. His re-staging CT and biopsy of inguinal node confirmed the presence of metastatic squamous cell carcinoma. The patient was subsequently treated with inguinal node dissection and adjuvant radiation therapy. At 2.5 years follow-up, the patient remains disease-free. Our case illustrates the importance suspecting squamous cell carcinoma in patients with chronic infections and diligent follow up for patients with Marjolin's ulcers.

INTRODUCTION

Marjolin's ulcer was was first coined by a French surgeon named Jean-Nicholas Marjolin as "ulcers canceroides" in his classic essay in 1828[1]. These lesions generally arise after a latency period of years from the original injury, and it is hypothesized that they result from a malignant degeneration caused by chronic inflammation in non-healing wounds[2,3]. Potential etiologies include burn eschars, pressure sores, venous stasis ulcers, traumatic wounds, osteomyelitis, and fistulas[4]. These patients present with symptoms refractory to treatment and include pain, bleeding, and growing exophytic mass[5, 6]. Once malignant transformation occurs, these lesions can invade into the deep tissue and surrounding structures, requiring aggressive surgical treatment. To our knowledge, there has not been any previous detailed reports of lymphatic spread of Marjolin's ulcers. In this paper, we present a case report of a 44-year old male with squamous cell carcinoma transformation and local metastasis from a chronic sinus tract and osteomyelitis of the left tibia.

CLINICAL CASE

A previously healthy 44-year old gentleman presented to the orthopaedic tumor clinic for evaluation of an enlarging exophytic mass of his left leg. He had a history of a farming accident at the age of 15 involving his bilateral lower extremities, including an open left pilon fracture and ipsilateral tibia plateau fracture. He was initially treated with an open reduction internal fixation and skin grafting. His post-operative course was complicated by a necrotic left leg wound that required muscle excision and left leg venous bypass. He also had recurrent infections requiring multiple incisions and drainage as well as multiple courses of intravenous (IV) antibiotics. About ten years later, he underwent a left transmetatarsal amputation, which at that time relieved his persistent drainage.

Twenty-eight years after his initial injury, he presented to his primary care physician (PCP) due to a recurrence of serosanguinous drainage from the fracture wound site at his anterior distal leg. He was subsequently treated with IV antibiotics for several months. During a routine follow-up appointment with his PCP, an exophytic mass was discovered on the left tibia and he was referred to a local orthopedist. Plain films at that time revealed an expansile 5.1 cm lytic lesion in the distal left fibular diaphysis with lateral soft tissue swelling and slightly sclerotic bony margins concerning for malignancy. Given these findings, he was referred to an orthopaedic oncologist.

At his initial orthopaedic oncology clinic visit, physical exam revealed a 2.5 by 2.5 cm circular friable exophytic mass on the anterolateral middle of the left tibia with a separate proximal draining sinus (Figure 1). He was neurovascularly intact with no other abnormalities noted

---

University of Iowa Hospitals and Clinics

*Corresponding Author:
Craig C. Akoh, MD
200 Hawkins Drive
Iowa City, Iowa 52242
Email: Craig-Akoh@uiowa.edu
Phone: 319-356-1616

The authors declare no coflicts of interest.

Figure 1: exophytic left distal anterior leg mass

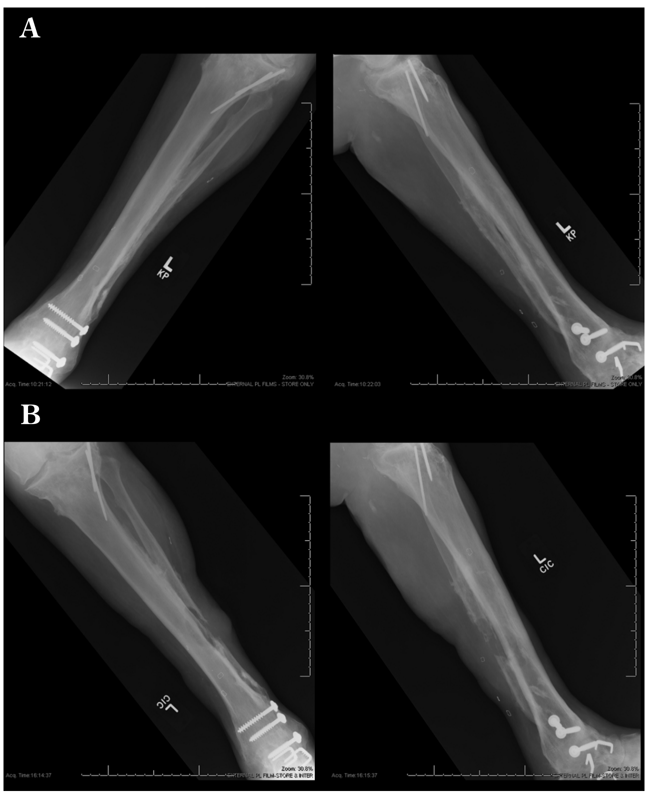


Figure 2: Radiographs of the left leg
(A) Initial plain radigographs obtained at an OSH (B) 6 months later xrays show an increase in the lytic fibula diaphyseal lesion.

on physical exam. Labs showed elevated inflammatory markers as follows: white blood cell count (WBC) 8.6 with a normal differentiation, erythrocyte sedimentation rate (ESR) 42, and C-reactive protein (CRP) of 7.4. Repeat plain radiographs showed an interval increase in size of the lytic fibula diaphyseal lesion (Figure 2).

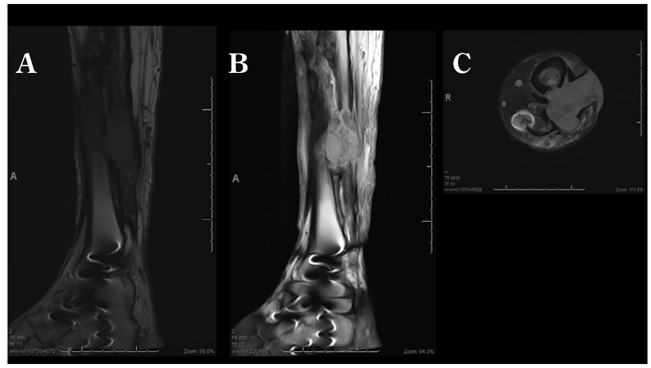


Figure 3: MRI of the left leg
(A) T2 sagittal, (B) T1 sagittal , and T2 axial images of the left tibia-fibula reveal a 4.7 x 3.4 cm2 lytic lesion in the left fibula with soft tissue extension

Magnetic resonance imaging (MRI) showed a 4.7 x 3.4 cm2 lytic lesion in the left fibula with a significant soft tissue component that eroded through the cortex (Figure 3). A computed tomography (CT) scan of the chest/abdomen/pelvis was negative for any extraosseus primary malignancy or regional lymph node metastasis. He subsequently underwent an incisional biopsy in the operating room, and histology showed an invasive, moderately-differentiated (T4N0M0) squamous cell carcinoma consistent with a Marjolin's ulcer (Figure 4) Wound cultures obtained in the operating room grew *Prevotella buccae, Haemophilus parainfluenzae, Actinomyces odontolyticus, Corynebacterium simulans,* and *Moraxella nonliquificiens.*

Given the invasive nature of the patient's Marjolin's ulcer without evidence of metastasis, he underwent a left below knee amputation (BKA). Intraoperatively, he was noted to have extensively fibrotic tissue in his deep posterior compartment without evidence of gross purulence. Operative gross pathology results showed a 4.2 cm diameter SCC mass that invaded 3.2 cm deep with negative 3.9 cm tissue margins. He was discharged with a 6 week course of IV daptomycin 500 mg and IV ertapenem 1 gm. At the 4 month post-operative follow-up, the patient was doing well and reported no complications.

Five months following his BKA, the patient presented to his PCP with a small bump on the lateral aspect of his BKA stump and a new mass in his left groin. He denied any constitutional symptoms and his ESR and CRP were 20 and 2.3, respectively. A 5 mm punch biopsy of the distal stump lesion was negative for SCC. Re-staging with CT scan of the chest/abdomen/pelvis and positron emission tomography-computed tomography (PET-CT) scan revealed a 2 cm left inguinal lymph node without evidence of organ metastasis (Figure 4). A fine needle aspiration (FNA) was performed of the lymph node was positive for metastatic SCC. Due to the presence

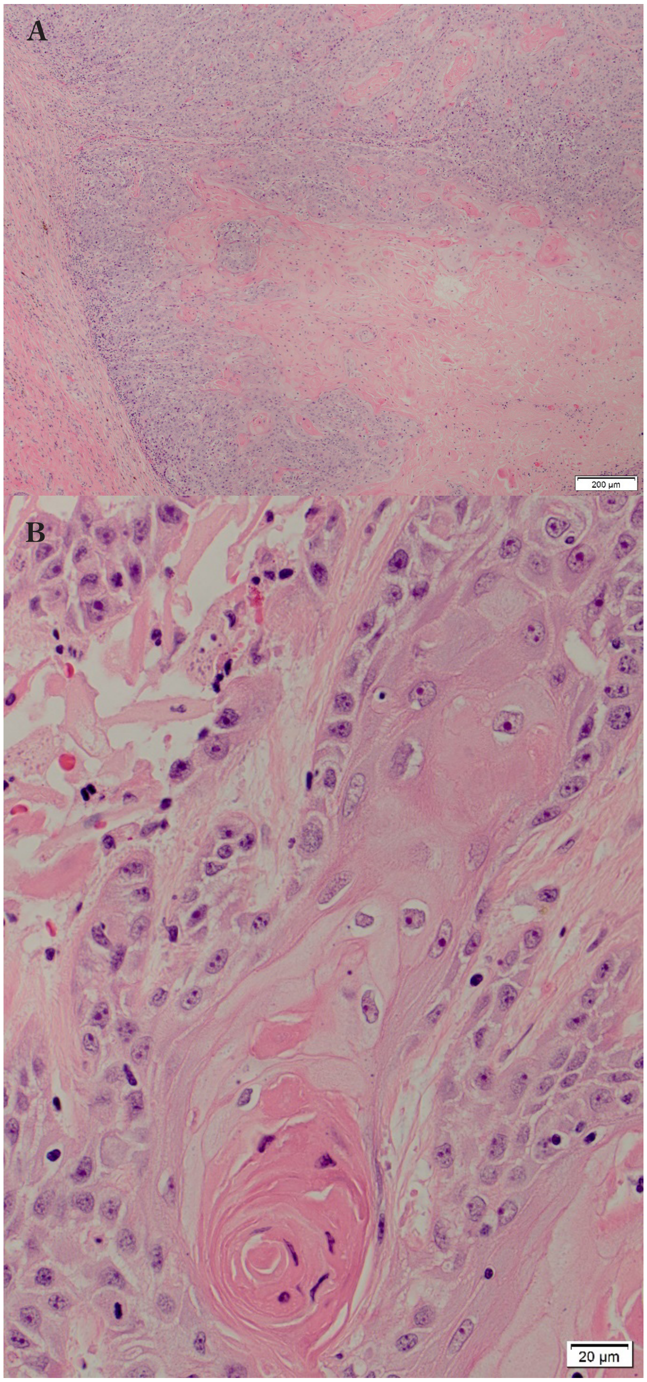


Figure 4: Incisional Biopsy Pathology
(A)Low and (B) High-powered pathology slides demonstrating a moderately-differentiated squamous cell carcinoma

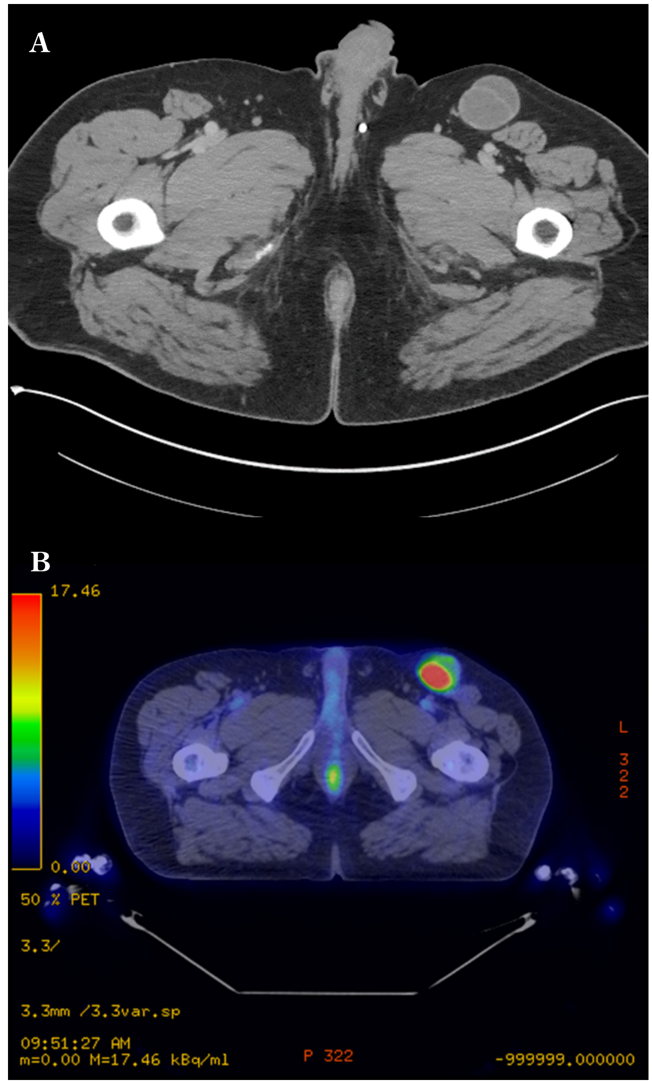


Figure 5: Regional lymphatic metastasis
Axial image of a (A) CT abdomen and (B) PET-CT scan reveals a 2 cm left inguinal lymph node

of regional metastatic disease, he was referred to a surgical-oncologist and underwent an inguinal lymph node resection with adjuvant radiation therapy 7 months after his BKA. His intraoperative pathology showed 2 macro-metastatic nodes, the largest being 3.6 cm, with 6 other negative nodes. Following his inguinal nodal dissection, he completed 6 weeks of adjuvant radiation therapy (6,600 cGy in 33 fractions). Surveillance CT scans of the chest/abdomen/pelvis at 8 and 12 months postoperatively were negative for new lesions and did not show any recurrence of cancer.

DISCUSSION

This case study presented a young healthy male with malignant transformation of a chronic infection and subsequent regional lymph node metastasis of a Marjolin's ulcer. Marjolin's ulcer is a rare entity and is estimated to occur in 1.7% of all chronic wounds[7] with a mean latency of 28.7 years[4]. A literature review of 443 cases showed that the most common etiology for Marjolin's ulcer is a burn wound (76.5% cases), followed by

Table 1: Cierny-Mader classification of adult osteomyelitis

Anatomic type	
Type 1	Medullary osteomyelitis (nidus is endosteal). No dead space management. Etiology often hematogenous, post-intramedullary rod.
Type 2	Superficial Osteomyelitis. Limited to surface of bone. No dead space management but needs soft tissue coverage
Type 3	Localized osteomyelitis. Full thickness of cortex. Complex dead space management, simple osseous stabiliization
Type 4	Diffuse osteomyelitis. Circumference of cortex. Biomechanically unstable. Complex dead space and osseous management.
Physiologic host	
A Host	Normal host. Normal immune system. Normal vascularity.
B Host	Bs: systemic compromise Bl: local compromise Bsl: systemic and local compromise
C Host	Treatment morbidity worse than present condition with low prognosis for cure.

Adapted from: Cierny, G., 3rd, J.T. Mader, and J.J. Penninck, A clinical staging system for adult osteomyelitis. Clin Orthop Relat Res, 2003(414): p. 7-24.

traumatic wounds (8.1%), venous stasis ulcers (6.3%), and osteomyelitis (2.6%),[4]. Another study showed that up to 23% of patients with chronic osteomyelitis can undergo this malignant transformation[8]. Although the exact pathophysiology is largely questioned, the prevailing theory is that it arises from a state of chronic inflammation and cell proliferation[2]. This subsequently increases the expression of proto-oncogenes in the epithelial cell line, leading to self-sustainability and ability to evade apoptosis[2, 9]. Early recognition and management is key to preventing long-term complications, such as local tissue destruction and metastatic spread[9]. Additionally, chronic avascular scar tissue limits the ability of immune cells to suppress mutated cells during oncogenic development[4].

The etiology of our case's malignant transformation was from chronic osteomyelitis and chronic sinus tract infection developed from an open tibia shaft fracture and fixation. Osteomyelitis is an ancient disease first described by Hippocrates around 460-370 BC[10]. Officially published by Bromfield in 1773, osteomyelitis is an inflammatory process that can lead to progressive bone destruction[5, 11]. Radiographs and advanced imaging assists with the extent of lytic lesion, cortical involvement, and the presence of a sequestrum or involucrum[5, 12]. The Cierny-Mader classification system for osteomyelitis incorporates four anatomic types with three physiologic classes to define 12 clinical stages (Table 1)[13]. These clinical stages depend on the condition of the host, the anatomic site of infection, functional impairment caused by the disease, and the extent of bony necrosis[13, 14]. Using the Cierny-Mader classification aids in treatment, with more aggressive debridement, revascularization, optimization of host co-morbidities, and potential bone stabilization for higher grade lesions[12]. Our case report would be designated as diffuse type 4A chronic osteomyelitis of the left fibula in an immunocompetent host due to direct inoculation from the time of his open tibia farm injury. Although a rare occurrence, malignancies found within chronic wounds are well-documented[15-17].

The tibia is the most common location for osteomyelitis and the incidence approaches 10% in open traumatic injuries[18,19]. The most common pathogen is *Staphylococcus aureus*[20]. Other common pathogens include *Staphylococcus epidermidis*, gram-negative bacilli, and anaerobes[21]. Biolfilm formation by bacteria represents a protective layer that is the key to the pathophysiology of chronic osteomyelitis[22]. Catalase is secreted into this protective layer by bacteria, neutralizing the hydrogen peroxide generated by host neutrophils[23]. Additionally, this biofilm layer allows for bacteria to adhere to bone, aggregate, and communicate with each other while evading host immune cells. Chronic osteomyelitis is characterized clinically by recurrence of pain in a patient with a history of osteomyelitis and swelling in association with a draining sinus[20]. These symptoms are similar to malignant transformation.

Clinically, Marjolin's ulcers present with increased pain, ulceration, fibrotic zones, bleeding, and irregular margins[24]. Our patient presented with an exophytic left leg mass with chronic serosanguinous wound drainage. The evaluation of Marjolin's ulcer includes clinical evaluation, inflammatory labs, plain radiographs and MRI imaging to assess the extent of the lesion[5]. Properly staging Marjolin's ulcers includes using CT imaging and the American Joint Committee on Cancer (AJCC) classification system[25]. Careful planning for tissue biopsy is necessary to ensure an accurate and timely diagnosis while avoiding complications[26]. Histologically, our case report was found to have moderately-differentiated SCC (T4N0M0). SCC is the most common variant of Marjolin's ulcer, accounting for up to 96% of cases[24]. However, other malignancies such as fibrosarcoma, myeloma, lymphoma, plasmacytoma, angiosarcoma, rhabdomyosarcoma, and malignant fibrous histiocytoma have also been reported[8, 27]. Histologic features of squamous cell carcinomas include atypical keratinocytes, increased nuclear pleomorphism, abnormal keratinization, and frequent mitotic figures. The choice of treatment is ultimately guided by having a thorough evaluation.

The discovery of regional metastasis in our case study added significant complexity in his Marjolin's ulcer treatment. Cutaneous squamous cell carcinomas have a relatively low rate of metastasis, ranging from 0.5-3.0%[15]. However, those arising from invasive Marjolin's ulcers have metastasis rates of 20-30%[28]. Risk factors for metastatic SCC include thickness >2mm, Clark level ≥IV, perineural invasion, and poorly or undifferentiated histologic grade[25]. In Kerr-Valentic's case series of 10 patients with Marjolin ulcer reported one patient that developed metastasis into a sentinel pelvic lymph node. Eastman et al published a separate case series of patients with Marjolin's ulcers secondary to upper extremity burn scars and found that 4 out of 5 cases had positive lymph nodes for occult metastasis despite not having clinical symptoms[29]. Lack published a case report of distant metastasis of a Marjolin ulcer to the inguinal lymph nodes and lung in a paraplegic patient with recalcitrant pelvic osteomyelitis and decubitus ulcer[30]. Despite these cases, our report illustrates the first detailed report of symptomatic lymph node metastasis for Marjolin's ulcer secondary to chronic long bone osteomyelitis.

The treatment of Marjolin's ulcer is complex and depends on the extent of the disease. Localized Marjolin's ulcers are treated wide resection with 2 to 4 cm margins[24]. For more invasive cases, amputation proximal to the tumor is advocated[5]. Radical hemipelvectomy has been described in the paraplegic population with malignancy of more proximal axial lesions[30, 31]. The treatment for regional metastasis is surgical dissection with adjuvant radiation therapy[32]. The dose of adjuvant radiation is 45-55 Gy in daily fractions of 2.0-2.5 Gy[33]. In contrast, if distant metastasis is present, first-line treatment is chemotherapy[32]. Despite having moderately-differentiated SCC and adequate surgical margins after a BKA, our patient developed regional metastatic disease. De Lima Vazquez showed that the survival of trunk and extremity T3N0M0 and T4N0M0 SCC with regional lymph node recurrence was not significantly different to patients without lymph node recurrence (34.1% and 43.3%, respectively)[34]. De Lima Vazquez did show that higher grade T4 lesions had worse 5-year survival than T3 lesions (24.2% and 48.7%, respectively). Our patient developed metastatic disease to his regional lymph nodes despite having a BKA of his invasive tumor. Following his subsequent superficial inguinal node dissection, the patient completed a 6-week course of adjuvant radiation, with a total of 6,600 cGY in 33 fractions. He was found to be disease-free at his 2.5 year follow-up.

CONCLUSION

Marjolin's ulcer is a rare sequalae of chronic wound infection and inflammation. Patients often presenting after a latency period with increased pain, exophytic mass, and drainage. In the absence of obvert clinical symptoms, progressive osteolysis on serial plain radiographs may be the only imaging sign, and a high clinical suspicion is warranted. Despite not having any signs of metastasis on presentation, Marjolin ulcers of the extremity have the potential risk of metastasis. After undergoing surgical dissection and adjuvant radiation of his regional inguinal lymph nodes, our patient has remained disease-free at 2.5 years surveillance. Our case illustrates the importance of performing an extensive workup and diligent follow up for the proper diagnosis and management of a Marjolin's ulcer.

REFERENCES

1. **JN., M.**, Ulcere, in In Dictionnaire de Medecine. 1828, Bechet: Paris. p. 31–50.
2. **Multhoff, G., M. Molls, and J. Radons**, Chronic inflammation in cancer development. Front Immunol, 2011. 2: p. 98.
3. **Yu, N., et al.**, Marjolin's ulcer: a preventable malignancy arising from scars. World J Surg Oncol, 2013. 11: p. 313.
4. **Kerr-Valentic, M.A., et al.**, Marjolin's ulcer: modern analysis of an ancient problem. Plast Reconstr Surg, 2009. 123(1): p. 184-91.
5. **Panteli, M., et al.**, Malignant transformation in chronic osteomyelitis: recognition and principles of management. J Am Acad Orthop Surg, 2014. 22(9): p. 586-94.
6. **Wolf, H., P. Platzer, and V. Vecsei**, Verrucous carcinoma of the tibia arising after chronic osteomyelitis: a case report. Wien Klin Wochenschr, 2009. 121(1-2): p. 53-6.
7. **Trent, J.T. and R.S. Kirsner**, Wounds and malignancy. Adv Skin Wound Care, 2003. 16(1): p. 31-4.
8. **Johnston, R.M. and J.S. Miles**, Sarcomas arising from chronic osteomyelitic sinuses. A report of two cases. J Bone Joint Surg Am, 1973. 55(1): p. 162-8.
9. **Hanahan, D. and R.A. Weinberg**, Hallmarks of cancer: the next generation. Cell, 2011. 144(5): p. 646-74.
10. **Klenerman, L.**, A history of osteomyelitis from the Journal of Bone and Joint Surgery: 1948 TO 2006. J Bone Joint Surg Br, 2007. 89(5): p. 667-70.
11. E, C., in De l'osteo-myelite 1852, Bull Mem Soc Chir: Paris. p. 431–436.
12. **Parsons, B. and E. Strauss**, Surgical management of chronic osteomyelitis. Am J Surg, 2004. 188(1A Suppl): p. 57-66.
13. **Cierny, G., 3rd, J.T. Mader, and J.J. Penninck**, A clinical staging system for adult osteomyelitis. Clin Orthop Relat Res, 2003(414): p. 7-24.

14. **Cierny, G., 3rd and D. DiPasquale**, Treatment of chronic infection. J Am Acad Orthop Surg, 2006. 14(10 Spec No.): p. S105-10.
15. **Copcu, E., et al.**, Thirty-one cases of Marjolin's ulcer. Clin Exp Dermatol, 2003. 28(2): p. 138-41.
16. **Fitzgerald, R.H., Jr., N.S. Brewer, and D.C. Dahlin**, Squamous-cell carcinoma complicating chronic osteomyelitis. J Bone Joint Surg Am, 1976. 58(8): p. 1146-8.
17. **Reich-Schupke, S., et al.**, Squamous cell carcinomas in chronic venous leg ulcers. Data of the German Marjolin Registry and review. J Dtsch Dermatol Ges, 2015. 13(10): p. 1006-13.
18. **Patzakis, M.J. and J. Wilkins**, Factors influencing infection rate in open fracture wounds. Clin Orthop Relat Res, 1989(243): p. 36-40.
19. **Gustilo, R.B. and J.T. Anderson**, Prevention of infection in the treatment of one thousand and twenty-five open fractures of long bones: retrospective and prospective analyses. J Bone Joint Surg Am, 1976. 58(4): p. 453-8.
20. **Calhoun, J.H. and M.M. Manring**, Adult osteomyelitis. Infect Dis Clin North Am, 2005. 19(4): p. 765-86.
21. **Lew, D.P. and F.A. Waldvogel**, Osteomyelitis. Lancet, 2004. 364(9431): p. 369-79.
22. **Patzakis, M.J. and C.G. Zalavras**, Chronic posttraumatic osteomyelitis and infected nonunion of the tibia: current management concepts. J Am Acad Orthop Surg, 2005. 13(6): p. 417-27.
23. **Raukar, N.P. and B.J. Zink**, Bone and Joint Infections, in Rosen's emergency medicine : concepts and clinical practice. 2014, : Eighth edition. p. 1831-1850.
24. **Bozkurt, M., et al.**, Current concepts in the management of Marjolin's ulcers: outcomes from a standardized treatment protocol in 16 cases. J Burn Care Res, 2010. 31(5): p. 776-80.
25. **Warner, C.L. and C.J. Cockerell**, The new seventh edition American Joint Committee on Cancer staging of cutaneous non-melanoma skin cancer: a critical review. Am J Clin Dermatol, 2011. 12(3): p. 147-54.
26. **Mankin, H.J., C.J. Mankin, and M.A. Simon**, The hazards of the biopsy, revisited. Members of the Musculoskeletal Tumor Society. J Bone Joint Surg Am, 1996. 78(5): p. 656-63.
27. **Saglik, Y., et al.**, Squamous cell carcinoma arising in chronic osteomyelitis. Int Orthop, 2001. 25(6): p. 389-91.
28. **Pekarek, B., S. Buck, and L. Osher**, A Comprehensive Review on Marjolin's Ulcers: Diagnosis and Treatment. J Am Col Certif Wound Spec, 2011. 3(3): p. 60-4.
29. **Eastman, A.L., et al.**, Sentinel lymph node biopsy identifies occult nodal metastases in patients with Marjolin's ulcer. J Burn Care Rehabil, 2004. 25(3): p. 241-5.
30. **Lack, W. and T. McKinley**, Marjolin's ulcer: incidental diagnosis of squamous cell carcinoma on hemipelvectomy for recalcitrant pelvic osteomyelitis. Iowa Orthop J, 2010. 30: p. 174-6.
31. **Fairbairn, N.G. and S.A. Hamilton**, Management of Marjolin's ulcer in a chronic pressure sore secondary to paraplegia: a radical surgical solution. Int Wound J, 2011. 8(5): p. 533-6.
32. **Burton, K.A., K.A. Ashack, and A. Khachemoune**, Cutaneous Squamous Cell Carcinoma: A Review of High-Risk and Metastatic Disease. Am J Clin Dermatol, 2016. 17(5): p. 491-508.
33. **Stratigos, A., et al.**, Diagnosis and treatment of invasive squamous cell carcinoma of the skin: European consensus-based interdisciplinary guideline. Eur J Cancer, 2015. 51(14): p. 1989-2007.
34. **de Lima Vazquez, V., et al.**, Prognostic factors for lymph node metastasis from advanced squamous cell carcinoma of the skin of the trunk and extremities. World J Surg Oncol, 2008. 6: p. 73.

LESSONS AND ADVICE FROM OUR PATIENTS: A FOCUS GROUP OF SARCOMA SURVIVORS

Jill Kain, MSN, FNP-C[1,2], Amanda Carlson, BBA[2], Justin Kahler, MHA[2], Julianna Bemboom, BA[2], Katelyn McDonald, BS[1], and Benjamin Miller, MD, MS[1,2]

ABSTRACT

Background: Sarcomas are a rare, encompassing a heterogeneous group of malignancies. Success treatment often requires a combination of surgical resection, chemotherapy, and/or radiation. These life-altering interventions can have lasting impact on function and quality-of-life. There is little known about treatment outcomes from the perspective of sarcoma patients.

Purpose: The initial goal of this investigation was to determine the sources and categories of information patients sought at various time points in their care. In addition, we investigated how participants coped with physical and psychological issues that accompany treatment. Finally, we elicited advice on what the care team did well, and could have been done differently, during their diagnosis and recovery.

Methods: A qualitative, focus group research method was utilized. A purposive sample of participants with a diagnosis of a sarcoma was identified. Three focus groups (20 total participants) were formed and audio/video recorded. The transcripts were analyzed to identify common themes and a scissor-and-sort technique was used to attribute participant comments to the identified themes.

Results: Themes were identified and categorized into four major areas: 1) Information at diagnosis, 2) Relationship with care team, 3) Social support, and 4) Restoration to "normal."

Conclusion: We identified several areas that can be addressed to enhance patient counseling, emotional understanding, and expectations of treatment. These can serve as a guide for future research endeavors and program development.

Key Words: sarcoma, focus group, quality-of-life

BACKGROUND

Sarcomas are a rare, heterogenous group of bone and connective tissue malignancies often affecting the extremities or pelvis. They account for an estimated 1% of all cancer, affecting over 15,000 people a year in the U.S.[7] Standard treatment for non-metastatic sarcoma is a complete surgical resection, with variable use of chemotherapy and radiation as adjuvant treatments depending on histopathologic subtype. These dramatic and life-altering treatments can have lasting impact on the function and quality of life (QoL) of sarcoma survivors. While sarcoma survivors are known to have a physical functioning level that is below the level of functioning in the general population,[11] there is a paucity of reports focusing on limitations and uncertainties from the perspective of the patient.

Literature Review

A review of literature was performed to evaluate existing qualitative data regarding the unique informational needs of patients facing a sarcoma diagnosis and how those needs change over time. There have been very few studies to date that highlight sarcoma patient perspectives about these issues. Although many modern reports on results after sarcoma treatment utilize validated outcome tools specific to sarcoma patients (e.g. Musculoskeletal Tumor Society Score, Toronto Extremity Salvage Score), these do not directly consider the patients' unique perspective regarding information desired or coping with the diagnosis, treatment, and long-term effects. In 2012, Tang and colleagues performed a systematic review of QoL studies in adult extremity sarcoma survivors and highlighted that there is no gold standard QoL measure for extremity sarcoma patients that includes emotional and social domains, rather current tools focus on subjective physical function and objective functional impairment.[11] Payne et al[8] conducted a pilot support group intervention for soft tissue sarcoma (STS) patients with no evidence of disease in which patients had time for general discussion of personal concerns in addition to the use of a modified thematic counseling model

[1]University of Iowa Department of Orthopaedics and Rehabilitation

[2]University of Iowa Holden Comprehensive Cancer Center

Correspondence:
Jill Kain
University of Iowa Hospitals & Clinics Department of Orthopedics
200 Hawkins Dr. 01007JPP Iowa City, IA 52242
319-384-6061 (w) 319-384-9307 (f) 515-554-2345 (h)
jill-kain@uiowa.edu

Conflicts of Interest and Source of Funding: University of Iowa Sarcoma Multidisciplinary Group provided funding for this study. No conflicts of interest declared for the authors.

to provide information regarding the disease, stress management, relaxation techniques, and coping skills. The goal of this study was to address the informational needs of STS patients and reduce psychological distress. In a 2009 prospective study by Davidge et al[1], sarcoma patient's pre-operative expectations were associated with functional outcome. Education, dispositional optimism, tumor location, tumor stage and baseline function were significant predictors of expectations. Although numerous studies exist in the general oncology literature about information seeking behavior among cancer patients as a whole, sarcoma patients are far underrepresented in these reports, most likely due to the relative rarity of the disease. As the treatment of sarcoma, specifically the focus on limb-sparing surgery of the extremities, is unquestionably unique compared to other malignancies, an investigation designed specifically to address expectations and results of sarcoma patients is needed.

Purpose

We have observed in our clinical experience that questions of prognosis and survival are the most pressing informational needs at initial diagnosis. However, as time progresses after a cancer diagnosis and successful treatment, patients are increasingly concerned about QoL and functional issues. In order to gain a more patient-oriented perspective on this topic, we proposed a qualitative focus group of sarcoma survivors. The primary interest for this research project was to determine general categories of information (e.g. basic cancer information, survival statistics, plan of care, long-term function) patients want to know at various time points in their care, as well as the main sources of their information. Second, we investigated how patients coped with various physical and psychosocial issues that may occur with sarcoma treatment. Lastly, we elicited advice from participants on what the care team could have done differently during the course of treatment.

METHODS

A focus group study design was chosen as there is limited information in the literature with regard to the patient experience over the course of sarcoma treatment and recovery, how sarcoma patients obtain information, and what information is important to them at different points in their treatment and survivorship. Focus groups are increasingly being used in health-related research in order to gain a better understanding of individual beliefs, experiences, and health-related behaviors.[9] The focus groups were lead by the orthopaedic oncology nurse practitioner (JMK); the treating surgeon (BJM) was not present during any of the groups. The study was submitted and approved by the University of Iowa Institutional Review Board prior to initiation of patient contact. Funding for the study was provided by the University of Iowa Sarcoma Multidisciplinary Oncology Group.

Participants

A purposive sample of English speaking potential participants ≥18 years old was identified from all sarcoma surgeries performed by a single Orthopaedic Oncology surgeon (BJM) between 2011 and 2015 at the University of Iowa Hospitals and Clinics. Participants were offered an incentive of $50 for participation in a session. All sarcoma histologic subtypes, grade, and stage were included, except for atypical lipomatous tumors and dermatofibrosarcoma protuberans, as treatment of these very low-grade tumors are different than the majority of sarcoma. Two hundred seventeen potential participants were identified, and informational letters and response cards were sent via mail, with follow-up phone calls to confirm interest and select workable dates. Three focus groups, made up of 4, 9, and 7 participants (20 total), were completed in February 2016 (Table 1).

Data Collection

Focus groups were held in clinic conference rooms. No additional family members or friends joined the participants. The sessions were lead by a moderator with 2-3 note takers. Note takers were responsible for recording patient behaviors and reactions that would not be gleaned from review of the transcripts. We obtained informed consent from each participant prior to the beginning of the session. The sessions were audio and video recorded for transcription purposes. A discussion guide (Appendix A) developed by the research team was used by the moderator to ensure research aims were being met during the discussion. The moderator did not go through each question verbatim, rather the conversation occurred organically among participants and the discussion guide was utilized as needed if discussion slowed. Each focus group had approximately 75 continuous minutes of dialogue. At the conclusion of the study, participants were given a list of psychosocial resources and thanked for their participation.

Data Analysis

After each focus group, the moderator and note takers held a debriefing session. A standard debriefing was done for each focus group to discuss emerging themes, contradictions to previous focus group comments, unclear or confusing remarks, individual behaviors or interactions that would not be easily identified on transcription, and any clarifications that should be made for future groups. This was an important part of the initial data analysis in order to continually evolve the research questions and techniques utilized as part of the iterative nature of qualitative research.[2] Transcripts were generated by a third party, the University of Iowa Social Sci-

Table I. Demographic breakdown of participants

Characteristic	Number
Age (years)	
Average (range)	51 (22-79)
Sex	
Male	11
Female	9
Location	
Upper extremity	4
Lower	15
Pelvis	1
Type	
Bone	7
Soft	13
Histology	
Undifferentiated pleomorphic sarcoma	4
Myxofibrosarcoma	4
Chondrosarcoma	5
Osteosarcoma	2
Leiomyosarcoma	2
Malignant peripheral nerve sheath tumor	1
Fibromyxosarcoma	1
Synovial sarcoma	1
Grade	
1	7
2	2
3	11
Stage	
Localized	17
Metastatic	3
Adjuvant Treatment	
Chemotherapy	4
Preoperative radiation	6
None	10
Surgery	
Resection only	16
Curettage and cementation	1
Distal femur prosthesis	2
Acetabular reconstruction	1
Time Since Surgery (years)	
Average (range)	2.2 (0.6-4.8)

ence Resource Center (SSRC). They were typed verbatim initially then edited to remove superfluous remarks. Transcripts were not returned to patients for comment or correction. The transcripts were analyzed by the research team to identify common themes via multiple readings of the transcripts and then a scissor-and-sort technique was used to attribute participant comments to the identified themes. Observations not inherently obvious, but potentially important, from the language of the transcripts (such as clearly emotional topics) were noted on transcripts. The SSRC staff independently reviewed the transcripts and provided a summary of findings, which was used to assist in validation of the themes identified by the primary research team. The SSRC highlighted comparable themes to that of the research team. The Consolidated criteria for reporting qualitative studies (COREQ) checklist was used as a framework to assess the rigor of this qualitative approach.[12]

RESULTS

Four categories of findings emerged during data analysis: information about diagnosis and treatment, relationship with the care team, social support, and restoration to "normal." We created a summary of direct patient quotations (Table 2) and the primary discussion points (Table 3).

Information about Diagnosis and Treatment

As with other cancer diagnoses, health information-seeking behavior was identified as a highly individualized trait among sarcoma patients, with some displaying an active information-seeking style and others more moderately active or passive. The sarcoma medical team was identified by many individuals as the primary source of information about their cancer and treatment. The Internet was used differently among participants, with younger patients unsurprisingly demonstrating a greater predilection toward virtual resources. Some utilized the Internet to research their diagnosis initially, but felt dissatisfied or frightened by the information they found or felt they could not find information that was applicable to them. Others identified the Internet as a way to seek support in dealing with their diagnosis or to establish camaraderie with other sarcoma survivors. Open and closed Facebook groups were specifically mentioned as a way to speak to other sarcoma survivors and seek support. As time passed after diagnosis, several noted that their need for continued information regarding the diagnosis decreased, but still highlighted the psychological and emotional impact of continued information seeking.

The desire to know survival statistics varied among participants, with some expressing their desire to have a general understanding of the extent of their disease at diagnosis. In contrast, others did not seek this in-

Table II. Lessons and advice from analysis of focus groups

Theme	Lessons	Advice
Information at diagnosis	• Information seeking behavior is a highly individualized trait • Although the internet was utilized, the oncology provider was the primary source of information • Younger patients were more likely to use internet-based resources and social media to supplement information they received about diagnosis • Genetic component and familial risk was a common concern • Functional limitations were more significant than anticipated	• Desire for survival statistics was variable with many patients expressing a desire not to know • The need for specific information (survival estimates, housing options during treatment, financial support, coping strategies) should be revisited at different time points during treatment and recovery
Relationship with care team	• Trust in oncology providers is very important – many had lost faith due to the perceived delays in diagnosis • Access to care team is important and was suboptimal for those located remotely from the treating institution • Patients were surprised and frustrated that their primary care providers did not know the details of their diagnosis and treatment	• Local access (outreach clinics)would be beneficial • Better care coordination between specialists and general practitioners is desired – a treatment summary and survivorship plan would help
Social support	• Family and friends provided most of the support (physical care and logistics) but can also be a source of stress and anxiety • Discussion with others with similar challenges was helpful – did not necessarily have to be other sarcoma patients • Social media was a good source of emotional/psychological support	• A social worker to help navigate the logistics of care and financial concerns would be helpful • A social media forum of sarcoma patients (e.g. a closed Facebook page) would provide a means for social support
Restoration to "normal"	• Was the most emotional and passionate topic • Frustration that physical therapy was not focused on reaching a pre-treatment level of activity • Expectations for recovery differed by individual, with some expecting attaining a high level of function • Managing psychological recovery can be more challenging than the physical limitations	• Recovery should be expected to be slow, with "good" and "bad" days • Physical therapy is important and should be tailored to the individual • A distress questionnaire may help identify those in need of additional psychological services

formation or only wanted to know if the statistics were optimistic. Many participants expressed concern with whether or not there was a hereditary component to sarcoma. Others highlighted the initial shock and feeling overwhelmed at the time of diagnosis and provided suggestions for relaying information to patients at various time points in their care.

Relationship with the Care Team

Establishing a trusting relationship with the sarcoma team was important to many participants. The sarcoma team provided information as well as reassurance during diagnosis, throughout treatment, and beyond. Many expressed a loss of trust in local healthcare providers due to delays in diagnosis, and reestablishing confidence in the medical system was important for many. It was spontaneously highlighted numerous times that the lack of geographic proximity to the treatment team proved frustrating and isolating. This is a real and continuing challenge as much sarcoma treatment is regionalized and consolidated in tertiary referral centers. This regionalization guarantees that patients are treated with appropriate and modern interventions, but may have some negative consequences regarding access to treating specialists. Practical aspects of coordination of care and fragmentation of the medical system were highlighted as areas of frustration. Participants recognized lack of communication regarding the surveillance plan after treatment and coordination of tests, imaging, lab, and records transfer as significant stressors and areas of potential improvement.

Social Support

Several comments highlighted the ongoing psychosocial and emotional support that is needed throughout sarcoma treatment and survivorship and numerous participants provided suggestions that were helpful for them. These included speaking with an oncology social worker, connecting with other sarcoma survivors via Facebook, and speaking with other non-sarcoma cancer survivors. Although the purpose of the focus groups was not meant to be a support group, some people expressed their preference for in-person discussions rather than virtual interaction. Many participants highlighted the important

Table III. Verbatim quotations from focus group patients

Information about Diagnosis and Treatment
I think in our society, instinctively you always go to the internet. I mean that's what we do and whether you believe everything that you read or you don't. I went and there was hardly anything on it and what I found I didn't like.
Yeah, I wouldn't say that I research but like I participate in Sarcoma Alliance Facebook group and another sarcoma support group on Face-book
I think too much information can be more damage. Cause if you start reading on it goes from the different things into the different areas and it works on you. So I just quit looking on the computer about the sarcoma and the different stuff and I think I've done pretty well, you know, since I quit and because the mind can play really tricks on you.
Well, my thought was where else have I got it, you know?
I was in high school, I was diagnosed at seventeen. So they pulled me out of school and told me and it was just this slow two weeks of, I have no idea what's going on, but I didn't get a lot of information on survivorship, which I really appreciated. Until just this last year or so Dr. Miller started talking to me about survivorship rates at this point in my treatment and I find that helpful because they sound good. I think if they sounded bad I wouldn't want them, so.
I don't recall hearing that and I don't think I would have wanted to know. I just wanted to know what I was up against,what the plan was and… how to get through it.
As for survivor rates I don't remember being told, I'm sure I was at some point in time but it wasn't something that was a priority for me at that point in time I just wanted it fixed so I could get back to my life… Either way for me, I don't think it necessarily hindered, for me, because they're just rates and I and I can be either one side or the other so.
I think that was one of the first questions I asked. Is if the kids would be able-you know, catching this and Dr. Miller right away said "no."
Maybe at the time that they're sending those brochures home, you're just SO overwhelmed with all the information.
You can do some FAQ's and ask questions at the various stages, diagnosis, prognosis, surgery, options or recovery expectations.
Relationship with Care Team
Well, they're the resident experts.
I kind of rely on physicians and the oncologists to give me information.
I think Dr. Miller gave me a lot of peace in mind. He was very helpful in that regard. He was honest and direct.
It's like its one less thing to worry about because you know. Somebody's looking out for ya that knows what they're doing.
I had post-operative complications. I had an infection and some other stuff but in my case it was the problem was that I couldn't just "pop in" and see Dr. Miller since I was working and Iowa City is two hours away and all that.
Mercy and Unity Point have support groups and things available but they're mostly promoted to their customers. And since we go to the University of Iowa, we're left high and dry. That's how I felt.
I had seen my physician fairly recently I guess and …she thought everything was done up in Iowa City and I did have some abnormal blood work too. So it was kinda like oh well (laughs) (whispers: I guess I) that was odd I thought because there was not that communication there. She just thought everything had been done.
Social Support
It's not good enough just to offer it at the outset when somebody hasn't been going through all of this, but to be aware of, maybe how they're feeling, responding to all of this.
I have a real good friend that's a breast cancer survivor and had different paths of treatment and different hospitals, but the thing that she really helped me with is just trying to explain the weird feelings and I'm not like a big emotional type, I mean so I felt like a wreck cause I felt like I can't think straight I can't sleep I don't know, this isn't me. So talking to her just even getting "those things are expected, you know don't feel like your falling apart or you're weird because you feel this way all of the sudden" but so that was a big help for me.
I'm more of a high touch person than a high tech so it would have been nice if there was something in the hospital where people my age.
You need family support. That's the biggest thing right there.
Family is a big deal too. I got eight. There are eight in our family. I got six sisters and one brother and I came down for radiation everyday five days a week and I had a different driver every day, which was remarkable.
I stopped bringing my family with me to my appointments, started bringing friends, instead of my family because my mom really winds me up. I think she would-she worried MORE and I would have more anxiety leaving there than I would with a friend.

Table III. Verbatim quotations from focus group patients

Restoration to "Normal"
I didn't expect it to be as long, kind of thought maybe it would be a quicker recovery and I still have some complications that are frustrating to me even a year and a half later but you guys have reassured me and it was more of a mental thing.
I went to physical therapy after my surgery and that was a big help to get me back to moving again.
I think it [physical therapy] was extremely important even though I could walk fairly well it was still important for it to make- to get that function back that I wanted.
I think that most of the time it was like let's just get me back to functioning even like with my lungs get back to the point where you can walk to the mailbox and still have your air and I'm like NO I want to run I want to get it back to teaching (Ta-Kwon-Doe) and being really physical.
To get physically back and I don't know that I realized the complications of some of the nerve damage, and scar tissue damage and things like that that I have had to do extra kind of alternative massage therapy and things like that to kind of break down some of that scar tissue and extra exercises to build up certain muscles.
Well I'd say attitude is a big thing. I mean keep a positive attitude.
I know I'll never be back to where I was, I know I will never be back to what I was but as best as I can be now and as happy as I can be now you know.
You want to be back to normal as fast as possible and it's not that way. I think you know you gotta find your new normal. You know it's not, you're not going to be like you were before but you're going to be a new normal. So you find a good goal where you can cope and you go on with life.
It's not just the physical, it's the emotional and the long term.

role of family, particularly as caregivers and advocates. Some noted that family, despite virtuous intentions, could at times increase anxiety or stress.

Restoration to "normal"

The topic of returning to "normal" was the most passionate topic discussed in the focus groups. Many comments were associated with emotionally charged language and non-verbal evidence of emotion, such as crying, increased tone and volume, and increased participation by group members. Many participants expressed the long physical and emotional recovery process after sarcoma surgery. The importance of physical therapy was highlighted by many as a way to optimize recovery after surgery. The expectations for recovery varied among participants' pre-diagnosis level of functioning and goals despite the reality of their limitations due to surgery. This appears consistent with a previous study that demonstrated patients expecting a difficult recovery and those with uncertain expectations had worse functional outcomes than patients anticipating an easy recovery.1 With some participants a discrepancy seemed to exist between the surgeon's satisfaction with function and the patient's satisfaction with function. Some made comments that highlighted the reality of a "new normal" after sarcoma treatment and the challenges associated with coping and moving on after the diagnosis. It was noted in a previous systematic review of sarcoma survivors that being optimistic was associated with good functional outcomes11 and in a study of long-term sarcoma survivors, 94% of participants felt that the cancer had made them a "better person."[13] Several comments from the focus group emphasized remaining positive despite the diagnosis and unanticipated adverse events during treatment and recovery.

CONCLUSION

Several implications for orthopedic oncology practice emerge from this work. Patients with orthopedic tumors benefit from a team approach to their care. Recognizing that specialists are the predominant source of information regarding diagnosis and treatment is important for the care team to keep in mind when counseling patients. Patient education should be individualized and based on the patient's desire for information and preferred method of receiving it. Additionally, various topics should be revisited and multiple times throughout active treatment and survivorship. The care team should strive for seamless coordination of care among sub-specialties and keep the patient's primary care provider apprised of their patient's treatment and follow-up plan. Counseling patients regarding recovery expectations and re-entry into life after sarcoma is important for patients. Providing psychosocial support or making referrals to aid in addressing these issues also proved to be an important aspect of care for sarcoma survivors.

REFERENCES

1. **Davidge, K., Bell, R., Ferguson, P., Wunder, J., Davis, A.** (2009). Patient expectations for surgical outcome in extremity soft tissue sarcoma. J Surg Oncol, 100(5). 375-381. Doi: 10.1002/jso.21301
2. Family Health International. (n.d.). Qualitative Research Methods: A Data Collector's Field Guide. "Focus Groups." pp 51-82
3. **Kitzinger J.** (1994). The methodology of focus groups: the importance of interaction between research participants. Sociology of Health, 16 (1): 103-21.
4. **Kitzinger J.** (1995). Introducing focus groups. British Medical Journal, 311: 299-302.
5. **Lalazaryan, A. & Zare-Farashbandi, F.** (2014). A review of models and theories of health information seeking behavior. Intl J Health Sys & Disaster Mgmt, 2(4). 193-203.
6. **Marbach, TJ.** (2011). Patient preferences concerning treatment plans, survivorship care plans, education, and support services. Oncology Nursing Forum, 38(3): 335-342
7. National Cancer Institute (2014). A snapshot of sarcoma. Retrieved from http://www.cancer.gov/research/progress/snapshots/sarcoma
8. **Payne, DK, Lundberg, JC, Brennan, MF, & Holland, JC.** (1997). A psychosocial intervention for patients with soft tissue sarcoma. Psycho-Oncology, 6(1): 65-71. Doi: 10.1002/(SICI)1009-16119.
   Rabiee, F. (2004). Focus-group interview and data analysis. Proceed Nutr Society, 63, 655-660. Doi: 10.1079/PNS2004399
10. **Shingler, SL, Swinburn, P, Loyd, A, Diaz, J, Isbell, R, Manson, S, Benson, C.** (2013). Elicitation of health state utilities in soft tissue sarcoma. Qual Life Res, 22:1697-1706. Doi: 10.1007/s11136-012-0301-9
11. **Tang, M, Pan, D, Castle, D, Choong, P.** (2012). A systematic review of the recent quality of life studies in adult extremity sarcoma survivors. Sarcoma, 12. Doi: 10.1155/2012/171342
12. **Tong, A, Sainsbury, P, and Craig, J.** (2007). Consolidated criteria for reporting qualitative research (COREQ): a 32-item checklist for interviews and focus groups. Intl J Qual Health Care, 19(6): 349-357. Doi: 10.1093/intqhc/mzm042
13. **Weiner, L, Battles, H, Bernstein, D. et al.** (2006). Persistent psychological distress in long-term survivors of pediatric sarcoma: the experience at a single institution. Psycho-Oncology, 15(10). pp 898-910.

Appendix A. Discussion Guide Questions

1. What did you want to hear most about when you were 1st diagnosed with sarcoma?

Probes: Did you want to hear survival statistics?
Were you able to think long-term (i.e. life after cancer)?

2. When you were first diagnosed, were you able to get the information you needed?
If not, why not? What got in the way of your getting that information?

Probes: Didn't know enough to ask questions?
Didn't know where to look?
Too stressful to process (i.e. cancer diagnosis was too overwhelming to think about any specific details)?

3. Where did you turn to for information regarding sarcoma?

4. Have you turned to different sources for information as your needs have changed?

5. Who has been most helpful in dealing with your concerns about sarcoma? Least helpful?

6. Did the kind of information you needed change over time? How?

7. Is there anything you know now that you wish you would have known when you were first diagnosed? Any advice you would give to yourself?

8. We'd like you to think about the physical side of having sarcoma. Are there things that have been particularly helpful to you in dealing with physical issues such as managing pain, changes in the way your body functions, or changes in your appearance? We are not asking that you go into detail about the physical issues themselves, but more about what was helpful in dealing with them.
Are there things you didn't get that would've been helpful?

Probes: Managing pain, change in the way your body functions, disability, appetite/nutrition, living with chronic illness

9. Looking back, do you feel you understood how surgery or treatment of your sarcoma would affect your daily function? If not, is there anything that you feel would've been helpful in understanding this?

Probes: Talk to other survivors, diagrams/pictures/handouts

10. What do you think is the biggest gap in the programs, services, or supports for sarcoma survivors? We would like to hear from everyone on this question.

11. If you were to talk to other people with sarcoma, what advice (based on your own experience) would you give?

12. What is the most important message you would want to send to sarcoma doctors?

AN OSTEOLOGICAL STUDY ON THE PREVALENCE OF OSTEOCHONDROMAS

Gregory R. Gaumer, BS, Doug S. Weinberg, MD, Christopher D. Collier, MD,
Patrick J. Getty, MD, Raymond W. Liu, MD

ABSTRACT

Background: Osteochondromas are frequently reported to be the most common benign tumor of bone. However, there is not definitive data on their prevalence rate as they are often clinically silent, with previous studies estimating 1-3%.

Methods: We examined a large osteologic collection of 2954 skeletons to identify likely osteochondromas. One author examined all bones excluding the skull in each skeleton for atypical cortical projections. These candidates were then evaluated by an orthopedic resident and then a fellowship trained pediatric orthopedic surgeon for final inclusion using strict criteria.

Results: 13 cases of osteochondroma were identified from 2954 skeletons to yield a prevalence of 0.44% (95% confidence interval 0.20% – 0.68%) in the study population. All were located on long bones: three in the humerus, six in the femur and four in the tibia.

Conclusions: We found a prevalence of 0.44% for osteochondromas, which is approximately half the lowest value reported in previous literature.

INTRODUCTION

Osteochondromas are defined according to WHO classification as a cartilage-capped bony projection arising on the external surface of bone and containing a marrow cavity that is continuous with that of the underlying bone.[1] The lesions can be pedunculated or sessile, and they have been reported as the most common benign tumor of bone based on pathological and radiographic series, although the true relative prevalence is unclear.[1-5] Osteochondromas typically arise in children at the metaphysis of long bones, especially the distal femur, proximal humerus, proximal tibia and fibula. It is rare to find involvement of the carpal or tarsal bones, patella, sternum, skull or spine, although any bone can be affected.[1, 2] There is no sexual predilection for this disorder.[1]

Osteochondromas are slow growing lesions with rare malignant transformation but can raise cosmetic concerns and impinge on local structures, including nerves, vessels and tendons, leading to symptomatology.[2,6,7] The majority of lesions are solitary, but they can occur as multiple lesions as part of the syndrome hereditary multiple exostosis (HME), which affects approximately 15% of patients with osteochondromas and is an autosomal dominant inherited disorder.[4,9,10]

Earlier studies of osteochondromas have estimated prevalence at 1-3%. These are based on estimates of patients undergoing detailed radiographical evaluation, and pathology series.[7,10] Pedunculated osteochondromas are considered to be more common. However, to our knowledge, true prevalence data does not exist for osteochondromas, with estimation difficult given that clinical prevalence studies are highly subject to bias and as many of these lesions are discovered incidentally. Osteochondroma incidence is reported as 35% of benign and 8% of all bone tumors, though this is considered an underestimate as most are asymptomatic.[1] Most cases are diagnosed within the first three decades of life, commonly in children or adolescents between 10 and 15 years of age.[8] This study looked at a large osteological collection to estimate prevalence of osteochondromas.

METHODS

This study examined 2954 skeletons in the Hamann-Todd Osteological Collection for evidence of osteochondromas. This collection is maintained at the Cleveland Museum of Natural History and complete demographic information is available for 2499 of the specimens. The skeletons were from individuals that ranged between less than one year and 80 years of age, with an average age of 51 ± 13 years. There were 83 specimens of children aged between one year of age and 17 years. The sexual distribution was 2121 males and 378 females. The racial distribution was 1631 Caucasian, 859 black, five American Indian, and four other. The majority of the skeletons were complete with all of the bones except the skull examined.

One author (GG) screened all bones for potential os-

Division of Pediatric Orthopaedic Surgery
Case Western Reserve University
Rainbow Babies and Children's Hospital
11100 Euclid Avenue, RBC 6081
Cleveland, OH 44106

Disclosure: No external source of funding was used for this study.

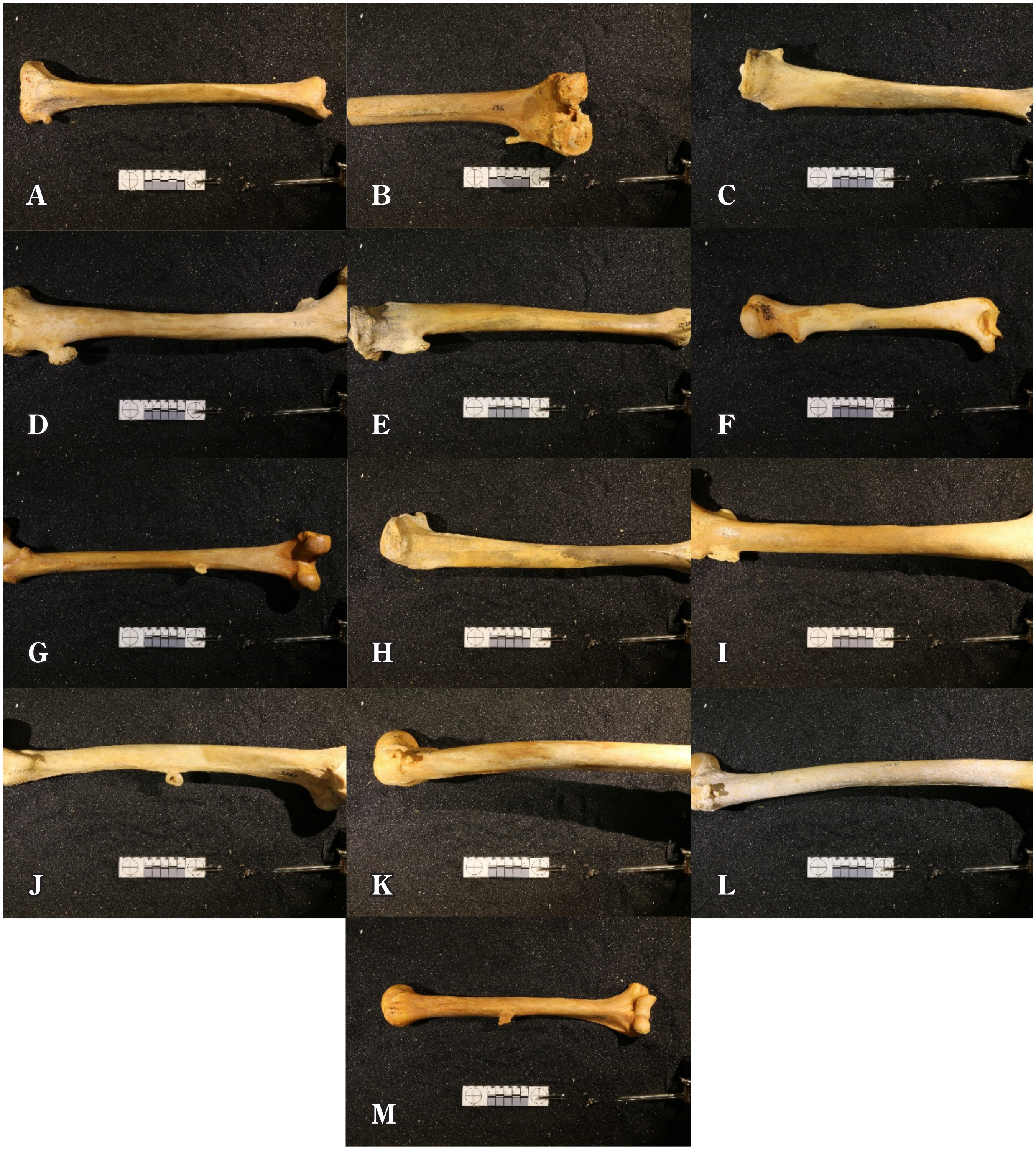


Figure1. A. Anterior lateral proximal tibia B. Anterior medial distal femur (bone cut during processing) C. Posterior medial proximal tibia D. Anterior lateral distal femur. E. Posterior lateral proximal tibia. F. Anterior medial proximal humerus. G. Posterior lateral midshaft femur. H. Posterior lateral proximal tibia. I. Anterior lateral proximal femur. J. Posterior midshaft femur. K. Anterior proximal humerus L. Anterior lateral proximal femur. M. Posterior medial midshaft humerus.

Table I.

Specimen	Age	Sex	Race	Location of Lesion
HTH 0088	35	Male	White	Tibia
HTH 0186	68	Male	White	Femur
HTH 0452	38	Male	White	Tibia
HTH 1086	21	Male	Black	Femur
HTH 1831	26	Male	Black	Tibia
HTH 1925	30	Female	Black	Humerus
HTH 2379	67	Male	Black	Femu
HTH 2388	45	Male	White	Tibia
HTH 2678	40	Male	Black	Femur
HTH 3115	57	Male	White	Femur
HTH 3250	42	Male	Black	Humerus
HTH 3261	58	Male	White	Femur
HTH 3385	44	Male	Black	Humerus

teochondromas. Special emphasis was placed on the long bones of the arm and leg. Bones with abnormal boney outgrowths then examined by an orthopedic resident (DW) to help rule in and out specimens before they were examined a final time by an attending fellowship-trained pediatric orthopedic surgeon (RL) for inclusion to the final count of osteochondromas.

Criteria for inclusion included location on the metadiaphyseal side of the growth plate, direction of growth away from the growth plate and the shape of the ossification. We excluded florid reactive ossifications, which were identified as large disorganized growths of osseous material, most often around joints; traction exostoses; and possible sessile osteochondromas as they could not be adequately identified or differentiated from other normal boney variants.

RESULTS

Out of 2954 skeletons examined, >100 examples of abnormal ossification were found. These included normal variants, infections, florid reactive periostitis, traction exostoses and osteochondromas. Careful review produced 13 highly likely pedunculated osteochondromas (Figure 1, Table 1). We therefore report a prevalence of 4.4 per 1000 (0.44%, 95% confidence interval 0.20% – 0.68%) in the sample population. All of the lesions were located on long bones: four (31%) were located on the tibia, six (46%) on the femur and three (23%) on the humerus. We did not locate any definite lesions on the flat bones in this study. Ten (77%) were located near the metaphysis of the bones, while three (23%) were located in the diaphysis.

All of the osteochondromas were found on skeletons that had complete demographic information. We compared the demographic information of affected individuals to the subset of the museum collection that had complete demographic information (2499 of the 2954 total subjects). The average age of skeleton that included an osteochondroma was 44 years, while the average age of the specimens in the collection was 51 years. One female specimen had an osteochondroma, for a prevalence of 0.26%. The male prevalence was 0.56%. There were 5 lesions in black specimens, for a prevalence of 0.81%. The remaining 8 tumors were in white specimens, for a prevalence of 0.37%.

DISCUSSION

In our evaluation of a large osteologic collection we report a prevalence value of 4.4 per 1000 (0.44%). This is lower than estimated by other reports. This is one of the few direct estimates of this lesion on a random large population, and the only one that uses an osteological collection to evaluate this lesion. We believe our results are lower than the literature values for several reasons. First, although the bones are well maintained, it is possible that some pedunculated tumors could have been lost through handling and processing of the collection. We believe that this is unlikely to be a major source of error though, as damage would likely have left behind remnants of the stalk or a hole in the cortex of the bone that could have been identified. Second, it is possible that additional tumors on smaller and irregular bones, like the bones of the carpus or the vertebrae, were missed. Third, we only included pedunculated tumors and none of the sessile osteochondroma variants. Pedunculated lesions are considered more common than sessile, but earlier reports we reviewed did not give an analysis of the relative rates. Sessile osteochondromas could not be adequately differentiated from the numerous traction exostoses that were identified in the collection. Fourth, there have been reports of spontaneous resorption of osteochondromas, although this is felt to be fairly uncommon.[11,12] Finally, our screen included pediatric skeletons where a potential future osteochondroma might not have formed yet, although the proportion of immature skeletons in the collection is proportionally small. Despite all these possibilities, it is also possible that given that previous reports likely were influenced by a higher capture rate secondary to symptomatic or prominent osteochondromas, our data is a more realistic representation of the true disease prevalence.

Evaluating the demographics of specimens with osteochondromas did not reveal any obvious factors correlated with development of a lesion. The prevalence amongst females was 0.26% and amongst males was 0.56%. However, with the smaller number of females represented within the collection there was just one female osteochondroma, making statistical comparison impossible. The prevalence in whites was 0.37% and in blacks it was 0.81%, and were similarly at low enough prevalence that meaningful analysis was not possible. Finally, the average age of the specimens with an osteochondroma was 44 years, versus an overall average of 50 years for the collection, which suggests that the lesions did not significantly alter lifespan in this population.

SUMMARY

In this study we found an incidence of osteochondromas of 0.44%. We did not find a significant sexual or racial predilection for development of solitary lesions in this cohort. Lesions were most likely to develop on long bones, with no observed lesions on flat bones. This data suggests a lower prevalence of osteochondroma than previously thought.

REFERENCES

1. **Khurana J, Abdul-Karim F and Bovée JVMG**: Osteochondroma. In: World Health Organization Classification of Tumours. Pathology and Genetics of Tumours of Soft Tissue and Bone. Fletcher CDM, Unni KK and Mertens F (eds.). Lyon, France: IARC; 2002. pp. 234-236.
2. **Saglik Y, Altay M, Unai VS, Basari K and Yildiz Y**: Manifestations and management of osteochondromas: a retrospective analysis of 382 patients. Acta Orthop Belg. 2006; 72: 748-755.
3. **Porter DE and Simpson AHRW**: The neoplastic pathogenesis of solitary and multiple osteochondromas. J Pathol. 1999; 188: 19-125.
4. **Bovée JVMG and Hogendoorn PCW**: Multiple Osteochondromas. In: World Health Organization Classification of Tumours. Pathology and Genetics of Tumours of Soft Tissue and Bone. Fletcher CDM, Unni KK and Mertens F (eds.). Lyon, France, IARC; 2002. pp. 360-362.
5. **Canella P, Gardin F and Borriani S**: Exostosis: development, evolution and relationship to malignant degeneration. Ital J Orthop Traumatol. 1981; 7: 293-298.
6. **Lee K, Davies A, Cassar-Pullicino V**: Imaging the Complications of Osteocondromas. Clinical Radiology. 2002; 57: 18-28.
7. **Murphey MD. Choi JJ. Kransdorf MJ, Flemming DJ. Gannon FH.** Imaging of osteochondroma: variants and complications with radiologic-pathologic correlation. Radiographics. 2000; 20(5):1407-1434.
8. **Mavrogenis A, Papagelopoulos P, Soucacos P.** Skeletal Osteochondromas Revisited. Orthopedics. 2008; 31(10):1018-1028
9. **Stieber JR, Dormans JP.** Manifestations of hereditary multiple exostoses. J Am Acad Orthop Surg. 2005; 13(2):110-120.
10. **Kitsoulis P, Galani V, Stefanaki K, Paraskevas G, Karatzias G, Agnantis NJ, Bai M.** Osteochondromas: Review of the clinical, radiological and pathological features. In Vivo. 2008; 22(5):633-646.
11. **Arkader A, Dormans J, Gaugler R, Davidson R.** Case Report: Spontaneous regression of solitary osteochondroma: Reconsidering our approach. Clinical orthopaedics and related research. 2007; 460: 253-257.
12. **Hill C, Boyce L, van der Ploeg I.** Spontaneous resolution of a solitary osteochondroma of the distal femur: a case report and review of the literature. Journal of Pediatric Orthopaedics. 2014; 23:73-75

SIGNIFICANCE OF PIRANI SCORE AT BRACING-IMPLICATIONS FOR RECOGNIZING A CORRECTED CLUBFOOT

Mansoor Ali Khan, MBBS, FCPS, Muhammad Amin Chinoy, MBBS, FRCS,
Rida Moosa, MBBS, Kamran Ahmed MBBS, FCPS

ABSTRACT

Background: The aim of clubfoot treatment by Ponseti method is to achieve a corrected foot, with at least 15° dorsiflexion and 70° abduction, and fit comfortably into a brace at the recommended setting. This study aimed to acknowledge the validity and reliability of the Pirani scoring system, while investigating if a corrected clubfoot has a Pirani score of zero. The study hypothesized that a corrected clubfoot may or may not have a Pirani score of zero.

Methods: 706 patients with clubfoot were treated by Ponseti's method of weekly manipulations and casting, from November 2011 to May 2016, at a tertiary care hospital, making a total of 1055 feet. All data was entered into the International Clubfoot Network Database, along with Pirani scoring. Tenotomy was performed in eligible patients.

Results: The mean Pirani score at the end of treatment phase of casting and initiation of the maintenance phase of bracing for the right foot was 1.1 (SD=0.55) and left foot was 1.2 (SD=0.58). These feet not only fit the criteria of a corrected clubfoot, 70° abduction and 15° dorsiflexion, but also fit well in a foot abduction brace.

Of the 1055 diagnosed Clubfeet, 643 required tenotomy (60.9%).

Conclusion: The study shows that the affected foot does not need to have a Pirani score of zero to be considered a corrected foot. Pirani score is an excellent tool used over the years to evaluate clubfoot. Pirani score does not assess adequately the transition from the treatment phase of casting to the maintenance phase of bracing. The use of the International Clubfoot Database-Treatment visit form, including all components of clubfoot and the Pirani score, provides a clear understanding of whether the patient has achieved foot correction or not.

Level of Evidence: Level IV

Keywords: clubfoot, pirani score, ponseti method, dorsiflexion, abduction

INTRODUCTION

Clubfoot, also known as Congenital Talipes Equinovarus, is a common congenital deformity that affects more than 100,000 infants worldwide each year[1], with an incidence of one to two per 1000 live births[2]. It is a complex deformity with four components: Ankle Equinus, Hindfoot Varus, Forefoot Adductus, and Midfoot Cavus. Over the years there have been a number of scoring systems described for clubfoot. These include the Ponseti-Laaveg classification[3], The Dimeglio classification[4] etc. These are quite cumbersome to use and have not proved popular. In order to assess the level of severity of each of the components of Clubfoot effectively, Shafique Pirani MD, designed a convenient and easy tool known as the 'Pirani Score'[5]. The Pirani score demonstrates its importance with regards to assessing the severity of clubfoot, mainly at presentation and for monitoring patient's progress. The Pirani scoring system works by assessing six clinical signs of contracture, which may score 0 (no deformity), 0.5 (moderate deformity) or 1(severe deformity)[6,7]. The total score is recorded after every visit. Pirani scoring is known to be valid and reliable[8] for providing a good forecast about the potential treatment for an individual foot, such that a higher score at presentation may indicate the requirement of a higher number of casts to correct the deformity. By logical extension it can be assumed that the Pirani score of six means the most severe deformity and the Pirani score of zero would be a corrected clubfoot.

Initial, gold standard, treatment of congenital idiopathic clubfoot is considered to be Ponseti's method of manipulation[9,10]. It has two stages; our study was based on the critical transition from the treatment phase of manipulation and casting to the maintenance phase of bracing. According to Ponseti, a corrected clubfoot is one that achieves at least 15° dorsiflexion and 70°

Department of Orthopaedics
The Indus Hospital

Corresponding Author:
Mansoor Ali Khan, MBBS, FCPS
The Indus Hospital
Plot C-76, Sector 31/5
Korangi Crossing, Karachi
Pakistan
Makbonedoc65@gmail.com
(+92) 300-8202537

The authors report no conflict of interest.

VARIABLES:

Sex

Clubfoot type

Treatment of right/left foot

Pirani score of right/left foot

Total score of right/left foot

Figure 1. Variables in the study.

LEFTFOOT

Varus:	( ) Varus	( ) Neutral	( ) Valgus
Cavus:	( ) Present	( ) Corrected	
Adductus°	(-30 to 70) :	____________	
Equinus°	(-50 to 30):	____________	

Figure 2. International Clubfoot Network Database- Dorsiflexion and Abduction assessment[12]

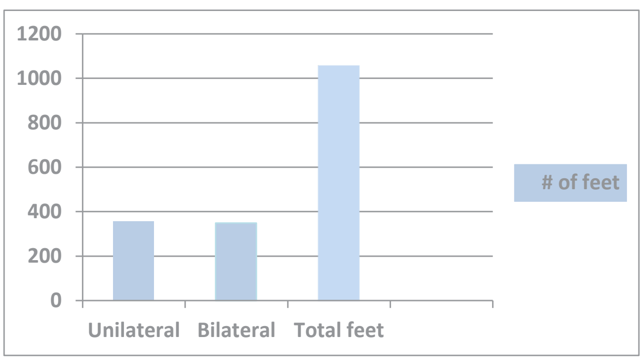


Figure 3. The bar graph illustrates the number of feet diagnosed with clubfoot.

abduction[11], moreover it fits comfortably into a brace at the recommended setting. It would naturally be assumed that this position, as described by Ponseti, would be a corrected clubfoot at a Pirani score of zero. Clinical experience has shown that in order to achieve a Pirani score of zero, clinicians tend to overcast the affected foot, even if it has reached the desired corrected position as described by Ponseti. The rationale of the study is to elaborate on the transition between the treatment phase of manipulation and casting, and the maintenance phase of bracing.

This study acknowledges the validity and reliability of the Pirani scoring system, while investigating if a corrected clubfoot has a Pirani score of zero. We hypothesized that the mean Pirani score of a clinically corrected clubfoot, after Ponseti's method of manipulation and casting, may or may not be zero. Our aim is to raise understanding that clubfoot scoring system is not accurate for the initiation of bracing.

METHODS

We reviewed the data of clubfoot patients at a clinic in a tertiary care hospital, where they received free of cost treatment from November 2011 to May 2016. The inclusion criteria were: All children identified in the clinic less than 5 years of age at enrolment (with parental consent) while the exclusion criteria were: children more than 5 years old, consent refusal by parents, children with neurologic clubfoot or clubfoot part of other syndromes. The study included 706 children, who were diagnosed with clubfoot. 357 had unilateral clubfoot and 349 were bilateral leading to a total of 1055 feet.

Parents or guardians of patients who were enrolled were given information about the nature and duration of treatment, and their signatures/thumb prints were taken. Patients were assessed through comprehensive history and physical examination. Correction was achieved using Ponseti 's technique of weekly serial manipulation and casting, followed by Abduction bracing, Pirani scoring was obtained and pictures of the affected foot/feet were taken at every visit. Tenotomies were performed in eligible patients only. The aim of the program was to accomplish a corrected clubfoot according to Ponseti's criteria, at least 15° dorsiflexion and 70° abduction. All data was entered into the International Clubfoot Network Database[12].

The records were studied in relation to Pirani Score at the time of bracing. The study includes the following variables:

Descriptive statistics include frequencies for mean and standard deviation for variables such as total score of right and left foot and the number of unilateral and bilateral feet (Figure 1).

In addition to Pirani score, changes in foot abduction and dorsiflexion were recorded using the International Clubfoot Network Database-Treatment Visit Form. Records were studied in relation to improvement of Pirani Score and the degree of abduction and dorsiflexion (Figure 2).

RESULTS

Out of the 1055 feet diagnosed with clubfoot, 357 were unilateral and 349 were bilateral clubfeet (Figure 3).

Of the 1055 diagnosed Clubfoot, 643 required tenotomy (60.9%) (Table 1). The mean Pirani score at the initiation of bracing for the right foot was 1.1 (SD=0.55).

Table I. Summary of Patients Enrolled

Years	Enrolled Children n (%)	Feet Under Treatment n (%)	Cast n (%)	Tenotomy n (%)	Children Progressed to Brace n (%)
1	104 (15)	138 (13)	739 (10)	72 (11)	83 (14)
2	140 (20)	212 (20)	1749 (25)	97 (15)	101 (17)
3	176 (25)	271 (26)	2057 (39)	140 (22)	154 (24)
4	170 (24)	247 (23)	1592 (23)	197 (31)	166 (27)
5 (7.5 months)	116 (16)	187 (18)	915 (13)	137 (21)	100 (17)
OVERALL	706	1055	7052	643	604

Table II. Descriptive analysis of right and left Pirani score, at the beginning of bracing

Total Number of Feet	Left Foot	Right Foot
N= 1055	1.2±0.58	1.1±0.55

Figure 4. Photographs show corrected clubfoot after manipulation and casting

The mean Pirani score at the initiation of bracing for the left foot is 1.2 (SD=0.58) (Table 2). The range for the average Pirani score for both feet was 0 to 3 and the average number of casts required for correction was 5-6.

Of the 865 feet that were assessed at the time of bracing, 99.1% feet had a Pirani score of more than zero at the end of the treatment phase of casting and initiation of maintenance phase of bracing.

DISCUSSION

Congenital talipes equinovarus (CTEV), also known as clubfoot, is the most common congenital orthopedic anomaly requires intensive treatment immediately or very soon after birth to guarantee high success rates[13,14]. In 1963, Ignacio Ponseti proposed treating clubfoot by serial manipulations and casting[11], which is the gold standard non-surgical method of treatment[9,10]. The Ponseti treatment of clubfoot has two stages; our study was based on the critical transition from the treatment phase of manipulation and casting to the maintenance phase of bracing. Our study hypothesized that at the end of the treatment phase of manipulation and casting, the mean Pirani score may or may not be zero. In order to achieve a Pirani score of zero, medical personnel tend to overcast the foot. This leads to unnecessary tenotomy procedures and is a mindless dissipation of natural resources.

It has excellent long term results and benefits for clubfoot[8,15] with a low relapse rate. Due to the large number of patients, it was substantiated that it is impractical to expect the demand for treatment to be met by the physicians. For this particular reason, Ponseti's method of casting and manipulation has been proved valuable because it requires relatively lower level of skills and can be successfully managed by non-specialist personnel[16]. It's non-invasive and less expensive, factors that are very crucial for developing countries. Pirani score has been used worldwide by not only clinicians but Allied Health Professionals like cast technicians as an effective tool for diagnosis and follow up of clubfoot treatment by Ponseti method[16]. Several authors have shown the benefit of using the Pirani score in predicting the course of treatment and the likely number of casts required to correct the deformity[6]. It also predicts the need for tenotomy in the patient[17]. Our study hypothesized that at the end of the treatment phase of manipulation and casting, the mean Pirani score may or may not be zero. In order to achieve a Pirani score of zero, medical personnel tend to overcast the foot. This leads to unnecessary tenotomy procedures and is a mindless dissipation of natural resources.

In our study, the mean Pirani score at the end of the treatment phase of manipulation and casting, and maintenance phase of bracing was 1.1 in the right foot, and 1.2 in the left foot. These feet were pain free and clinically corrected with good mobility. We did not continue to cast the foot, in search of a Pirani score of 0 (Figure 4).

Lack of understanding and poor compliance of pa-

Table III. Pirani Score[7]

Pirani Score	
1	Posterior Crease
2	Empty Heel
3	Rigid Equinus
4	Medial Crease
5	Curvature of Lateral Border
6	Position of Talar Head

Minimum total score is 0 and the maximum total score is 6. A high Pirani score indicates a severe deformity.

Figure 5. The photograph shows a foot-ankle abduction brace. In this patient, feet were clinically corrected, had a Pirani score of greater than zero and fit well in the brace. Three straps present on the brace holds the foot firmly in the shoe.

tients' parents due to poor socio-economic status, improper casting technique, failure to perform a tenotomy, under-corrected deformity, ill-fitting splints can all affect a positive outcome and are the most common problems experienced during clubfoot studies[18].

When we started our clubfoot program and used the Pirani score to assess patients, in our experience, the patients who we casted reached a corrected foot according to Ponseti's criteria but the Pirani score did not reach zero (Table 3). This is in contrast to the majority of clinical scoring systems that show strong relation between the clinical score and patient's outcome. Towards the bottom end of the scoring scale, the Pirani score and the clinical picture does not correlate in all patients. For example, a widely used clinical scale is the VAS scale to measure pain intensity, is most commonly anchored by "no pain" (score of zero) and "worst imaginable pain" (score of 100)[19]. Similarly, it is assumed that a Pirani score of zero is a corrected clubfoot, when in some patients it does not reach zero.

At the lower end of the Pirani score, the only weakness is its inability to assess the four components of Clubfoot: cavus, adductus, varus and equinus. In the present study, 1055 feet with clubfoot were studied. The mean Pirani scoring at the end of treatment phase with casting and initiation of maintenance phase with bracing was 1.1 for right foot and 1.2 for left foot. These feet were clinically corrected and fit well in a foot abduction brace (Figure 5).

The present study concluded that as per the Ponseti criteria of a corrected clubfoot, the Pirani score of a corrected clubfoot may or may not be 0. According to the study, the Pirani does not assess the degree of foot abduction and dorsiflexion in all patients, which defines corrected clubfoot according to Ponseti's criteria[11]. A foot can easily fit in foot abduction brace and may not have a Pirani score of zero. Pirani score at initiation of bracing, in clinically corrected feet, in our research was ranging from 0.5-1.5. A score greater than two cannot justify correction. These findings provide a platform for clinicians to understand the importance of Pirani scoring system and its relevance to the number of casts. This is why the International Clubfoot Registry Database includes the Pirani score as well as foot position as measured by angles of cavus, abduction, varus, and equinus as the Pirani score may not capture them in all patients.

Pirani score is considered very effective for the assessment of clubfoot[7]. It is useful for the evaluation of severity, progress of Ponseti treatment and the need for tenotomy. We are not trying to invalidate the significance of Pirani score as it is hugely important for clubfoot care. It, however, does not reflect adequately the critical transition from treatment phase of casting to maintenance phase of bracing in all patients. The use of the International Clubfoot Database-Treatment visit form includes all components of clubfoot and thus provides a clear understanding of whether the patient has achieved foot correction or not.

Low tenotomy rate and restrospective analysis of data are our two major limitations. It is essential to understand that with the aim to achieve a Pirani score of zero, excessive casting is not required. This is because, as concluded by the study, a corrected clubfoot may not have a Pirani score of zero in all patients.

ACKNOWLEDGMENT

We would like to thank everyone working with the Pehla Qadam Program for their significant contribution to this study.

REFERENCES

1. **Staheli L.** Clubfoot: Ponseti Management: Global HELP Organization; 2009.
2. **Anand A, Sala DA.** Clubfoot: Etiology and treatment. Indian journal of orthopaedics. 2008;42(1):22-8.
3. **Zwick EB, Kraus T, Maizen C, Steinwender G, Linhart WE.** Comparison of Ponseti versus surgical treatment for idiopathic clubfoot: a short-term preliminary report. Clinical Orthopaedics and Related Research®. 2009;467(10):2668-76.
4. **Scher DM, Feldman DS, van Bosse HJ, Sala DA, Lehman WB.** Predicting the need for tenotomy in the Ponseti method for correction of clubfeet. Journal of Pediatric Orthopaedics. 2004;24(4):349-52.
5. **Dyer P, Davis N.** The role of the Pirani scoring system in the management of club foot by the Ponseti method. Bone & Joint Journal. 2006;88(8):1082-4.
6. **Dyer PJ, Davis N.** The role of the Pirani scoring system in the management of club foot by the Ponseti method. The Journal of bone and joint surgery British volume. 2006;88(8):1082-4.
7. **Pirani S, Outerbridge H, Sawatzky B, Stothers K, editors.** A reliable method of clinically evaluating a virgin clubfoot evaluation. 21st SICOT congress; 1999.
8. **Dobbs MB, Nunley R, Schoenecker PL.** Long-Term Follow-up of Patients with Clubfeet Treated with Extensive Soft-Tissue Release. The Journal of Bone & Joint Surgery. 2006;88(5):986-96.
9. **Oš ádal M, Chomiak J, Dungl P, Frydrychová M, Burian M.** Comparison of the short-term and long-term results of the Ponseti method in the treatment of idiopathic pes equinovarus. International orthopaedics. 2013;37(9):1821-5.
10. **Pavone V, Testa G, Alberghina F, Lucenti L, Sessa G.** Effectiveness of Ponseti Method for the Treatment of Congenital Talipes Equinovarus: Personal Experience. Pediatrics & Therapeutics. 2015;2015.
11. **Ponseti IV.** Treatment of congenital club foot. The Journal of bone and joint surgery American volume. 1992;74(3):448-54.
12. Pakistan Clubfoot Program: International Clubfoot Registry [Internet]. Ponseti; [cited 2016 14/7/2016]. Available from: https://icr.uiowa.edu/ponsetipakistan/.
13. **Gupta N, Sudesh P, Prakash M, Tripathy SK, Dhillon MS.** Is Sonographic Calculation of Talonavicular Angle During Ponseti Correction of Clubfoot a Reliable Prognostic Indicator? Journal of Postgraduate Medicine Education and Research. 2012;46(4):190-5.
14. **Awang M, Sulaiman AR, Munajat I, Fazliq ME.** Influence of Age, Weight, and Pirani Score on the Number of Castings in the Early Phase of Clubfoot Treatment using Ponseti Method. The Malaysian journal of medical sciences : MJMS. 2014;21(2):40-3.
15. **Bor N, Coplan JA, Herzenberg JE.** Ponseti treatment for idiopathic clubfoot: minimum 5-year followup. Clinical orthopaedics and related research. 2009;467(5):1263-70.
16. **Jillani SAA, Aslam MZ, Saleem A, Chinoy MA, Khan MA, Ahmed SK.** A comparison between orthopedic surgeon and allied health worker in pirani score. JPMA The Journal of the Pakistan Medical Association. 2014;64(12 Suppl 2):S127-30.
17. **Rijal R, Shrestha BP, Singh GK, Singh M, Nepal P, Khanal GP, et al.** Comparison of Ponseti and Kite's method of treatment for idiopathic clubfoot. Indian journal of orthopaedics. 2010;44(2):202-7.
18. **Smith PA, Kuo KN, Graf AN, Krzak J, Flanagan A, Hassani S, et al.** Long-term Results of Comprehensive Clubfoot Release Versus the Ponseti Method: Which Is Better? Clinical Orthopaedics and Related Research®. 2014;472(4):1281-90.
19. **Hawker GA, Mian S, Kendzerska T, French M.** Measures of adult pain: Visual analog scale for pain (vas pain), numeric rating scale for pain (nrs pain), mcgill pain questionnaire (mpq), short-form mcgill pain questionnaire (sf-mpq), chronic pain grade scale (cpgs), short form-36 bodily pain scale (sf-36 bps), and measure of intermittent and constant osteoarthritis pain (icoap). Arthritis care & research. 2011;63(S11):S240-S52.

RAPID PROTOTYPING 3D MODEL IN TREATMENT OF PEDIATRIC HIP DYSPLASIA: A CASE REPORT

Andrew M. Holt MD[1,2], Zbigniew Starosolski PhD[2,3], J. Herman Kan MD[2,3], Scott B. Rosenfeld MD[2,4]

ABSTRACT

Background: Rapid prototyping is an emerging technology that integrates common medical imaging with specialized production mechanisms to create detailed anatomic replicas. 3D-printed models of musculoskeletal anatomy have already proven useful in orthopedics and their applications continue to expand.

Case Description: We present the case of a 10 year-old female with Down syndrome and left acetabular dysplasia and chronic hip instability who underwent periacetabular osteotomy. A rapid prototyping 3D model was created to better understand the anatomy, counsel the family about the problem and the surgical procedure, as well as guide surgical technique. The intricate detail and size match of the model with the patient's anatomy offered unparalleled, hands-on experience with the patient's anatomy pre-operatively and improved surgical precision.

Conclusions: Our experience with rapid prototyping confirmed its ability to enhance orthopedic care by improving the surgeon's ability to understand complex anatomy. Additionally, we report a new application utilizing intraoperative fluoroscopic comparison of the model and patient to ensure surgical precision and minimize the risk of complications. This technique could be used in other challenging cases. The increasing availability of rapid prototyping welcomes further use in all areas of orthopedics.

INTRODUCTION

Rapid prototyping is an emerging technology that creates detailed anatomic replicas from common medical imaging data. With roots in industrial product development, rapid prototyping was first applied to orthopedics in 1979 with the development of a custom pelvic implant.[1] Initial widespread use was limited by cost and availability of production equipment. Recently, the technology has rapidly progressed and cost has greatly decreased. As a result, its use in medicine has increased in the last ten years.[2,3]

Current rapid prototyping hinges on the integration of medical imaging – computed tomography (CT) or magnetic resonance imaging (MRI) – with highly specialized production mechanisms. One such mechanism is three dimensional (3D) printing, where a life-sized replica is produced out of layered photopolymer-based resin.[4] These replicas provide excellent anatomic detail with accuracy to 0.1 mm.[2] High-resolution models of the skeletal system provide a unique tactile and visual experience useful in diagnosis, surgical planning, patient communication, and medical education.[3] The models can also be used intraoperatively to guide technique and minimize surgical complications.

As rapid prototyping becomes more common in orthopedics, its use will continually evolve. Given the paucity of data on use of 3D models to help direct care in the orthopedic literature, it is important to disseminate helpful clinical experiences with these models. As with

Affiliations:
[1]University of Tennessee - Campbell Clinic Department of Orthopedics & Biomedical Engineering
1211 Union Ave, Suite 510, Memphis, TN 38104, USA
[2]Baylor College of Medicine
1 Baylor Plaza, Houston, TX 77030, USA
[3]The Singleton Department of Pediatric Radiology, Texas Children's Hospital
6701 Fannin Street, Suite 470, Houston, TX 77030, USA
[4]Division of Orthopedic Surgery, Texas Children's Hospital
6701 Fannin St, Suite 660, Houston, TX 77030, USA
Roles/Titles:
[1]AMH: Orthopedic Surgery Resident at University of Tennessee Health Science Center, Memphis TN
[2]ZS: Senior Research Scientist, The Singleton Department of Pediatric Radiology at Texas Children's Hospital and Assistant Professor of Radiology, Baylor College of Medicine, Houston, TX
[3]JHK: Section Chief, Musculoskeletal Radiology, The Singleton Department of Pediatric Radiology at Texas Children's Hospital, Houston TX and Associate Professor of Radiology, Baylor College of Medicine, Houston TX
[4]SBR (corresponding author):
Orthopedic Surgeon, Associate Professor of Orthopedic Surgery, Baylor College of Medicine, Houston TX and Director of Hip Preservation Program, Texas Children's Hospital, Houston TX
Scott B. Rosenfeld, MD
Texas Children's Hospital Division of Orthopedic Surgery
6701 Fannin St., Suite 660
Houston, TX 77030
Email: sbrosenf@texaschildrens.org
Fax: 832-825-9019
Phone: 832-822-3117

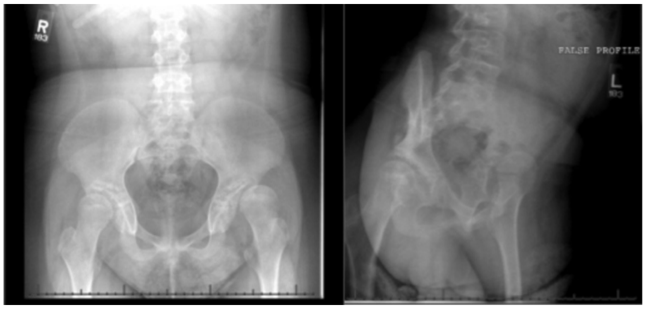


Figure 1. AP pelvis (left) and false profile left hip (right) radiographs demonstrating left hip dysplasia and subluxation.

Figure 2. Rapid prototyping 3D model of the patient's pelvis.

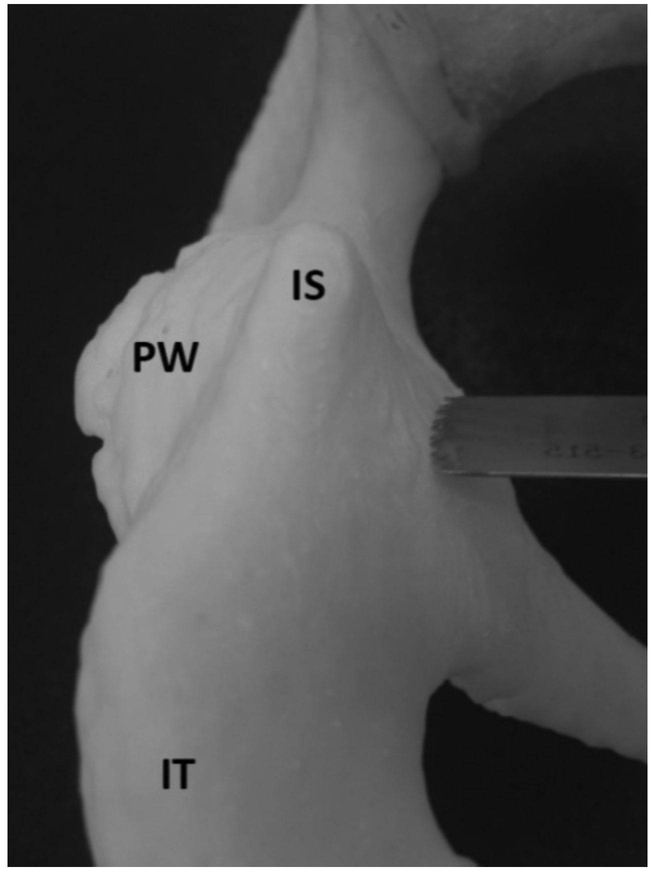


Figure 3. Posterior view of the 3D model of the patient's pelvis demonstrating the very narrow and triangular shaped posterior column. IS=Ischial spine, PW=Posterior wall of the acetabulum, IT=Ischial tuberosity.

the implementation of any new technology, such cooperation can accelerate the learning curve to improve the standard of orthopedic care.

The purpose of this report is to describe our experience with and the benefits of rapid prototyping models in the treatment of orthopedic conditions in pediatric patients. We present a challenging case of a patient with hip instability and left acetabular dysplasia who underwent periacetabular osteotomy (PAO). The 3D model was utilized throughout the treatment process, which included anatomical demonstrations for the family, preoperative planning and simulation of the case, and intraoperative guidance of the surgery. Written informed consent was provided for print and electronic publication of this case report.

CASE REPORT

A 10 year-old female with trisomy 21 presented with chronic bilateral hip instability and multiple prior left hip dislocations that failed non-operative treatment. A PAO and a varus derotational femoral intertrochanteric osteotomy of the left hip were planned for definitive correction.

Pre-operative Evaluation

Radiographs and CT imaging of the pelvis were obtained two weeks prior to surgery (Figure 1). Radiographs showed 80% subluxation of the left hip. The lateral center edge angle (LCEA) was -32 degrees, the anterior center edge angle (ACEA) was 0 degrees, and the acetabular index was 43 degrees. CT rotational evaluation showed that the left acetabulum was anteverted 2 degrees with significant posterior-lateral deficiency and that the left femoral neck was anteverted 30 degrees. A life-sized rapid prototyping 3D model of the patient's pelvis and left proximal femur was created from the CT imaging data using Slicer 4.1.1 software and a Replicator 3D printer (Makerbot; Brooklyn, NY, USA) (Figure 2). It was composed of acrylonitrile butadiene styrene (ABS) filament. The model was utilized during the preoperative visit to demonstrate the abnormal anatomy to

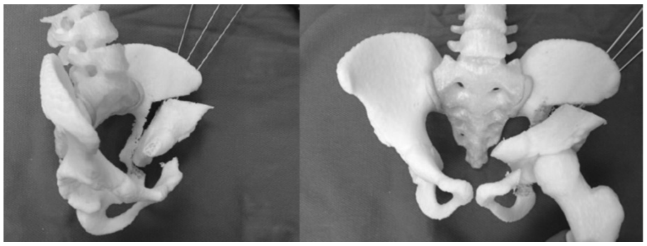


Figure 4. Corrected fragment position after simulation of the PAO on the 3D model.

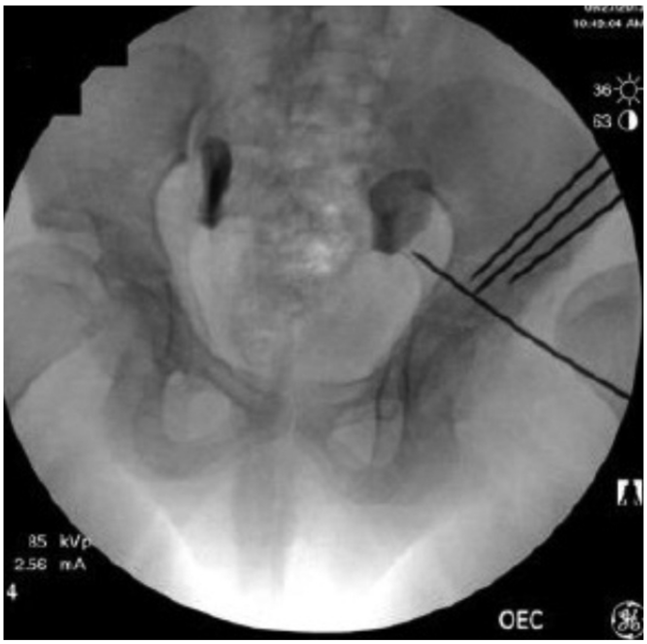


Figure 5. Fluoroscopic image of the model pelvis held over the patient's pelvis to demonstrate size match. The Steinman pins are in the model.

the patient's family. The family was better able to understand the anatomy and where the osteotomies would be made. Prior to surgery, the osteotomies were templated on the model and the osteotomy fragment was rotated into a position which best stabilized the hip. During this surgical templating it was recognized that the posterior column was particularly narrow and angular (Figure 3) and that this cut may be difficult at surgery. The morning of surgery, the osteotomized and corrected models were shown to the patient's family so that they would better understand the procedure (Figure 4).

Procedure

In the operating room prior to surgery, the osteotomized model was examined under fluoroscopy, both independently and while held over the patient's pelvis to confirm a relative size match (Figure 5). A false profile image was taken of the osteotomized model and a

Figure 6. Fluoroscopic false profile image of the model pelvis with Steinman pin held against the posterior-medial wall of the acetabulum. The posterior column cut can be seen between the articular surface and the sciatic notch.

Steinman pin was placed against the posteromedial wall of the acetabulum. This was done to demonstrate that a posterior column cut using that specific angle for the false profile view would ensure that neither the articular surface nor the sciatic notch would be penetrated (Figure 6). The model was then used to guide the iliac and posterior column osteotomies. The angle used for the false profile image of the 3D model was duplicated for the patient's pelvis by comparing anatomic landmarks, including the distance between the left ischial spine and right pubic eminence and the shape of the obturator foramen. These fluoroscopic landmarks at similar angles optimized the angle of the posterior column osteotomy (Figure 7).

During surgery, the left varus derotational femoral intertrochanteric osteotomy was performed first using standard technique without complication. Following this, the PAO was performed utilizing the direct anterior abductor-sparing approach as described by Murphy et al.5 Comparing fluoroscopic images of the patient's pelvis with the osteotomized and corrected model pelvis, the fragment was oriented similarly to the position found to allow for maximal hip stability in the 3D model. After internal fixation of the fragment, the hip was stable to full range of motion in all directions. All osteotomies were performed successfully without violation of either the sciatic notch or articular surface.

Figure 7. Intraoperative comparison of false profile views of the model (right) and patient's pelvis (left) used to obtain the correct fluoroscopic view with which to safely make the posterior column osteotomy.

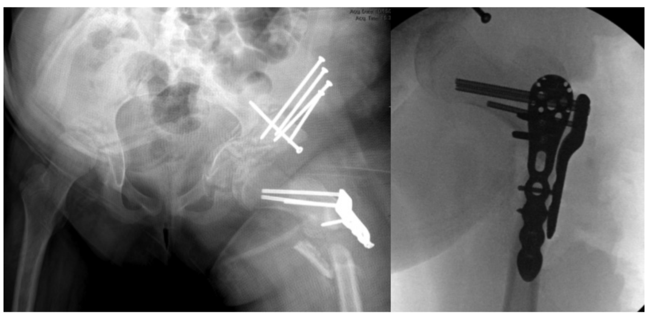


Figure 8. Three week post-operative radiograph showing periprosthetic femur fracture (left). Intra-operative fluoroscopic view of anterior plating of the periprosthetic fracture (right).

Post-operative Course

Post-operatively, the patient was placed in a single-leg spica cast due to concerns about adherence to weight bearing restrictions and discharged home on post-operative day four. At three weeks follow-up, radiographs in the cast showed a periprosthetic fracture at the inferior aspect of the femoral fixation plate. She was subsequently brought back to the operating room for fixation of this fracture with a locking proximal humeral plate placed anteriorly as the osteotomy plate had remained stably fixed to the proximal fragment (Figure 8). The hip remained stable in all directions. The rest of her post-operative course was unremarkable. She ambulated independently without pain at six months and demonstrated complete radiographic healing by 10 months (Figure 9). The post-operative LCEA, ACEA and acetabular index measured 25, 25, and 2 degrees respectively at that time. 21 months after her first surgery, the patient underwent the same procedure on the right hip. At 33 months follow-up from the original procedure, her hips remained clinically and radiographically stable with no complications (Figures 10A and B).

Figure 9. Frog-leg (top), AP (bottom left), and false profile (bottom right) views of the hip 10 months after the index surgery.

DISCUSSION

The use of 3D models in orthopedics has quickly expanded in recent years, likely due to decreased cost and improved quality of the models. Much of the interest and benefits are in patient-specific customization (unique surgical guides, implants, and fracture characterization), improved understanding of complex anatomy, patient communication, and the potential for increased surgical safety. Other benefits include the added advantage of "hands-on" evaluation.[6] Reductions in operative time and amount of intra-operative fluoroscopy have also been noted, though we could not assess these findings in our case.[7,8]

Our case report confirmed many of the above findings. However, this case is unique in that it demonstrates the benefits of 3D printing at each stage of orthopedic surgical care, including its utility in performing a challenging PAO for a patient with global hip instability and unusual anatomy. Rapid prototyping models have been used in orthopedics for peri-operative guidance, but no previous studies have mentioned intra-operative fluoroscopic comparison of the model to the patient's actual anatomy. This technique, as illustrated in this case report is simple and effective. It requires no additional equipment or training, but provides additional operative guidance above standard imaging. Such a technique may

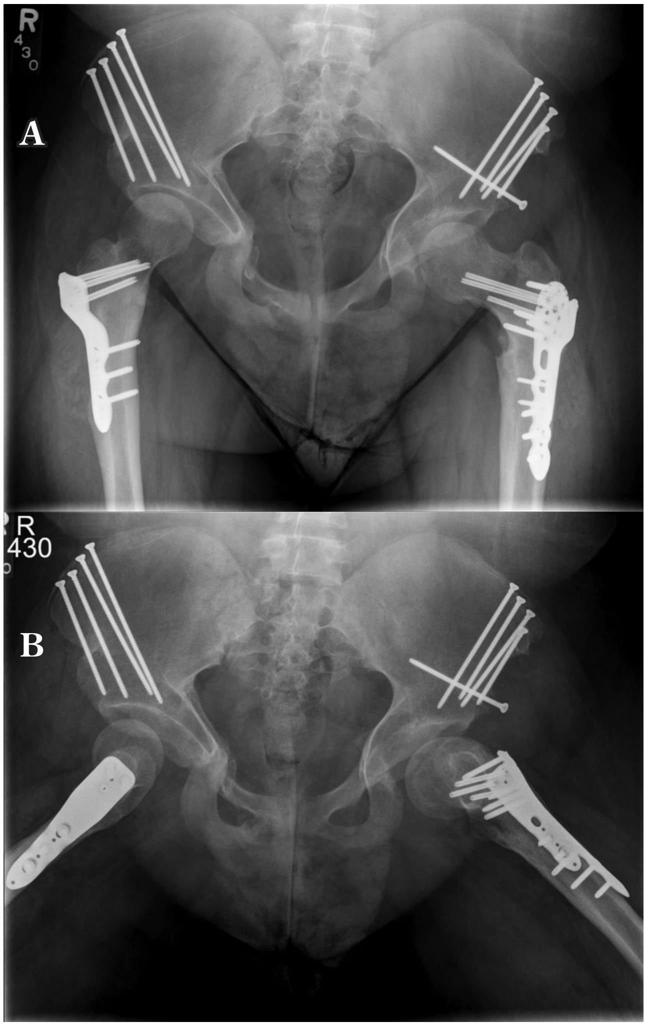


Figure 10. A) AP view of the pelvis 33 months after the index surgery. B) Frog lateral view of the hip 33 months after the index surgery.

prove useful in cases with three dimensional complexity and limited operative visibility.

The early literature surrounding rapid prototyping in surgery is sparse and dominated by oral and maxillofacial surgery, where complex reconstructions benefit from having an accurate template for planning. Notable applications in this field include pre-bending plates based on 3D models and creating custom implants for craniofacial defects based on the model.[9,10] The technology has also been used in neurosurgical education, where simulated surgery on 3D models allowed hands-on instruction with the opportunity to repeat procedures in a low risk setting until comfortable with the new skill.[11] Custom-made guiding systems can now be produced from virtual models to optimize surgical approaches and implant positioning.[12-15] Other computer-aided surgical techniques, such as navigational markers and patient-specific instrumentation, have enhanced outcomes and can include the use of rapid prototyping 3D models.[13,15-17]

Clinically, 3D prototyping was beneficial in our case in several ways. It was initially created with the intent to further define the patient's exact anatomy and understand the area of greatest acetabular deficiency. The model confirmed a globally dysplastic left acetabulum with deficiency most severe posterior-laterally. We were able to perform the osteotomies on the model and determine the amount and direction of correction necessary to result in improved stability of the hip.

Hands-on evaluation of the model demonstrated a uniquely narrow and angular posterior column that could result in increased risk of penetration into the articular surface or the sciatic notch during the posterior column cut of the PAO. The replica's intricate detail allowed the surgeon to better understand this anatomy and recognize that the standard intra-operative imaging technique might not be sufficient. Utilizing intra-operative fluoroscopy of the model we were able to identify the angle for the false profile image that would provide a view in the plane of the posterior column osteotomy in order to ensure protection of the sciatic notch and the acetabular articular surface.

In addition to clinical implications, 3D prototyping was beneficial in patient/caregiver communication. During the preoperative clinic visit, the model was used to physically demonstrate the instability of the dysplastic hip and explain to the patient and family the cuts that would be made in the bone. This enhanced their understanding of the problem and proposed solution.

In conclusion, we report our positive experience utilizing a 3D printed model in clinical practice to treat a patient with uniquely challenging anatomy. In doing so, we confirm previously reported positive experiences with 3D models in orthopedics. Similarly challenging or atypical cases could benefit from rapid prototyping models in the future. The increasing availability and diverse clinical, educational, and surgical applications of rapid prototyping make it a practical tool for the modern orthopedic surgeon.

ACKNOWLEDGMENTS

The authors would like to thank Ifeoma A. Inneh (Director of Research, Baylor College of Medicine/Texas Children's Hospital Division of Orthopedic Surgery) and Lee S. Haruno (Research Assistant, Texas Children's Hospital Division of Orthopedic Surgery) for their support and input in the preparation of this manuscript.

SOURCE OF FUNDING

None

REFERENCES

1. **Frame M, Huntley JS.** Rapid prototyping in orthopaedic surgery: a user's guide. Scientific World Journal. 2012; 2012:838575.
2. **McGurk M, Amis AA, Potamianos P, Goodger NM.** Rapid prototyping techniques for anatomical modelling in medicine. Ann R Coll Surg Eng. 1997; 79:169-74.
3. **Starosolski ZA, Kan JH, Rosenfeld SD, Krishnamurthy R, Annapragada A.** Application of 3-D printing (rapid prototyping) for creating physical models of pediatric orthopedic disorders. Pediatr Radiol. 2014; 44(2):216-21.
4. **Esses SJ, Berman P, Bloom AI, Sosna J.** Clinical applications of physical 3D models derived from MDCT data and created by rapid prototyping. Am J Roentgenol. 2011; 196(6):W683-8.
5. **Murphy SB, Millis MB.** Periacetabular osteotomy without abductor dissection using direct anterior exposure. Clin Orthop Relat Res. 1999; (364): 92-8.
6. **Guarino J, Tennyson S, McCain G, Bond L, Shea K, King H.** Rapid prototyping technology for surgeries of the pediatric spine and pelvis. J Pediatr Orthop. 2007; 27(8): 955-60.
7. **Brown GA, Firoozbakhsh K, Decoster TA, Reyna JR Jr, Moneim M.** Rapid prototyping: the future of trauma surgery? J Bone Joint Surg. 2003; 85:49-55.
8. **Yang JC, Ma XY, Xia H, W ZH, Ai FZ, Zhang K, Yin QS.** Clinical application of computer-aided design-rapid prototyping in C1-C2 operation techniques for complex atlantoaxial instability. J Spinal Disord Tech. 2014; 27(4):E143-50.
9. **Azuma M, Yanagawa T, Ishibashi-Kanno N, Uchida F, Ito T, Yamagata K, Hasegawa S, Sasaki K, Adachi K, Tabuchi K, Sekido M, Bukawa H.** Mandibular reconstruction using plates prebent to fit rapid prototyping 3 dimensional printing models ameliorates contour deformity. Head Face Med. 2014; 10:45.
10. **Fernandes da Silva AL, Borba AM, Simao NR, Pedro FL, Borges AH, Miloro M.** Customized polymethyl methacrylate implants for the reconstruction of craniofacial osseous defects. Case Rep Surg. 2014; 2014: 358569.
11. **Waran V, Narayanan V, Karuppiah R, Pancharatnam D, Chandran H, Raman R, Rahman ZA, Owen SL, Aziz TZ.** Injecting realism in surgical training- initial simulation experience with custom 3D models. J Surg Educ. 2014; 71(2):193-7.
12. **Chai W, Xu M, Zhang GQ, Zhang LH, Gou WL, Ni M, Chen JY.** Computer-aided design and custom-made guide in corrective osteotomy for complex femoral deformity. J Huazhong Univ Sci Technolog Med Sci. 2013; 33(3):398-405.
13. **Iannotti J, Baker J, Rodriguez E, Brems J, Ricchetti E, Mesiha M, Bryan J.** Three-dimensional preoperative planning software and a novel information transfer technology improve glenoid component positioning. J Bone Joint Surg Am. 2014; 96(9):e71.
14. **Otsuki B, Takemoto M, Kawanabe K, Awa Y, Akiyama H, Fujibayashi S, Nakamura T, Matsuda S.** Developing a novel custom cutting guide for curved peri-acetabular osteotomy. Int Orthop. 2013; 37(6):1033-8.
15. **Zhang YZ, Lu S, Chen B, Zhao JM, Liu R, Pei GX.** Application of computer aided design osteotomy template for treatment of cubitus varus deformity in teenagers: a pilot study. J Shoulder Elbow Surg. 2011; 20:51-6
16. **Araujo PH, Moloney G, Rincon G, Carey R, Zhang X, Harner C.** Use of a fluoroscopic overlay to guide femoral tunnel placement during posterior cruciate ligament reconstruction. Am J Sports Med. 2014; 42(11):2673-9.
17. **Dobbe JGG, Kievit AJ, Schafroth MU, Blankevoort L, Streekstra GJ.** Evaluation of a CT-based technique to measure the transfer accuracy of a virtually planned osteotomy. Med Eng Phys. 2014; 36:1081-7

CLOSED AND OPEN REDUCTION OF DISPLACED PEDIATRIC LATERAL CONDYLE HUMERAL FRACTURES, A STUDY OF SHORT-TERM COMPLICATIONS AND POSTOPERATIVE PROTOCOLS

Caitlin Justus PA-C[1], Lee S. Haruno BS[1,2], Mary K. Riordan BA[1], Lisa Wilsford PA-C[1], Tyler Smith BS[2], Shannon Antekeier MD[1], Scott D. McKay, MD[1,2]

ABSTRACT

Background: Displaced lateral condyle humeral fractures in children are treated operatively to maximize function and growth of the elbow. Traditionally an open approach is used for reduction of the fracture, but recent series have shown promising results with closed reduction. Percutaneous pins are typically used for fixation, no matter the reduction method. This retrospective review compares our experience with early complications after open and closed reduction of these fractures.

Methods: We retrospectively reviewed charts and radiographs of operatively treated lateral condyle fractures. The Song and Jakob classification systems were utilized to determine fracture severity. High-grade displacement was defined as Song stage 4 and 5, or Jakob type 3. Data was analyzed by fracture type (high-grade or low-grade) and by treatment method to look for differences in complication rates and treatment differences. Complications were defined as delayed union and infection.

Results: 172 fractures were analyzed, 141 were treated open, and 31 were treated closed. There were no statistically significant differences in pin duration, total cast time, additional procedures, or short term complications between the open and closed treatment groups, or the high and low-grade fracture groups. High-grade fractures were more likely to be treated with open reduction ($p<0.0001$). Pin duration prior to removal was not associated with increased incidence of infection or delayed union.

Conclusions: Closed reduction and percutaneous pinning of lateral condyle fractures amenable to this treatment does not seem to require any changes in postoperative treatment or alter the incidence of early complications when compared to open procedures.

Level of Evidence: IV

Affiliations:
[1]Texas Children's Hospital Division of Orthopedic Surgery
[2]Baylor College of Medicine

Corresponding author:
Scott D. McKay, MD
Assistant Professor
Orthopedic Surgery, Baylor College of Medicine
Texas Children's Hospital Division of Orthopedic Surgery
6701 Fannin St., Suite 660
Houston, TX 77030
sdmckay@texaschildrens.org
832-470-5880

Sources of funding: None

INTRODUCTION

Lateral condyle humeral fractures are the second most common operative pediatric elbow fracture comprising approximately 17% of all distal humeral injuries (Figure 1a). Due to the high incidence of poor functional, cosmetic, and radiographic outcomes of conservative treatment, operative treatment of displaced lateral condyle fractures has been recommended.[1] Complications of the injury or subsequent surgery include delayed or non-union, growth disturbance, lateral condyle overgrowth, limited range of motion, and residual deformity.[2]

Traditionally, open reduction with percutaneous pinning (ORPP) was preferred in order to assure anatomic reduction of this physeal, intra-articular fracture.[3] In the last decade, there has been renewed interest in alternative approaches such as arthroscopy and closed reduction.[4-8] Closed reduction with percutaneous pinning (CRPP) has been shown to provide both reproducible and satisfactory outcomes in minimally-displaced fractures.[6,9] In addition, the utility of this approach is also evidenced in more severe injuries, as high-grade fractures have been recently reported to heal uneventfully if reduction within 2mm can be achieved with CRPP.[7,8] Closed reduction is attractive as it avoids soft tissue dissection, potentially decreases pain, and limits the risk of superficial scarring. After either closed or open reduction, fixation is most commonly achieved with percutaneous smooth wires which are then left external to the skin or buried just beneath it (Figure 1b, 1c).[10-12]

Given this recent interest and the promising results of closed reduction, surgeons operating at our institution have attempted closed reduction more frequently for both low and high-grade fractures as described by Song et al (Table 1).[7,8] Our providers consist of surgeons who have trained in different locations and have varying perspectives on postoperative immobilization protocols after the treatment of lateral condyle humeral fractures.

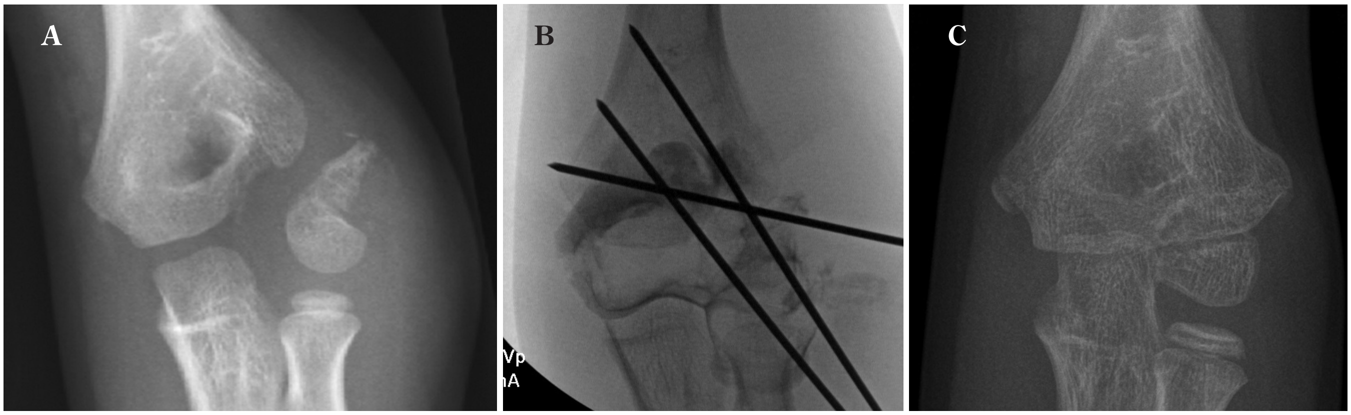


Figure 1a - Anteroposterior view of a displaced and rotated lateral condyle humerus fracture.
Figure 1b - Intraoperative arthrogram following closed reduction and percutaneous pinning of the fracture depicted in Figure 1a.
Figure 1c - Follow-up anteroposterior view of the healed fracture from Figures 1a and 1b.

Table 1. Summary of the classification system and treatment algorithm proposed by Song et al.[8]

Song stage	Degree of displacement	Fracture pattern	Suggested treatment	Classification for purposes of our study
1	≤ 2 mm*	Limited fracture line within metaphysis	Long arm cast	Low grade
2	≤ 2 mm*	Lateral gap	Long arm cast or in situ fixation	Low grade
3	≤ 2 mm**	Gap as wide laterally as medially	CRPP, if failed proceed to open reduction and internal fixation (ORIF)	High grade
4	> 2 mm**	Without rotation of fragment	CRPP, if failed proceed to ORIF	High grade
5	> 2 mm**	With rotation of fragment	ORIF likely	High grade

*As determined on internal oblique and anteroposterior radiographs, **as determined on internal oblique or anteroposterior radiographs

For example, some elect to remove the percutaneous pins at 3-4 weeks and continue with casting for an additional 2-3 weeks. Others decide to leave the pins for up to six weeks and subsequently remove the pins and cast simultaneously.

This study provides a unique opportunity to retrospectively evaluate institutional experiences and short-term morbidity with CRPP and ORPP in association with early complications and variations in postoperative management.

METHODS

After approval from the Institutional Review Board, a retrospective chart review was performed on pediatric patients (1-13 years old) who underwent operative treatment for displaced lateral condyle humeral fractures. Only patients with sufficiently complete medical records were used in this analysis.

Closed or open reduction was performed at the discretion of the surgeon. When closed reduction was attempted for high-grade fractures, the technique described by Song et al. (consisting of closed manipulation supplemented by percutaneous joysticking) was employed.[8] An intraoperative arthrogram was used to evaluate the reduction after percutaneous pin fixation. If the reduction failed or was found to be suboptimal, open reduction was performed. No matter the reduction method, long-arm immobilization (casting) and pins were placed for 4-6 weeks prior to removal at the discretion of the operating surgeon.

The following variables were collected and subsequently analyzed: age at surgery, sex, height and weight, injury date, operative date and time, method of treatment, arthrogram images, number of pins, time to pin removal and latest clinical and radiographic follow-up, complications (including infection and delayed or malunion), healing type (normal or delayed), length of immobilization, and need for additional operation.

Fractures were classified by a single reviewer (CJ) both with the Jakob and Song radiographic classifications (Table 1 and Table 2) under the direction of the senior author (SDM).[8,13] The senior author performed random

Table 2. Jakob classification of lateral condyle fractures[13]

Classification	Description	Classification for purposes of our study
Type 1	Non-displaced; fracture line does not cross through articular surface	Low grade
Type 2	Minimally displaced; fracture line extends to the articular surface; there is no rotation or displacement of the capitellum	Low grade
Type 3	Completely displaced; fracture line extends through the articular surface and there is rotation or displacement of the capitellum	High grade

Figure 2a - Anteroposterior view of lateral condyle fracture
Figure 2b - Internal oblique view of the lateral condyle fracture depicted in figure 2a allowing improved visualization of the degree of displacement

sampling of the data to ensure the accuracy of radiographic classification. Both CJ and SM referenced the original studies periodically during imaging review for quality-control. Fracture displacement was determined using both anteroposterior and internal oblique radiographs, with the maximal grade of displacement (usually seen on the interior oblique view) recorded (Figure 2a and 2b). High-grade displacement was classified as either Jakob type 3 or Song stage 4 and 5. The data were analyzed by method of treatment (open versus closed), and fracture displacement (high-grade versus low-grade).

The continuous variables were summarized by mean and standard deviation, and compared via the Wilcoxon rank test. The categorical variables were summarized by counts and percentages, and were compared via Fisher's exact test. Statistical significance was set at $p<0.05$. A patient with either an abnormal healing type or an infection related to the surgery or surgical site was considered to have a complication.

RESULTS

235 patients underwent treatment for lateral condyle humeral fractures during the study interval. 63 patients were excluded due to incomplete medical records and/or follow up data. In total, 172 patients (ages 1-13 years old) were included in this study. 31 (18%) were treated with CRPP and 141 (82%) were treated with ORIF. A summary of variables compared by treatment type is depicted in Table 3.

The demographic data was similar between the two groups (age, weight, and gender). There was no statistically significant difference in complication rates, pin

Table 3. Summary of patient variables by treatment (open vs. closed)

Variable	Treatment			
	Closed (N = 31)	**Open (N = 141)**	**Overall (N = 172)**	**P-value**
	Mean ± SD	**Mean ± SD**	**Mean ± SD**	
Age at injury (years)	5.16 ± 2.15	5.29 ± 2.27	5.26 ± 2.25	0.94
Height (cm)	110 ± 15.1	112 ± 15.7	111.52 ± 15.59	0.64
Weight (kg)	21.9 ± 7.83	24.7 ± 12.6	24.18 ± 11.91	0.42
Pin duration (weeks)	4.91 ± 0.7	5.13 ± 1.07	5.09 ± 1.01	0.46
Total length of immobilization (weeks)	4.94 ± 0.73	5.37 ± 1.36	5.29 ± 1.28	0.19
	Count (%)	**Count (%)**	**Count (%)**	
Gender				0.54
Female	9 (29)	50 (35.5)	59 (34)	
Male	22 (71)	91 (64.5)	113 (66)	
Additional Operation				0.59
No	31 (100)	136 (96)	167 (97)	
Yes	0 (0)	5 (4)	5 (3)	
Stage				<0.0001
High*	17 (55)	119 (84.5)	136 (79)	
Low	14 (45)	22 (15.5)	36 (21)	
Immobilization following pin removal?				1.00
No	17 (55)	78 (55)	95 (55)	
Yes	14 (45)	63 (45)	77 (45)	
Healing type				1.00
Normal	31 (100)	140 (99)	171 (99.5)	
Delayed	0 (0)	1 (1)	1 (0.5)	
Infection				1.00
No	29 (93.5)	130 (92)	159 (92)	
Yes	2 (6.5)	11 (8)	13 (8)	
Complication				1.00
No	29 (93.5)	129 (91.5)	158 (92)	
Yes	2 (6.5)	12 (8.5)	14 (8)	
Song stage				<0.0001
2	2 (6)	1 (1)	3 (2)	
3	12 (39)	21 (15)	33 (19)	
4	13 (42)	36 (25)	49 (28)	
5	4 (13)	83 (59)	87 (51)	
Jakob type				<0.0001
1	1 (3)	1 (1)	2 (1)	
2	23 (74)	50 (35)	73 (42)	
3	7 (23)	90 (64)	97 (56)	
*Song score 4 or 5, or Jakob's type 3, all others considered low-grade				

Table 4. Summary of patient variables by degree of displacement (high vs. low grade)

Variable	Degree of Displacement			
	High* (N = 136)	Low (N = 36)	Overall (N = 172)	P-value
	Mean ± SD	Mean ± SD	Mean ± SD	
Age at injury (years)	5.31 ± 2.13	5.1 ± 2.67	5.26 ± 2.25	0.47
Height (cm)	112 ± 14.8	111 ± 19	111.52 ± 15.59	0.72
Weight (kg)	24.1 ± 11.9	24.3 ± 12	24.18 ± 11.91	0.98
Pin duration (weeks)	5.17 ± 1.04	4.78 ± 0.83	5.09 ± 1.01	0.085
Total length of immobilization (weeks)	5.37 ± 1.35	4.99 ± 0.88	5.29 ± 1.28	0.18
	Count (%)	Count (%)	Count (%)	
Gender				0.33
Female	44 (32)	15 (42)	59 (34)	
Male	92 (68)	21 (58)	113 (66)	
Method of treatment				<0.0001
Closed	17 (12.5)	14 (39)	31 (18)	
Open	119 (87.5)	22 (61)	141 (82)	
Additional Operation				0.59
No	131 (96)	36 (100)	167 (97)	
Yes	5 (4)	0 (0)	5 (3)	
Immobilization following pin removal?				0.85
No	76 (56)	19 (53)	95 (55)	
Yes	60 (44)	17 (47)	77 (45)	
Healing type				1.00
normal	135 (99)	36 (100)	171 (99.5)	
delayed	1 (1)	0 (0)	1 (0.5)	
Infection				0.31
No	124 (91)	35 (97)	159 (92)	
Yes	12 (9)	1 (3)	13 (8)	
Complication				0.31
No	123 (90)	35 (97)	158 (92)	
Yes	13 (10)	1 (3)	14 (8)	

*Song score 4 or 5, or Jakob's type 3, all others considered low-grade

duration, total time of immobilization (with and without percutaneous pins), and the need for additional operation. On average, surgically inserted pins remained in place for 4.92 and 5.11 weeks for closed and open reduction respectively (p=0.16). The mean length of total clinical and radiographic follow up for our patient population was 18.17 and 16.13 weeks respectively.

The summary of the variables compared by degree of displacement (high or low grade) is displayed in Table 4. Only the method of treatment was shown to be significantly different between the high grade and low grade fractures. High-grade fractures (Jakob type 3 or Song stage 4 and 5) were more likely to be treated with ORPP (p<0.0001).

There were 14 complications (8% of total patients) between the two treatment cohorts (13 infections and one delayed union). Two incidences of infection occurred in the CRPP cohort (both were superficial). The remaining 11 infections occurred in the ORPP group and were primarily superficial although there was one documented case of osteomyelitis and another report of wound dehiscence. The single delayed union was a high-grade fracture treated with ORPP. There were no neurologic deficits documented in the perioperative period. Five patients (3% of total) required a second procedure to address their infection (n=4) or refracture (n=1); all underwent ORPP initially. There was no significant association between postoperative pin duration (prior to removal) and incidence of complication (pin duration: 5.0 ± 1.1 versus 5.1 ± 1.0 weeks for patients with and without complications respectively).

DISCUSSION

Closed reduction and percutaneous fixation of displaced lateral condyle fractures is an attractive option for fractures amenable to this treatment. This study corroborates the findings of other recent studies exploring this treatment alternative.

Silva and Cooper recently published a prospective series of 191 lateral condyle fractures, 28 of which were treated with CRPP. A CRPP approach was only utilized for fractures with 2-4 mm of displacement. There was no significant difference in postoperative range of motion, complications, fracture healing, or incidence of poor outcomes when compared to ORPP.[6]

An extensive retrospective review by Weiss et al over a period of seven years, reported an overall complication rate of 25% (including radiographic and/or clinical bumps, infections, and delayed or nonunion). They proposed a classification system based on degree of displacement and articular congruency. It was determined that complication rates were increased (three times greater) in complete fractures compared to those with an intact articular surface (hinge).

Song, et al. prospectively studied a classification system and treatment algorithm in 63 displaced lateral condyle fractures. Their classification system designated fracture displacement on a scale from one (least severe) to five (most severe) (Table 1). They reported their experience with stages 3-5. CRPP was initially attempted for all of these fractures, but open reduction was deemed necessary if reduction within 2 mm of normal anatomic orientation could not be achieved. Of the 17 stage 3 fractures, 13 (76%) were treated with CRPP. Of the 40 stage 4 fractures, 30 (75%) were treated with CRPP. Of the six stage 5 fractures, three (50%) were treated with CRPP.[8] We chose to use this classification system in our study because of the high degree of interobserver and intraobserver reliability, and because it used well-defined descriptors of displacement and rotation. The same group later reported successful CRPP of 18 of the 24 (75%) completely displaced and rotated fractures (Song type 5, and Jakob type 3), further demonstrating the utility of the technique for higher-grade injuries.[7]

Given the documented success of the CRPP approach, we sought to examine the variation in surgical technique at our own institution and explore any associations with complication rates or the need for different postoperative management. This analysis reports experience with high and low-grade lateral condyle fractures treated with CRPP and ORPP in the hands of multiple surgeons. We were especially interested in the infection rate, duration of pin fixation and immobilization (i.e. postoperative treatment protocols), and incidence of delayed union. There were no significant differences in postoperative treatment or complications between the two operative approaches.

There are limitations of this study which must be acknowledged. First, the follow up period is too short to determine the incidence of osteonecrosis, growth disturbance (i.e. resulting cubitus varus or valgus), fishtail deformity, or other long term complications. Additionally, the short follow-up necessitated including patients who had incomplete, but appropriate healing as judged by the treating physician. This means we could have potentially missed some of the delayed unions in this review. Second, the retrospective study design suffers from typical limitations including the lack of a standardized treatment protocol (for example guiding initial treatment with CRPP versus ORPP) and follow up documentation. Because of the short follow up, we could not document range of motion or other functional outcomes, which are of interest when comparing the effectiveness of closed and open techniques.

CONCLUSIONS

In our experience, high-grade displaced lateral condyle fractures were more likely to be treated with open reduction. Whether compared by treatment type or severity of fracture-displacement, there were no statistically significant differences in patient demographics, postoperative pin duration and cast immobilization time, and short-term complications, or reoperation.

This study presents low-level evidence demonstrating that CRPP and ORPP can follow the same postoperative immobilization protocol without subsequent variation in the incidence of complications such as infection or delayed union. More prospective and comparative data is needed to determine if closed reduction should be used more widely for the routine treatment of displaced lateral condyle fractures.

REFERENCES

1. **Flynn JM, Skaggs DL, Waters PM.** *Rockwood and Wilkins' Fractures in Children*. Philadelphia: Lippincott Williams & Wilkins; 2014.
2. **Weiss JM, Graves S, Yang S, Mendelsohn E, Kay RM, Skaggs DL.** A new classification system predictive of complications in surgically treated pediatric humeral lateral condyle fractures. *J Pediatr Orthop*. 2009;29(6):602-605. doi: 10.1097/BPO.0b013e3181b2842c.
3. **Sullivan JA.** Fractures of the lateral condyle of the humerus. *J Am Acad Orthop Surg*. 2006;14(1):58-62.
4. **Perez Carro L, Golano P, Vega J.** Arthroscopic-assisted reduction and percutaneous external fixation of lateral condyle fractures of the humerus. *Arthroscopy*. 2007;23(10):1131.e1-.e4. doi:10.1016/j.arthro.2006.11.030.
5. **Hausman MR, Qureshi S, Goldstein R, et al.** Arthroscopically-assisted treatment of pediatric lateral humeral condyle fractures. *J Pediatr Orthop*. 2007;27(7):739-742. doi:10.1097/BPO.0b013e3181558ac5.
6. **Silva M, Cooper SD.** Closed Reduction and Percutaneous Pinning of Displaced Pediatric Lateral Condyle Fractures of the Humerus: A Cohort Study. *J Pediatr Orthop*. December 2014. doi:10.1097/BPO.0000000000000376.
7. **Song KS, Shin YW, Oh CW, Bae KC, Cho CH.** Closed reduction and internal fixation of completely displaced and rotated lateral condyle fractures of the humerus in children. *Journal of Orthopaedic Trauma*. 2010;24(7):434-438. doi:10.1097/BOT.0b013e3181de014f.
8. **Song KS, Kang CH, Min BW, Bae KC, Cho CH, Lee JH.** Closed reduction and internal fixation of displaced unstable lateral condylar fractures of the humerus in children. *J Bone Joint Surg Am*. 2008;90(12):2673-2681. doi:10.2106/JBJS.G.01227.
9. **Mintzer CM, Waters PM, Brown DJ, Kasser JR.** Percutaneous pinning in the treatment of displaced lateral condyle fractures. *J Pediatr Orthop*. 1994;14(4):462-465.
10. **Chan LWM, Siow HM.** Exposed versus buried wires for fixation of lateral humeral condyle fractures in children: a comparison of safety and efficacy. *J Child Orthop*. 2011;5(5):329-333. doi:10.1007/s11832-011-0358-y.
11. **Launay F, Leet AI, Jacopin S, Jouve J-L, Bollini G, Sponseller PD.** Lateral humeral condyle fractures in children: a comparison of two approaches to treatment. *J Pediatr Orthop*. 2004;24(4):385-391.
12. **De Das S, Bae DS, Waters PM.** Displaced humeral lateral condyle fractures in children: should we bury the pins? *J Pediatr Orthop*. 2012;32(6):573-578. doi:10.1097/BPO.0b013e318263a25f.
13. **Jakob R, Fowles JV, Rang M, Kassab MT.** Observations concerning fractures of the lateral humeral condyle in children. *J Bone Joint Surg*. 1975;57-B(4):430-436.

MANAGEMENT OF PAINFUL PATELLAR CLUNK AND CREPITANCE: RESULTS AT A MEAN FOLLOW-UP OF FIVE YEARS

J. Joseph Gholson, MD[1], Devon D. Goetz, MD[2], Robert W. Westermann, MD[1], John Hart, MD[3], John J. Callaghan, MD[1]

ABSTRACT

Introduction: Painful patellar clunk and crepitance (PCC) is a known complication of total knee arthroplasty (TKA) with posterior-stabilized designs. Arthroscopic management of PCC has been proposed as a treatment option for PCC.

Methods: We reviewed all cases of PCC from a consecutive single-surgeon series using a specific posterior stabilized (PS) design treated with arthroscopy for PCC. In a series of 1,488 TKA cases, forty-six patients (3.1%) were identified to have clinical signs and symptoms of PCC during post-operative clinic follow-up.

Results: Patients elected for arthroscopic excision of the supra-patellar lesion in eighteen of the forty-six cases (39%), after failing conservative management, for a 1.2% incidence of arthroscopic excision for PCC in the TKA cohort. All cases were followed for a minimum of two years. Three of the cases had recurrence of PCC after arthroscopy (16.7%), and each of these patients was successfully treated with a second arthroscopic excision procedure. Patient satisfaction after arthroscopic excision was rated extremely satisfied or very satisfied in 79% of patients and moderately satisfied in 21% of patients. Several radiographic measurements were considered in the PCC cohort, and only increased posterior tibial slope was associated with the need for arthroscopic excision. At final follow-up, the mean knee society score was 92.4, the mean WOMAC score was 82.9, and mean range of motion was 0-119.7 degrees.

Discussion: The incidence of PCC requiring arthroscopic excision with the Sigma PS design was relatively low, at 1.2% of patient. Patients who underwent arthroscopic excision for PCC had high patient satisfaction and low recurrence rates. In recurrent cases, repeat excision also resolved symptoms. Thus, arthroscopic excision is an effective treatment option for PCC in symptomatic patients.

[1]Orthopaedics, University of Iowa Hospitals and Clinics
[2]Orthopaedics, Des Moines Orthopaedic Surgeons
[3]Orthopaedics, University of North Carolina

Corresponding Author:
J. Joseph Gholson
Department of Orthopedics
University of Iowa Hospitals and Clinics
200 Hawkins Dr.
Iowa City, IA 52242
james-gholson@uiowa.edu

There are no conflicts of interest or industry relationships for any of the authors in this study.

INTRODUCTION

Successful long-term outcomes of total knee arthroplasty (TKA) with multiple posterior stabilized (PS) designs have been reported.[1,2] Patellofemoral soft tissue impingement (either crepitance or clunk) has been noted in a percentage of patients with PS TKA designs, and there are several reports of the rates of crepitance and clunk with various designs.[3-11] The purpose of the present study was to determine the prevalence of patella crepitance and clunk of a consecutive series of patients with a specific PS design performed by a single surgeon who specifically evaluated patients with crepitance or clunk. Furthermore, we sought to document the percentage of cases that went on to arthroscopic debridement and revision arthroscopic debridement for recurrent symptoms, and to determine patient-reported functional outcomes after athroscopic debridement for painful patellar crepitance and clunk (PCC).

MATERIALS AND METHODS

Following Institutional Review Board (IRB) approval, a retrospective review was conducted from clinical charts identifying all cases of PCC after knee arthroplasty between April 1997 and April 2008. All cases and follow-up exams were performed by a single surgeon (DDG) who routinely documented the presence or absence of PCC in patients postoperatively. During the study period, 1488 total knee arthroplasties were performed using a single implant design: the Press-Fit Condylar (PFC) Sigma Posterior (Cruciate Substituting) by DePuy, Warsaw, IN. All cases of PCC had a minimum follow-up of 2 years (mean 5.1, range 2-8 years).

After identification, patients with clinically documented PCC were reviewed for the date of the index knee replacement, time of diagnosis of PCC and time

Table I. Radiographic Measurements

Arthroscopy	Conservative				
	Mean	SD	Mean	SD	p
Pre-op alignment (degrees)	-0.21	5.72	1.03	4.96	0.53
Pre-op Modified Insall-Salvati Ratio	1.47	0.26	1.58	0.36	0.35
Pre-op patellar tendon length (mm)	54.78	7.96	58.53	9.47	0.24
Pre-op patellar thickness (mm)	27.25	3.11	27.61	4.27	0.79
Post-op alignment	-3.35	3.03	-2.1	3.23	0.24
Post-op Modified Insall-Salvati Ratio	1.44	0.22	1.46	0.28	0.78
Post-op patellar tendon length (mm)	54.48	6.21	56.24	8.5	0.47
Patellar component thickness (mm)	10.89	2.89	12.41	2.31	0.1
Post-op patellar tilt (degrees)	5.32	4.12	6.01	3.78	0.61
Composite patellar thickness (mm)	24.07	4.7	19.89	10.34	0.08
Posterior femoral condyle offset (mm)	33.28	2.85	34.24	5.01	0.47
Femoral component flexion	-0.79	3.06	-1.03	3.28	0.83
Anterior/posterior tibial tray offset (mm)	0.88	1.96	2.01	2.07	0.1
Posterior tibial slope (degrees)	11.2	2.39	9.1	2.77	0.02
Change in jt line (mm)	-0.51	7.89	2.23	9.36	0.38

of subsequent operations or need for re-operation. Knee Society Scores, WOMAC scores, and SF-36 scores were collected preoperatively and at final follow-up. Patients were also asked to rate their satisfaction level with arthroscopic management of PCC at their final follow-up appointment.

Patient demographics were collected on all cases including age, BMI, history of previous surgeries, preoperative and postoperative range of motion, time from index arthroplasty to arthroscopic surgery and PCC classification (crepitus versus clunk). Operative variables were evaluated including component size (tibial, femoral, and patella). Polyethylene thickness and patellar component shape were also collected. Preoperative and postoperative radiographs were assessed for several factors pertinent to PCC pathology.[5] A single reviewer (JH) performed all pre and postoperative measurements. All radiographs obtained prior to digitalization were performed with a goniometer. Digital radiographs were measured using pre-installed software inherent to the imaging systems. The measurements were performed as described by Dennis et al.[5]

Statistical analysis was performed using Microsoft Excel, Microsoft Corp, Redmond, WA and SAS Software Cary, NC. Continuous variables were assessed using the Student's t-test, and categorical variables were analyzed using either chi squared or Fischer's exact test (2-tailed).

RESULTS

During the study period, 46/1488 patients (3.1%) were identified to have clinical signs and symptoms of PCC. Of these, 18 patients (1.2%) failed conservative management (including lower extremity quadriceps and hamstrings strengthening) and underwent arthroscopic excision. Of the patients in the surgically managed group, 7/18 (38.9%) had clunk and 11/18 (61.1%) had crepitance. The mean time to presentation and diagnosis of PCC was 11.3 months (±10.48, range 3-50). The mean age of patients undergoing arthroscopic management of PCC was 67 (range 54-80), the mean BMI was 31.4, and 44.5% of patients were female. Range of motion did not significantly change postoperatively at final follow-up (pre-operative mean ROM 1.8-117.4 degrees, and postoperative mean 0 – 119.7). Oval patellar components were used in 56% of cases, round were used in 44% of cases, and the most common size was a 32mm implant, used in 56% of cases (range 41-32).

The radiographic analysis demonstrated no significant differences between operatively and non-operatively managed patients with PCC with regard to preoperative and postoperative alignment, modified Insall-Salvati Ratio, patellar tendon length, patellar tendon thickness, patellar component thickness, composite patellar component thickness, patellar tilt, posterior femoral condyle offset, femoral component flexion, anterior/posterior tibial tray offset, or joint line elevation. Only one radiographic pa-

Table II. Outcomes of Treatment

Outcome Measure	Outcome Score
Post KSS	92. 4 (67-100)
WOMAC	82.9 (56-97)
SF-36 PCS	58.8 (27-80)
SF-36 MCS	76.1 (53-94)

Table III. Satisfaction Ratings at Final Follow-up

	Treated (n=14)	Non-Operative (n=24)	Total
Extremely	7 (50%)	7 (28%)	14
Very	4 (29%)	7 (28%)	11
Moderately	3 (21%)	9 (36%)	12
Slightly	0	1 (4%)	1
Not at all	0	1 (4%)	1

rameter was found to be different between groups: the posterior tibial slope. Posterior tibial slope was found to be greater (11.2 degrees) in the surgical group compared to the non-operative group (9.1 degrees) p=0.023 (Table 1).

Of the patients treated operatively, the Knee Society Score was 92.4, indicating an excellent clinical and functional outcome at final follow-up. The mean WOMAC score at final follow-up was 82.9. The mean SF-36 PCS was 58.8 and the mean MCS was 76.1 at follow-up (Table 2). Satisfaction ratings were obtained in 14/18 patients at final follow-up. Fifty percent of patients were extremely satisfied (7/14), 29% of patients were very satisfied (4/14), and 21% of patients were moderately satisfied (3/14). No patient was unsatisfied or slightly satisfied, thus 100% of patients were at least moderately satisfied with the results of arthroscopic excision (Table 3). There was recurrence of PCC symptoms in 3/18 cases (16.67%), requiring repeat arthroscopic excision. There was no recurrence of symptoms in this group after treatment with repeat arthroscopic excision.

DISCUSSION

We report a single surgeon series of 46 cases of PCC (3.1% incidence) in a consecutive series of 1488 TKA cases using the Press-Fit Condylar Sigma (PS) implant, of which 18 patients (39%) required arthroscopic excision. A total of 1.2% of all TKA cases in the consecutive series required arthroscopic debridement. The majority of patients treated with arthroscopic excision had an excellent functional outcome following surgery as measured by the KSS and the WOMAC, and all patients were at least moderately satisfied after arthroscopic excision.

The incidence of PCC has been reported to range from 1-21%.[3,4,7-10,12,13] While most reports of PCC are associated with PS arthroplasty designs, the phenomenon has been reported following arthroplasty with cruciate retention.[6] Our rate of PCC compares favorably with the current literature reported for this design, with an incidence ranging from 0-13.3%.[4,13-16]

Several radiographic findings associated with PCC have been reported. Dennis et al found PCC to be associated with decreased patellar composite thickness, increased posterior femoral condylar offset, and flexion of the femoral component.[5] No prior study, to our knowledge, has compared radiographic measurements between patients treated non-operatively to those treated surgically. Using the same measurement techniques described,[5] we only detected a significant difference between groups with respect to posterior tibial slope. This has not been reported previously. An increase in posterior tibial slope may increase the flexion gap and put increased stress on the quad mechanism. This may predispose patients to PCC and may help identify patients who will not succeed with conservative management.

Patellar thickness was not found to be significantly different between groups in our study. Dennis et al concluded that decreased patellar thickness was a potential contributing factor to PCC[4,5], while Choi et al found no significant differences with regard to patellar thickness.[4] The majority of patients in this study had a relatively small, 32mm patellar component. Dennis et al also demonstrated higher rates of crepitance with smaller patellar components.[5]

Postoperative range of motion has been investigated as a factor that may contribute to PCC.[4,5,12,17-19] With increases in knee flexion, patellofemoral joint forces increase, as the patellar component engages the femoral component more distally and posteriorly. In theory, this motion subjects soft tissue superior to the patella to impingement in the intercondylar box in PS designs. In a study by Peralta-Molero et al, flexion past 110 degrees has been associated with PCC and they determined every additional degree of flexion correlated with a 4.2% increase in the rate of PCC.[18] While there is some evidence to support this association[17,19], several studies have found no difference in postoperative knee flexion between patients who develop PCC and those that do not.[4,5,12] In our study, the average flexion at final follow-up was a relatively high 119.7 degrees.

The present study has several strengths. It is a non-selected consecutive series of patients treated and followed by a single surgeon. Additionally, the mean follow-up for our study was 5.1 years, and all patients had a minimum of two years follow-up. There were a few limitations of this study. First, the study was of retrospective design. Second, only patients who were symptomatic from PCC were included in the study, and we did not compare patient outcomes for patients having arthroscopic excision of PCC to all patients having TKA during the study period (n = 1442). Additionally, only patients who returned to clinic were evaluated for PCC and thus the overall incidence may be underestimated, although the surgeon routinely evaluated knees for PCC and recorded its presence or absence in his routine follow-up notes. Furthermore, the low numbers in the present study, while similar to other recent reports, increases the probability of type II error in statistical analysis. Finally, while a single implant design and single surgeon series is a strength of the study, it may also limit the generalizability of our data.

In conclusion, operative management for PCC was required in 1.2% of patients having TKA with the Sigma PS design. PCC can be self-limiting, as surgical management was necessary in only 39% of cases. Patients having arthroscopic excision had an 83% success rate with the index operation. Patient outcomes after arthroscopic excision for PCC were generally excellent as measured by the Knee Society Score and the WOMAC. Additionally, all patients reported at least some satisfaction with the decision to undergo arthroscopic treatment of PCC. The results of this data suggest that PCC is a relatively rare phenomenon after TKA with the Sigma PS design. These finding corroborate a relatively low incidence of crepitance and clunk with this device compared to some other PS devices. If PCC occurs with this design, arthroscopic excision results in resolution of symptoms and high patient satisfaction rates in the majority of patients. In addition, when there was a need for repeat excision, re-debridement was successful in all cases. The data presented provides a benchmark for comparison of future PS designs aiming to limit PCC phenomenon postoperatively.

REFERENCES

1. **Colizza WA, Insall JN, Scuderi GR.** The posterior stabilized total knee prosthesis. Assessment of polyethylene damage and osteolysis after a ten-year-minimum follow-up. The Journal of Bone & Joint Surgery. 1995;77(11):1713-1720.
2. **Insall JN, Lachiewicz PF, Burstein AH.** The posterior stabilized condylar prosthesis: a modification of the total condylar design. Two to four-year clinical experience. The Journal of Bone & Joint Surgery. American volume. Dec 1982;64(9):1317-1323.
3. **Yau W-P, Wong JW, Chiu K-Y, Ng T-P, Tang W-M.** Patellar clunk syndrome after posterior stabilized total knee arthroplasty. The Journal of Arthroplasty. 2003;18(8): 1023-1028.
4. **Choi WC, Ryu K-J, Lee S, Seong SC, Lee MC.** Painful patellar clunk or crepitation of contemporary knee prostheses. Clinical Orthopaedics and Related Research®. 2013;471(5):1512-1522.
5. **Dennis DA, Kim RH, Johnson DR, Springer BD, Fehring TK, Sharma A.** The John Insall Award: control-matched evaluation of painful patellar Crepitus after total knee arthroplasty. Clinical Orthopaedics and Related Research. Jan 2011;469(1):10-17.
6. **Niikura T, Tsumura N, Tsujimoto K, Yoshiya S, Kurosaka M, Shiba R.** Patellar clunk syndrome after TKA with cruciate retaining design: a report of two cases. Orthopedics. Jan 2008;31(1):90.
7. **Aglietti P, Buzzi R, Gaudenzi A.** Patellofemoral functional results and complications with the posterior stabilized total condylar knee prosthesis. J Arthroplasty. 1988;3(1):17-25.
8. **Clarke HD, Fuchs R, Scuderi GR, Mills EL, Scott WN, Insall JN.** The influence of femoral component design in the elimination of patellar clunk in posterior-stabilized total knee arthroplasty. The Journal of Arthroplasty. 2006;21(2):167-171.
9. **Agarwala SR, Mohrir GS, Patel AG.** Patellar clunk syndrome in a current high flexion total knee design. The Journal of Arthroplasty. 2013;28(10):1846-1850.
10. **Hozack WJ, Rothman RH, Booth Jr RE, Balderston RA.** The Patellar Clunk Syndrome: A Complication of Posterior Stabilized Total Knee Arthropiasty. Clinical Orthopaedics and Related Research. 1989;241:203-208.
11. **Hwang B-H, Nam C-H, Jung K-A, Ong A, Lee S-C.** Is further treatment necessary for patellar crepitus after total knee arthroplasty? Clinical Orthopaedics and Related Research®. 2013;471(2):606-612.
12. **Lonner JH, Jasko JG, Bezwada HP, Nazarian DG, Booth RE, Jr.** Incidence of patellar clunk with a modern posterior-stabilized knee design. American Journal of Orthopedics (Belle Mead, N.J.). Oct 2007;36(10):550-553.
13. **Ranawat AS, Ranawat CS, Slamin JE, Dennis DA.** Patellar crepitation in the P.F.C. sigma total knee system. Orthopedics. Sep 2006;29(9 Suppl):S68-70.
14. **Fukunaga K, Kobayashi A, Minoda Y, Iwaki H, Hashimoto Y, Takaoka K.** The incidence of the patellar clunk syndrome in a recently designed mobile-bearing posteriorly stabilised total knee replacement. The Journal of Bone and Joint Surgery. British volume. Apr 2009;91(4):463-468.
15. **Hamilton WG, Sritulanondha S, Engh CA, Jr.** Prospective randomized comparison of high-flex and standard rotating platform total knee arthroplasty. J Arthroplasty. Sep 2011;26(6 Suppl):28-34.

16. **Pollock DC, Ammeen DJ, Engh GA.** Synovial entrapment: a complication of posterior stabilized total knee arthroplasty. The Journal of Bone & Joint Surgery. American volume. Dec 2002;84-A(12):2174-2178.
17. **Frye BM, Floyd MW, Pham DC, Feldman JJ, Hamlin BR.** Effect of femoral component design on patellofemoral crepitance and patella clunk syndrome after posterior-stabilized total knee arthroplasty. J Arthroplasty. Jun 2012;27(6):1166-1170.
18. **Peralta-Molero JV, Gladnick BP, Lee YY, Ferrer AV, Lyman S, Gonzalez Della Valle A.** Patellofemoral crepitation and clunk following modern, fixed-bearing total knee arthroplasty. J Arthroplasty. Mar 2014;29(3):535-540.
19. **Schroer WC, Diesfeld PJ, Reedy ME, LeMarr A.** Association of increased knee flexion and patella clunk syndrome after mini-subvastus total knee arthroplasty. J Arthroplasty. Feb 2009;24(2):281-287.

POPLITEAL (BAKER'S) CYSTS IN THE SETTING OF PRIMARY KNEE ARTHROPLASTY

Josef N. Tofte, MD[1]; Andrew J. Holte, BA[2]; Nicolas Noiseux, MD[1], MS, FRCSC

ABSTRACT

Background: Popliteal (Baker's) Cysts are rare complications of knee arthroplasty. Enlargement, irritation, or rupture of the cyst can lead to significant pain, tightness, and tenderness. The literature regarding popliteal cysts occurring following knee arthroplasty is limited and does not report prevalence, natural history, and treatment of popliteal cyst in the setting of knee arthroplasty.

Methods: Following Institutional Review Board approval, 2,025 primary total and partial knee arthroplasties by four surgeons at one institution from 2011-2016 were reviewed for occurrence of popliteal cysts. Twelve cases occurring after arthroplasty were identified, including four unicompartmental knee arthroplasties and eight total knee arthroplasties. Demographic data were evaluated and symptoms, time of onset following arthroplasty, attempted treatment strategies, and success or failure of attempted treatments or interventions were recorded.

Results: The mean age of patients that presented with a popliteal cyst was 63.6 years old (range = 45 – 78 years). There were 5 males and 7 females. The mean BMI was 26.32 (range = 19.0 – 35.0). In 2,205 primary knee arthroplasties performed from 2011-2016 (including 175 partial and 1850 total), the prevalence of popliteal cysts following surgery was 0.6% (n=12). All popliteal cysts were discovered between six weeks and two years following surgery, with the majority occurring during the first year. Twenty-five percent (3/12) of patients presented with minimal symptoms. These were managed expectantly. Seventy-five percent (9/12) were symptomatic. One patient had only a diagnostic ultrasound, two patients underwent ultrasound-guided aspiration and steroid injection, three underwent simple aspiration. Two underwent surgical excision. One cyst ruptured. All cases went on to symptomatic resolution.

There was no association with diabetes, smoking, or body mass index. A disproportionately high number (25% or 4/12) occurred in partial knee arthroplasty.

Conclusion: While popliteal cysts following primary total knee arthroplasty are rare, they can become a persistent and even disabling problem for arthroplasty patients. Given the lack of formalized recommendations in the existing literature, we propose a treatment algorithm that has been successful in our clinic, including observation initially, ultrasound-guided injection/aspiration if symptomatic, and surgical excision as a last resort.

Level of Evidence: Level IV

Keywords: total knee arthroplasty, baker's cyst, popliteal cyst

INTRODUCTION

Popliteal (Baker's) cysts represent an enlargement of the popliteal bursa or an outpouching of the synovial tissue, most commonly through the posterior wall of the knee joint capsule[1]. They are typically secondary to joint injury or degenerative or auto-inflammatory disease and may result from the overproduction of synovial fluid. In the native knee, popliteal cysts often develop due to underlying knee pathology including osteoarthritis, rheumatoid arthritis, and meniscal tears[2].

Popliteal cysts, when asymptomatic, are usually found incidentally. However, they have the potential to become symptomatic, appearing as palpable swellings in the posterior knee that may mimic other pathologies. While there exists a substantial body of literature concerning popliteal cysts in the native knee, discussion of popliteal cysts following knee arthroplasty is limited to a few case reports[3–10]. Though popliteal cysts are an infrequently reported complication of a knee arthroplasty, it is evident

[1]University of Iowa Hospitals and Clinics Department of Orthopaedics and Rehabilitation.

[2]University of Iowa Roy J. and Lucille A. Carver College of Medicine.

Address correspondence to:
Josef N. Tofte, MD
Department of Orthopaedics and Rehabilitation
University of Iowa Hospitals and Clinics
200 Hawkins Drive, 01008 JPP
Iowa City, IA 52242
Email: josef-tofte@uiowa.edu
Telephone: 218 349 0563
Fax: 319 353 6754

No authors have any disclosures related to this work.

Funding: There were no sources of funding for this work.

that patients develop popliteal cysts at an appreciable rate following knee arthroplasty. Popliteal cysts that occur following knee arthroplasty should not be confused with preexistent popliteal cysts that fail to resolve following knee arthroplasty, which remain symptomatic in 31% of patients and resolve only 15% of the time[11]. Among other causes of knee pain in the setting of knee arthroplasty, rupture or enlargement of a popliteal cyst can lead to acute calf pain and tightness, tenderness, or erythema[10]. Rarely, peripheral nerve symptoms can occur as a result of tibial nerve compression[12]. Several treatment methods for popliteal cysts in the setting of knee arthroplasty are described, including percutaneous aspiration and/or injection, arthroplasty revision, as well as a two-stage operation including arthroplasty revision followed by complete resection of the cyst.

The etiology, incidence, natural history, and role for treatment of popliteal cysts following knee arthroplasty remain unclear. The purpose of this study is to elucidate the natural history popliteal cysts in the setting of knee arthroplasty and propose a treatment algorithm based upon clinical outcomes.

MATERIALS AND METHODS

Following Institutional Review Board approval, 2,025 primary total and partial knee arthroplasties by four surgeons at one institution from 2011-2016 were reviewed for occurrence of popliteal cysts. Twelve cases occurring after arthroplasty were identified, including four unicompartmental knee arthroplasties and eight total knee arthroplasties. An additional seven cases were identified that presented prior to knee arthroplasty. Demographic data, including age, gender, body mass index (BMI), laterality, smoking status, and presence or absence of diabetes were noted. Clinical notes were reviewed to determine the symptomatology of popliteal cysts, time of onset following arthroplasty, attempted treatment strategies, and success or failure of attempted treatments or interventions. Prevalence was estimated by dividing new presentations by the total number of knee arthroplasties performed over the study period.

RESULTS

The mean age of patients that presented with a popliteal cyst was 63.6 years old (range = 45 – 78 years). There were 5 males and 7 females. The mean BMI was 26.32 (range = 19.0 – 35.0). In 2,205 primary knee arthroplasties performed from 2011-2016 (including 175 partial and 1850 total), the prevalence of popliteal cysts following surgery was 0.6% (n=12). All popliteal cysts were discovered between six weeks and two years following surgery, with the majority occurring during the first year. Twenty-five percent (3/12) of patients presented with minimal symptoms or had popliteal cysts that were incidentally noted on exam. These either resolved with expectant management including physical therapy or remained asymptomatic without further intervention. Seventy-five percent (9/12) of patients with a popliteal cyst presented with significant swelling and pain in the posterior popliteal fossa. One patient had only a diagnostic ultrasound, two patients underwent ultrasound-guided aspiration and steroid injection, and three underwent simple aspiration. One patient was noted to have pigmented villonodular synovitis in addition to a popliteal cyst and underwent cyst excision, and another patient had an arthroscopic synovectomy. An additional patient became symptomatic when a popliteal cyst ruptured, and received a steroid injection. All cases went on to symptomatic resolution.

There was no association with diabetes, smoking, or body mass index. A disproportionately high number (25% or 4/12) occurred in partial knee arthroplasty. An additional seven Baker's cysts were detected pre-operatively, all of which resolved or remained asymptomatic following primary knee arthroplasty.

DISCUSSION

Popliteal cysts are an infrequently reported complication of primary knee arthroplasty. In our series, they occur rarely in 0.6% of knee arthroplasties and generally become symptomatic and evident during the first post-operative year. Several treatment strategies for symptomatic popliteal cysts in the native knee have previously been proposed. Conservative management is often the first strategy attempted, followed by aspiration and/or injection, with or without ultrasound[13,14]. Surgical treatment options include correction of the intra articular knee pathology[15], closure of the communication between the cyst and the articular cavity to eliminate flow of synovial fluid[16], expansion of the communication between the cyst and cavity to eliminate unidirectional flow of synovial fluid[2,16–19]. and removal of the cyst wall[20,21]. Existing literature discussing treatment of popliteal cysts that result following a total knee arthroplasties is limited to case reports. In two studies, dissecting popliteal cysts were reported as the presenting symptom of a malfunctioning total knee arthroplasty. In this series, the cysts resolved with revision of the TKA and did not require further treatment[6,10].

In our series, several different treatment strategies were employed. All were eventually successful in alleviating symptoms caused by popliteal cysts. In cases that did not resolve with expectant management or observation, ultrasound-guided aspiration and/or injection provides similar results to its performance in the native knee[13,14]. Based on our experience, we propose a treatment algorithm that has been successfully utilized in our clinic for partial and total knee arthroplasty patients. For initial management of a symptomatic popliteal cysts we recommend observation and expectant management. If observation fails or if the cysts remain persistently symptomatic, ultrasound-guided aspiration and steroid injection is a safe and viable treatment strategy. Lastly, surgical excision of the Bakers cyst is a treatment option that is effective, but that should be used as a last resort due to the invasive nature of the procedure.

This study has several limitations. It is possible that this study underreports the prevalence among our study population. Current procedural terminology codes were used to locate charts with popliteal cysts. Additionally, it is possible that not all asymptomatic popliteal cysts were detected on exam. The investigation is limited by its small number of patients treated. Finally, it is possible that some of our reported popliteal cysts were simply never noticed pre-operatively and did not in fact occur initially in the post-operative knee.

While popliteal cysts following a primary total knee arthroplasty are rare, they should be recognized as a potential cause of pain and dysfunction with an expected rate of occurrence, and should be treated in a systematic way to provide symptomatic relief.

REFERENCES

1. **Kim K Il, Lee SH, Ahn JH, Kim JS.** Arthroscopic anatomic study of posteromedial joint capsule in knee joint associated with popliteal cyst. Arch Orthop Trauma Surg. 2014;134(7):979–84.
2. **Sansone V, De Ponti A.** Arthroscopic treatment of popliteal cyst and associated intra-articular knee disorders in adults. Arthroscopy. 1999;15(4):368–72.
3. **Niki Y, Matsumoto H, Otani T, Yoshimine F, Inokuchi W, Morisue H.** Gigantic Popliteal Synovial Cyst Caused by Wear Particles after Total Knee Arthroplasty. J Arthroplasty. 2003;18(8):1071–5.
4. **Moretti B, Patella V, Mouhsine E, Pesce V, Spinarelli A, Garofalo R.** Multilobulated popliteal cyst after a failed total knee arthroplasty. Knee Surgery, Sport Traumatol Arthrosc. 2007;15(2):212–6.
5. **Moyad TF.** Massive baker cyst resulting in tibial nerve compression neuropathy secondary to polyethylene wear disease. Am J Orthop (Belle Mead NJ) [Internet]. 2015;44(4):E113-6. Available from: http://www.ncbi.nlm.nih.gov/pubmed/25844593
6. **Hsu W-H, Hsu RW-W, Huang T-J, Lee K-F.** Dissecting popliteal cyst resulting from a fragmented, dislodged metal part of the patellar component after total knee arthroplasty. J Arthroplasty [Internet]. 2002;17(6):792–7. Available from: http://www.ncbi.nlm.nih.gov/pubmed/12216038
7. **Pavlov H, Steinbach L, Fried SH.** A posterior ascending popliteal cyst mimicking thrombophlebitis following total knee arthroplasty (TKA). Clin Orthop Relat Res [Internet]. 1983;(179):204–8. Available from: http://www.ncbi.nlm.nih.gov/pubmed/6617018
8. **Ghanem G, Ghanem I, Dagher F.** Popliteal cyst in a patient with total knee arthroplasty: a case report and review of the literature. Le J médical libanais Leban Med J [Internet]. 2001 Jan [cited 2016 Mar 29];49(6):347–50. Available from: http://www.ncbi.nlm.nih.gov/pubmed/12744639
9. **Yamakado K.** Dissecting a popliteal cyst after failed unicompartmental knee arthroplasty. Arthroscopy [Internet]. 2002 Jan [cited 2016 Mar 29];18(9):1024–8. Available from: http://www.ncbi.nlm.nih.gov/pubmed/12426547
10. **Dirschl DR, Lachiewicz PF.** Dissecting popliteal cyst as the presenting symptom of a malfunctioning total knee arthroplasty. Report of four cases. J Arthroplasty [Internet]. 1992 Mar [cited 2016 Mar 29];7(1):37–41. Available from: http://www.ncbi.nlm.nih.gov/pubmed/1564464
11. **Hommel H, Perka C, Kopf S.** The fate of Baker's cyst after total knee arthroplasty. Bone Joint J. 2016;98–B(9):1185–8.
12. **Moyad TF.** Massive baker cyst resulting in tibial nerve compression neuropathy secondary to polyethylene wear disease. Am J Orthop (Belle Mead NJ) [Internet]. 2015 Apr [cited 2016 Mar 29];44(4):E113-6. Available from: http://www.ncbi.nlm.nih.gov/pubmed/25844593
13. **Di Sante L, Paoloni M, Ioppolo F, Dimaggio M, Di Renzo S, Santilli V.** Ultrasound-guided aspiration and corticosteroid injection of Baker's cysts in knee osteoarthritis: a prospective observational study. Am J Phys Med Rehabil Assoc Acad Physiatr [Internet]. 2010;89(12):970–5. Available from: http://content.wkhealth.com/linkback/openurl?sid=WKPTLP:landingpage&an=00002060-201012000-00003
14. **Smith MK, Lesniak B, Baraga MG, Kaplan L, Jose J.** Treatment of Popliteal (Baker) Cysts With Ultrasound-Guided Aspiration, Fenestration, and Injection: Long-term Follow-up. Sport Heal A Multidiscip Approach [Internet]. 2015;7(5):1941738115585520-. Available from: http://sph.sagepub.com/cgi/content/short/1941738115585520v1
15. **Rupp S, Seil R, Jochum P, Kohn D.** Popliteal cysts in adults. Prevalence, associated intraarticular lesions, and results after arthroscopic treatment. Am J Sports Med [Internet]. 2002;30(1):112–5. Available from: http://www.ncbi.nlm.nih.gov/pubmed/11799006

16. **Tanaka N, Yamamura M, Ishii S.** Anterior arthroscopic synovectomy plus capsuloplasty with a pedicle graft for the treatment of rheumatoid popliteal cysts. J Rheumatol. 1999;26(7):1481–5.
17. **Kanekasu K, Nagashima K, Yamauchi D, Yamakado K.** [A clinical study of arthroscopic cystectomy on popliteal cysts associated with rheumatoid arthritis]. Ryumachi. 1997;37(6):761–9.
18. **Ahn JH, Lee SH, Yoo JC, Chang MJ, Park YS.** Arthroscopic treatment of popliteal cysts: clinical and magnetic resonance imaging results. Arthroscopy [Internet]. 2010;26(10):1340–7. Available from: http://dx.doi.org/10.1016/j.arthro.2010.02.012
19. **Smith MK, Lesniak B, Baraga MG, Kaplan L, Jose J.** Treatment of Popliteal (Baker) Cysts With Ultrasound-Guided Aspiration, Fenestration, and Injection: Long-term Follow-up. Sports Health [Internet]. 2015 Jan [cited 2016 Mar 29];7(5):409–14. Available from: http://www.ncbi.nlm.nih.gov/pubmed/26502415
20. **Cho JH.** Clinical results of direct arthroscopic excision of popliteal cyst using a posteromedial portal. Knee Surg Relat Res [Internet]. 2012;24(4):235–40. Available from: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3526761&tool=pmcentrez&rendertype=abstract
21. **He R, Guo L, Yang L, Chen G, Duan X, Luo C.** [Knee arthroscopic resection of articular capsule valvular treat popliteal cysts]. Zhonghua Wai Ke Za Zhi [Internet]. 2013;51(5):417–20. Available from: http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L603140458

HOW RELIABLE IS THE ACETABULAR CUP POSITION ASSESSMENT FROM ROUTINE RADIOGRAPHS?

Jaime A. Carvajal Alba, MD[1], Heather K. Vincent, PhD, FACSM[2], Jagdeep S. Sodhi, MD[3], Loren L. Latta, PhD, PE[4], Hari K. Parvataneni, MD[5]

ABSTRACT

Background: Cup position is crucial for optimal outcomes in total hip arthroplasty. Radiographic assessment of component position is routinely performed in the early postoperative period.

Aims: The aims of this study were to determine in a controlled environment if routine radiographic methods accurately and reliably assess the acetabular cup position and to assess if there is a statistical difference related to the rater's level of training.

Methods: A pelvic model was mounted in a spatial frame. An acetabular cup was fixed in different degrees of version and inclination. Standardized radiographs were obtained. Ten observers including five fellowship-trained orthopaedic surgeons and five orthopaedic residents performed a blind assessment of cup position. Inclination was assessed from anteroposterior radiographs of the pelvis and version from cross-table lateral radiographs of the hip.

Results: The radiographic methods used showed to be imprecise specially when the cup was positioned at the extremes of version and inclination. An excellent inter-observer reliability (Intra-class coefficient > 0,9) was evidenced. There were no differences related to the level of training of the raters.

Conclusions: These widely used radiographic methods should be interpreted cautiously and computed tomography should be utilized in cases when further intervention is contemplated.

INTRODUCTION

Adequate component position is essential to ensure optimal clinical results and prosthetic implant survival in total hip arthroplasty.[1,2] Optimizing acetabular cup orientation can help reduce component instability and dislocations, minimize liner wear and increase the impingement free range of motion (ROM) of the hip.[3,4,5,6]

Implant position is routinely assessed from standardized radiographs during the early postoperative period. Anteroposterior (AP) radiographs of the hip and the pelvis and a cross-table lateral (CTL) radiograph of the hip are usually obtained. As described by Engh et al,[7] the cup inclination angle is obtained by the intersection of a line passing through the inferior aspect of the radiographic teardrops and a line tangential to the rim of the cup from an AP radiograph of the pelvis. Good accuracy, inter- and intra-observer reliability for this method has been reported.[8,9,10,11,12] Radiographic version assessment from plain radiographs is less standardized and not highly reliable.[13] Using AP radiographic views of the pelvis, several mathematic, trigonometric and protractor methods have been proposed.[12,14,15,16,17] For accurate calculations, a clear visualization of a perfect ellipse of the acetabular cup is required. Several factors including patient position, pelvic tilt/obliquity and direction of the X-ray beam adversely affect the accuracy of these methods.[8,9,14] Woo and Morrey[18] described one of the most currently used methods to assess the acetabu-

[1]Jaime A. Carvajal Alba, M.D.
Department of Orthopaedics, University of Miami.
1611 NW 12th Ave. Suite 303. Miami, FL 33136. USA.
Corresponding Author:
jcarvajal@miami.edu
Phone: (786) 897-9002

Department of Orthopaedics and Rehabilitation, University of Florida
3450 Hull Road, Gainesville, FL 32607. USA
vincehk@ortho.ufl.edu

Jagdeep S. Sodhi, M.D.
BayCare Orthopaedics
1160 Kepler Drive, Green Bay, WI 54311. USA
JSodhi@baycare.net

Loren L. Latta, Ph.D., P.E.
Max Biedermann Institute of Biomechanics
Department of Orthopaedics, University of Miami
1611 NW 12th Ave. Suite 303. Miami, FL 33136. USA
LLatta@med.miami.edu

Hari K. Parvataneni, M.D.
Department of Orthopaedics and Rehabilitation, University of Florida
3450 Hull Road, Gainesville, FL 32607. USA.
parvahk@ortho.ufl.edu

The following are the statements related to this research project: Each of the authors represents that he, or she, has read and approved the final manuscript. Each author certifies that he or she has no commercial associations that might pose a conflict of interest in connection with the submitted article. All authors contributed to either planning, doing, or analyzing the study or writing the paper. This project did not involve human subjects, and thus, it did not required IRB approval. This research project was performed at the Department of Orthopaedics of the University of Miami and the Department of Orthopaedics and Rehabilitation of the University of Florida.

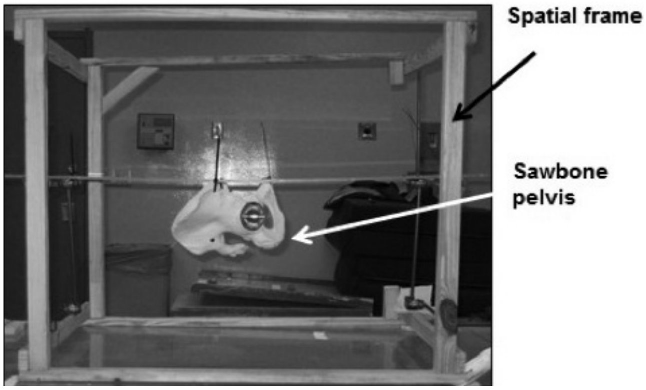


Figure 1. Experimental setup. Sawbones pelvis in fixed to a spatial frame to recreate a true coronal AP pelvic plane position.

lar cup version from CTL radiographs of the hip. The cup version angle is formed by a tangential line to the acetabular cup rim and a line perpendicular to the long axis plane of the body. Yao et al[19] found that standardization of the orientation of the X-ray beam when using this method is essential to improve accuracy. When analyzing model data, there appears to be a strong correlation between the version angles obtained by this method and the trigonometric method[15] using AP radiographs of the hip. However, when analyzing clinical data, the mean and standard deviation between the two measurements was 5° ±4.2°.[20] Correlation of the version values obtained from CTL radiographs and those obtained by computed tomography (CT) has been also reported.[21]

CT of the pelvis remains the most accurate test to determine the acetabular cup position.[9,22,23] Several limiting factors such as costs, availability, and higher radiation exposure when compared to plain radiographs decrease its utility for routine use.[11] CT is reserved for complex cases where a clinical decision has to be made regarding the revision of malpositioned or dislocated components.

There is current general awareness about the major clinical impact of cup positioning in the outcomes following total hip arthroplasty. However, available data is conflicting regarding the accuracy and reliability of the radiographic methods routinely used to assess the position of the acetabular cup. Most of these studies were performed in-vivo where confounding variables such as body habitus, pelvic tilt, lumbosacral deformities or lack of standardization in radiographic technique are not taken into account and could significantly affect the assessment of these methods. The aim of this study is to evaluate, in a controlled environment, the accuracy and inter-rater reliability of two of the most commonly used methods to assess cup position from standardized plain radiographs and the effect of the level of training of the raters on these parameters.

MATERIALS AND METHODS

Design

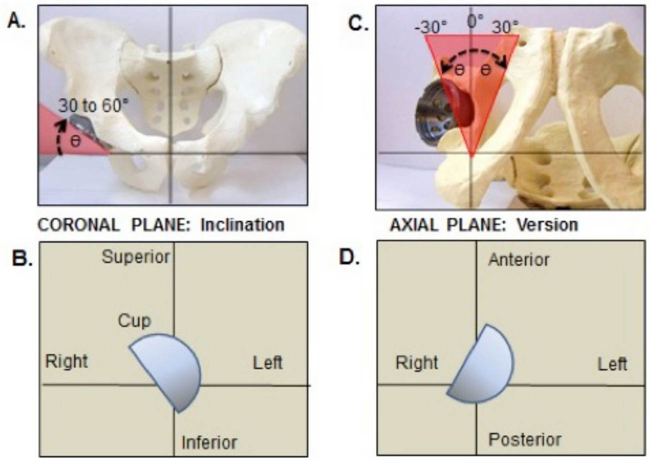
This was an experimental, comparative pilot study. A pelvis model was built to recreate experimental changes in version and inclination angle of the acetabular cup. Radiographs of the cup in nine different positions were obtained. Ten observers including five fellowship-trained orthopaedic surgeons and five orthopaedic residents performed a blind assessment of acetabular cup position in the experimental conditions.

Experimental Set Up

One sawbone pelvis (Sawbones®, reference 1301-1) was carefully mounted in a spatial Plexiglas frame to obtain a standardized true coronal AP pelvic plane as shown in Figure 1. Three 13 mm holes were drilled into the pelvis model. One hole was positioned 0.5 cm from the top of each anterior superior iliac spine (ASIS) and one hole was positioned 0.5 cm to the right of the center of the pubic symphysis. Direct contact between the Plexiglas plate and the two ASIS and the pubic symphysis was guaranteed with the use of cable ties in order to achieve a true coronal AP pelvic plane with a neutral pelvic tilt for the experimental conditions. A standardized 56 mm titanium hemispherical shell (Trident®, Stryker, Mahwah, NJ, USA) was used. Standardization of the cup position was performed with the use of a metallic bar secured in the transverse plane of the pelvis (through the ischial tuberosities) and a magnetic goniometer. Once the planned cup position was achieved, the acetabular cup was fixed into the right acetabulum using one titanium screw (25 mm/6.5mm) in the postero-superior aspect of the acetabular wall. Cup position was reassessed with the goniometer after fixation to guarantee reliability of the standardization. Controlled positioning of the acetabular cup was performed combining 30°, 45° (neutral) or 60° of inclination and neutral version (0°), 30° of anteversion or 30° of retroversion. Similar to other studies, these cup positions represent the far ends of the spectrum of recommended acetabular cup orientation.[24] In total, nine different experimental conditions were recreated using the three different version and three different inclination angles (Figure 2).

Imaging

A series of two radiographic views were obtained from each of the nine conditions. These included an AP view of the pelvis and a CTL view of the right hip. Standardization of the radiographic technique was necessary to prevent inflicted sample variations. Radiographic films of 35x43 cm were used. The central ray was standardized at 80 kVp and 12 mA. The pelvic to radiographic beam distance, or Source Image Receptor Distance (SID), was 110 cm as standardized by Clarke et al,[25]



Figures 2A-D. Inclination (2A-B) and version (2C-D) of the sawbone pelvis for the experimental conditions. 2A) Inclination is represented as the red triangle, where the θ is 30°, 45° or 60° in the coronal plane; 2B) Position of the acetabular cup in the spatial frame for the inclination measures; 2C). Version is represented as the red triangle, where the θ is 30° (anteversion), 0°(neutral) or -30° (retroversion) in the coronal plane; 2D) Position of the acetabular cup in the spatial frame for the version measures.

and the pelvis to radiographic plate, or Object Image Receptor Distance (OID), was 10 cm. The examination table supporting the spatial frame was parallel to the floor (0°). Collimator light borders were adjusted to the image receptor borders. The central ray was directed to the midway between the level of both anterior superior iliac spine and the pubic symphysis for AP views of the pelvis. The central ray was positioned perpendicular to the plane of the image receptor and perpendicular to the examination table. For the CTL view of the hip, the central ray was directed toward the center of rotation of the acetabulum and positioned perpendicular to the image receptor, parallel to the examination table and at 45° to the long axis of the pelvis.[12] The mounted pelvis, radiographic beam and radiographic plate were placed in the same position for each of the nine conditions to be evaluated. Reproducibility of the radiographic technique was carefully scrutinized after each obtained radiograph.

Radiographs were numbered randomly. Ten blinded observers consisting of five orthopaedic surgeons subspecialized in joint reconstructive surgery and five orthopaedic surgery residents with different level of training (one second year, one third year, one fourth year and 2 fifth year residents) performed a blinded radiographic evaluation for cup positioning. An orthopaedic goniometer and a radiograph pencil were provided to each of the reviewers at the time of the evaluation. All the evaluations were performed independently.

The AP views of the pelvis were evaluated in terms of quantitative inclination using the method described by Engh et al.[7] CTL radiographs were evaluated in terms of quantitative version using the method described by Woo and Morrey,[18] with 0° indicating a neutral cup, negative values indicating a retroverted cup and positive values indicating an anteverted cup.

Statistics

The Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS; version 22.0). Data are expressed as means ± standard deviations (SD). The students' t-test was used to assess the existing differences between the experimental conditions (nine permutations for inclination angle and version) and between the raters (practicing surgeons and residents). The rater group was the independent variable and the rater evaluations were the dependent variables.

Intra-class coefficients (ICC) for reliability were determined for each radiograph view type (AP, CTL). ICC were interpreted as follows: 0-0.2 indicated poor agreement: 0.3-0.4 indicated fair agreement; 0.5-0.6 indicated moderate agreement; 0.7-0.8 indicated strong agreement; and >0.8 indicates almost perfect agreement. To determine whether differences existed between the proportions of practicing surgeons and residents who estimated acetabular cup angle to within ±5° of the actual cup angle in the AP view, Mann-Whitney U tests were used; the outcomes were "yes" and "no" based on the ability to correctly detect the cup angle. Significance was established at $p<0.05$ for all statistical tests.

RESULTS

The results of the readings from AP and CTL radiograph views are shown in Tables 1 and 2 respectively. Regarding the assessment of cup inclination from AP radiographs (Table 1), imprecision of the rating was more notorious with extremes of cup version (+30° and -30°) and cup inclination (30° and 60°). The worst-case scenario was seen with a vertical and retroverted cup (60° of inclination and 30° of retroversion). The average of ratings was closest to the actual cup position with the cup placed in neutral inclination (45°) and neutral version (0°). There were no statistically significant differences in cup angle estimates between practicing surgeon and resident readings.

When assessing cup version from CTL views (Table 2), a trend for differences in estimates between practicing surgeons and residents was observed for the inclination angle of 45° at neutral version (0°) condition in the CTL view (1.0°±2.2° vs. -2.6°±3.2°; $p=0.074$), but this did not achieve significance. No significant differences were found for the averaged rated and real cup positions for any of the nine positions in the CTL radiographs. Table 3 provides the percentage of readings of version that were within ±5° from the actual cup position. Overall, when

Table I.

Condition		All raters	Practicing Surgeons	Residents	p (sig)
Real Inclination angle	Version				
30°	30° anteversion	39.6 ± 5.8	38.6 ± 6.4	40.6 ± 5.8	.286
	0° neutral version	36.9 ± 3.3	36.0 ± 3.8	37.8 ± 2.8	.418
	30° retroversion	37.7 ± 3.1	38.8 ± 2.9	36.6 ± 3.4	.620
45° (neutral)	30° anteversion	40.6 ± 3.5	39.4 ± 1.9	41.8 ± 2.5	.319
	0° neutral version	47.7 ± 2.1	46.8 ± 1.6	48.6 ± 2.2	.180
	30° retroversion	40.6 ± 3.5	39.4 ± 4.4	41.8 ± 2.5	.319
60°	30° anteversion	50.9 ± 5.5	50.8 ± 3.7	51.0 ± 7.4	.958
	0° neutral version	64.5 ± 4.1	64.0 ± 2.3	65.0 ± 4.1	.650
	30° retroversion	48.4 ± 4.2	48.2 ± 2.9	48.6 ± 2.9	.892

Acetabular cup inclination assessment from AP radiographic views of the pelvis in the nine experimental permutations of cup inclination and version. Means ± standard deviations are shown. All values are in degrees.

Table II.

Condition		All raters	Practicing Surgeons	Residents	p (sig)
Inclination angle	Real Version				
30°	30° anteversion	25.0 ± 6.0	25.8 ± 5.3	24.2 ± 7.1	.138
	0° neutral version	-1.0 ± 2.5	0.0 ± 0.0	-2.0 ± 3.5	.233
	30° retroversion	-25.7 ± 4.4	-23.6 ± 2.5	-27.8 ± 5.1	.699
45° (neutral)	30° anteversion	36.8 ± 6.7	37.0 ± 5.7	36.6 ± 8.4	.362
	0° neutral version	-0.8 ± 3.2	1.0 ± 2.2	-2.6 ± 3.2	.074
	30° retroversion	-28.8 ± 3.3	-27.8 ± 3.0	-29.8 ± 3.5	.932
60°	30° anteversion	28.9 ± 3.6	29.2 ± 2.4	28.6 ± 4.5	.839
	0° neutral version	-2.6 ± 7.0	0.0 ± 0.0	-5.2 ± 9.6	.263
	30° retroversion	-32.6 ± 5.7	-33.0 ± 6.7	-32.2 ± 5.2	.811

Acetabular cup version assessment from Cross Table Lateral (CTL) radiographic views in the nine experimental permutations of cup inclination and version. Means ± standard deviations are shown. All values are expressed in degrees and negative values denote retroversion.

Table III.

Condition	All raters		Practicing Surgeons	Residents
Version	Inclination angle			
30° retroversion	30°	60.0	60.0	60.0
	45°	80.0	80.0	80.0
	60°	80.0	80.0	80.0
0° (neutral)	30°	90.0	100.0	80.0
	45°	90.0	100.0	80.0
	60°	80.0	80.0	80.0
30° anteversion	30°	50.0	40.0	60.0
	45°	50.0	40.0	60.0
	60°	90.0	100.0	80.0
Total correct		76.7	75.6	73.3

Percentage of correct radiographic readings (within ±5° of actual acetabular cup position) using

Table IV.

Inter-Item Correlation Matrix

	rater1	rater2	rater3	rater4	rater5	rater6	rater7	rater8	rater9	rater10
rater1	1.000	.996	.998	.954	.977	.985	.996	.996	.997	.999
rater2	.996	1.000	.993	.928	.966	.982	.987	.991	.992	.993
rater3	.998	.993	1.000	.947	.971	.984	.998	.997	.999	.999
rater4	.954	.928	.947	1.000	.952	.944	.958	.952	.948	.950
rater5	.977	.966	.971	.952	1.000	.974	.979	.976	.973	.976
rater6	.985	.982	.984	.944	.974	1.000	.988	.986	.983	.985
rater7	.996	.987	.998	.958	.979	.988	1.000	.998	.998	.998
rater8	.996	.991	.997	.952	.976	.986	.998	1.000	.999	.998
rater9	.997	.992	.999	.948	.973	.983	.998	.999	1.000	.999
rater10	.999	.993	.999	.950	.976	.985	.998	.998	.999	1.000

Raters 1, 5, 6, 8 and 9 are surgeons.

Raters 2, 3, 4, 7 and 10 are residents.

Intra-class coefficients for radiographic interpretation of the acetabular cup inclination using AP radiographs. Each correlation represents the reliability of the nine experimental evaluations between two raters.

Table V.

Inter-Item Correlation Matrix

	rater1	rater2	rater3	rater4	rater5	rater6	rater7	rater8	rater9	rater10
rater1	1.000	.982	.996	.979	.985	.981	.983	.992	.986	.996
rater2	.982	1.000	.987	.956	.969	.979	.972	.991	.978	.988
rater3	.996	.987	1.000	.976	.984	.987	.986	.997	.992	.996
rater4	.979	.956	.976	1.000	.982	.968	.971	.975	.970	.974
rater5	.985	.969	.984	.982	1.000	.976	.977	.982	.983	.980
rater6	.981	.979	.987	.968	.976	1.000	.978	.991	.984	.989
rater7	.983	.972	.986	.971	.977	.978	1.000	.984	.974	.984
rater8	.992	.991	.997	.975	.982	.991	.984	1.000	.989	.998
rater9	.986	.978	.992	.970	.983	.984	.974	.989	1.000	.985
rater10	.996	.988	.996	.974	.980	.989	.984	.998	.985	1.000

Raters 1, 5, 6, 8 and 9 are surgeons.

Raters 2, 3, 4, 7 and 10 are residents.

Intra-class coefficients for radiographic interpretation of the acetabular cup version using CTL radiographs. Each correlation represents the reliability of the nine experimental evaluations between two raters.

the cup version was set as neutral, ratings were correct in more than 80% of the cases independently from the cup inclination. As opposed to inclination, a horizontal cup placed in extreme degrees of version appeared to impact accuracy of version assessment from CTL views of the hip as demonstrated by the low percentages.

Tables 4 and 5 provide the ICC values among all raters for the nine conditions in the AP and CTL views respectively. All of the correlations between the raters exceeded 0.9, indicating excellent agreement.

DISCUSSION

Several studies have reported on the positive correlation of routine postoperative radiographs to assess cup position when compared to CT scans of patients after hip arthroplasty.[21,22] In our study, despite controlling and standardizing cup and pelvic position and radiographic technique, none of the routinely used radiographic methods above described resembled an optimal way to accurately determine the position of the acetabular cup.

The amount of anteversion or retroversion from the neutral cup position seems to be directly proportional to the probability of inaccurate measurement of inclination from the AP radiographs of the pelvis. Less than half of the observers agreed with the real angle of the cup (+/- 5°). In this study, the least agreement between observers regarding cup inclination was noted when the cup was retroverted and vertical. By obscuring the rim of the cup, version makes more difficult to measure the inclination of the cup. Pelvic tilt and obliquity seen in real life may further impact the accuracy of this measurement.[26]

On average, ratings of cup version from CTL views were within 5 degrees from the real version angle except for few outliers as shown in Table 2. McArthur et al[22] reported on the impact of cup inclination on accuracy of cup version assessment from CTL radiographs and proposed a modified CTL radiographic technique in which the angle of the radiographic beam is matched to the cup inclination angle obtained on an AP radiograph of the pelvis. This allows the cup rim to appear as a line facilitating the assessment of version and improving its accuracy. For both, the inclination and the anteversion assessment, level of training did not seem to influence the radiographic interpretation of cup position.

The tested radiographic methods showed a high inter-observer reliability as evidenced by an ICC of >0.9 in all of the radiographic ratings. These results are in agreement with previous studies.[11,12] Mahmood et al[10] reported an intra-class correlation of coefficient of 0.87 for the assessment of cup inclination and 0.96 for the assessment of cup version.

CT clearly remains the gold standard method to assess the acetabular cup position due to its accuracy and reliability.[9,22] Costs, availability and concerns about cumulative radiation exposure avoid the generalized use of this test. Merging technology such as the low-dose digital stereography (EOS imaging system, Cambridge, MA) could help to feasibly solve the problem of inaccuracy when assessing the postoperative position of the cup from routine radiographs. Journé et al[27] reported that the method using the EOS system had an accuracy of 2.6° when assessing cup inclination in comparison to 3° and 2° for the radiographic method and the CT method respectively. Measuring cup version, the EOS imaging system showed an accuracy of 3.9° compared to 9.2° and 2.9° of radiographs and CT respectively. The EOS is associated with less cumulative radiation exposure and lower costs but the lack of wide availability is its main clear disadvantage.

Limitations and Strengths

Our experimental model provided a controlled environment from which to study accuracy and inter-rater agreement of radiographic ratings, when all variables other than inclination and version angles were held constant. Previous studies have investigated the accuracy of these methods using radiographs and CT images of patients but poor standardization in radiographic technique, differences in patient's body habitus and pelvic tilt may add a source of error in the analysis of these variables. Chandler et al[28] reported an error of as much as 15 degrees on the assessment of acetabular cup inclination with a pelvic tilt of 15 degrees. The number of raters with different levels of training provides a more comprehensive assessment of inter-rater reliability and accuracy. Extremes of cup retroversion and anteversion were chosen to magnify the impact of this parameter in component position assessment. Computed tomography of the mounted pelvis was not obtained but the checkpoints performed to ensure standardization of the cup position was deem optimal. Digital imaging is not universally available but additional testing could include the use digital radiographic measurements of a pelvic model recreating different angles of pelvis tilt and obliquity or whole cadaveric specimens with different types of body habitus.

CONCLUSIONS

Component position is essential for optimal surgical outcomes in total hip arthroplasty. The CT scan remains the gold standard and most accurate test to assess the postoperative component position. Despite the excellent inter-observer reliability, routine postoperative radiographic assessment of cup position showed to be imprecise. Therefore, these widely used radiographic methods should be interpreted cautiously and computed tomography should be utilized in cases when further intervention is contemplated.

This study was founded by the Department of Orthopaedics of the University of Miami research fund.

REFERENCES

1. **Angadji A, Royle M, Collins SN, Shelton J.** Influence of cup orientation on the wear performance of metal-on-metal hip replacements. Proc Inst Mech Eng H. 2009;223:449-457.
2. **Daines BK, Dennis DA.** The importance of acetabular component position in total hip arthroplasty. Orthop Clin North Am. 2012;43(5):e23-34.
3. **Barrack RL, Krempec JA, Clohisy JC, McDonald DJ, Ricci WM, Ruh EL, Nunley RM.** Accuracy of acetabular component position in hip arthroplasty. J Bone Joint Surg Am. 2013;95:1760-1768.
4. **Biedermann R, Tonin A, Krismer M, Rachbauer F, Eibl G, Stöckl B.** Reducing the risk of dislocation after total hip arthroplasty. J Bone Joint Surg Br. 2005;87:762-769.

5. **Patil S, Bergula A, Chen PC, Colwell CW Jr, D'Lima DD.** Polyethylene wear and acetabular component orientation. J Bone Joint Surg Am. 2003;85(4):56-63.
6. **Wan Z, Boutary M, Dorr LD.** The influence of acetabular component position on wear in total hip arthroplasty. J Arthroplasty. 2008;23:51-56.
7. **Engh CA, Griffin WL, Marx CL.** Cementless acetabular components. J Bone Joint Surg Br. 1990;72:53-59.
8. **Derbyshire B.** Correction of acetabular cup orientation measurements for X-ray beam offset. Med Eng Phys. 2008;30:1119-1126.
9. **Kalteis T, Handel M, Herold T, Perlick L, Paetzel C, Grifka J.** Position of the acetabular cup–accuracy of radiographic calculation compared to CT-based measurement. Eur J Radiol. 2006;58:294-300.
10. **Mahmood SS, Al-Amiry B, Mukka SS, Baea S, Sayed-Noor AS.** Validity, reliability and reproducibility of plain radiographic measurements after total hip arthroplasty. Skeletal Radiol. 2015;44:345-351.
11. **Seradge H, Nagle KR, Miller RJ.** Analysis of version in the acetabular cup. Clin Orthop Relat Res. 1982;166:152-157.
12. **Siebenrock KA, Kalbermatten DF, Ganz R.** Effect of pelvic tilt on acetabular retroversion: a study of pelves from cadavers. Clin Orthop Relat Res. 2003;407:241-248.
13. **Tiberi JV, Pulos N, Kertzner M, Schmalzried TP.** A more reliable method to assess acetabular component position. Clin Orthop Relat Res. 2012;470(2):471-476.
14. **Hassan DM, Johnston GH, Dust WN, Watson G, Dolovich AT.** Accuracy of intraoperative assessment of acetabular prosthesis placement. J Arthroplasty. 1998;13:80-84.
15. **Lewinnek GE, Lewis JL, Tarr R, Compere CL, Zimmerman JR.** Dislocations after total hip-replacement arthroplasties. J Bone Joint Surg Am. 1978;60:217-220.
16. **Liaw CK, Yang RS, Hou SM, Wu TY, Fuh CS.** Measurement of the acetabular cup anteversion on simulated radiographs. J Arthroplasty. 2009;24:468-474.
17. **Widmer KH.** A simplified method to determine acetabular cup anteversion from plain radiographs. J Arthroplasty. 2004;19:387-390.
18. **Woo RY, Morrey BF.** Dislocations after total hip arthroplasty. J Bone Joint Surg Am. 1982;64:1295-1306.
19. **Yao L, Yao J, Gold RH.** Measurement of acetabular version on the axiolateral radiograph. Clin Orthop Relat Res. 1995;316:106-111.
20. **Arai N, Nakamura S, Matsushita T.** Difference between 2 measurement methods of version angles of the acetabular component. J Arthroplasty. 2007;22:715-720.
21. **Nunley RM, Keeney JA, Zhu J, Clohisy JC, Barrack RL.** The reliability and variation of acetabular component anteversion measurements from cross-table lateral radiographs. J Arthroplasty. 2011;26(6):84-87.
22. **McArthur B, Cross M, Geatrakas C, Mayman D, Ghelman B.** Measuring acetabular component version after THA: CT or plain radiograph? Clin Orthop Relat Res. 2012;470:2810-2818.
23. **Mian SW, Truchly G, Pflum FA.** Computed tomography measurement of acetabular cup anteversion and retroversion in total hip arthroplasty. Clin Orthop Relat Res. 1992;276:206-209.
24. **Kosashvili Y, Omoto D, Backstein D, Safir O, Lakstein D, Gross AE.** Acetabular alignment and primary arc of motion for minus, skirtless, and skirted 28-, 32-, 36-, and 40-mm femoral heads. J Arthroplasty. 2013;28:279-285.
25. **Clarke IC, Gruen T, Matos M, Amstutz HC.** Improved methods for quantitative radiographic evaluation with particular reference to total hip arthroplasty. Clin Orthop Relat Res. 1976;121:83.
26. **McBride A, Flynn J, Miller G, Barnes M, Mackie S.** Body mass index and acetabular component position in total hip arthroplasty. ANZ J Surg. 2013;83(3):171-174.
27. **Journé A, Sadaka J, Bélicourt C, Sautet A.** New method for measuring acetabular component positioning with EOS imaging: feasibility study on dry bone. Int Orthop. 2012;36:2205-2209.
28. **Chandler DR, Tarr RR, Gruen TA, Sarmiento A.** Radiographic assessment of acetabular cup orientation. A new design concept. Clin Orthop Relat Res. 1984;186:60-64.

DETECTION OF RETAINED FOREIGN OBJECTS IN UPPER EXTREMITY SURGICAL PROCEDURES WITH INCISIONS OF TWO CENTIMETERS OR SMALLER

Josef N. Tofte, MD[1], Lindsey S. Caldwell, MD[1]

ABSTRACT

Background: While the true incidence of retained foreign bodies after surgery is unknown, it has been approximated at 1:5,500 operations overall, with substantially less frequency in hand and upper extremity procedures. Despite the rarity of foreign body retention in hand and upper extremity surgery, universal radiofrequency scanning for electronically-tagged sponges and automatic radiographic evaluation for incorrect sponge counts are employed for all surgical procedures at our institution. We demonstrate the infeasibility of retaining an operative sponge of a standard size in commonly performed hand and upper extremity procedures with incision sizes of two centimeters or less, and establish that visual detection of sponges in these cases is adequate.

Methods: Eighteen trigger finger releases, five carpal tunnel releases, three trigger thumb releases, and three de Quervain's tenosynovitis releases were successfully performed upon five cadaveric specimens by residents under supervision of fellowship-trained hand surgeons for a total of 29 two-centimeter or smaller incisions. Randomized surgical sponge placement was evaluated by a blinded observer at two distances and incision sizes were quantified. Kappa values were calculated to determine the acuity of visual detection versus the actual presence of a sponge.

Results: The maximum length of the standard surgical sponge that could be contained within an incision was three centimeters. When compared with the gold standard (whether the sponge had been placed or not by the operating resident), the placement of a standard surgical sponge could be detected correctly in 100% of cases at both "across the room" and "at the table" distances, for kappa values of 1.0 and 1.0 respectively. This did not vary with incision size or surgical procedure.

Conclusions: The added cost and time from radiofrequency detection of retained sponges and radiographic evaluation in the event of incorrect sponge counts can be safely eliminated if sponges can be reliably visually detected.

Clinical Relevance: This cadaveric study informs patient safety practices by demonstrating that visual detection of surgical sponges is adequate for certain upper extremity procedures.

Keywords: retained foreign body, retained foreign object, radiofrequency, upper extremity, hand, quality improvement, patient safety

INTRODUCTION

Retained foreign bodies following surgery are preventable medical errors that may result in patient harm. The Centers for Medicare and Medicaid Services (CMS) consider these to be "never events," and do not reimburse for any additional care required[1]. While the true incidence of retained foreign bodies after surgery is unknown, it has been approximated at 1:5,500 operations[2]. The majority of these items in the reported literature are surgical sponges with greater than 80% of those being retained in major body cavities such as the abdomen, pelvis and thorax[3]. While standardized counting of surgical instruments and sponges has been widely implemented to help prevent retained foreign bodies, more than half of the retained foreign bodies in the reported literature occurred when the sponge count was pronounced correct at the end of the case[3].

Recently, the use of adjunctive technologies such as radiofrequency sensors and electronically tagged sponges have begun to play an important role in the detection of retained foreign bodies. One study noted that when sponges with a radiofrequency chip were placed behind the abdomen radiofrequency wand detection of the sponges was accurate 100% of the time, even in morbidly obese patients[4].

1. University of Iowa Hospitals and Clinics Department of Orthopaedics and Rehabilitation.

Address correspondence to:
Josef N. Tofte, MD
Department of Orthopaedics and Rehabilitation
University of Iowa Hospitals and Clinics
200 Hawkins Drive, 01008 JPP
Iowa City, IA 52242
Email: josef-tofte@uiowa.edu
Telephone: 218 349 0563
Fax: 319 353 6754

No authors have any disclosures related to this work.

No sources of funding were obtained for this study.

The incidence of foreign object retention is rare in the orthopaedic literature, particularly with regard to surgeries with incisions less than two centimeters, such as arthroscopy and hand and upper extremity procedures. An evaluation of the arthroscopy literature reveals one report of a broken outflow cannula removed from a knee arthroscopy patient 10 years post operatively[5] and a single report of a scalpel blade removed from a knee 10 years post operatively[6]. Two additional reports addressing instrument failure or retained foreign bodies in arthroscopy from 1978 and 1988 reflect significantly different arthroscopic techniques and equipment than are used today[7,8].

Regarding hand and upper extremity surgery specifically, there is sparse literature concerning retained foreign bodies. One case report notes a retained catheter fragment in the radial artery after anesthesia insertion of an arterial line9 and another reports retained peg guides on a distal radius locking plate[10]. One large review of 28,737 hand and upper extremity cases performed at a freestanding ambulatory surgery center found no incidences of retained foreign bodies[11].

Despite the apparent extreme rarity of foreign body retention in hand and upper extremity surgery, standard precautions to avoid sponge retention still apply universally to all surgical procedures including upper extremity procedures at our institution. These precautions include radiofrequency scanning for electronically-tagged operative sponges, and in the event that sponge counts are incorrect, automatic radiographic evaluation of the surgical site requiring additional expense and operative delay while an attending-level radiologist evaluates the film. The purpose of this study is to rigorously demonstrate the infeasibility of retaining an operative sponge of a standard size in commonly performed hand and upper extremity procedures with incision sizes of two centimeters or less, and to establish that visual detection of sponges in these cases is non-inferior. We hypothesize that the added cost and time from radiofrequency detection of retained sponges and radiographic evaluation in the event of incorrect sponge counts may be safely eliminated if sponges can be reliably visually detected.

METHODS

Five cadaveric upper extremity specimens were obtained for educational purposes using departmental funding. Orthopaedic residents, supervised by fellowship trained hand surgeons, performed simulated operations including a total of 18 trigger finger releases, five carpal tunnel releases, three trigger thumb releases, and three de Quervain's tenosynovitis releases on these specimens. Carpal tunnel incisions were measured at two centimeters, and all other incisions were less than two centimeters. Following completion of each individual procedure, the operating resident was randomized to place or not place a standard Ray-tec® 8" x 4" operative sponge into the surgical incision, packing as much of the sponge into the incision as reasonably possible. Randomization was performed via a random number generator with an even number prompting sponge placement and an odd number prompting no sponge placement. Clean, unused, non-sterile surgical discard sponges were used for this study.

A second resident blinded to sponge placement then entered the lab and from a pre-marked 10-foot distance "across the room" visualized the cadaver specimen, then indicated verbally whether there was visual detection of a retained sponge. This was repeated for a closer "at the table" distance. If a sponge had been placed in the wound it was then removed and the length in centimeters contained within the wound was recorded.

Verbal consent was obtained prior to participation from all involved orthopaedic surgery residents, and data collection occurred during regularly scheduled resident cadaver labs. An analysis of inter-rater agreement (at "across the room" and "at the table" distances) was compared with the gold standard (sponge placement by the operating resident) and kappa values were calculated, as a function of both distance and incision size.

RESULTS

Eighteen trigger finger releases, five carpal tunnel releases, three trigger thumb releases, and three de Quervain's tenosynovitis releases were successfully performed upon five cadaveric specimens by residents under supervision of fellowship-trained hand surgeons. All carpal tunnel incisions were measured at two centimeters, and all additional incisions were determined to be less than two centimeters, for a total of 29 incisions two centimeters or smaller in length. The maximum length of the standard eight-inch surgical sponge that could be contained within any surgical incisions was three centimeters for a carpal tunnel release. When compared with the gold standard (whether the sponge had been placed or not by the operating resident), the placement of a standard surgical sponge could be detected correctly in 100% of cases at both "across the room" and "at the table" distances, for kappa values of 1.0 and 1.0 respectively. This did not vary with incision size or surgical procedure.

DISCUSSION

With the increasing focus on cost of medical care and optimizing the utilization of available operative room time, there has been renewed enthusiasm for implementing cost and time saving measures that do not negatively impact patient safety. At our institution, radiofrequency scanning for electronically tagged surgical sponges been instituted for all operative cases as an addition to standard counting procedures to evaluate for retained sponges. Additionally, incorrect sponge counts still automatically prompt radiographic examination of the involved extremity, which causes a mandatory surgical delay until the radiograph can be read by an attending-level radiologist.

Many commonly performed hand surgical procedures have a brief surgical time between five and ten minutes, with some surgeons performing as many as 10 cases per day. Especially with full operative schedules, quick turnover times, and often concurrent or staggered rooms, the elongation of surgical case time for additional scanning or radiographic safety procedures can create significant delays leading to measurable decreases in surgical efficiency and increased costs with operating room time valued at $62 per minute by some estimates[12].

Radiofrequency scanning is not without additional expense. Radiofrequency sponges cost an additional $0.55 per individual sponge, and each use of a radiofrequency wand requires the placement of a $1.95 ($2.11 at our institution) disposable sterile sleeve[13]. While this may not appear to be a significant expense, the use of radiofrequency scanning for cases that have no possibility of sponge retention would prove quite costly over time at high volume surgical institutions.

Intraoperative count discrepancies are estimated to occur in as many as one percent of cases, causing an average time of 18 minutes of surgical delay[13]. The cost of a single intraoperative radiograph has been estimated conservatively at $122, but may in fact be closer to $450 when consideration is given to the cost of a radiography technician and radiologist fees[13].

Our results suggest that the use of radiofrequency sponges and scanning procedures is unnecessary to ensure patient safety in common hand and upper extremity cases with surgical incisions of two centimeters or less. Additionally, we have demonstrated that radiographic evaluation of an upper extremity wound two centimeters or less does not provide any benefit over visual inspection if the operative sponge count is incorrect at the end of the case.

This study has several limitations. It does not address retained foreign objects other than standard surgical sponges. It is a cadaveric study that uses cadaver tissues which can only simulate living surgical patients. Additionally, we have evaluated a specific subset of upper extremity procedures which may have similar wound sizes but different wound characteristics compared to other upper extremity procedures and may have uncertain generalizability as a result.

CONCLUSION

The results of this study suggest that radiofrequency scanning and radiographic evaluation of hand and upper extremity wounds with incisions two centimeters or less provide no additional benefit to the detection of standard operative sponges when compared with visual detection.

REFERENCES

1. National Quality Forum. Serious Reportable Events in Healthcare - 2011 Update [Internet]. Washington, DC; 2011. Available from: https://www.qualityforum.org/Publications/2011/12/SRE_2011_Final_Report.aspx
2. **Cima RR, Kollengode A, Garnatz J, Storsveen A, Weisbrod C, Deschamps C.** Incidence and Characteristics of Potential and Actual Retained Foreign Object Events in Surgical Patients. J Am Coll Surg. 2008;207(1):80–7.
3. **Wan W, Le T, Riskin L, Macario A.** Improving safety in the operating room: a systematic literature review of retained surgical sponges. Curr Opin Anaesthesiol [Internet]. 2009 Apr [cited 2017 Feb 1];22(2):207–14. Available from: http://content.wkhealth.com/linkback/openurl?sid=WKPTLP:landingpage&an=00001503-200904000-00012
4. **Steelman VM.** Sensitivity of detection of radiofrequency surgical sponges: a prospective, cross-over study. Am J Surg. 2011;201(2):233–7.
5. **Bansal M, Heckl F, English K.** Retained broken outflow cannula recovered 6 years post-knee arthroscopy. Orthopedics [Internet]. 2011 Dec 6 [cited 2017 Feb 1];34(12):e945-7. Available from: http://www.slackinc.com/doi/resolver.asp?doi=10.3928/01477447-20111021-32
6. **Rajadhyaksha AD, Mont MA, Becker L.** An Unusual Cause of Knee Pain 10 Years After Arthroscopy. Arthrosc - J Arthrosc Relat Surg. 2006;22(11).
7. **Dick W, Glinz W, Henche HR, Ruckstuhl J, Wruhs O, Zollinger H.** [Complications of arthroscopy. A review of 3714 cases (author's transl)]. Arch Orthop Trauma Surg [Internet]. 1978 Aug 11 [cited 2017 Feb 1];92(1):69–73. Available from: http://www.ncbi.nlm.nih.gov/pubmed/727912
8. **Small NC.** Complications in arthroscopic surgery performed by experienced arthroscopists. Arthrosc J Arthrosc Relat Surg [Internet]. 1988;4(3):215–21. Available from: http://www.sciencedirect.com/science/article/pii/S0749806388800306
9. **Kumar A.** A retained catheter in the radial artery. J Perioper Pract [Internet]. 2015 Mar [cited 2017 Feb 1];25(3):39. Available from: http://www.ncbi.nlm.nih.gov/pubmed/26016280

10. **Sugg KB.** First hand: The case of the retained peg guide. J Hand Surg Am [Internet]. 2013 Jul [cited 2017 Feb 1];38(7):1395–7. Available from: http://www.ncbi.nlm.nih.gov/pubmed/23951577
11. **Goyal KS, Jain S, Buterbaugh GA, Imbriglia JE.** The Safety of Hand and Upper-Extremity Surgical Procedures at a Freestanding Ambulatory Surgery Center: A Review of 28,737 Cases. J Bone Joint Surg Am [Internet]. 2016 Apr 20 [cited 2017 Feb 1];98(8):700–4. Available from: http://content.wkhealth.com/linkback/openurl?sid=WKPTLP:landingpage&an=00004623-201604200-00011
12. **Macario A.** What does one minute of operating room time cost? Journal of Clinical Anesthesia. 2010;22(4):233–6.
13. **Williams TL, Tung DK, Steelman VM, Chang PK, Szekendi MK.** Retained Surgical Sponges: Findings from Incident Reports and a Cost-Benefit Analysis of Radiofrequency Technology. J Am Coll Surg [Internet]. 2014 Sep [cited 2017 Feb 1];219(3):354–64. Available from: http://www.ncbi.nlm.nih.gov/pubmed/25081938

INFLUENCE OF 45S5 BIOACTIVE GLASS IN A STANDARD CALCIUM PHOSPHATE COLLAGEN BONE GRAFT SUBSTITUTE ON THE POSTEROLATERAL FUSION OF RABBIT SPINE

Andrew J. Pugely[1], Emily B. Petersen[1], Nicole DeVries-Watson[2], Douglas C Fredericks[1]

ABSTRACT

Introduction: Spinal fusion surgery is an effective but costly treatment for select spinal pathology. Historically iliac crest bone graft (ICBG) has remained the gold standard for achieving successful arthrodesis. Given well-established morbidity autograft harvest, multiple bone graft replacements, void fillers, and extenders have been developed. The objective of this study was to evaluate the in vivo efficacy and safety of two mineralized collagen bone void filler materials similar in composition. Both bone void fillers were composed of hydroxyapatite (HA), tricalcium phosphate (TCP) and bovine collagen. The first test article (Bi-Ostetic bioactive glass foam or "45S5") also contained 45S5 bioactive glass particles while the second test article (Formagraft or "FG") did not. 45S5 and FG were combined with bone marrow aspirate and iliac crest autograft and compared to ICBG in an established posterolateral spine fusion rabbit model.

Materials and Methods: Sixty-nine mature New Zealand White rabbits were divided into 3 test cohorts: ICBG, 45S5, and FG. A Posterolateral fusion model previous validated was utilized to assess fusion efficacy. The test groups were evaluated for spine fusion rate, new bone formation, graft resorption and inflammatory response using radiographic, µCT, biomechanical and histological endpoints at 4, 8 and 12 weeks following implantation.

Results: There were 4 clinical complications unrelated to the graft materials and were evenly split between groups (ICBG graft harvest complications; hind limb mobility, chronic pain) and were euthanized. These omissions did not affect the overall outcome of the study. Radiographic scoring of the fusion sites indicated a normal healing response in all test groups, with no adverse reactions and similar progressions of new bone formation observed over time. All groups demonstrated significantly less range of motion in both flexion/extension and lateral bending compared to normal not-fused controls, which supports fusion results observed in the other endpoints. Fusion occurred earlier in the 45S5 group: ICBG 0%, FG 0%, and 45S5 20% at 4 weeks; ICBG 43%, FG 38%, and 45S5 50% at 8 weeks; and ICBG 50%, FG 56%, and 45S5 56% at 12 weeks. Histopathology analysis of the fusion masses, from each test article and time point, indicated an expected normal response for resorbable calcium phosphate (HA/TCP) and collagen graft material. Mild inflammation with macrophage and multinucleated giant cell response to the graft material was evident in all test groups.

Discussion: This study has confirmed the biocompatibility, safety, efficacy and bone healing characteristics of the HA-TCP collagen (with or without 45S5 bioactive glass) composites. The results show that the 3 test groups had equivalent long-term fusion performance and outcome at 12 weeks. However, the presence of 45S5 bioactive glass seemed to accelerate the fusion process as evidenced by the higher fusion rates at 4 and 8 weeks for the HA-TCP-collagen composite containing bioactive glass particles. The results also demonstrate that the HA-TCP-45S5 bioactive glass-collagen composite used as an extender closely mirrors the healing characteristics (i.e. amount and quality of bone) of the 100% autograft group.

INTRODUCTION

Spinal fusion surgery is an effective but costly treatment for spinal disorders. Successful long-term spinal arthrodesis requires inter-segmental stability. To achieve this, bone growth and maturation must occur across the

Author Affiliations:
[1]University of Iowa
Department of Orthopaedics
200 Hawkins Drive, 01029 JPP
Iowa City, Iowa 52242

[2]University of Iowa
College of Engineering
Iowa City, Iowa 52242

Corresponding Author:
Douglas C. Fredericks
University of Iowa Carver College of Medicine
Biomedical Research Support Facility (BRSF)
2292 Old Farmstead Rd
Coralville, IA 52241

The authors declare no relevant conflicts of interest.

spinal segments. Iliac crest autograft has been used for many years as a bone graft in spinal fusion despite issues associated with the quantity available and complications associated with the harvesting procedure[1-11]. Given morbidity associated with ICBG, alternatives and extenders have been developed. In general these can be classified as allografts, demineralized bone matrices, ceramics, bone morphogenetic proteins (BMPs), and autologous growth factors. While the safety and efficacy of most of these substances have been extensively studied, the use of ceramic bone void fillers as a viable option for posterolateral spine fusions has not been fully established.

Calcium phosphate materials have been employed clinically as bone void fillers for decades. It was discovered that corals had a similar microarchitecture to bone[12]. From this, various ceramics including calcium sulfate, hydroxyapatite, calcium carbonate, and others were developed. These materials are most often provided in the form of small, porous granules that can be packed to fill the wide variety of size and shape of bony defects encountered. They lack osteogenic and osteoinductive properties, but ceramics allow for fibrovascular ingrowth of osteoid matrix via osteoconduction[13]. In spinal fusion surgery, several studies have demonstrated the clinical efficacy of ceramics as bone graft extenders[14,15]. Others have shown inferiority to ICBG alone[16].

Recently, spongious strips of HA-TCP-45S5 bioactive glass-collagen composite (Bi-Ostetic bioactive glass foam) were developed by Berkeley Advanced Biomaterials by simply substituting some of the HA-TCP granules with 45S5 bioactive glass. The graft form allows for versatility in handling and ease-of-use. The strips can be hydrated with bone marrow aspirate (BMA) and/or extended with autograft. Such composite shows excellent osteoconduction and provides a scaffold for cell attachment, supporting the formation of osseous tissue across bony defects. The objective of this study was to investigate the effect of 45S5 bioactive glass combined with a HA-TCP-collagen matrix by comparing the in vivo performance of 2 bone void filler materials, Bi-Ostetic bioactive glass foam (45S5) and Formagraft (FG) in an established posterolateral spine fusion rabbit model using ICBG as a control. Performance was evaluated by specifically assessing fusion rates, new bone formation, graft resorption, and host inflammatory response.

MATERIALS AND METHODS

A well-established rabbit posterolateral fusion model, previous validated by Boden et al.,[17,18] was employed to assess fusion efficacy among two treatment and one control group. The test groups were evaluated for spine fusion rate, new bone formation, graft resorption and inflammatory response using radiographic, μCT, biomechanical and histological endpoints at 4, 8 and 12 weeks following implantation. A total of 69 mature New Zealand White rabbits were included into 3 groups: ICBG, 45S5, and FG. Each had 23 rabbits.

Group 1 (control): Iliac Crest Bone Graft (ICBG)

Utilized autologous bone graft extracted from the iliac crest, morselized into 2-3 mm pieces.

Group 2: Formagraft (FG)

Formagraft is a bone graft substitute consisting of resorbable purified fibrillar collagen and partially resorbable 60% HA - 40% TCP ceramic. The bovine fibrillar collagen component is biocompatible and has low immunogenicity. Formagraft strips were morselized into 2-3 mm pieces then mixed with bone marrow aspirate (BMA) and approximately 1.5 cc of morselized ICBG. The homogenous mix of FG-BMA-ICBG was molded into 3.0 cc rectangular blocks.

Group 3: Bi-Ostetic bioactive glass foam (45S5)

45S5 is composed of Bi-Ostetic (60%HA - 40%TCP) granules and 45S5 bioactive glass embedded in a bovine collagen matrix. 45S5 divided into 1.5 cc volumes was hydrated with 1.5cc BMA, and mixed with 1.5 cc of morselized ICBG. The homogenous mix of 45S5-BMA-ICBG was molded into 3.0 cc rectangular blocks.

Surgical Procedure

Each animal was under general anesthesia for initial surgical procedures. Appropriate antibiotic(s) were given throughout the conduct of the study. All animals were prepared for surgical procedures. After the pre-anesthetic had taken effect, rabbits were clipped free of fur over the surgical areas. The surgical areas were scrubbed with Chlorhexidine soap and wiped with isopropyl alcohol. Chlorhexidine solution was applied just prior to surgical incision.

The surgical approach to the spine was identical in all rabbits. A dorsal midline skin incision, approximately 15 centimeters long, was made from L1 to the sacrum, and then the fascia and muscle were incised over the L5-L6 transverse processes (TPs). The TPs were then decorticated with a high-speed burr. Approximately 3 cc of corticocancellous bone graft from the iliac crest was obtained bilaterally (~6 cc total). Approximately 3 cc per side of test article hydrated with bone marrow aspirate (BMA, 1.5 cc) + ICBG (1:1 ratio) were placed in the paraspinal bed between the TPs. Fascia and skin were closed with 3-0 Vicryl and the skin was stapled.

Radiographic Assessment

Ventral/dorsal radiographs were obtained with a Simon DR (Quantum) RAD-X High Frequency Radiographic Imaging System. Radiographs were examined to confirm graft placement, assess graft migration, osteolysis, fracture, or any other adverse events. In addition, radiographs were graded for bilateral fusion, new bone formation, and graft resorption. Radiographs were assessed by 3 blinded reviewers to determine unilateral and bilateral fusion rates for each study group at each time point. Both the left and right side fusion masses were graded as "fused" or "not fused" based on the presence of a continuous trabecular pattern within the intertransverse fusion mass[17]. Final fusion results were determined by agreement of at least 2 of the 3 observers. Radiographs were also scored bilaterally by 3 blinded reviewers for new bone formation and graft resorption per the scoring scale: none, some, moderate, and extensive.

Five specimens (histology animals) underwent µCT analysis. They were scanned using a SkyScan 1176 µ-CT using a similar technique as computerized tomography systems in medicine (MDCT-scans) but at a higher resolution (as thin as 9µm). X-ray images (2D) were acquired in multiple planes, internal structures were reconstructed as a series of 2D cross-sections that were then used to analyze the 2- and 3-dimensional morphological parameters of the specimen. Each specimen was analyzed for Total Area (TA), Bone Area (BA), Implant Area (GA), Soft Tissue Area (SA).

Necropsy

Animals were euthanized using Euthasol solution. Necropsy included examination of the external surface, all orifices, cranial, thoracic, abdominal and pelvic cavities including contents. The entire lumbar column was removed "en-bloc". Soft tissues were immediately removed from the surgically treated spinal unit after the spine was dissected out of the body. The grafted site was examined for graft migration, infection, and soft tissue abnormalities. Spines from the 4 and 8-weeks animals were placed in 10% neutral buffered formalin. Spines from the 12-weeks animals were immediately tested for biomechanical stiffness.

Mechanical Testing

Biomechanical non-destructive stiffness testing was performed following manual palpation in the 12-weeks group. Testing consisted of flexion/extension, lateral bending, and torsion to a predetermined, sub-failure load.

The vertebral bodies cranial and caudal to the fused motion segment were embedded in Bondo/Fiberglass material using 2-inch PVC piping. The specimens were mounted in a biaxial servo-hydraulic materials testing machine (858 Bionix II, MTS Corporation, Eden Prairie, MN, USA) retrofitted with 2 spine gimbals and a passive XZ table. Custom-made rigid body markers comprised of three infrared light emitting diodes affixed between 2 small aluminum plates were placed on each vertebral body and the 2 gimbals to track the segmental motions. Nondestructive flexibility tests were performed about each axis of rotation (i.e., flexion-extension, right-left lateral bending, and right-left axial rotation) by applying an isolated ±0.27 Nm (0 Nm, 0.09 Nm, 0.18 Nm, and 0.27 Nm) moment about each of the primary axes. Each test initiated and concluded in the neutral position with zero load. Three loading and unloading cycles were performed with motion data collected on the third cycle (the first two cycles served as preconditioning). The displacement of each vertebrae was measured using an optoelectronic motion capture system (Optotrak, Northern Digital, Waterloo, Ontario, Canada); the output of which was synchronized with that of the MTS. During testing the specimens were kept moist with saline solution spray. Stiffness was determined and compared to normal controls (10 normal rabbit lumbar columns, historic internal laboratory controls).

Histology

Fusion sites of each animal were processed for histology and sectioned in the sagittal plane to obtain a total of 6 sections per animal (3 per side of the fusion mass). For each side, sections were created adjacent to the vertebral body, through the center of the fusion mass, and through the lateral aspect of the fusion mass, spaced approximately 3-mm apart. Sections were stained with H&E. All 6 sections from each fusion mass (3 per side) were subject to scoring based on a standard protocol.

Statistical Analysis

Statistical analysis was performed on the µCT and histomorphometry data, as well as the flexion-extension, lateral bending and axial rotation data from the flexibility analysis. All data was analyzed to a 95% confidence level ($p<0.05$) using a 2-tailed t-test assuming unequal variance in Microsoft Excel. Unless otherwise noted, data is reported as the mean and one standard deviation.

RESULTS

Radiographs at 4, 8 and 12 weeks showed a normal healing response over time with no adverse reactions for all test groups. The loss of graft distinction at the host bone margins indicates a progression in host integration, implant remodeling and new bone formation over time. No fractures, osteolysis, or other adverse reactions were evident during radiographic examination for all test groups. Graft position migration from immediate post-operative radiographs to radiographs greater than 1-week post-operation is typically observed as the forces of overlaying muscle compresses the graft. These migration observations are typical of synthetic bone grafts applied in this animal model and are not a confounding variable.

Radiographs of the fusion masses were evaluated for new bone formation and implant resorption. The radiographic scoring shows an increase in new bone formation and implant resorption from 4 to 12 weeks for all test groups.

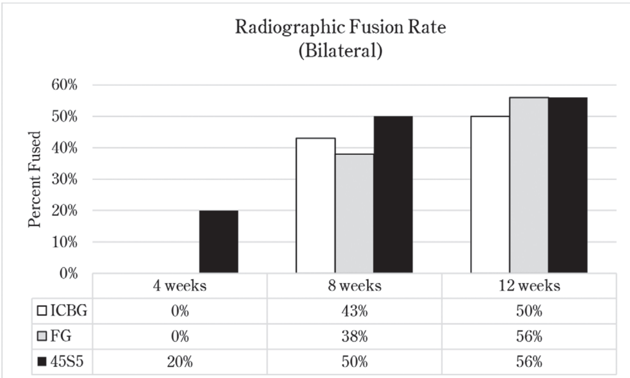


Figure 1. Radiographic Bilateral Fusion Analysis Summary. An increase in fusion rates at early time interval indicates that the presence of 45S5 in the graft tends to accelerate fusion kinetics.

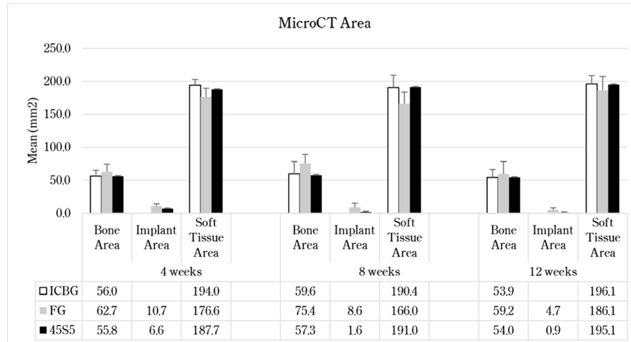


Figure 2. µCT Mean Areas of Bone, Implant, and Soft Tissue with Standard Deviations. Both ICBG and 45S5 fusion masses show earlier signs of graft remodeling with more lamellar bone and stiffer fusion masses compared to FG fusions.

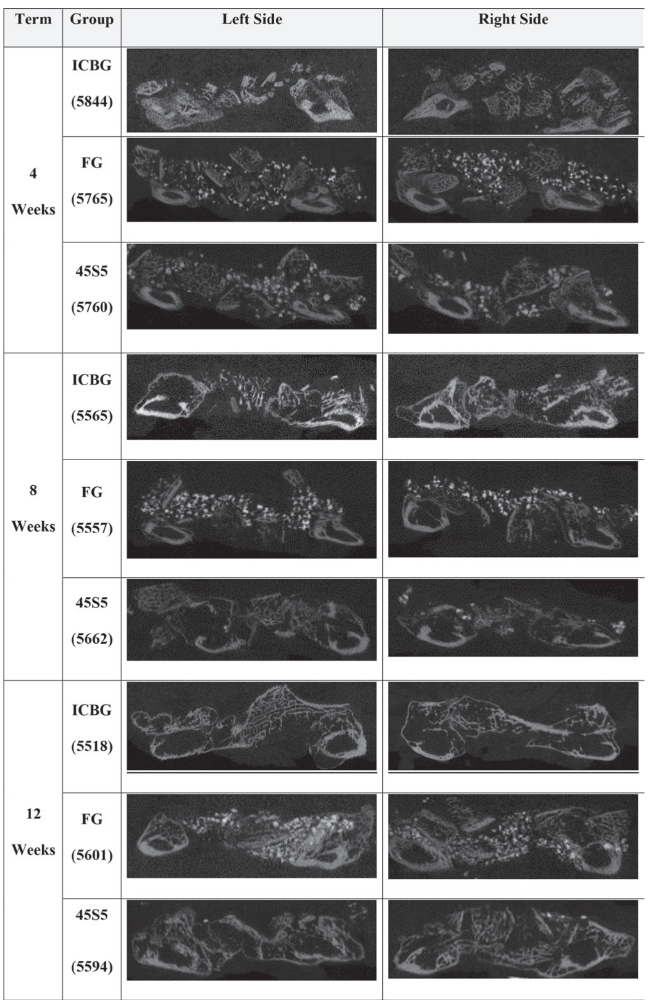


Figure 3. Representative µCT Scans From Each Test Group and Time Point. The scans confirm that the 45S5 used as an extender leads to an healing outcome that closely resembles that of the ICBG.

The radiographic fusion analysis is summarized in Figure 1. Fusion rates for ICBG and FG test groups were: ICBG 0%, FG 0%, and 45S5 20% at 4 weeks; ICBG 43%, FG 38%, and 45S5 50% at 8 weeks; and ICBG 50%, FG 56%, and 45S5 56% at 12 weeks ($p > 0.05$).

The µCT scans supported radiographic findings, showing a normal osteoconductive healing response over time with no adverse reactions for all test groups. The 4-weeks µCT scans showed host integration and new bone formation originating from the TP margins in all animals. The 8- and 12-weeks scans showed a progression of new bone formation and graft remodeling across the paraspinal bed from the 4-week time point. (Figures 2 and 3, and Table 1).

Spine fusion was assessed by manual palpation of the treated motion segments. At 4 weeks, only one 45S5 rabbit was graded as fused. At 8 weeks, 43% of the ICBG, 38% FG and 50% of 45S5 spine were fused mechanically. At 12 weeks, ICBG spine was fused 50%, FG 56%, and 45S 56%. General findings from the biomechanics indicate that the 3 groups had significantly less motion than the not-fused normal (Figure 4). There was no significant difference between the ICBG and the two test articles (FG and 45S5) specimens (Table 2).

Histopathology analysis of the fusion masses, from each test article and time point, indicated an expected normal response for resorbable calcium phosphate (HA/TCP) and collagen graft material. The majority of specimens, regardless of implant type or time of implantation, had mild inflammation. Most often there were very low numbers of macrophages and multinucleated giant cells with some scattered, often lymphocytes and plasma cells. In all sections there is moderate neovascularization and fibrosis. Graft resorption and new bone formation increased with time from 4 to 12 weeks. Ultimately, there was no difference in histiologic response between groups.

Table I. µCT Statistical Analysis (T-Test: 2-Tailed, Unequal Variance). The analysis demonstrates that the fusion kinetics of the 45S5 animal group match closely that of the ICBG group.

Test Group	Bone Area		Implant Area		Soft Tissue Area	
4 Weeks	*FG*	*45S5*	*FG*	*45S5*	*FG*	*45S5*
ICBG	0.200	0.971	N/A	N/A	0.006	0.325
FG	-	0.339	-	0.054	-	0.140
8 Weeks	*FG*	*45S5*	*FG*	*45S5*	*FG*	*45S5*
ICBG	0.045	0.747	N/A	N/A	0.007	0.930
FG	-	0.004	-	0.007	-	0.002
12 Weeks	*FG*	*45S5*	*FG*	*45S5*	*FG*	*45S5*
ICBG	0.472	0.992	N/A	N/A	0.216	0.869
FG	-	0.487	-	0.003	-	0.272

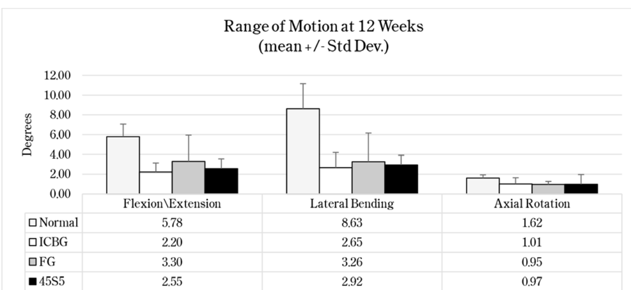


Figure 4: Mean Maximum Motion at 0.27 Nm with Standard Deviation. * Normal data baseline obtained from historical internal laboratory data of normal not-fused rabbits.

DISCUSSION

The objective of this study is to quantify the effect on fusion rate of 45S5 bioactive glass combined with an HA-TCP-collagen matrix by comparing the in vivo performance of 2 bone void filler materials, Bi-Ostetic bioactive glass foam (45S5) and Formagraft (FG), in an established posterolateral spine fusion rabbit model using ICBG as a control.

The test groups were evaluated for spine fusion rate, new bone formation, graft resorption and inflammatory response using radiographic, µCT, biomechanical and histological endpoints at 4, 8 and 12 weeks following implantation.

Radiographic scoring of the fusion sites indicated a normal healing response in all test groups, with no adverse reactions and similar progressions of new bone formation observed over time. Fusion rates for ICBG and FG test groups were: ICBG 0%, FG 0%, and 45S5 20% at 4 weeks; ICBG 43%, FG 38%, and 45S5 50% at 8 weeks; and ICBG 50%, FG 56%, and 45S5 56% at 12 weeks. µCT scans supported the radiographic observations, showing a normal osteoconductive healing response in all groups with remodeling of the fusion site over time.

Table II. Flexibility Testing Statistical Analysis (t-test: 2-tailed, unequal variance)

p-values	ICBG	FG	45S5
Flexion/Extension			
Normal (Not fused)	0.0000	0.0266	0.0017
ICBG		0.2669	0.6550
FG	0.2669		0.5200
45S5	0.6550	0.5200	
Lateral Bending			
Normal (Not fused)	0.0000	0.0006	0.0001
ICBG		0.5824	0.7761
FG	0.5824		0.7906
45S5	0.7761	0.7906	
Axial Rotation			
Normal (Not fused)	0.0184	0.0003	0.0124
ICBG		0.8101	0.9003
FG	0.8101		0.9315
45S5	0.9003	0.9315	

Histopathology analysis of the fusion masses, from each test article and time point, indicated an expected normal response for resorbable HA, TCP and collagen graft materials. Mild inflammation with macrophage and multinucleated giant cell response to the graft material was evident in all test groups. Similar to µCT analysis, residual graft resorption and new bone formation increased over time. Both the ICBG and 45S5 fusion masses showed earlier signs of graft remodeling with more lamellar bone and stiffer fusion masses compared to the FG fusions.

The results of this study suggest that Bi-Ostetic bioactive glass foam is safe and effective in producing posterolateral fusion when employed as a bone graft extender. Some of the limitations of this study include the use of this rabbit animal model. Animal models cannot be directly translated to clinical application, and direct application of the test material in a clinical setting is appropriate. Additionally, with the growing cost concerns in medicine and spine care, surgeons and hospitals should assess the short- and long-term cost-effectiveness of implantable products like the bone graft substitutes and extenders.

CONCLUSION

This study has confirmed the biocompatibility, safety, efficacy and bone healing characteristics of the HA-TCP collagen (with or without 45S5 bioactive glass) composites. The results show that the 3 test groups had equivalent long-term fusion performance and outcome at 12 weeks. However, the presence of 45S5 bioactive glass seemed to accelerate the fusion process as evidenced by the higher fusion rates at 4 and 8 weeks for the HA-TCP-collagen composite containing bioactive glass particles. The results also demonstrate that the HA-TCP-45S5 bioactive glass-collagen composite used as an extender closely mirrors the healing characteristics (i.e. amount and quality of bone) of the 100% autograft group.

REFERENCES

1. **Arrington, ED; Smith, WJ; Chambers, HG; Bucknell, AL; and Davino, NA**: Complications of iliac crest bone graft harvesting. Clin Orthop Relat Res, (329): 300-9, 1996.
2. **Ebraheim, NA; Elgafy, H; and Xu, R**: Bone-graft harvesting from iliac and fibular donor sites: techniques and complications. J Am Acad Orthop Surg, 9(3): 210-8, 2001.
3. **Hu, RW, and Bohlman, HH**: Fracture at the iliac bone graft harvest site after fusion of the spine. Clin Orthop Relat Res, (309): 208-13, 1994.
4. **Kahn, B**: Superior gluteal artery laceration, a complication of iliac bone graft surgery. Clin Orthop Relat Res, (140): 204-7, 1979.
5. **Kurz, LT; Garfin, SR; and Booth, RE, Jr.**: Harvesting autogenous iliac bone grafts. A review of complications and techniques. Spine (Phila Pa 1976), 14(12): 1324-31, 1989.
6. **Lim, EV; Lavadia, WT; and Roberts, JM**: Superior gluteal artery injury during iliac bone grafting for spinal fusion. A case report and literature review. Spine (Phila Pa 1976), 21(20): 2376-8, 1996.
7. **Sasso, RC; Williams, JI; Dimasi, N; and Meyer, PR, Jr.**: Postoperative drains at the donor sites of iliac-crest bone grafts. A prospective, randomized study of morbidity at the donor site in patients who had a traumatic injury of the spine. J Bone Joint Surg Am, 80(5): 631-5, 1998.
8. **Silber, JS; Anderson, DG; Daffner, SD; Brislin, BT; Leland, JM; Hilibrand, AS; Vaccaro, AR; and Albert, TJ**: Donor site morbidity after anterior iliac crest bone harvest for single-level anterior cervical discectomy and fusion. Spine (Phila Pa 1976), 28(2): 134-9, 2003.
9. **St John, TA; Vaccaro, AR; Sah, AP; Schaefer, M; Berta, SC; Albert, T; and Hilibrand, A**: Physical and monetary costs associated with autogenous bone graft harvesting. Am J Orthop (Belle Mead NJ), 32(1): 18-23, 2003.
10. **Summers, BN, and Eisenstein, SM**: Donor site pain from the ilium. A complication of lumbar spine fusion. J Bone Joint Surg Br, 71(4): 677-80, 1989.
11. **Xu, R; Ebraheim, NA; Yeasting, RA; and Jackson, WT**: Anatomic considerations for posterior iliac bone harvesting. Spine (Phila Pa 1976), 21(9): 1017-20, 1996.
12. **Chiroff, RT; White, EW; Weber, KN; and Roy, DM**: Tissue ingrowth of Replamineform implants. J Biomed Mater Res, 9(4): 29-45, 1975.
13. **Boden, SD; Kang, J; Sandhu, H; and Heller, JG**: Use of recombinant human bone morphogenetic protein-2 to achieve posterolateral lumbar spine fusion in humans: a prospective, randomized clinical pilot trial: 2002 Volvo Award in clinical studies. Spine (Phila Pa 1976), 27(23): 2662-73, 2002.
14. **Chen, WJ; Tsai, TT; Chen, LH; Niu, CC; Lai, PL; Fu, TS; and McCarthy, K**: The fusion rate of calcium sulfate with local autograft bone compared with autologous iliac bone graft for instrumented short-segment spinal fusion. Spine (Phila Pa 1976), 30(20): 2293-7, 2005.
15. **Xie, Y; Chopin, D; Morin, C; Hardouin, P; Zhu, Z; Tang, J; and Lu, J**: Evaluation of the osteogenesis and biodegradation of porous biphasic ceramic in the human spine. Biomaterials, 27(13): 2761-7, 2006.
16. **Korovessis, P; Repanti, M; and Koureas, G**: Does coralline hydroxyapatite conduct fusion in instrumented posterior spine fusion? Stud Health Technol Inform, 91: 109-13, 2002.
17. **Boden, SD; Schimandle, JH; and Hutton, WC**: An experimental lumbar intertransverse process spinal fusion model. Radiographic, histologic, and biomechanical healing characteristics. Spine (Phila Pa 1976), 20(4): 412-20, 1995.
18. **Schimandle, JH, and Boden, SD**: Spine update. The use of animal models to study spinal fusion. Spine (Phila Pa 1976), 19(17): 1998-2006, 1994.

THE SURGICAL INCIDENCE TO PUBLICATION (SIP) INDEX: A NOVEL EQUATION USED TO FOCUS FUTURE

Matthew J. Kraeutler MD[1], Eric C. McCarty MD[1], Jonathan T. Bravman MD[1]

ABSTRACT

Background: With increased publication rates across all fields of medicine, some research topics become heavily weighted in the literature while other, equally important topics do not receive the same exposure. The purpose of this study is to present a simple equation which can be used to measure the current level of research interest on any particular surgical procedure or medical diagnosis.

Methods: The SIP Index (surgical incidence/publications) is calculated as shown below,

$$SIP\ Index = \frac{Incidence\ of\ X}{Number\ of\ publications\ on\ X}$$

where X can be any particular surgical procedure. The numerator, utilized as a surrogate for the actual number of a particular case performed in a given time period, was estimated by the total number of cases presented during Part-II of the American Board of Orthopaedic Surgery (ABOS) certification examination from 1999-2003. The denominator was taken from a PubMed search for several of the most common orthopaedic procedures submitted to ABOS from 1999-2003.

Results: Based on the SIP Index, subacromial decompression and arthroscopic knee chondroplasty were found to be significantly under-researched procedures, while rotator cuff repair and total hip and knee arthroplasty were significantly over-researched during the study period.

Conclusions: The SIP Index can be used to assess national or worldwide research efforts on any particular surgical procedure or medical diagnosis. This study provides an example of how this equation can be applied to a set of incidence data on common orthopaedic surgical procedures. When used in this way, the SIP Index can provide some insight into which procedures are relatively over- or under-researched.

Keywords: surgical incidence; subacromial decompression; rotator cuff repair; total hip arthroplasty; total knee arthroplasty

INTRODUCTION

In the field of orthopaedic surgery, as is the case in many other medical specialties, interesting new research topics frequently arise and result in a large influx of publications over a period of time. As an example, our group has noticed that research manuscripts on anterior cruciate ligament (ACL) reconstruction have been heavily weighted in the orthopaedic literature in recent years. In 2013 alone, there were 544 manuscripts published on ACL reconstruction (ACLR) in PubMed journals, a significant increase from 173 manuscripts published in 2003 on the same topic.

Research efforts worldwide are certainly increasing, which is the main reason for the recent surge in publications on ACLR. It is important for researchers to focus on medical conditions which interest them. At the same time though, it would be helpful to define a way of assessing relative over- or under-research of certain conditions and to make adjustments of national or international research efforts based on this information. To date, no published study has systematically aimed to investigate the research efforts within the field of orthopaedic surgery. The purpose of this study is to present a simple equation which can be used to measure the current level of research interest on any particular surgical procedure or medical diagnosis and thus be used to guide future research efforts, and to apply this formula to some of the most common orthopaedic surgical procedures.

METHODS

Literature Search

A literature search was performed to locate a surrogate for the total number of orthopaedic surgery procedures performed in the US. During this search,

1 University of Colorado School of Medicine, Department of Orthopedics, Aurora CO 80045

Corresponding Author:
Matthew J. Kraeutler, MD
CU Sports Medicine and Performance Center
2150 Stadium Drive, 2nd Floor
Boulder, CO 80309
Fax: (303) 441-2219
Phone: (610) 745-6797
matthew.kraeutler@ucdenver.edu

Table I. Search terms used in PubMed

Procedure	Search terms
Upper extremity	
Arthroscopic subacromial decompression	(“arthroscopic” OR “arthroscopy”) AND (“subacromial decompression” or “acromioplasty”)
Carpal tunnel surgery	“carpal tunnel release” OR “carpal tunnel surgery”
Distal clavicle excision	“distal clavicle excision” OR “distal clavicle resection”
Rotator cuff repair	“rotator cuff repair”
Repair of radial/ulnar fracture	(“distal radius” AND “fracture”) OR (“distal ulna” AND “fracture”) AND (“repair” OR “fixation”)
Lower extremity	
Arthroscopic knee meniscectomy/meniscal repair	“meniscectomy” OR “meniscal repair”
Arthroscopic knee chondroplasty	“knee” AND (“arthroscopic” OR “arthroscopy”) AND [“chondroplasty” OR (“articular cartilage” AND “debridement”)]
Anterior cruciate ligament reconstruction	“anterior cruciate ligament reconstruction” OR “ACL reconstruction”
Total knee replacement	“total knee replacement” OR “total knee arthroplasty”
Repair of femoral neck fracture	“femoral neck fracture” OR (“fracture” AND “neck” AND “femur”) AND “repair”
Repair of intertrochanteric femur fracture	“intertrochanteric femur fracture” OR (“intertrochanteric fracture” AND “femur”) AND “repair”
Total hip replacement	“total hip replacement” OR “total hip arthroplasty”
Repair of ankle fracture	“ankle” AND “fracture” AND (“repair” OR “fixation”)

we located the total number of cases presented to the American Board of Orthopaedic Surgery (ABOS) during Part-II of the certification examination from 1999 to 2003.[1]

In addition, we searched the literature using PubMed for several of the most common orthopaedic procedures submitted to ABOS from 1999-2003. Studies included were to be written in English and encompassed all results given the search terms shown in Table 1. Studies were not limited to primary research or excluded based on level of evidence.

Calculations

The SIP Index (surgical incidence/publications) is calculated as shown below,

$$SIP\ Index = \frac{Incidence\ of\ X}{Number\ of\ publications\ on\ X}$$

where X can be any particular surgical procedure, such as anterior cruciate ligament reconstruction or rotator cuff repair.

As mentioned above, the numerator, utilized as a surrogate for the actual number of a particular case performed in a given time period, was estimated by the total number of cases presented during ABOS Part-II from 1999-2003. The denominator was taken from the PubMed search described above. This calculation was performed for each procedure in Table 1 during each year from 1999-2003.

For repair of intertrochanteric femur fractures, CPT codes 27244 (repair with dynamic or sliding hip screw) and 27245 (repair with intramedullary hip screw) were added together. Similarly, for repair of radial/ulnar fractures, CPT codes 25611 (percutaneous reduction of distal radius/ulna fracture) and 25620 (open reduction of distal radius/ulna fracture) were added together. Repair of ankle fractures (CPT codes 27814 and 27792) were also summed. Because ABOS cases of distal clavicle excision were not reported in 1999-2001, the SIP Index for this procedure was based on 2002-2003 data.

Statistical Analysis

One-way analysis of variance (ANOVA) tests were used to compare SIP Indexes between procedures from 1999-2003. Tukey’s range test was performed in conjunction with an ANOVA test with $p < .05$.

RESULTS

The number of publications (i.e. the denominator of the SIP Index) found in a PubMed search for each procedure is shown in Table 2. The numerator of the SIP Index was retrieved from ABOS data published by Garrett et al1. Calculations of the SIP Index were performed for each procedure during each year from 1999-2003 and are presented in Table 3. Statistically significant differences were found in the SIP Index between upper extremity procedures ($p = 0.016$) and lower extremity procedures ($p < 0.0001$) over the years 1999-2003.

Table II. Number of Publications

Procedure/Year	1999	2000	2001	2002	2003	Total 1999-2003
Upper extremity						
Arthroscopic subacromial decompression	19	15	11	22	22	89
Carpal tunnel surgery	33	30	27	31	52	173
Distal clavicle excision	4	3	1	5	5	18
Rotator cuff repair	11	17	22	25	28	103
Repair of distal radius/ulna fracture	33	42	37	38	34	184
Lower extremity						
Arthroscopic knee meniscectomy/meniscal repair	50	52	50	52	67	271
Arthroscopic knee chondroplasty	5	5	12	11	12	45
ACL reconstruction	140	102	134	193	157	726
Total knee replacement	255	202	346	322	321	1446
Repair of femoral neck fracture	1	112	109	128	137	610
Repair of intertrochanteric femur fracture	163	173	152	202	184	874
Total hip replacement	318	313	362	393	424	1810
Repair of ankle fracture	54	63	84	79	68	348

Searches were performed in PubMed using the search terms shown in Table 1. Studies were to be written in English.

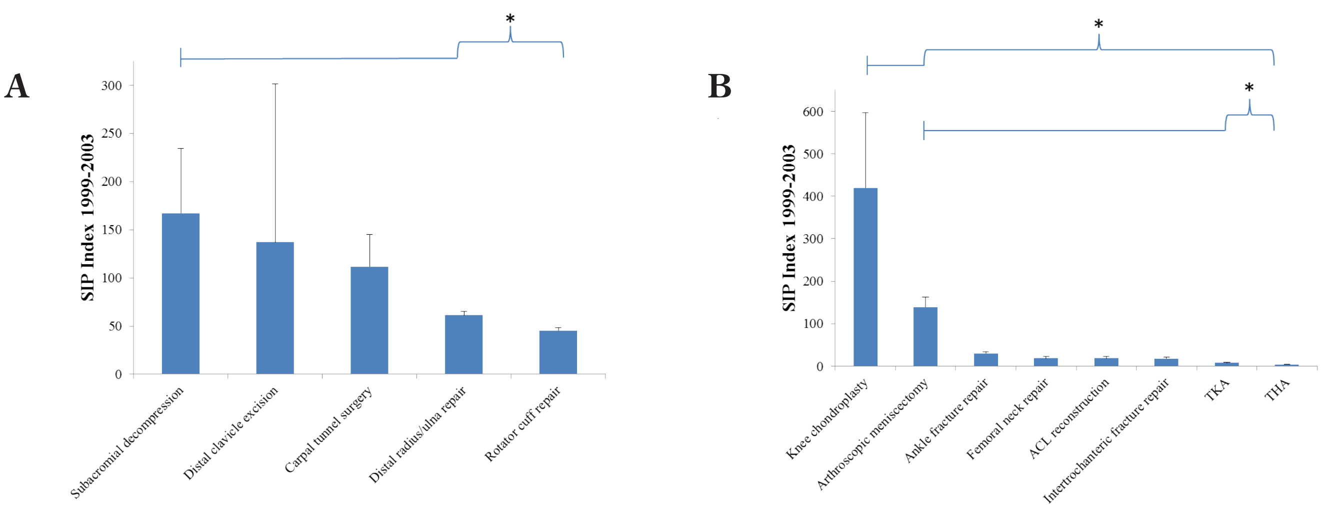


Figure 1. A) Upper extremity and B) lower extremity SIP Indexes. An average SIP Index was calculated from 1999-2003 for each procedure and compared across procedures. Error bars represent standard deviations. *Significant differences were found between paired groups using Tukey's range test. ACL = anterior cruciate ligament, TKA = total knee arthroplasty, THA = total hip arthroplasty

Tukey's range test was performed to determine significant differences in the SIP Index (SIPI) between pairs of procedures. Several significant differences in the SIPI were found between groups. Within the upper extremity group, the SIPI for arthroscopic subacromial decompression was significantly greater than that of distal radius/ulna fracture repair and rotator cuff repair (RCR). Within the lower extremity group, the SIPI for arthroscopic knee chondroplasty was significantly greater than that for all other lower extremity procedures. The SIPI for arthroscopic knee meniscectomy was also significantly greater than that of total knee arthroplasty and total hip arthroplasty. No other significant differences were found between groups (Figure 1).

DISCUSSION

We have developed a statistic known as the SIP Index which can be used to assess national or worldwide research efforts on any particular surgical procedure or medical diagnosis, and have provided an example of how

Table III. SIP Indexes

Procedure/Year	1999	2000	2001	2002	2003	Average 1999-2003
Upper extremity						
Arthroscopic subacromial decompression	89	159	275	152	162	167
Carpal tunnel surgery	97	126	135	141	60	112
Distal clavicle excision	-	-	-	21	253	137
Rotator cuff repair	44	49	48	43	45	46
Repair of distal radius/ulna fracture	59	56	64	63	64	61
Lower extremity						
Arthroscopic knee meniscectomy/meniscal repair	128	150	163	150	106	139
Arthroscopic knee chondroplasty	556	659	305	319	261	420
ACL reconstruction	16	26	20	14	15	18
Total knee replacement	7.8	9.6	6.9	8.9	6.6	8.0
Repair of femoral neck fracture	16	21	23	19	15	19
Repair of intertrochanteric femur fracture	17	19	23	16	15	18
Total hip replacement	4.1	3.9	4.2	4.5	3.0	3.9
Repair of ankle fracture	32	34	28	27	29	30

this equation can be applied to a set of incidence data on common orthopaedic surgical procedures. Based on this statistic, we found that arthroscopic subacromial decompression and arthroscopic knee chondroplasty were under-researched during the years 1999-2003, while rotator cuff repair and total knee and hip arthroplasty were relatively over-researched during this same time period. It is important to specify that the incidence data used for this manuscript represents the best publically available surrogate for the number of orthopaedic surgery procedures performed in the US. Thus, the results shown in this study are only to be perceived as an example of how this calculation can be performed. They should not be understood as a demonstration of current research efforts within the field of orthopaedic surgery, as the data used in this study is now more than 10 years old. However, the same methods shown in this study may be applied to more current incidence data.

There is a wide range of applicability for the SIP Index. The SIPI can be calculated for any surgical or medical diagnosis as long as the incidence data is available. Until normative values of the SIPI are established, SIP Indexes should not be interpreted alone but rather should be used to compare two or more procedures/diagnoses. When used in this way, the SIPI can provide some insight into which procedures are relatively over- or under-researched. There is, however, an inherent limitation of the SIP Index in that it does not take into account the impact of each procedure in terms of quality-adjusted life years (QALYs), cost-effectiveness, morbidity and mortality risk, etc. The SIPI must be viewed in the context of these other factors. For example, the SIP Index values for carpal tunnel surgery were relatively high. However, carpal tunnel release is a simple and short procedure with high success rates and low complication risk, and therefore the need for more research on this procedure is relatively low despite its relatively high SIP Index.

There are limitations to this study. The SIP Indexes presented in Table 3 represent an estimate of the true values. Rather than using the total number of procedures performed in the US each year, we estimated these proportions by using the number of cases presented to the American Board of Orthopaedic Surgery during Part-II of the certification examination. We assume that these numbers would be a close approximation to the proportion of all cases, but this is just an assumption. In addition, we searched only for articles written in English in order to correspond with the ABOS case numbers. However, there are many international author groups publishing in American journals, and therefore the publication numbers in Table 2 represent an overestimation of the number of manuscripts published by American research groups during each year. However, there is no reason to believe why this overestimation would be significantly greater for any one procedure compared to another. Finally, the SIPI values presented in Table 3 may not be an accurate estimate of their current value but again, these values should only be viewed as an example of how to calculate and interpret the SIP Index.

There is a wide range of applicability for the SIP Index. The SIPI can be calculated for any surgical or medical diagnosis as long as the incidence data is available. Future research efforts should focus on establishing normative values of the SIP Index for various procedures/diagnoses. Once normative values have been established, these can be used not only to compare current research efforts between procedures, but also to track research efforts for a particular procedure over time. This will be critical knowledge that we envision will ultimately be utilized in addition to population burden in regards to cost per diagnosis to help guide funding and research support moving forward. While it is important for researchers to focus on topics that personally interest them, the ultimate goal of medical research should be to improve medicine for current and future patients. We hope that the new statistic we have developed will be used to guide national and international research efforts such that there is an advantageous balance of research across the landscape of orthopaedic or other surgical procedures/diagnoses.

REFERENCES

1. **Garrett WE Jr, Swiontkowski MF, Weinstein JN, Callaghan J, Rosier RN, Berry DJ, Harrast J, Derosa GP.** American Board of Orthopaedic Surgery practice of the orthopaedic surgeon: Part-II, certification examination case mix. J Bone Joint Surg Am. 2006 Mar;88(3):660-7. PMID: 16510834

HAVE RESIDENTS PRODUCED MORE RESEARCH SINCE THE INCEPTION OF THE 80-HOUR WORKWEEK?

David M. Levy, MD, Timothy J. Luchetti, MD, Brett R. Levine, MD

ABSTRACT

Background: This study hypothesizes that resident involvement in research has increased since institution of the maximum 80-hour workweek in 2002.

Methods: All 571 papers published in the Journal of Bone and Joint Surgery (JBJS) in 1997 and 2007 (five years before and after the start of the 80-hour workweek) were reviewed. To identify resident authors, a search was performed in the American Board of Orthopaedic Surgery (ABOS) database for any U.S. author with a medical doctorate (MD). Any authors who were board-certified more than two years after the publication date were identified as "residents." Two-tailed Fisher's exact tests were used to assess proportional changes over time.

Results: Between 1997 and 2007, the percentage of U.S. MD authors who were orthopaedic residents increased significantly from 12% to 18% ($p = 0.01$). U.S. publications with a resident first-author increased from 17% to 27% ($p = 0.02$), and contributions from foreign nations also increased significantly ($p < 0.001$). The number of total authors per paper increased ($p < 0.001$), but linear regression showed that this had no particular association with the proportion of residents ($p = 0.20$). The relative proportions of MD and non-MD authors did not change between years. The LOE of resident-authored papers improved significantly over time ($p = 0.005$), while that of international papers did not.

Conclusions: Proportional resident authorship has increased significantly in one of the highest-impact, peer-reviewed orthopaedic journals. LOE of resident-authored papers has improved, and basic science papers are more likely to have a resident first author.

Level of Evidence: III, retrospective cohort study

Key Words: residents; attendings; level of evidence; publications; orthopaedic; research

INTRODUCTION

With the reduction of resident work hours to 80 per week, the expectation is that additional time devoted to medical research has likely increased. In residency programs, many residents dedicate time and energy to research, and the goal of this paper was to determine if orthopaedic residents have been doing more of that lately. Nearly 75% of residents may prefer to do a separate academic activity than conduct research,[1] and evidence has already shown that orthopaedic authorship has increased dramatically in the last 50 years.[2] While the level of evidence has improved significantly,[3] this creates a new ordering of resident responsibilities and inappropriately favors research over academic instruction and improvement. Authorship proliferation has become an increasingly problematic trend,[4] but that does not change the expectations residents put on themselves and have put on them. In addition, the number of authors cited has been correlated positively with the number of times an article is referenced,[5] so the trend toward increased authorship among residents has only been enhanced.

The focus of this paper is to determine the proportion of residents involved in clinical research published in one of the preeminent orthopaedic journals, the Journal of Bone and Joint Surgery (JBJS). We have hypothesized that more articles have been authored by residents and international writers since the institution of the mandated 80-hour workweek in 2002.

MATERIALS AND METHODS

In 2016, the two lead authors (DML, TJL) reviewed all 571 papers published in JBJS in 1997 and 2007, which was five years before and after the start of the 80-hour workweek. The study design, level of evidence (LOE) (general standardized ranking of the quality of

David M. Levy, MD
Department of Orthopedic Surgery
Rush University Medical Center
1611 W Harrison St., Suite 300
Chicago, IL 60612
davidlevy42@gmail.com

Timothy J. Luchetti, MD
Orthopaedic Surgery, Rush University Medical Center
timothy_j_luchetti@rush.edu

Brett R. Levine, MD
Orthopaedic Surgery Rush University Medical Center
brett.levine@rushortho.com

Table I. Comparison of publications between 1997 and 2007

	1997	2007	P-value
Publications	219	352	
International *(% of publications)*	46 *(21%)*	115 *(33%)*	**0.003***
U.S.	173	237	
Authors	821	1621	
Authors per publication	3.8 ± 1.7	4.6 ± 2.0	**< 0.001***
MD Authors$^{\lambda}$ *(% of all authors)*	662 *(81%)*	1303 *(80%)*	0.91
International *(% of MD)*	191 *(29%)*	566 *(43%)*	**< 0.001***
U.S.	471	737	
MDs not found in ABOS database (including other specialties) *(% of U.S. MD)*	112 *(24%)*	184 *(25%)*	0.68
Orthopaedic attendings *(% of U.S. MD)*	326 *(69%)*	481 *(65%)*	0.17
Orthopaedic residents *(% of U.S. MD)*	58 *(12%)*	132 *(18%)*	**0.01***
Non-MD Authors$^{\lambda}$ *(% of all authors)*	157 *(19%)*	326 *(20%)*	0.59
PhD, ScD, DVM, or DDS *(% of non-MD)*	75 *(48%)*	145 *(45%)*	0.50
Bachelor's degree *(% of non-MD)*	35 *(22%)*	82 *(25%)*	0.57

*** = statistically significant**

λ = authors with multiple degrees were only counted once. Any patient with an MD or equivalent was considered an MD author; in all other cases, the highest educational degree was selected.

Abbreviations: JBJS = Journal of Bone and Joint Surgery; U.S. = United States; MD = doctor of medicine; ABOS = American Board of Orthopaedic Surgery; PhD = doctor of philosophy; ScD = doctor of science; DVM = doctor of veterinary medicine; DDS = doctor of dental surgery

research), country of origin, number of authors, and authors' educational degrees were abstracted from each article. In order to identify resident authors, a search was performed in the American Board of Orthopaedic Surgery (ABOS) database for any United States (U.S.) author with a medical doctorate (MD). To account for the traditional lag of board certification, any authors who were board-certified more than two years after the publication date were identified as "residents." All other MD authors were considered "attendings" and verified in the ABOS database. Doctors of osteopathic medicine (DO) and international medical doctorates were recorded as MDs. Some international authors could not be deconstructed into orthopaedic attendings or residents, and, for this reason, they were excluded from our review. Standard chi-square tests were used to assess proportional changes over time.

RESULTS

The number of articles in JBJS increased significantly from 219 in 1997 to 352 in 2007 ($p < 0.001$) (Table 1), and the number of publications based internationally increased significantly from 46 (21%) to 115 (33%) ($p = 0.003$). The number of authors per article increased significantly from 3.8 ± 1.7 to 4.6 ± 2.0 ($p < 0.001$). The percentage of MD authors did not change significantly from 81% to 80% ($p = 0.91$), but the number of international MD authors did increase significantly from 191 (29%) to 566 (43%) ($p < 0.001$). The relative number of MD authors not found in the ABOS database and that of orthopaedic attendings did not change over time from 112 (24%) to 184 (25%) ($p = 0.68$) and 326 (69%) to 481 (65%) ($p = 0.17$). In addition, the relative number of non-MD authors did not change significantly over time from 157 (19%) to 326 (20%) ($p = 0.59$). The relative number of orthopaedic residents, however, did increase significantly over time from 58 (12%) to 132 (18%) ($p = 0.01$).

While the percentage of residents involved in basic science studies did not change significantly over time (22% to 22%, $p = 1.0$) (Table 2), 30% of basic science studies in 2007 had a resident first author, which was significantly greater than 11% in 1997 ($p = 0.05$). The percentage of residents involved in non-basic science studies with LOE I or II increased significantly from 2.2% to 20% ($p = 0.005$).

This same trend was not observed for international publications, for the percentage of international publications of basic science did not change significantly from 6.5% to 5.2% ($p = 0.72$), and the percentage of international authors involved in non-basic science studies with LOE I or II did not change significantly from 21% to 28% ($p = 0.54$).

Table II. Time-dependent changes in study design and level of evidence (LOE) for resident-authored and international publications

	1997	2007	P-value
Resident authors	58	132	
Basic science *(% of residents)*	13 *(22%)*	29 *(22%)*	1.0
Not basic science	45	103	
LOE I or II *(% of non-basic science)*	1 *(2.2%)*	21 *(20%)*	**0.005***
LOE III, IV, or V	44	82	
International publications	46	115	
Basic science *(% of international)*	3 *(6.5%)*	6 *(5.2%)*	0.72
Not basic science	43	109	
LOE I or II *(% of non-basic science)*	9 *(21%)*	30 *(28%)*	0.54
LOE III, IV, or V	34	79	
ALL publications	219	352	
Basic science *(% of all)*	39 *(18%)*	46 *(13%)*	0.15
Not basic science	180	306	
LOE I or II *(% of non-basic science)*	18 *(10%)*	67 *(22%)*	**0.004***
LOE III, IV, or V	162	239	

*** = statistically significant**

Abbreviations: LOE = level of evidence

When reviewing all publications, the percentage of basic science studies did not change significantly between years from 18% to 13% ($p = 0.15$). Studies that were not basic science but involved LOE I or II did increase significantly from 10% to 22% ($p < 0.001$). The number of total authors per paper increased ($p < 0.001$), but linear regression showed that this had no particular association with the proportion of residents ($p = 0.20$). The relative proportions of MD and non-MD authors did not change between years.

The percentage of first authors with a bachelor of arts (BA) or science (BS) degree increased significantly from only two (0.91 per study) in 1997 to 13 (3.7) in 2007 ($p = 0.04$), while the number of bachelor degree authors in general did not change significantly from 35 (0.16) in 1997 to 82 (0.23) in 2007 ($p = 0.09$). Overall, the number of non-MD authors increased significantly from 157 (0.72) to 326 (0.93) ($p = 0.04$). The number of doctor of philosophy (PhD), doctor of science (ScD), doctor of veterinary medicine (DVM), and doctor of dental surgery (DDS) authors did not change significantly from 75 (0.34) to 145 (0.41) ($p = 0.15$) nor did the number of authors with exclusively a masters degree change from 36 (0.16) to 63 (0.18) ($p = 0.68$). The number of authors with a physical trainer (PT) or athletic trainer (ATC) degree did not change significantly from 8 (0.037) to 9 (0.026) ($p = 0.53$). Finally, the number of authors with a physician's assistant (PA), nursing (RN), or bachelor of science in nursing (BSN) degree did not change significantly from to 4 (0.018) to 17 (0.048) ($p = 0.06$).

The number of MD authors increased significantly from 662 (3.0) to 1303 (3.7) ($p < 0.001$). Those who were confirmed to not have an orthopaedic degree did not change significantly from 112 (0.64) to 184 (0.76) ($p = 0.26$), while those who were confirmed to have an orthopaedic degree increased significantly from 438 (2.5) to 698 (2.9) ($p = 0.02$). Orthopaedic authors greater than 2 years before their certification date also increased significantly from 58 (0.34) to 132 (0.55) ($p = 0.002$), while those after their certification date did not change significantly (326 [1.9] to 481 [2.0]) ($p = 0.52$). International authors with an MD degree increased significantly from 191 (0.88) to 566 (1.6) ($p < 0.001$).

With respect to the actual studies themselves, there were no significant changes in the number of basic science studies from 39 (0.18) to 46 (0.13) ($p = 0.12$), animal studies from 13 (0.06) to 21 (0.06) ($p = 0.99$), and cadaver studies from 20 (0.09) to 20 (0.06) ($p = 0.12$). The level of evidence did significantly improve between years from 4.1 ± 1.0 in 1997 to 3.7 ± 1.3 in 2007 ($p < 0.001$), and there were a significantly greater proportion of case reports in 1997 (44) than in 2007 (39) ($p = 0.003$). In addition, a significantly greater proportion of studies were international in 2007 (0.33, or 115) than in 1997 (0.21, or 46) ($p = 0.003$).

DISCUSSION

It is well known that institution of the 80-hour work-week has had a profound effect on resident quality of life, sleep, and fatigue.[6,7] The effects it has had on education and patient safety has been debated since its inception.[8] As a result, physicians who were trained during the pre-work-hour restriction period have long argued that training has been negatively impacted. They cite a lack of volume,[9] poor continuity of care,[10] and other factors related to less time spent in the hospital.

Recently, a study assessed the possible effects of changing the 80-hour workweek restrictions to more flexible ones.[11] This study randomized general surgery residents into two groups, one with the current restrictions and the other with less stringent restrictions. This study was instituted in an effort to assess the implications of a return to longer work periods with less "sign-out" events on patient outcomes. The study is currently ongoing, but there is clearly a significant cohort of academic physicians who are suspicious of the possible negative effects of the 80-hour workweek.[11] While this is a hotly debated topic, the goal of this paper is not to confirm or deny specific criticism of the 80-hour workweek but rather to describe a novel benefit of it via increasing academic pursuits in clinical and basic science research.

While the proportion of attending and non-MD authors did not change over time, there was a significant increase in the percentage of resident authors in articles published in one of the premiere orthopaedic journals. The relative number of orthopaedic resident authors increased significantly over time from 58 (12%) to 132 (18%) ($p = 0.01$). This confirmed the primary hypothesis of our study. In addition, the proportion of resident first authors increased significantly from 11% in 1997 to 30% in 2007. The number of total authors per paper also increased ($p < 0.001$), but linear regression showed that this had no particular association with the proportion of residents. This data clearly demonstrates a trend toward greater orthopaedic resident activity toward time-consuming, high-impact literature.

There are limitations related to the content of this study. Given its retrospective nature, our findings are inherently subject to confounding. While it is difficult to assess the temporal relationship of our findings with those of the institution of the 80-hour workweek, we attempted to minimize this bias by choosing to collect data from publication years that are similarly spaced before and after institution of the 80-hour workweek in 2003. Similarly, only one top-tier orthopedic journal was evaluated, which limits the conclusions to other high-quality publications. In addition, our data collection is subject to misclassification bias. To minimize this bias, the two lead authors took steps to define clearly the various categories of authors and study type. Likewise, we utilized the American Academy of Orthopaedic Surgeons (AAOS) guidelines for levels of evidence when defining each individual study.

CONCLUSION

To our knowledge, this is the first study to show a significant association between institution of the 80-hour workweek and resident involvement in research endeavors. There has been significant debate regarding the effects that such work restrictions have had on surgical training. While causality cannot be assumed based on the data presented here, there is no question that residents are involved in more research today than previously. Moving forward, an improved focus on academic pursuits and cultivation of a new generation of academic leaders should be an important consideration.

REFERENCES

1. **Silcox LC, Ashbury TL, VanDenKerkhof EG, Milne B.** Residents' and program directors' attitudes toward research during anesthesiology training: a canadian perspective. Anesth Analg. 2006;102(3):859-864. doi:10.1213/01.ane.0000194874.28870.fd.
2. **Camp M, Escott BG.** Authorship proliferation in the orthopaedic literature. J Bone Joint Surg Am. 2013;95(7):e44. doi:10.2106/JBJS.L.00519.
3. **Hanzlik S, Mahabir RC, Baynosa RC, Khiabani KT.** Levels of evidence in research published in The Journal of Bone and Joint Surgery (American Volume) over the last thirty years. J Bone Joint Surg Am. 2009;91(2):425-428. doi:10.2106/JBJS.H.00108.
4. **Rahman L, Muirhead-Allwood SK.** How many orthopedic surgeons does it take to write a research article? 50 years of authorship proliferation in and internationalization of the orthopedic surgery literature. Orthopedics. 2010;33(7):478. doi:10.3928/01477447-20100526-06.
5. **Figg WD, Dunn L, Liewehr DJ, et al.** Scientific collaboration results in higher citation rates of published articles. Pharmacotherapy. 2006;26(6):759-767. doi:10.1592/phco.26.6.759.
6. **Harris JD, Staheli G, LeClere L, Andersone D, McCormick F.** What effects have resident work-hour changes had on education, quality of life, and safety? A systematic review. Clin Orthop Relat Res. 2015;473(5):1600-1608.doi:10.1007/s11999-014-3968-0.
7. **Lockley SW, Cronin JW, Evans EE, Cade BE, Clark JL, Landrigan CP, Rothschild JM, Katz JT, Lilly CM, Stone PH, Aeschbach D, Czeisler CA.** Effect of reducing interns' weekly work hours on sleep and attentional failures. N Engl J Med. 2004;351(18):1829-1837. doi:10.1056/NEJMoa041404.

8. **Hutter MM, Kellogg KC, Ferguson CM, Abbott WM, Warshaw AL.** The impact of the 80-hour resident workweek on surgical residents and attending surgeons. Ann Surg. 2006;243(6):864-875. doi:10.1097/01.sla.0000220042.48310.66.
9. **Kairys JC, McGuire K, Crawford AG, Yeo CJ.** Cumulative operative experience is decreasing during general surgery residency: a worrisome trend for surgical trainees? J Am Coll Surg. 2008;206(5):804-811. doi:10.1016/j.jamcollsurg.2007.12.055.
10. **Barden CB, Specht MC, McCarter MD, Daly JM, Fahey TJ III.** Effects of limited work hours on surgical training. J Am Coll Surg. 2002;195(4):531-538. doi:10.1016/S1072-7515(02)01242-5.
11. **Bilimoria KY, Hoyt DB, Lewis F.** Making the case for investigating flexibility in duty hour limits for surgical residents. JAMA Surg. 2015;150(6):503-504. doi:10.1001/jamasurg.2015.0239.

EPONYMOUS INSTRUMENTS IN ORTHOPAEDIC SURGERY

M. Ayodele Buraimoh, MD[1], Jane Z. Liu, MD[1], Stephen B. Sundberg, MD[2], Michael P. Mott MD[1]

ABSTRACT

Every day surgeons call for instruments devised by surgeon trailblazers. This article aims to give an account of commonly used eponymous instruments in orthopaedic surgery, focusing on the original intent of their designers in order to inform how we use them today. We searched PubMed, the archives of longstanding medical journals, Google, the Internet Archive, and the HathiTrust Digital Library for information regarding the inventors and the developments of 7 instruments: the Steinmann pin, Bovie electrocautery, Metzenbaum scissors, Freer elevator, Cobb periosteal elevator, Kocher clamp, and Verbrugge bone holding forceps. A combination of ingenuity, necessity, circumstance and collaboration produced the inventions of the surgical tools numbered in our review. In some cases, surgical instruments were improvements of already existing technologies. The indications and applications of the orthopaedic devices have changed little. Meanwhile, instruments originally developed for other specialties have been adapted for our use. Although some argue for a transition from eponymous to descriptive terms in medicine, there is value in recognizing those who revolutionized surgical techniques and instrumentation. Through history, we have an opportunity to be inspired and to better understand our tools.

[1]Department of Orthopaedics, Henry Ford Hospital; 2799 West Grand BLVD; Detroit, MI 48202

[2]Department of Orthopaedics, Gillette Children's Specialty Healthcare; 200 University Ave E, Saint Paul, MN 55101

Corresponding Address:
Jane Z Liu MD
Department of Orthopaedic Surgery
Henry Ford Health System
2799 West Grand Blvd, CFP 642
Detroit, MI 48202
Email: JLIU4@hfhs.org

Conflict of Interest Disclosure:
The authors report no actual or potential conflict of interest in relation to this article.

INTRODUCTION

The majority of surgical instruments are eponymous. Indeed, "Freer" is one of the few names that can be misconstrued as descriptive. Although some argue for a transition from eponymous to descriptive medical terminology, there is value in honoring surgical pioneers. A handful of survey articles discuss the origins of eponymous instruments in orthopaedic surgery.[1-4] These articles are biographical and focus on the accomplishments of the inventors. Few concentrate on the instruments themselves and the circumstances surrounding their invention.

We discuss 7 eponymous instruments commonly used by orthopaedic surgeons, exploring (1) their original intent, (2) the circumstances of their invention, and (3) whether their usefulness has changed. Our list of instruments – the Steinmann pin, Bovie electrocautery, Metzenbaum scissors, Freer elevator, Cobb periosteal elevator, Kocher clamp, and Verbrugge bone holding forceps – is by no means complete. Nevertheless, we hope our discussion will enlighten and entertain the reader. Short biographies of the inventors of other eponymous instruments are provided in the literature, including Key's periosteal elevator, Lambotte's osteotome, Martin's bandage, Kirschner's wire, Stryker's saw and several retractors.[3,4]

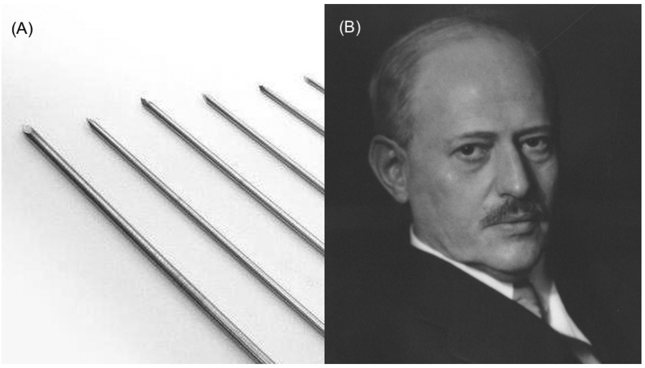
SEARCH STRATEGY AND CRITERIA

We searched PubMed, Google Scholar, Google Books, the Internet Archive, the HathiTrust Digital Library, and the annals of the Journal of Bone and Joint Surgery and the Journal of the American Medical Association for the above noted instruments and inventors. Any non-English texts were translated to English with Microsoft Word for Mac 2011 (Microsoft Corp.; Redmond, WA) and Google Translate (Google Inc.; Mountain View, CA).

STEINMANN PIN

Fritz Steinman (1872-1932)

The inventor of the Steinmann pin (Figure 1A) was Fritz Steinmann (Figure 1B) of Berne, Switzerland. Dr. Steinmann completed his medical training at Lausanne and Berne in 1898. He subsequently served as an assistant to Dr. Theodor Kocher for 5 years before starting



Figures 1. (A) Steinmann pins arve depicted. (B) A Photograph of Dr. Fritz Steinmann is shown courtesy of the Institute of the History of Medicine at the University of Berne.

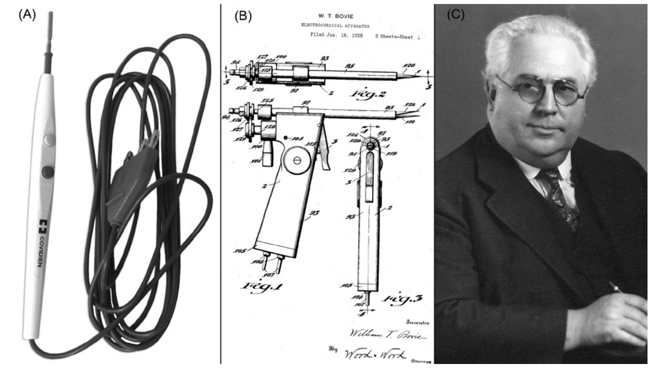


Figure 2. (A) A modern Bovie electrocautery device is depicted. (B) A cartoon of original Bovie apparatus from its patent application is shown. (C) A photograph of Dr. William T. Bovie in 1908 is depicted courtesy of the Albion College Collection through Flickr using Creative Commons Licensure.

private practice.[3,5,6] A first-hand account of Steinmann's invention was presented in the British Medical Journal in 1912.[7] The early Steinmann pins were 3-5 mm in girth. Their diameter and length were determined by the size of the target bone and its soft tissue envelope. The ends of the pins were pyramidal in shape with 4 sides converging on a point similar to a trocar, which prior to 1900, was used to drain deep fluid collections.[8-10] In the absence of autoclaves, Steinmann sterilized his pins by boiling them before loading them into a hand drill. Interestingly, these pins were placed in the same pin sites we use today, which were selected to minimize infection. These pins were then fixed to an "extension apparatus" (balanced traction). This technique had several advantages over "plaster extension" (casting).[7] Skeletal traction allowed for access to the soft tissues and permitted motion at the joints adjacent to the fracture site. Skeletal traction also controlled shortening better than plaster casts. Without a doubt, Steinmann revolutionized the management of acute fractures.

Interestingly, history is not without controversy. While Steinmann presented his method for treating acute fractures in 1907, an Italian surgeon, Dr. Alessandro Codivilla, independently described a method for correcting lower extremity malunions with skeletal traction in 1903.[7,11,12] Not surprisingly, public debate raged between Steinmann and Codivilla regarding who had primacy until 1913, when it is possible that Steinmann won by default after Codivilla fell to cancer.[3,5,6] Regardless, both deserve credit.[13,14]

Today the Steinmann-Codivilla pin can list among its descendants the Kirschner wire,[3] the "splint nail extension" (external fixator),[7,15,16] and likely the Schanz screw.[17,18] Although internal fixation has supplanted skeletal traction in the management of long bone fractures, temporary skeletal traction is indicated for acute femoral shaft fractures, a retained intraarticular fragment after hip dislocation reduction, and some subtrochanteric fractures.[19]

BOVIE ELECTROCAUTERY

William T. Bovie (1882-1958)

The Bovie electrosurgical instrument (Figures 2A-B) has decreased intraoperative bleeding and become indispensable in modern surgery. Dr. William T. Bovie (Figure 2C), the inventor of the Bovie electrocautery pencil, hailed from rural Michigan.[1] Interestingly, he began his education in stenography before studying biology. Bovie's interest in biology led him to the research bench, rather than the ward or operating room. He received his doctorate at Harvard University, where he was later hired as an Assistant Professor of Biophysics.

Bovie's genius lied in that he devised separate electrical currents for cutting and cautery. His device had 2 modes and 3 distinct uses: superficial desiccation (painting), cutting, and coagulation.[20,21] For superficial desiccation, the Bovie electrode was held away from tissue while heat from its sparks created a thin dry layer. When cutting, an electrical arc of continuous current stayed ahead of the electrode "volatizing" and dividing tissue. For coagulation en masse, the electrode was placed in direct contact with tissue. The original Bovie was shaped like a pistol and had foot controls. These were quickly changed to hand controls to allow freedom of movement and better operator handling. Today's Bovie is shaped like a pencil, but its function has not changed.

The famed Dr. Harvey Cushing was the first surgeon to test the Bovie prototype, which he used to excise a vascular meningioma on October 1, 1926. He had aborted the procedure a few days prior due to uncontrollable hemorrhage.[1] After his success, Cushing worked with Bovie to tackle previously inoperable cases and to

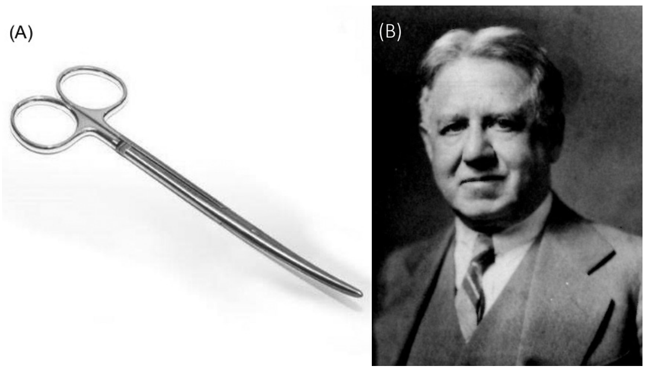


Figure 3. (A) Metzenbaum scissors are shown. (B) Dr. Myron Metzenbaum is depicted courtesy of Dr. Ralph Metson, nephew of Dr. Myron Metzenbaum.

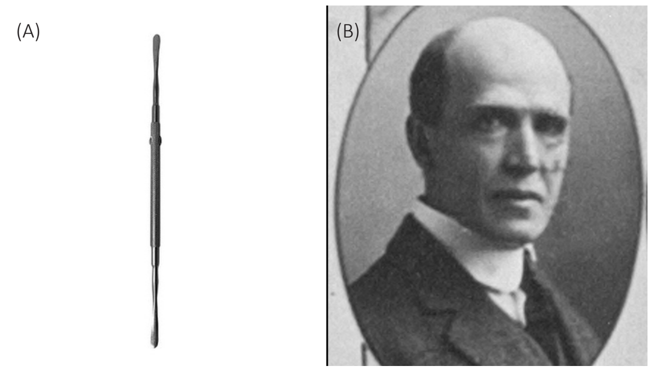


Figure 4. (A) A Freer elevator is portrayed. (B) A photo of Dr. Otto Tiger Freer in 1916 is shown courtesy of the Rush University Medical Center Archives.

gain acceptance for the Bovie among the surgical community, including other neurosurgeons like Dr. Alfred Adson.[20,22] Their collaboration is cited as the beginning of translational research: the partnering of scientists and physicians to create novel devices and treatments for patient care.[1] Of note, Bovie sold his patent rights to a manufacturer for only $1.

METZENBAUM SCISSORS

Myron F. Metzenbaum (1876-1944)

Metzenbaum scissors (Figure 3A) are known by many names: dissecting scissors, tonsillectomy scissors, and “metz.” Myron F. Metzenbaum (Figure 3B) developed the scissors for tonsillectomy and perineal operations. Dr. Metzenbaum came from Cleveland, Ohio where his father sold linen. Metzenbaum attended the Adelbert College of Western Reserve. Afterwards, he worked under Dr. George Crile, a co-founder of the Cleveland Clinic. Metzenbaum went on to have a number of academic accomplishments. He made advancements in ether anesthesia, conducted research in radium, developed techniques for repairing traumatic injuries of the nasal septum, and invented his scissors. He also was a founding member of the American Board of Plastic Surgery in 1937.[23]

It is not clear when exactly the famed dissector was invented. An advertisement for new instruments in the Detroit Medical Journal in 1912 estimates the timeframe of its invention and describes its value. The scissors are described as “useful for any operation where a keen-cutting, blunt-pointed dissecting scissors is desired [as] the blades of the scissors are thin, slightly tapering, with blunt points, and when closed form an excellent dry dissector.”[24] Today in orthopaedic surgery, Metzenbaum scissors are used for subcutaneous and intermuscular tissue dissection. Like Weitlaner and Bovie, Metzenbaum never profited financially from the invention of his scissors. Other examples of his beneficence are that he voluntarily set up a city ambulance service for Cleveland residents while in medical school and that he once paid out of his own pocket for one of his pediatric patient’s hospital bills and travel expenses.[23]

FREER ELEVATOR

Otto Tiger Freer (1857-1932)

The inventor of the Freer elevator (Figure 4A) was born in Chicago, Illinois in 1857. Dr. Otto Freer (Figure 4B) was a physician’s son. His father, Joseph Warren Freer, was President of Rush Medical College. Freer entered directly into Rush Medical College after high school and obtained his medical doctorate in 1879. He then did fellowships at the Universities of Munich, Vienna, and Heidelberg. Ultimately, he interned at Cook County Hospital in Chicago and specialized in laryngology. During his career, he served as Secretary (1903-1905) and Chairman (1905-1906) of the Laryngology section of the American Medical Association.[25,26] He was also a founder of Henrotin Hospital in Chicago.[26]

Freer was influenced by a contemporary Chicago laryngologist named Ephraim Ingals, who also attended Rush Medical College and interned at Cook County Hospital.[27] Much of Freer’s notoriety stemmed from him perfecting and publicizing Ingals’ technique for correcting nasal septum deviation via submucosal resection.[26] The gradual nature of this perfection is noted in Freer’s consecutive publications on the Ingals’ procedure in 1902 and 1903.[28,29] In this, we see the emergence of the famed Freer elevator, which he used to carry out submucosal dissection to expose underlying nasal cartilage with minimal “traumatism” to the mucosa. He called the instrument a “dental spatula.” This instrument was single-ended and existed in 2 forms, blunt and sharp.[28,29] Today, orthopaedic surgeons employ the Freer “dental spatula.” It is used in a similar fashion to elevate soft tissue from hard surfaces, while removing a nail to expose a nail bed or elevate periosteum.[26]

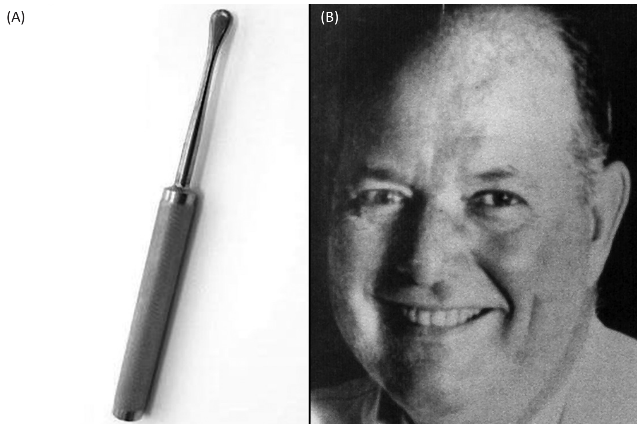


Figure 5. (A) A Cobb periosteal elevator is depicted. (B) Dr. John R. Cobb is depicted courtesy of Dr. David B. Levine.

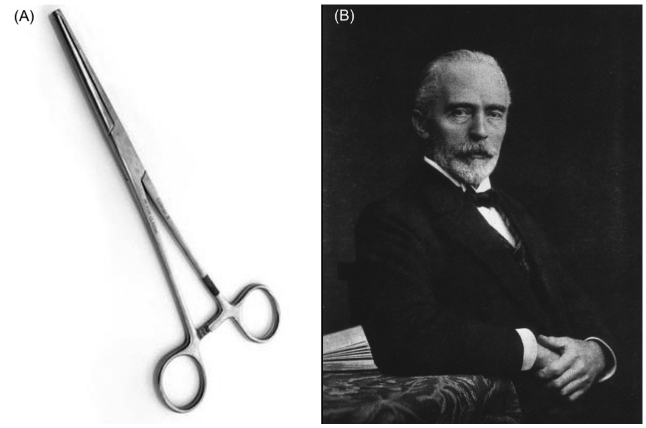


Figure 6. (A) Kocher clamp is shown. (B) Dr. Emil Theodor Kocher is depicted courtesy of the National Library of Medicine.

COBB'S PERIOSTEAL ELEVATOR

John Robert Cobb (1903–1967)

The designer of the Cobb elevator (Figure 5A), John Robert Cobb, was a well-respected leader in scoliosis treatment who developed the Cobb method for reproducibly measuring scoliosis.[30] John R. Cobb (Figure 5B) was born in New York City, attended a military high school in Virginia, and completed his undergraduate studies at Brown University. He commenced from the Yale School of Medicine in 1930 and then began his internship and orthopaedic training at New Haven Hospital. In 1934, Cobb became an orthopaedic fellow at the Hospital for the Ruptured and Crippled in New York, now the Hospital for Special Surgery. He spent the remainder of his career at this institution and developed their first scoliosis service.[5,31]

Most know that Cobb devised the Cobb angle; however, that he was also an innovative and masterful surgeon is less often discussed. Cobb was known by many accounts to be caring and meticulous in his work. He mastered and modified Hibbs' method for uninstrumented posterior spinal fusion. Cobb even welcomed observers from far and near in his operating room. One pillar of scoliosis surgery, John Moe, M.D., noted that meticulous subperiosteal dissection set Cobb apart from other scoliosis surgeons.[32] Cobb designed a periosteal elevators and gouge for spine fusion.[33] Dr. David Roux, a South African orthopaedic surgeon, visited with Cobb for a year, and in 1964, he wrote a full account of Cobb's fusion method with a level of detail that allows the modern surgeon to envision the case unfolding step by step. For Cobb, a meticulous periosteal dissection was crucial for minimizing blood loss. He used his periosteal elevator and wound packing to meet this goal.[34]

Interestingly, Cobb's dedication to curtailing blood loss mirrors that of George Wagoner, who is credited with describing in detail the subperiosteal approach to the posterior spine in 1937.[33,35] After splitting deep fascia over the midline of the spinous process, Wagoner performed subperiosteal dissection with a scalpel while levering paraspinal muscles taut with a blunt elevator at the base of the spinous process. He then utilized the blunt elevator to gently retract muscle over the facets and toward the transverse processes. It seems that Cobb developed a 2-in-1 instrument, a pushing elevator and a proximally weighted lever. This likely allowed him to effectively and efficiently "[slip] between the periosteum and the spinous process" before gently exposing more lateral structures.[10,34] Of note, Cobb endeavored to leave the facet joints untouched to preserve stability, which was different from his contemporaries.[32,34] Today, the Cobb elevator continues to have its greatest usefulness for exposure in posterior spine surgery.

KOCHER CLAMP

Emil Theodor Kocher (1841-1917)

The Kocher clamp (Figure 6A) is ubiquitous throughout the field of surgery. Its inventor, Emil Kocher (Figure 6B), was born in Bern, Switzerland and was the son of a civil engineer. He completed medical school at the University of Bern in 1865.[5,31] After medical school, he embarked on a travelling fellowship, which included a research experience in Berlin and surgical observation in Paris and London.[36] He then returned to the Surgical Clinic of Bern University as an assistant surgeon and became chair in 1872.[37]

Kocher's contributions to surgery and medicine reach far beyond devising an arterial clamp and surgical approaches. He performed orthopaedic, neurological, abdominal, and thyroid procedures, among others. In

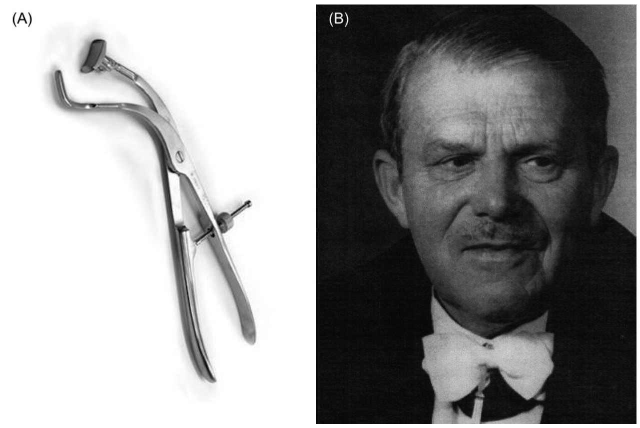


Figure 7. (A) A Verbrugge bone holding forceps are depicted. (B) Dr. Jean Verbrugge is depicted courtesy of Professors Jean-Jacques Rombouts and Robercht Van Hee.

addition to several papers, he shared his knowledge through an authoritative surgical technique textbook called the Text-book of Operative Surgery, which had multiple editions and translations (English, French, Spanish, Italian, and Russian).[5,38] Kocher was also the first to emphasize the concept of internervous plane dissection.5 Finally, he won a Noble Prize in Medicine for his work on the physiology, pathology, and surgical management of Graves' disease.[36,37]

The usefulness of Kocher's arterial clamp is well known, but its origin is unsung. Interestingly, a Swiss-born French instrument maker named Joseph-Frédéric-Benoît Charrière invented the concept behind the modern arterial clamp, a one-handed, pivoting forceps with a proximal catching mechanism. Charrière published his design in 1852 at a time when surgeons paused procedures to tie a ligature or hold manual pressure to control hemorrhage. Now "forcipressure" clamps could be applied to individual vessels or tissues in mass, which allowed surgeons to continue procedures without pause.[39] Surgeons in the 1860s and 1870s made modifications to Charrière's instrument; among them was Dr. Thomas Spencer Wells.[10,39,40] Wells' specific contributions were a shortened jaw and heavy furrowed teeth to improve grip and compression.[10] Kocher presented his arterial clamp in 1882.[41] Kocher's clamp looked quite similar to Wells', except for its slightly longer, thinner jaws and terminal rat teeth.[10,42] It is unclear whether Kocher's clamp was modeled after Wells', or after Billroth's as Kocher once stated.[10,39,41-44] Nevertheless, Kocher's terminal rat teeth modification created a firm grasper for gripping soft tissue en masse and slippery tissue near bone.[43] In orthopaedics today, we continue to take advantage of the Kocher's firm grip and use it as a general grasper.

VERBRUGGE BONE HOLDING FORCEPS

Jean Verbrugge (1896-1964)

Verbrugge forceps (Figure 7A) can boast one of the most unique sounding names in orthopaedics. Jean Verbrugge (1896-1964) was born in Belgium in 1896 (Figure 7B). He completed his intermediary studies at Antwerp, after which he obtained a doctorate of medicine, surgery, and obstetrics from the University of Brussels in 1921. He then continued his education through a travelling fellowship. He trained in the United States at the Mayo Clinic, as well as in Italy and France. During his career, Verbrugge became a Professor of Orthopaedic Surgery at the University of Ghent, authored approximately 175 publications, and served as President of the Belgium Orthopaedic Association.[5] In 1946, Verbrugge presented "a new bone holding clamp...for fixation of fractures."[45] The new design was a one-handed, ratcheted clamp with a curved distal end. The design "facilitate[d] the prehension of bone and help[ed] in the fixation of plate or graft on the shaft" without "interfer[ing] with subsequent drilling or screwing."[45] Verbrugge later improved his design by changing the lower jaw to a sharp, pointed end to allow positioning of the Verbrugge without excessive soft tissue stripping.[46] His invention has withstood the test of time and remains an invaluable instrument for the treatment of diaphyseal fractures.

DISCUSSION

We explored the origins of 7 common eponymous tools in the basic orthopaedic instrument tray. Specifically, we attempted to explain the reasons that the instruments were invented, the historical context of their invention, and whether their usefulness had changed. One limitation to this project was that many of the works of the named surgeons are not indexed in modern databases. We used the text search function of Google Books and the HathiTrust Digital Library to improve our literature search.

Through the purview of history, it is not difficult to see that invention is born out of a combination of ingenuity, necessity, and circumstance. The instruments that were enumerated in this article were improvements or adaptations of already existing technologies. The indications for the use of the orthopaedic implants, the Steinmann pin, Cobb, and Verbrugge, have changed little. Meanwhile, the non-orthopaedic instruments, the Bovie, Metzenbaum, Freer, and Kocher, have been adapted for our use, none more so than the Freer. Surprisingly, at least 2 of the listed inventors, Bovie and Metzenbaum, did not patent their instruments.

Today's orthopaedic surgeon is encouraged to be creative and to invent new technologies or adapt old ideas to new uses. However, what constitutes intellectual property in the context of surgery? While both new surgical techniques and new devices can be patented, only device patents are enforceable. For good reason, the medical community, including the American Academy of Orthopaedic Surgeons and the American Medical Association, strongly discourage attempts at patenting surgical techniques. On the other hand, inventors of new devices are encouraged to obtain ownership right and to protect their ideas. Interestingly, these devices are sometimes key instruments for the new techniques.[47,48]

Much of the history of surgical innovation and advancement in the field of orthopaedics is waiting to be uncovered. Aside from Medline, the archives of longstanding journals such as the Journal of Bone and Joint Disease, the Journal of the American Medical Association, and the British Medical Journal are excellent resources for vintage articles. What is more, many out of print journals and textbooks are now digitized and housed in online libraries such as Google Books, the HathiTrust Digital Library, and the Internet Archive. These are replete with information that still guides surgical practices today.

ACKNOWLEDGMENTS

We thank Dr. Stephen P. Desilva, Henry Ford Hospital, for his constructive feedback. We thank Professor David B. Levine, Hospital for Special Surgery; Professor Rene Verdonk, University of Ghent; Professor Jean-Jacques Rombout, Université catholique de Louvain; catholique de Louvain; Professor Robercht Van Hee, University of Antwerp; Dr. Ralph Metson, Harvard Medical School; and Bruno Müller, Institute of the History of Medicine at the University of Berne, for their assistance in preparing figures. We also thank Stephanie Stebens, Henry Ford Hospital, Sladen Library, for assistance with manuscript preparation.

REFERENCES

1. **El-Sedfy A, Chamberlain RS.** Surgeons and their tools: a history of surgical instruments and their innovators-part II: the surgeon's wand-evolution from knife to scalpel to electrocautery. Am Surg. 2014;80(12):1196-1200.
2. **Harijan A, Halvorson EG.** Eponymous instruments in plastic surgery. Plast Reconstr Surg. 2011;127(1):456-465.
3. **Meals C, Wang J.** Origins of eponymous orthopaedic equipment. Clin Orthop Relat Res. 2010;468(6):1682-1692.
4. **Meals CG, Meals RA.** A history of surgery in the instrument tray: eponymous tools used in hand surgery. J Hand Surg Am. 2007;32(7):942-953.
5. **Mostofi SB, ed.** Who's who in orthopedics. London: Springer; 2005.
6. **Romm S.** Fritz Steinmann and the pin that bears his name. Plast Reconstr Surg. 1984;74(2):306-310.
7. **Steinmann F.** British Medical Association: report of the Committee on Treatment of Simple Fractures. Nail extension for fractures: an account of the method. Br Med J. 1912;2(2709):1534-1537.
8. **Ruedi T, Buckley R, Moran CG.** AO principles of fracture management. New York: Thieme; 2007.
9. **Moore AGN.** Reginal S. Southey, M.D. - 1835-1899. Available from: https://legacy.countway.harvard.edu/. Accessed February 21, 2015.
10. **Kirkup J.** The evolution of surgical instruments: an illustrated history from ancient times to the twentieth century. Novato, CA: Historyofscience.com; 2005.
11. **Codivilla A.** Sulla correzione della deformita de frattura del femore. Bull Sci Med (Bologna). 1903;74(8):246-249.
12. **Codivilla A.** On the means of lengthening, in the lower limbs, the muscles and tissues which are shortened through deformity. Am J Orthop Surg. 1905;22(4):353-369.
13. **Peltier LF.** A brief history of traction. J Bone Joint Surg Am. 1968;50(8):1603-1617.
14. **Peltier LF.** The role of Alessandro Codivilla in the development of skeletal traction. J Bone Joint Surg Am. 1969;51(7):1433.
15. **Brickner WM, ed.** Progression in surgery: a resume of recent literature. Extension methods. Am J Surg. 1914;28:52-54.
16. **VanHook W.** The principles of fracture treatment. Am J Surg. 1922;36(11):257-261.
17. **Schanz A.** Praktische Orthopädie. Berlin: Springer-Verlag; 1928.
18. **Wolf JH.** Alfred Schanz und sein Kunstgriff der Schraubenfixation zur Fragmentjustierung bei der Osteotomie. Oper Orthop Traumatol. 1990;2(4):302-307.
19. **Court-Brown CM, Heckman JD, McQueen MM, Ricci WM, Tornetta P, III, McKee MD.** Rockwood and Green's fractures in adults. 8th ed. Philadelphia: Wolters Kluwer; 2014.
20. **Goldwyn RM.** Bovie: the man and the machine. Ann Plast Surg. 1979;2(2):135-153.
21. **Bovie WT.** A preliminary note on a new surgical-current generator. 1928. Clin Orthop Relat Res. 1995(310):3-5.
22. **Sachs E.** Fifty years of neurosurgery; a personal story. New York: Vantage Press; 1958.
23. **Metson R.** Myron F. Metzenbaum, MD: innovative surgeon, caring physician. Otolaryngol Head Neck Surg. 1994;110(6):477-481.
24. **Dempster JH.** New instruments and devices: Metzenbaum dissecting scissors. Detroit Medical Journal. 1912;12(9):329-331.

25. Deaths. J Am Med Assoc. 1932;98(21):1829-1830.
26. **Chittiboina P, Connor DE, Jr., Nanda A.** Dr. Otto "Tiger" Freer: inventor and innovator. Neurosurg Focus. 2012;33(2):E12.
27. Deaths. J Am Med Assoc. 1918;70(18):1322-1323.
28. **Freer OT.** The correction of deflections of the nasal septum with a minimum of traumatism. J Am Med Assoc. 1902;38(10):636-642.
29. **Freer OT.** The window resection operation for the correction of deflections of the nasal septum. J Am Med Assoc. 1903;41(23):1391-1398.
30. **Cobb JR.** Outline for the study of scoliosis. In: Instructional Course Lectures, American Academy of Orthopaedic Surgeons. Vol 5. Ann Arbor, MI: J.W. Edwards; 1948:261-275.
31. **Stern V.** The first surgeon Nobel Prize winner: Emil Theodor Kocher, MD. General Surgery News. June 2014, 2014: 06.
32. **Moe JH.** A critical analysis of methods of fusion for scoliosis; an evaluation in two hundred and sixty-six patients. J Bone Joint Surg Am. 1958;40-A(3):529-554 passim.
33. **Campbell WC, Speed JS.** Campbell's operative orthopaedics. 3rd ed. St. Louis: C.V. Mosby Co.; 1956.
34. **Roux D.** The treatment of scoliosis: a practical approach. South African Journal of Physiotherapy. 1964;20(1):6-12.
35. **Gardocki RJ.** Spinal anatomy and surgical approaches. In: Canale ST, Beaty JH, eds. Campbell's Operative Orthopaedics. Philadelphia: Mosby Elsevier; 2007.
36. **Ulrich T.** Emil Theodor Kocher (1841-1917). Available from: www.jameslindlibrary.org. Accessed January 11, 2015.
37. Professor Theodor Kocher. BMJ. 1917;2(2953):168-169.
38. **Kocher T.** Text-book of operative surgery. 3rd english ed., authorized translation of the 5th german ed. New York: The Mackmillan Company; 1913.
39. **Pozzi S.** Treatise on gynaecology, medical and surgical. New York: William Wood & Company; 1892.
40. Menier. Catalogue Commercial Ou Prix Courant Général Des Drogues Simples, Produits Pharmaceutiques Et Chimiques...[etc]. 5th ed. Paris: Tipographie de Henri Plon; 1860.
41. **Kocher ET.** Ueber die einfachsten Mittel zur Erzielung einer Wundheilung durch Verklebung ohne Drainrˆhren. Leipzig: Breitkopt und Härtel; 1882.
42. **Berkeley C, Bonney V.** A text-book of gynaecological surgery. New York: Funk & Wagnalls; 1914.
43. **Mitchell-Heggs FS, Drew HGR.** The instruments of surgery. Springfield, IL: Thomas; 1963.
44. **Fritsch H.** The diseases of women: a manual for physicians and students. New York: William Wood & Company; 1883.
45. **Verbrugge J.** An improved bone clamp and a plate for internal fixation of fractures. J Bone Joint Surg Am. 1946;28:174.
46. **Verbrugge J.** A new clamp for use in fracture surgery. J Bone Joint Surg Am. 1953;35-A(3):773.
47. **Legaard B, Lyman R.** Protect your inventions and intellectual property. AAOS Now. 2009;3(5).
48. American Academy of Orthopaedic Surgeons. Medical and surgical procedure patents. Available from: http://www.aaos.org/about/papers/ethics/1209eth.asp. Accessed April 6, 2015.

THE SCARCITY OF ORTHOPAEDIC PHYSICIAN SCIENTISTS

Joseph A Buckwalter V, M.D., Ph.D.*, Jacob M Elkins, M.D., Ph.D.

ABSTRACT

Breakthrough advances in medicine almost uniformly result from the translation of new basic scientific knowledge into clinical practice, rather than from assessment, modification or refinement of current methods of diagnosis and treatment. However, as is intuitively understood, those most responsible for scientific conception and creation –scientists – are generally not the ones applying these advances at the patient's bedside or the operating room, and vice versa. Recognition of the scarcity of clinicians with a background that prepares them to develop new basic knowledge, and to critically evaluate the underlying scientific basis of methods of diagnosis and treatment, has led to initiatives including federally funded Physician-Scientist programs, whereby young, motivated scholars begin a rigorous training, which encompasses education and mentorship within both medical and scientific fields, culminating in the conferment of both MD and PhD degrees. Graduates have demonstrated success in integrating science into their academic medical careers. However, for unknown reasons, orthopaedic surgery, more than other specialties, has struggled to recruit and retain physician-scientists, who possess a skill set evermore rare in today's increasingly complicated medical and scientific landscape. While the reasons for this shortfall have yet to be completely elucidated, one thing is clear: If orthopaedics is to make significant advances in the diagnosis and treatment of musculoskeletal diseases and injuries, recruitment of the very best and brightest physician-scientists to orthopaedics must become a priority. This commentary explores potential explanations for current low-recruitment success regarding future orthopaedic surgeon-scientists, and discusses avenues for resolution.

INTRODUCTION

Knowledge in the medical sciences is growing by an astounding rate, and orthopaedics is no exception. As observed over a decade ago, "In the last twenty-five years, basic sciences have made such dramatic progress that it is difficult for even for the most scientifically inclined orthopaedists to understand current basic research."[1,2] After a decade of intense scientific enterprise, this observation rings even truer today. Given this widening gap between research and practice – between the bench and the bedside – how can we continue to efficiently and correctly apply new medical advances to the practice of orthopaedics? While there will always be those motivated few who devote precious time away from the practice of medicine and dabble in the basic sciences until they have reached the level of proficiency comparable to a scientist, we cannot collectively depend on these few to carry the torch of translational science. Thus, we must identify and nurture from an early educational stage those individuals devoted to such a career. Perhaps the best-known national initiative to bolster medical research by development of clinician-scientists is the Medical Scientist Training Program (MSTP). Initiated in 1964 by the National Institute of General Medical Sciences (NIGMS), the MSTP was established to promote careers in biomedical research and academic medicine by supporting trainees through both medical and research training, leading to the conferment of both MD and PhD degrees. Trainees typically receive full tuition waivers and are supported by a stipend throughout their training period, which typically lasts 8 years.[3] Additionally, there are approximately 75 additional medical schools that do not have NIGMS MSTP training grants, but also offer opportunities for MD-PhD students. The typical structure of MD-PhD programs is that the first two years are devoted to a traditional pre-clinical medical curriculum. Following this period, trainees are transitioned to their research lab, and produce their dissertation under their research mentor. Following completion of their PhD dis-

Mailing Addresses:
*Joseph A. Buckwalter V, M.D., Ph.D.
E-mail address: joseph-v-buckwalter@uiowa.edu

Jacob M Elkins, M.D., Ph.D.
E-mail address: jacob-elkins@uiowa.edu

University of Iowa Hospitals and Clinics
Department of Orthopaedics and Rehabilitation
200 Hawkins Drive
01085 JPP
Iowa City, Iowa 52242
Telephone: (319) 353-7656
Fax: (319) 353-6754

sertation, trainees again transition back into the medial realm, completing the final two years of clinical education prior to graduation. Currently, there are 911 MSTP slots at an average annual cost of $41,806, at a total of 43 participating institutions.[4] So, with an annual operating budget of nearly $40 million dollars, it is a fair question to ask whether the MST program is meeting its objective of training physician-scientist. In the largest analysis to-date of MSTP graduates, Brass et al.,[3] surveyed nearly ½ of the NIH-funded MSTP graduates during a 40-year period. They found 81% of alumni were employed in academia (vs. 16% in private practice). Of those employed in academia, 82% were involved in research, and 60% had research funding. Two-thirds devoted more than 50% of their effort to research, and nearly 40% of alumni reported 75% or greater of time devoted to research. Are MSTP graduates, therefore, successful? Despite the lack of a clear tidemark in establishing "success", these data seem to support the realization of NIGMS' charge to develop clinician scientists. However, a closer look at the data uncovers some concerning trends. Despite on 16% of alumni entering private practice (which for the sake of discussion can be seen as a direct failure of the MSTP mission), some specialties are seen to enter private practice at substantially higher rates. Greater rates of private practice were seen in fields that have recently increased in popularity, such as dermatology (44%), ophthalmology (44%) and surgical specialties (27%). Additionally, it was noted that matriculation into these fields by MSTP graduates have step-wise increased over the past four decades. Why do we see an increase failure rate of the physician-scientist model in these competitive, lucrative, and surgical-heavy specialties, including orthopaedic surgery? While true that time constraints are arguably greater for the surgeon-scientist as compared to the traditional physician-scientist, from simple arithmetic analysis of the previous data suggest that nearly 50% of MD-PhDs in surgery conduct research with at least a 50% time commitment. How about the remaining 50%? Data from Ahn et al.,[5] surveying orthopaedic resident's attitudes toward research, demonstrate that nearly all orthopaedic residents surveyed assert that orthopaedic research performed by orthopaedists was important, however only 42% felt they were likely to perform research in their careers. Reasons against intent to perform research following training include debt relief, protected time, and salary support. However, these general statistics are for the general orthopaedic resident. How about the rare MD-PhD orthopaedic resident? What motivations exist for a resident who has spent nearly a decade (or more) training for a career as a clinician-scientist to proverbially throw in the towel and submit to a career of private practice? This decision is troubling in the perspective that these residents were certainly vetted – at one time or another – for their commitment to pursue research. While it is tempting to place the onus on the individual, certain amount of responsibility certainly lies within the institution charged with training and preparing residents for their careers. What, then, are the institutional behaviors responsible for failure of the Surgeon-Scientist? Perhaps fault lies in a recent shift in emphasis toward clinical research. Perhaps more directly, fault can be placed upon not attracting MD-PhD candidates?

BASIC SCIENCE VS. CLINICAL RESEARCH

Certainly, research is an important component of most current orthopaedic residencies, however is arguably more emphasized at some institutions over others. It can be argued that only a small minority of "research" conducted at these institutions by orthopaedists or orthopaedic residents falls under the label of basic or translational science. As a point of reference, consider a recent annual (2014) meeting of a major regional orthopaedic research conference representing 20 states, including several dozen orthopaedic institutions, many of which are well known research powerhouses nationally. Of 208 paper presentations and 153 poster abstracts, only 51 represented a research project that was not primary composed of surveys, database searches, chart reviews, clinical studies, etc. Of these 51, the vast majority were comprised of radiographic studies, requiring only access to radiographic images. Only a select handful represented true basic science endeavors, including cell biology/biochemistry, anatomy, or biomechanical work. Furthermore, the academic degree of the presenting or primary author reveals that a physician was not primarily performing many of these projects. Review of previous years' submissions reveals similar statistics. If you allow for assumptions – first that if substantial research is performed by a resident then it would be submitted, and second that the research pattern of these 20 states mirrors those in the remaining 30 – then extrapolation of this single reference point illustrates that residents and/or young faculty are not performing basic science research at an appreciably meaningful volume. While clinical research is of paramount importance in our chosen profession, a strong argument can legitimately be made arguing in favor of the primacy of basic science in medicine in general and orthopaedics specifically. As argued by Brand et al.,[6] "advances in clinical practice continue to arise more often from the lab rather than from the clinic". In orthopaedics, these advances include tissue engineering, biologics, gene therapy, and imaging. Unless clinicians are involved in the development of the techniques, they are less likely to be efficiently transferred to the clinic." However, when one only has experience in the clinic, then understanding of the bench-to-

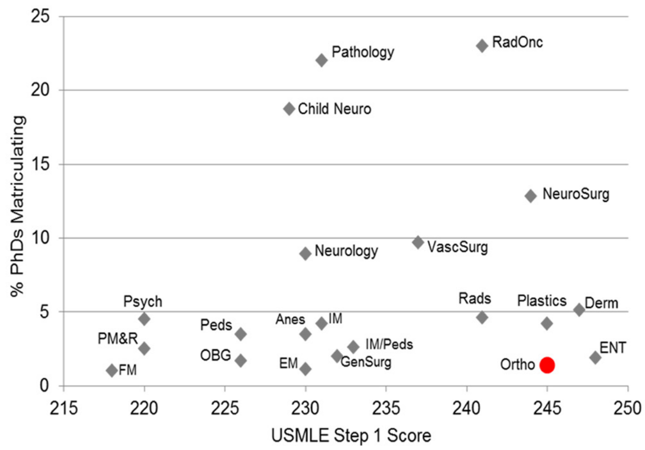


Figure 1. Percentage of PhDs matriculating into residency, ordered by average USMLE Step 1 score. For simple estimation of a specialty's competitiveness, USMLE Step 1 scores are considered as a surrogate. Orthopaedics, as illustrated with the red round marker, is near the bottom in terms of % matriculants with a PhD degree. Other specialties, including Otolaryngology (ENT), Dermatology (Derm), Plastic Surgery (Plastics), Neurologic Surgery (NeuroSurg), Radiation Oncology (RadOnc), Vascular Surgery (VascSurg), Internal Medicine (IM) and Internal Medicine-Pediatrics (IM/Peds), General Surgery (GenSurg), Neurology Anesthesia (Anes), Pediatrics (Peds), Obstetrics-Gynecology (OBG), Psychology (Psych), Physical Medicine and Rehabilitation (PM&R) all have a greater percentage of MD-PhD matriculation relative to orthopaedics. Only Family Medicine (FM) and Emergency Medicine (EM) have relatively fewer MD-PhD matriculants.

bedside paradigm is critically limited. Therefore, there is little surprise that the majority of orthopaedic surgeons view clinical research as more important than basic science.[7] Undeniably – especially in the recent era of "big data" – clinical research holds great advantage over that of basic science. Results are quick, and typically require little in terms of time or resource commitment. Projects are completed over a weekend with nothing more than a computer spreadsheet program and an email to a statistician. Rather than laboring to explore the timeless questions of "how?" and "why?" these projects march forward collecting and collating others' clinical observations. The relative increase in the ease of these studies has perpetuated the facility of publishing for the sake of publishing. However, such a pattern of publishing does little outside self-serving, and most certainly does not contribute to the body of new orthopaedic knowledge.[8]

Certainly, musculoskeletal research is alive and well, as can be easily attested by reviewing of any recent ORS annals. Moreover, a large volume musculoskeletal research is published in bioengineering or rheumatology journals often far from the view of practicing orthopaedists or orthopaedic residents in training. And although the most circulated and impactful orthopaedic journals, such as the Journal of Bone & Joint Surgery (JBJS) or Clinical Orthopaedics and Related Research (CORR) gladly welcome basic submissions, the number of basic science submissions is far lower than clinical research submissions. This trend comes at a price for orthopaedics. As cautioned during his Presidential Address to ORS in 2002,[9] Dr. Thomas Brown states that as more and more orthopaedic research is conducted by non-orthopaedists, orthopaedic exploration faces the risk of becoming more and more specialized as research "accelerates down the path of scientific virtuosity for virtuosity's sake", to the unfortunate detriment of our patients.

THE MD-PHD CANDIDATE

One of the first analyses into MD-PhDs in orthopaedics demonstrated that less than 1% of MD-PhD graduates had chosen orthopaedics for a career.[10] At the time of publication in 2001, only 12 graduates of MSTP had entered orthopaedics, and only an approximate 2% of US orthopaedic faculty held both degrees. Additional investigations re-affirm that orthopaedics is one of the least successful disciplines in terms of recruiting MD-PhD graduates.[11] But why? Perhaps a fair initial assessment would be to look at the relative importance of research in selecting orthopaedic residents. In a massive study of program directors across all specialties, of the top seven residency programs in terms of competiveness (plastics, ortho, ENT, ophtho, radiology, rad-onc and NSG), ortho ranks only behind radiology in terms of program directors' rated importance of published research.[12,13] When investigation is narrowed to only orthopaedics[14], a history of published research falls at number 14 of 26 resident-selection criteria for acceptance into orthopaedic residency, several spots below "formality at interview", "personal appearance" and "medical school reputation."[14] Perhaps even more troubling is the listing of "candidate is MD/PhD" at number 17, just one spot above "reputation of undergraduate institution" and three spots above "appearance of CV." Furthermore, in a similar analysis, orthopaedic applicants actually viewed the value of an MD-PhD less than program directors.[15] Therefore, in a field that values applicant and CV appearance as much as future clinician-scientists, is it really surprising that we are now facing a critical shortage of qualified surgeon-scientists? Equally predictable is the number of MD-PhDs currently in orthopaedic residency. Based on recent match data,[16] we find that orthopaedics ranks at the very bottom in terms of PhD matriculants for competitive specialties (Figure 1). When considering all specialties that participate in the NRMP Match, Orthopaedics ranks only behind Family Medicine and Emergency Medicine in terms of recruiting MD-PhD applicants. Interestingly, Physical Medicine and Rehabilitation (PM&R, aka Physiatry) – orthopaedics' musculoskeletal brethren – has a recruitment rate for MD-PhDs twice that of orthopaedics. Substantial gaps are also illustrated between orthopaedics and other surgical specialties, such as Plastic

Surgery (3-fold higher MD-PhD rate), Vascular Surgery (7-fold) and Neurosurgery (9-fold). With the relative similarity of orthopaedics to these specialties (as compared to anesthesia or radiation oncology, for example), it is fair to ask why these other specialties are successful in attracting MD-PhD trained residents. Perhaps MD-PhD senior medical students are applying to orthopaedics, but they are not successful in landing a residency spot. While there are no hard-and-fast numbers to support this, this is certainly a possibility. However, it is much more likely that these students simply are not applying to orthopaedics. As described by Ahn et al.,[17] while nearly 14% of MSTP students interviewed were interested in a surgical career, only 1.4% listed orthopaedics as their top choice. And while the authors applauded this level of interest and enthusiastically stated that at this rate the field may double the number of active clinician scientists within orthopaedics in just fifty years, these numbers should be regarded as unacceptably low. Recalling the "Knowledge Doubling Curve" as described by Buckminster Fuller,[18] it is estimated that the progress of medical science is currently doubling each 1.5 years. In this context, waiting 50 years to double the number of individuals willing and able to deal with such expanses of knowledge seems anything but a success.

Of course, there is always the importance of our collective environmental culture. Despite major recent technologic advances in surgery, perhaps many surgical fields have been unable to shake the stereotypes of being overly non-cerebral, as compared to traditional clinician-scientist realms such as Internal Medicine, Neurology and Pathology. And perhaps no other surgical specialty has found itself as stereotyped with the non-cerebral phenotype as orthopaedics: one needs few guesses to surmise which specialty a PubMed search for "strong as an ox" returns.[19] Additional slang references for orthopaedics[20] such as "caveman" and "knuckledragger" are pervasive in the medical environment, and unfortunately do not help dissuade the propagation of our paradoxical stereotype: despite becoming increasingly competitive while attracting the brightest and most accomplished medical students, orthopaedic residents and surgeons are regarded as (boneheadedly) stupid and slow. Despite this seeming insult, it is apparent that some in the orthopaedic community actually embrace this perception.[21,22] While a change in perception of orthopaedic surgeons is not expected to change overnight, a possible consequence may be MD-PhD applicants contemplating research careers shying away from orthopaedics and move toward pathways which appear to be more welcoming to their research pursuits.

While remaining at the level of conjecture currently, there are perhaps additional reasons for the relative scarcity of MD-PhD applicants in orthopaedics. There is perhaps resistance from various MSTP program directors at potential medical schools when applicants openly state that they want to earn a PhD and pursue a career in orthopaedics. Applicants maybe gently persuaded to pursue alternative research directions and clinical practices, which are more in line with traditional MD-PhD scholarly activity. Additionally, MD-PhD school matriculants are often exposed early in their training to a variety of research environments, a process designed to assist students identify a research area before making a commitment to a research mentor. Certainly an increased exposure to orthopaedic research at this pivotal time may serve to improve early interest in this fascinating field.

Orthopaedics has difficulty recruiting research-focused residents. However, the importance of this small demographic within our training organization cannot be overstated. Surgeon-scientists are important in that the driving scientific questions for which they are equipped to address arise from the bedside and the operating room which they receive constant exposure. This unique perspective is clearly different from research-only trained scientists, or clinicians who lack the necessary tools to formulate inquisition in line with the scientific process. And, unfortunately, we appear to be moving in the wrong direction. In a large survey of members of the Orthopaedic Research Society (ORS) and American Academy of Orthopaedic Surgeons (AAOS), Brand et al.,[23] identified that only 3.6% of AAOS members were also members of ORS. Additionally, this study identified that the overwhelming majority of orthopaedists are not the PI on most NIH grants for which they have collaborated on. Furthermore, over a 10-year period, only 64 orthopaedic surgeons were identified whom were PIs on NIH grants exceeding $100,000, and that there was a downward trend for NIH funding for the specialty. When assessed for reasons, demands of clinical services – and not funding – was the rationale for decreased participation of research by orthopaedic surgeons. In a fascinating follow-up,[6] these 64 surgeon-scientists were probed for factors associated with their research success. Among many enlightening elements, perhaps the strongest influence was early exposure to research. Of these successful surgeon-scientists, the vast majority had begun research prior to residency, and only 10% after. Additionally, 44% had specialized dedicated research training, most for greater than one year. Thus, the expectation (or hope) that many of these bright, accomplished (but research-naïve) newly recruited residents will one day be at the vanguard of orthopaedic research is not founded in precedent. Perhaps a better strategy would be to actively recruit those with dedicated research experience and drive into orthopaedics.

While certainly a good start, merely recruiting more MD-PhD candidates (or others similarly equipped for a research career) might not be the panacea for solving our problem of the scarcity of surgeon-scientists. As previously discussed, over a quarter of the MD-PhD graduates who have entered a surgical field have entered private practice. And while the exact percentage is unknown, given the correlation between field competitiveness and rate of entering private practice[3], it is likely that an even higher rate of private practice is expected for MD-PhDs in orthopaedics. And, of course, non PhD-trained MDs leave the realm of academic practice at equally alarming numbers. Attrition rates for academic physicians are high and are increasing, with nearly 30% of American full-time MD faculty either planning or considering leaving academic medicine.[24,25] Attrition rates for surgical faculty are even higher.[26] So, moving forward, our challenge will be to recruit – and retain – young physician-scientists.

NURTURING RESEARCH INTEREST

The alarm regarding the scarceness of the orthopaedic surgeon-scientist has been raised many times. Thoughtful analysis,[11,27-31] has identified numerous obstacles regarding successful integration of research into an orthopaedic career. These include infrastructure, economic constraints, clinical burden, etc. However, a common theme amongst these is the existence of a nurturing environment for potential surgeon-scientists in training. Not only does formal research training increase scholarly activity,[32] it provides an opportunity for the development of strong mentor-mentee bonds, which have been described as being perhaps the most important step in fostering research interest for those in training.[28,29]

CONCLUSION

"How can surgeons and scientists advance the integration of science into orthopaedic practice and thereby improve treatment? The three requisites are (1) scientists with an understanding of clinical problems; (2) surgeons with an understanding of science; and (3) critical scientific evaluation of the results of clinical practice."[1,2] This is the entire foundation behind the development of MST and MD-PhD programs. And while the absolute numbers of MD-PhD graduates have actually increased in recent years, the numbers of orthopaedic surgeon-scientists have been in steady decline for decades, and there is no indication recovery for this 'endangered species'. Many factors have been identified as obstacles toward developing a research career within orthopaedic surgery; however these usually describe a strategy to foster research in residents and young faculty who likely had little interest in scientific pursuits prior to matriculating into the field. Instead, an entire demographic of young, research trained and mostly advanced degree-holding applicants with great potential are largely ignored. Perhaps one of the greatest opportunities to expand the ranks of surgeon-scientists is to recruit them, rather than relying on training them. Until we as a field learn to value a commitment to research more than board scores and undergraduate/medical school reputation, orthopaedics may continue to watch potential physician-scientists move on to something more welcoming.

REFERENCES

1. **Buckwalter JA.** Integration of science into orthopaedic practice: implications for solving the problem of articular cartilage repair. The Journal of bone and joint surgery American volume 2003;85-A Suppl 2:1-7.
2. **Buckwalter JA.** Advancing the science and art of orthopaedics. Lessons from history. The Journal of bone and joint surgery American volume 2000;82-A:1782-803.
3. **Brass LF, Akabas MH, Burnley LD, Engman DM, Wiley CA, Andersen OS.** Are MD-PhD programs meeting their goals? An analysis of career choices made by graduates of 24 MD-PhD programs. Academic medicine : journal of the Association of American Medical Colleges 2010;85:692-701.
4. Committee to Study the National Needs for Biomedical B, and Clinical Research Personnel. Research Training in the Biomedical, Behavioral, and Clinical Research Sciences. Washington DC: National Academy of Sciences.; 2011.
5. **Ahn J, Donegan DJ, Lawrence JT, Halpern SD, Mehta S.** The future of the orthopaedic clinician-scientist: part II: Identification of factors that may influence orthopaedic residents' intent to perform research. The Journal of bone and joint surgery American volume 2010;92:1041-6.
6. **Brand RA, Hannafin JA.** The environment of the successful clinician-scientist. Clinical orthopaedics and related research 2006;449:67-71.
7. **Marsh JL, McMaster W, Parvizi J, Katz SI, Spindler K.** AOA Symposium. Barriers (threats) to clinical research. The Journal of bone and joint surgery American volume 2008;90:1769-76.
8. **Hurwitz SR, Buckwalter JA.** The orthopaedic surgeon scientist: an endangered species? Journal of orthopaedic research : official publication of the Orthopaedic Research Society 1999;17:155-6.
9. **Brown TD.** Toward better interaction between orthopaedists and researchers: a two-way street. The Journal of bone and joint surgery American volume 2002;84-A:1473-7.
10. **Clark JM, Hanel DP.** The contribution of MD-PhD training to academic orthopaedic faculties. Journal of orthopaedic research : official publication of the Orthopaedic Research Society 2001;19:505-10.

11. **Atesok KI, Hurwitz SR, Egol KA, et al.** Perspective: Integrating research into surgical residency education: lessons learned from orthopaedic surgery. Academic medicine : journal of the Association of American Medical Colleges 2012;87:592-7.
12. **Green M, Jones P, Thomas JX, Jr.** Selection criteria for residency: results of a national program directors survey. Academic medicine : journal of the Association of American Medical Colleges 2009;84:362-7.
13. **Hall JF.** Advanced degrees in academic colorectal surgery. Clin Colon Rectal Surg 2013;26:250-3.
14. **Bernstein AD, Jazrawi LM, Elbeshbeshy B, Della Valle CJ, Zuckerman JD.** Orthopaedic resident-selection criteria. The Journal of bone and joint surgery American volume 2002;84-A:2090-6.
15. **Bernstein AD, Jazrawi LM, Elbeshbeshy B, Della Valle CJ, Zuckerman JD.** An analysis of orthopaedic residency selection criteria. Bulletin (Hospital for Joint Diseases (New York, NY)) 2002;61:49-57.
16. Program NRM. Charting Outcomes in the Match: Characteristics of Applicants Who Matched to Their Preferred Specialty in the 2014 Main Residency Match2014.
17. **Ahn J, Man LX, Wanderer J, Bernstein J, Iannotti JP.** The future of the orthopaedic clinician-scientist. Part I: The potential role of MD-PhD students considering orthopaedic surgery. The Journal of bone and joint surgery American volume 2008;90:1794-9.
18. **Fuller RB, Kuromiya K.** Critical path: Macmillan; 1982.
19. **Subramanian P, Kantharuban S, Subramanian V, Willis-Owen SA, Willis-Owen CA.** Orthopaedic surgeons: as strong as an ox and almost twice as clever? Multicentre prospective comparative study. BMJ (Clinical research ed) 2011;343:d7506.
20. Doctors' slang, medical slang and medical acronyms. 2014.
21. **Budde S.** [Prospective multicenter comparison-Orthopedics: dumb and strong?]. Sportverletzung Sportschaden: Organ der Gesellschaft fur Orthopadisch-Traumatologische Sportmedizin 2012;26:139-40.
22. **Christiansson J.** Smart doctors playing stupid? BMJ (Clinical research ed) 2012;344:e413.
23. **Brand RA, Chaw ES, Karam MD.** The number and the scope of activity of orthopaedic clinician-scientists in the United States. The Journal of bone and joint surgery American volume 2003;85-A:374-9.
24. **Bunton SA, Corrice AM.** Evolving workplace flexibility for U.S. medical school tenure-track faculty. Academic medicine : journal of the Association of American Medical Colleges 2011;86:481-5.
25. **Pololi LH, Krupat E, Civian JT, Ash AS, Brennan RT.** Why are a quarter of faculty considering leaving academic medicine? A study of their perceptions of institutional culture and intentions to leave at 26 representative U.S. medical schools. Academic medicine : journal of the Association of American Medical Colleges 2012;87:859-69.
26. **Satiani B, Williams TE, Brod H, Way DP, Ellison EC.** A review of trends in attrition rates for surgical faculty: a case for a sustainable retention strategy to cope with demographic and economic realities. Journal of the American College of Surgeons 2013;216:944-53; discussion 53-4.
27. **Jackson DW.** The orthopaedic clinician-scientist. The Journal of bone and joint surgery American volume 2001;83-A:131-5.
28. **Moran CJ, Shannon FJ, Barry FP, O'Byrne JM, O'Brien T, Curtin W.** Translation of science to surgery: linking emerging concepts in biological cartilage repair to surgical intervention. The Journal of bone and joint surgery British volume 2010;92:1195-202.
29. **Goldstein C.** Success in academic spine surgery: the role of mentoring. Evidence-based spine-care journal 2013;4:90-5.
30. **Einhorn TA.** Funding the mandate for the orthopaedic clinician scientist. Clinical orthopaedics and related research 2006;449:76-80.
31. **Ley TJ, Rosenberg LE.** The physician-scientist career pipeline in 2005: build it, and they will come. JAMA 2005;294:1343-51.
32. **Konstantakos EK, Laughlin RT, Markert RJ, Crosby LA.** Assuring the research competence of orthopedic graduates. Journal of surgical education 2010;67:129-34.

VISUAL INTERPRETATION OF PLAIN RADIOGRAPHS IN ORTHOPAEDICS USING EYE-TRACKING TECHNOLOGY

Jessica Hanley, MD[1], David Warren, PhD[2], Natalie Glass, PhD[1], Daniel Tranel, PhD[3], Matthew Karam, MD[1] and Joseph Buckwalter, MD, PhD[1]

ABSTRACT

BACKGROUND: Despite the importance of radiographic interpretation in orthopaedics, there not a clear understanding of the specific visual strategies used while analyzing a plain film. Eye-tracking technology allows for the objective study of eye movements while performing a dynamic task, such as reading X-rays. Our study looks to elucidate objective differences in image interpretation between novice and experienced orthopaedic trainees using this novel technology.

METHODS: Novice and experienced orthopaedic trainees (N=23) were asked to interpret AP pelvis films, searching for unilateral acetabular fractures while eye-movements were assessed for pattern of gaze, fixation on regions of interest, and time of fixation at regions of interest. Participants were asked to label radiographs as "fractured" or "not fractured." If "fractured", the participant was asked to determine the fracture pattern. A control condition employed Ekman faces and participants judged gender and facial emotion. Data were analyzed for variation in eye movements between participants, accuracy of responses, and response time.

RESULTS: Accuracy: There was no significant difference by level of training for accurately identifying fracture images (p=0.3255). There was a significant association between higher level of training and correctly identifying non-fractured images (p=0.0155); greater training was also associated with more success in identifying the correct Judet-Letournel classification (p=0.0029). Response Time: Greater training was associated with faster response times (p=0.0009 for fracture images and 0.0012 for non-fractured images). Fixation Duration: There was no correlation of average fixation duration with experience (p=0.9632). Regions of Interest (ROIs): More experience was associated with an average of two fewer fixated ROIs (p=0.0047). Number of Fixations: Increased experience was associated with fewer fixations overall (p=0.0007).

CONCLUSIONS: Experience has a significant impact on both accuracy and efficiency in interpreting plain films. Greater training is associated with a shift toward a more efficient and thorough assessment of plain radiographs. Eyetracking is a useful descriptive tool in the setting of plain film interpretation.

CLINICAL RELEVANCE: We propose further assessment of eye movements in larger populations of orthopaedic surgeons, including staff orthopaedists. Describing the differences between novice and expert interpretation may provide insight into ways to accelerate the learning process in young orthopaedists.

Keywords: orthopaedic resident, orthopaedic surgery, technology, radiographs, eyetracking, resident education

INTRODUCTION

Orthopaedic graduate medical education is rapidly changing and evolving. One key to improving orthopaedic education is to promote efficient resident education and surgical skill development[1–4]. The established apprenticeship model of orthopaedic training is undergoing a transformation with new expectations regarding didactic knowledge, surgical skills, and professionalism in the challenging context of resident work-hour restrictions. Moreover, there are concerns that the current methods of evaluation are not adequately meeting changes in orthopaedic curricula[5].

In recent years, the American Academy of Orthopaedic Surgery (AAOS), the American Board of Orthopaedic Surgery (ABOS), the Resident Review Committee for Orthopaedic Surgery (RRC-OS), and orthopaedic residencies have all recognized the importance of focused

[1]University of Iowa, Department of Orthopaedics and Rehabilitation, Iowa City, IA

[2]University of Nebraska, Department of Neurological Sciences, Omaha, NE

[3]University of Iowa, Department of Neurology, Psychological & Brain Sciences, Iowa City, IA

Corresponding Author:
Jessica Hanley
200 Hawkins Dr.
Iowa City, IA 52245
jessica-m-hanley@uiowa.edu

orthopaedic training. Efforts have been made by several groups to improve surgical skills using stimulation and cadaver models to enhance preparation for the Orthopaedic In-Training Examination (OITE), and meet the Accreditation Council for Graduate Medical Education (ACGME) core competencies. These efforts insinuate that there is significant room for improvement[2,6–9].

Orthopaedic surgery demands an in-depth knowledge of anatomy and ability to interpret three-dimensional (3-D) anatomy based on two-dimensional (2-D) images, for example, to interpret a fracture pattern based on a radiographic plain film (X-rays). Currently, orthopaedic residencies employ traditional teaching methods on interpretation of X-rays, but there is often no explicit strategy for interpreting a plain film. Improvement in interpretation of plain films is generally based on repetitive experience, more than directed teaching. Essentially, training programs and educators utilize a blunt force approach of "more practice". Subsequent improvement is multifactorial, but is likely a combination of didactic knowledge and improved efficiency of interpretation. These two factors would be consistent with established theories of dissociable memory systems specialized for learning facts versus learning skills[10]. Despite the importance of this skill for clinical practice, to our knowledge no study has evaluated how orthopaedic residents develop or improve their interpretation of radiographs.

Eye-tracking technology allows experimenters to record an individual's eye movements, including stable points of fixation and rapid jumps between fixations (saccades)[11–13]. Eye movements can be tracked using non-invasive, covert methods while participants are performing dynamic tasks, as well as during apprehension of static, complex information. This methodology has previously been applied in the field of radiology, and has even been used to measure diagnostic decisions and error in human interpretation of medical images[14,15]. However, eye-tracking methods have been rarely used the realm of orthopaedics and have not been used to aid understanding of image interpretation to advance the education of residents.

This study was designed to examine the feasibility of the use of eye-tracking methods in orthopaedic plain film interpretation. Furthermore, we believe that analysis of eye movements during radiographic interpretation has the potential to support improved characterization and understanding of the differences in attentional allocation during assessment of plain films. We expected that experienced orthopaedic residents would have more organized, more efficient patterns of image inspection than those with less training. Further, we hypothesized that diagnostic accuracy and speed would be different with experienced trainees being faster and more accurate.

METHODS

Task Stimuli

Forty anterior-posterior (AP) pelvis films were gathered from a single institution's electronic medical record after Institutional Review Board (IRB) exception was granted. AP pelvis films of skeletally mature patients, ages 18 and older, were retrospectively obtained from the electronic medial record using ICD-9 code 808.0 (closed fracture of acetabulum). Images were obtained from both the emergency room and clinical settings. Images from 2005-2015 were carefully analyzed by two orthopaedic surgeons (authors JMH and JAB) for isolated unilateral acetabular fractures. Twenty fractured images and twenty non-fractured or "normal" AP pelvis X-rays were utilized. Exclusion criteria for a "normal" X-ray included: osteoarthritis, other fracture, CAM or Pincer impingement, hip dysplasia, tumor, AVN, incomplete or poor visualization of all bony architecture, and open physes. Acetabular fractures on the abnormal X-rays were classified using the Judet-Letournel classification system[16,17]. Exclusion criteria for "fractured" pelvis images included: other fracture, incomplete or poor visualization of bony architecture and images that did not fit the Judet-Letournel classification system of: (1) both column (2) posterior wall, (3) transverse or (4) T-type. These fracture patterns were selected based on a higher reported frequency in the population[16,18]. All fracture types were confirmed with Computed Tomography (CT) scan. Each plain film was then standardized for size, orientation and image intensity.

Participants

Orthopaedic residents and fourth year orthopaedic sub-interns from a single institution participated in the study. Consent was verbalized after a description of and prior to beginning the experimental task. Participants were given the opportunity to remove themselves from the study at any time for any reason. Basic demographic data was collected, including: gender, age, and level of training. Over a 3-month period, 23 orthopaedic residents and medical students were tested: 2 fourth-year medical students, 4 first-year residents, 4 second-year residents, 3 third-year residents, 6 fourth-year residents and 4 fifth-year residents. Average age was 29.1±2.9 years (25 to 38 years) with 5 (21.7%) females and 18 males (78.3%) (Table 1). All participants were screened for visual acuity during image calibration.

Experimental Task

Participants were asked to interpret AP pelvis films by looking for unilateral acetabular fractures while their eye movements were monitored. Specifically, participants were asked to interpret radiographs as fractured or

Table I. Participant Demographics

Age	Mean	SD
	29.13	2.91
Sex	**N**	**%**
M	18	78.26
F	5	21.74
Training Level	**N**	**%**
M4	2	8.70
R1	4	17.39
R2	4	17.39
R3	3	13.04
R4	6	26.09
R5	4	17.39

Table 1. The table demonstrates participant demographics (age, gender and level of training).

non-fractured and, if a fracture was present, to identify the type of fracture to the extent possible with the 2D radiograph. When the participant felt ready to generate an answer, s/he clicked the mouse button to advance to the first response phase.

If "not fractured" was selected, the participant was advanced to the next question. If the participant chose "fractured", s/he was shown a second display to select the specific pattern of fracture using the Judet-Letournel classification. The response options were: (1) both column; (2) posterior wall; (3) transverse; or (4) T-type (Figure 1). The participants were informed of the total number of images, however were not given any information regarding the relative proportion of fractured versus non-fractured stimuli.

During the task, participants were seated comfortably with their head positioned in a chinrest, facing the computer display at a distance of 50 cm. Eye movements were recorded with a temporal resolution of 1000 Hz using an EyeLink 1000 infrared camera system (SR Research, Ltd., Kanata, Ontario, Canada). Visual stimuli were presented on a 598 x 337-mm liquid crystal display monitor (model W2753VC; LG Electronics, Slough, Berkshire, UK) with a vertical refresh rate of 60 Hz and a resolution of 1920 x 1080 pixels. Visual stimuli were presented using MatLab (R2007b; The MathWorks, Inc., Natick, MA) with the Psychophysics Toolbox extension[19,20].

Prior to beginning the eye-tracking task, the EyeLink system was calibrated: participants fixated a visual stimulus at five locations on the screen (center, 15.98° up, 15.98° down, 29.58° left, and 29.58° right). Calibration accuracy was immediately validated by having participants fixate stimuli at the same five locations. If the calibrated eye position was not less than or equal to 0.58° from the stimulus position at each location, the calibration was repeated. If calibration was determined to have been disrupted during the task, the system was recalibrated between trials.

Control Task

In order to control for task understanding and an equivalent ability of participants to fixate upon and process visual stimuli, recognition of emotion and gender was used as a control condition. As suggested by P. Ekman, facial expressions of basic, primary emotions are universally recognized across cultures[21–23]. Using a set of pictures of facial affect[24], a control task was designed. Participants were first asked to identify gender: "male" or "female" after being shown an individual face demonstrating a generally accepted and recognizable emotion. Once participants identified each image as "male" or "female", they were asked to identify which of six emotions was displayed by the face: (1) happiness, (2) disgust, (3) surprise, (4) sadness, (5) fear or (6) anger.

Figure 1. This image shows an example of a fractured AP pelvis x-ray, with subsequent task screens.

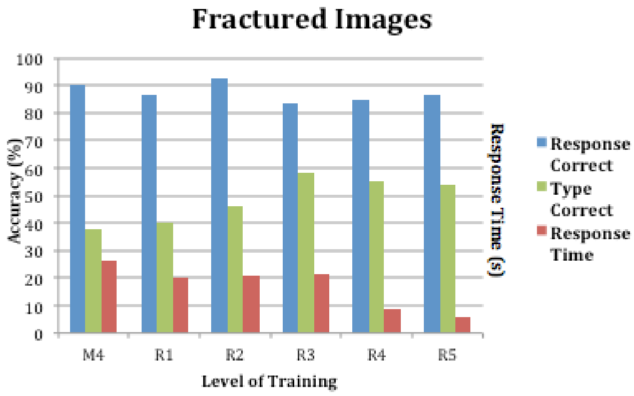


Figure 2. This graph demonstrates participant accuracy and speed of response after visualizing fractured images.

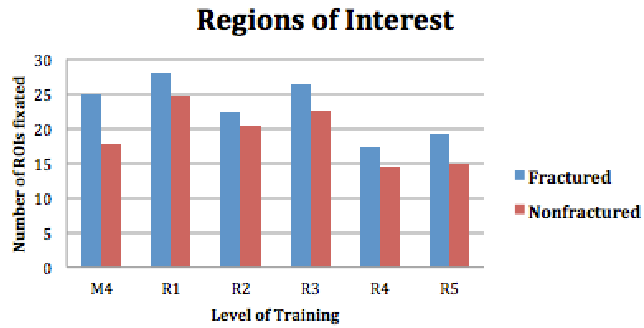


Figure 4. This graph demonstrates the regions of interest (number of pauses on a pre-determined area of importance) of fixation for each participant by level of training.

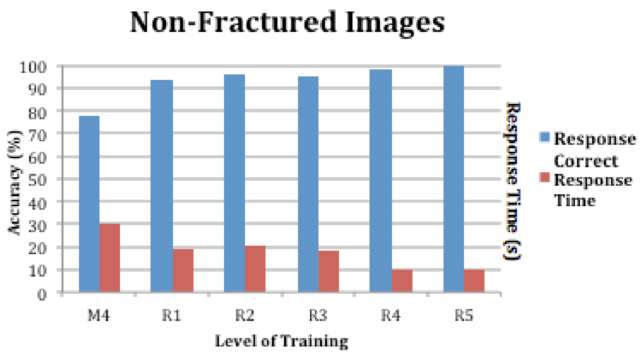


Figure 3. This graph demonstrates participant accuracy and speed of response after visualizing non-fractured images.

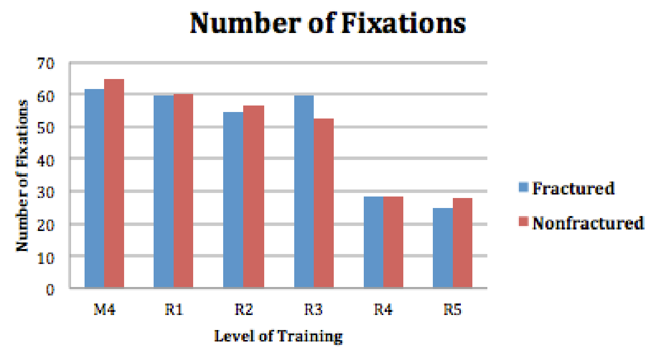


Figure 5. This graph demonstrates the number of fixations (total number of discrete pauses on the image) for each participant by level of training.

Data Analysis

In order to assess and analyze eye movements, each X-ray image was divided into a square grid. The authors JMH and JAB then specified ROIs that one would need to have perceived in order to correctly identify the image and answer the questions at hand. These were determined using commonly accepted radiographic landmarks on a pelvic radiograph: the teardrop, the ilioischial line, the ilioinguinal line, the anterior rim of acetabulum and the posterior rim of the acetabulum[25].

From these data, we were able to analyze the following variables: (1) the number of fixations per test display, which is defined as the number of discrete pauses in eye movements according to criteria including eye velocity and eye acceleration; (2) fixation duration, which is the length of time in which the eye pauses on the image (typically between 200–300 ms long); and (3) the number of regions of interest fixated, which is defined as the number of discrete regions of interest viewed within the image[26]. Eye-tracking data were analyzed separately in MATLAB, Python, and R (version 2.15.1; http://www.r-project.org) using custom software written by author DEW.

The association between level of training and correctly identified fractures as well as fracture type was analyzed using logistic regression adjusted for correlation between responses within participants. The association between speed of interpretation and level of training was evaluated using a linear mixed model. The accuracy and speed of the interpretation of Ekman faces of emotion and gender were utilized as control stimuli[21,22,27,28] and analyzed using similar methods. These data were analyzed using SAS software (V9.4, SAS Institute Inc., Cary, NC). For all statistical tests, alpha was set at $p<0.05$.

RESULTS

Accuracy: There was no significant difference by level of training for accurately identifying fracture images (OR=0.92, 95%CI=0.79-1.08, p=0.3255) (Figure 2). However, there was a significant association between higher level of training and correctly identifying non-fractured images (OR=2.05, 95%CI=1.15-3.66, p=0.0155) (Figure 3). Those with more experience were also more successful in identifying the correct Judet-Letournel classification that best fit each fractured image (OR=1.17, 95%CI=1.05-1.29, p=0.0029) (Figure 2). For the control task, there was no difference related to training duration in accuracy for identifying emotion (p=0.3547) or gender (p=0.9022) for Ekman faces (p>0.05).

Response Time: When controlling for age, participants with more training required less time to decide if a fracture was present or not (p=0.0009 for fracture images and 0.0012 for normal images). For the control task, there were no significant associations between response time and level of training (p>0.05). If Ekman face responses were controlled for age, p=0.1853 for gender identification, p=0.3541 for emotion identification. If age was not controlled for, p=0.2059 for gender identification and p=0.6447 for emotion response.

Fixation Duration: There was no difference of average duration of fixations between images (p=0.2526). Additionally, there was no correlation of average fixation duration with experience (p=0.9632).

Regions of Interest: Across groups, an average of one more grid ROI was fixated for fractured images when compared to non-fractured images (p=0.0005) (Figure 4). More experience was associated with an average of two fewer ROIs fixated (p=0.0047).

Number of Fixations: Increased experience was associated with fewer fixations (p=0.0007) (Figure 5). On average, each year of experience was associated with 9.4 fewer image fixations. In addition, there was a significant difference in the number of fixations between the fractured and non-fractured images (p=0.0005).

DISCUSSION

Eye-tracking is a feasible technique of identifying individual differences in image interpretation skill among orthopaedic residents and students of variable levels of training and experience. As one would expect, diagnostic accuracy and efficiency were generally better in students with more experience. However, these results also highlight specific and potentially modifiable elements of image interpretation behavior between experienced and novice orthopaedic trainees.

Myles-Worsley and colleagues surmised that radiologic expertise depends on two kinds of knowledge: 1) knowledge of the characteristic features of clinically normal exemplars of a class of X-ray films and 2) knowledge of the particular set of uncharacteristic features that signal pathology[29]. Focused study of this knowledge can improve performance measures in early training. Objective analysis of eye movements in novice and more experienced orthopaedic trainees may be sufficient to identify skill gaps based on where eye movements and attention are focused when viewing plain radiographs. Understanding the differences in image interpretation between early and late stages of training could help to formulate directed curriculums with the goal of instructing young residents in more efficient and accurate plain film interpretation.

Accuracy among training levels was similar when fractured images were viewed but there was a significant difference when scrutinizing normal images. The ability to properly identify a non-fractured pelvis was associated with year in residency: those with more training were more likely to correctly identify normal bony anatomy. This would suggest that novice orthopaedists have difficulty with fixating on subtle abnormalities and distinguishing relevant and irrelevant observations[30]. Different angles of the X-ray beam can create subtle shadows that may confuse those with less experience, leading them to interpret overlay of normal three-dimensional anatomy as a fracture.

Although participants with less experience could identify the presence of an acetabular fracture as well as those with more training, novices had a difficult time correctly characterizing fractures using a globally accepted classification system. This is likely related to a lack of familiarity and experience with the Judet-Letournel acetabular fracture classification system, and it underlines the importance of both recognition and interpretation of pathology in image interpretation.

Participants with more experience also tended to be more efficient in formulating a response. Those with more training required fewer fixations when viewing an image, as they presumably were familiar with certain characteristic fracture patterns. Fewer fixations could imply a more gestalt understanding of pelvic anatomy and a holistic approach to image visualization rather than a "search and find" strategy. This would be consistent with the suggestion that the improved performance demonstrated by the experienced orthopaedist involves a shift in the mechanism of image perception from a piecemeal approach a more holistic methodology[31]. Interestingly, more grid ROIs were fixated when an image was fractured, despite the fact that the entire pelvis would need to be examined to rule out fractures in a "normal" image. This pattern may have emerged because viewers required additional fixations to classify the specific fracture pattern, which generally necessitates the use of several different radiographic markers[25]. A variant of this study in which the task was simply to distinguish fractured from non-fractured images could address this prediction.

Our results are consistent with Wood et al 2013, whose study compared eye-tracking data among radiology students and experts while interpreting fractures in different anatomic locations with varying levels of complexity. Their results suggest that the performance advantage of expert radiologists is underpinned by superior pattern recognition skills, as evidenced by a quicker time to first fixate the pathology, and less time spent searching the image[32].

The literature suggests that expertise in image interpretation requires the recognition of patterns of abnormality, the interpretation of such patterns and the maintenance of flexibility in interpretation when new information is presented[30]. Visual experts believe that in order to improve performance, one must build a mental repertoire of patterns of normality and abnormality[29,30]. This should be in concert with specific directed feedback, as novices have limited ability to self-assess[33,34]. Dedicated time should be spent teaching the subtleties of interpreting angles from an X-ray beam and radiographic shadows.

With guidance and practice, a novice can develop a more gestalt understanding of three-dimensional anatomy from a 2D image, which in turn, leads to more efficient and accurate detection of the presence and characteristics of a fracture on plain radiographs. Furthermore, a structured curriculum for teaching X-ray interpretation would allow for frequent feedback and affirmation to ensure a novice continues to develop skill and understanding.

There are several limitations to this study. First, this is an experimental situation and the results must be interpreted within this setting. Participants were informed of the goal of our study prior as appropriate for experimental research. This could have potentially introduced study bias and selectively influenced the participant's eye movements and directed his/her attention toward the acetabulum only. While the images were standardized, the physical space and testing scenario controlled, and the task proctored by a member of the research team, participant attention and effort could have affected our data.

Additionally, this is a small population of participants at a single institution. Future studies should include more participants from other orthopaedic training programs to determine if our findings are generalizable. Lastly, the classification of an acetabular fracture on plain film often depends on the interpretation of Judet views, which were not presented to participants. This might be addressed by using a more sophisticated experimental task using oblique views.

The current work was limited to acetabular fracture identification, but has the potential to be applied to other anatomic locations (i.e. hand or knee radiographs) and broadly applied in the realm of orthopaedic education.

CONCLUSIONS

This study demonstrates that eyetracking is a useful, objective approach to quantifying and describing differences in radiographic image interpretation strategies in orthopaedists with varying levels of training. Our results suggest that experience has a significant impact on radiographic interpretation strategy, accuracy and efficiency. Analysis of differences associated with training identified several modifiable elements of image interpretation. Further work in this area may be useful in formulating directed curriculums to improve plain film interpretation in the young orthopaedist.

SOURCE OF FUNDING

Funding for this project was provided by a developmental research grant from the University of Iowa Department of Graduate Medical Education.

REFERENCES

1. **Marsh JL.** AOA Critical Issues AOA 2014-2015 Presidential Address : " Tipping Points " in Surgical Education AOA Critical Issues. J Bone Jt Surg Am. 2015;14:1-5.
2. **Pedowitz RA, Marsh JL.** Motor Skills Training in Orthopaedic Surgery : A Paradigm Shift Toward a Simulation-based Educational Curriculum. 2012;20(7):407-409. doi:10.5435/JAAOS-20-07-407.
3. **Karam MD, Kho JY, Yehyawi TM, et al.** Application of surgical skill simulation training and assessment in orthopaedic trauma. Iowa Orthop J. 2012;32:76-82. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3565418&tool=pmcentrez&rendertype=abstract. Accessed June 21, 2016.
4. **Karam MD, Pedowitz RA, Natividad H, Jayson M, Marsh JL.** Current and Future Use of Surgical Skills Training Laboratories in Orthopaedic Resident Education: A National Survey. J Bone Jt Surg. 2013;107(1):1-10. doi:10.2106/JBJS.F.01083.
5. **Samora JB, Bashook P, Jones A, Milbrandt T, Mazzocca AD, Quinn RH.** Orthopaedic Graduate Medical Education: A Changing Paradigm. doi:10.2106/JBJS.RVW.N.00005.
6. **Karam MD, Westerlind B, Anderson DD, Marsh JL,** UI Orthopaedic Surgical Skills Training CommitteeCorresponding. Development of an orthopaedic surgical skills curriculum for post-graduate year one resident learners - the University of Iowa experience. Iowa Orthop J. 2013;33:178-184. http://www.ncbi.nlm.nih.gov/pubmed/24027480. Accessed June 21, 2016.
7. **Yehyawi TM, Thomas TP, Ohrt GT, et al.** A Simulation Trainer for Complex Articular Fracture Surgery. J Bone Jt Surg. 2013;107(1):1-10. doi:10.2106/JBJS.F.01083.
8. **Vankipuram M, Kahol K, McLaren A, Panchanathan S.** A virtual reality simulator for orthopedic basic skills: A design and validation study. J Biomed Inform. 2010;43(5):661-668. doi:10.1016/j.jbi.2010.05.016.

9. **Atesok K, Mabrey JD, Jazrawi LM, Egol K** a. Surgical Simulation in Orthopaedic Skills Training. J Am Acad Orthop Surg. 2012;20(7):410-422. doi:10.5435/JAAOS-20-07-410.
10. **Cohen NJ, Squire LR.** Preserved learning and retention of pattern-analyzing skill in amnesia: dissociation of knowing how and knowing that. Science. 1980;210(4466):207-210. doi:10.1126/science.7414331.
11. **Mallett S, Phillips P, Fanshawe TR, et al.** Tracking eye gaze during interpretation of endoluminal three-dimensional CT colonography: visual perception of experienced and inexperienced readers. Radiology. 2014;273(3):783-792. doi:10.1148/radiol.14132896.
12. **Maeder A, Fookes C.** Assessing Viewing Pattern Consistency in Mammogram Readers. Reproduction. 2009.
13. **Soussou W, Rooksby M, Forty C, Weatherhead J, Marshall S.** EEG and Eye-Tracking Based Measures for Enhanced Screener Training - 04182070.pdf. 2012;14623:1623-1626. https://www2.lirmm.fr/lirmm/interne/BIBLI/CDROM/ROB/2012/EMB_2012/PDFs/Papers/04182070.pdf.
14. **Voisin S, Pinto F, Morin-Ducote G, Hudson KB, Tourassi GD.** Predicting diagnostic error in radiology via eye-tracking and image analytics: preliminary investigation in mammography. Med Phys. 2013;40(10):101906. doi:10.1118/1.4820536.
15. **Tourassi G, Voisin S, Paquit V, Krupinski E.** Investigating the link between radiologists' gaze, diagnostic decision, and image content. J Am Med Inform Assoc. 2013;20(6):1067-1075. doi:10.1136/amiajnl-2012-001503.
16. **Judet R, Judet J, Letournel E.** Fractures Of The Acetabulum: Classification And Surgical Approaches For Open Reduction. Preliminary Report. J Bone Joint Surg Am. 1964;46:1615-1646. http://www.ncbi.nlm.nih.gov/pubmed/14239854.
17. **Beaulé PE, Dorey FJ, Matta JM.** Letournel classification for acetabular fractures. Assessment of interobserver and intraobserver reliability. J Bone Joint Surg Am. 2003;85-A(9):1704-1709. http://www.ncbi.nlm.nih.gov/pubmed/12954828. Accessed July 27, 2016.
18. **Lawrence DA, Menn K, Baumgaertner M, Haims AH.** Acetabular fractures: Anatomic and clinical considerations. Am J Roentgenol. 2013;201(3):425-436. doi:10.2214/AJR.12.10470.
19. **Pelli DG.** The VideoToolbox software for visual psychophysics: transforming numbers into movies. Spat Vis. 1997;10(4):437-442.
20. **Brainard DH.** The Psychophysics Toolbox. Spat Vis. 1997;10(4):433-436.
21. **Ekman P, Davidson IR, Ellsworth P, Friesen W V.** Are There Basic Emotions ? 1992;99(3):550-553.
22. **Ekman P, Friesen W V, Sullivan MO, et al.** Personality Processes and Individual Universals and Cultural Differences in the Judgments of Facial Expressions of Emotion. 1987;5(4):712-717.
23. **Ekman P, Friesen W V.** The repertoire of nonverbal behavior: Categories, origins, usage, and coding. Semicota. 1969;(1):49-98.
24. **Ekman P, Friesen W V.** Pictures of Facial Affect. Consulting Psychologists Press; 1976.
25. **Saterbak a M, Marsh JL, Turbett T, Brandser E.** Acetabular fractures classification of Letournel and Judet–a systematic approach. Iowa Orthop J. 1995;15(lc):184-196. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2329054&tool=pmcentrez&rendertype=abstract.
26. **Hannula DE, Althoff RR, Warren DE, Riggs L, Cohen NJ, Ryan JD.** Worth a glance: using eye movements to investigate the cognitive neuroscience of memory. Front Hum Neurosci. 2010;4(October):166. doi:10.3389/fnhum.2010.00166.
27. **Gomez-Ibanez A, Urrestarazu E, Viteri C.** Recognition of facial emotions and identity in patients with mesial temporal lobe and idiopathic generalized epilepsy : An eye-tracking study. 2014;23:892-898. doi:10.1016/j.seizure.2014.08.012.
28. **Russell JA, Camras L, Chovil N, et al.** Is There Universal Recognition of Emotion From Facial Expression ? A Review of the Cross-Cultural Studies. 1994;115(1):102-141.
29. **Myles-Worsley M, Johnston W a, Simons M a.** The influence of expertise on X-ray image processing. J Exp Psychol Learn Mem Cogn. 1988;14(3):553-557. doi:10.1037/0278-7393.14.3.553.
30. **Wood BP.** Visual expertise. Radiology. 1999;211(1):1-3. doi:10.1148/radiology.211.1.r99ap431.
31. **Kundel HL, Nodine CF, Conant EF, Weinstein SP.** Holistic component of image perception in mammogram interpretation: gaze-tracking study. Radiology. 2007;242(2):396-402. doi:10.1148/radiol.2422051997.
32. **Wood G, Knapp KM, Rock B, Cousens C, Roobottom C, Wilson MR.** Visual expertise in detecting and diagnosing skeletal fractures. Skeletal Radiol. 2013;42(2):165-172. doi:10.1007/s00256-012-1503-5.
33. **Green DE, Maximin S.** Professional coaching in radiology: practice corner. Radiographics. 2015;35(3):971-972. doi:10.1148/rg.2015140306.
34. **Duvivier RJ, van Dalen J, Muijtjens AM, et al.** The role of deliberate practice in the acquisition of clinical skills. BMC Med Educ. 2011;11(1):101. doi:10.1186/1472-6920-11-101.

PATIENT FACTORS SYSTEMATICALLY INFLUENCE HOSPITAL LENGTH OF STAY IN COMMON ORTHOPAEDIC PROCEDURES

J. Joseph Gholson MD, Nicolas O. Noiseux MD MSc FRCSC,
Jesse E. Otero MD PhD, Yubo Gao PhD, Apurva S. Shah MD MBA

ABSTRACT

Introduction: As the United States healthcare system evolves towards improved value delivery, patient outcomes and healthcare costs are increasingly used to evaluate physicians and provider organizations. One such metric is hospital length of stay, which has the potential to be influenced by a variety of patient characteristics and comorbidities. Determining factors influencing length of stay represents an opportunity to increase value in healthcare delivery.

Methods: The American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP) database (2006-2012) was utilized to identify a cohort of 92,266 patients having one of 14 common orthopaedic procedures. A generalized linear model was utilized to identify patient factors that increase hospital length of stay.

Results: During the six-year study period, length of stay decreased significantly in the total joint arthroplasty population. Nine variables were independently associated with increased length of stay. Congestive heart failure and underweight status increased length of stay the most, at 1.46 and 1.01 days, respectively. Other factors increasing length of stay include: non-white race (0.69 days), chronic obstructive pulmonary disease (0.50 days), diabetes mellitus (0.25 days), morbid obesity (0.23 days), hypertension (0.10 days), and patient age (0.02 days for each additional year).

Discussion: In conclusion, congestive heart failure and underweight status are the greatest predictors of increased length of stay. COPD, diabetes, morbid obesity, and hypertension represent other modifiable risk factors that increase length of stay. This data can be used to counsel patients and their families regarding anticipated duration of hospitalization. Systematic targeting of patient factors known to increase length of stay represents an opportunity for cost reduction and improved value delivery. When utilizing hospital length of stay as a metric for evaluation, it is important to incorporate the factors that increase length of stay, so that orthopaedic surgeons and provider organizations can be evaluated based on representative patient population characteristics.

INTRODUCTION

The United States healthcare system is currently undergoing a process of evolution, from a system of fee for service and consumption based care to a value-based system in which patient outcomes and associated patient care costs are of paramount importance. With the development of a redefined healthcare system, metrics have been developed to increasingly evaluate surgeons' and hospitals' ability to provide cost-effective care while at the same time deliver care that leads to excellent patient outcomes. One of the most important metrics today is hospital length of stay, and this measure is increasingly used to evaluate both orthopaedic surgeons and hospitals.

The effect of patient comorbidities on length of stay in orthopaedics has been sparsely studied, with the largest studies focusing on total knee arthroplasty[1-3] and hip fractures.[4] The impact of comorbidities on hospital length of stay is still unknown for the majority of orthopaedic procedures. The largest of these studies found that the number of comorbidities significantly increased the cost of care in patients having total knee arthroplasty, with an increased cost of $400 in patients with 3 comorbidities and an increased cost of $4,000 in patient with 7 comorbidities, as well as increased length of stay in patients with multiple medical comorbidities.[1] Other studies have also showed increased cost of care in patients with an increasing number of comorbidities.[5,6] Furthermore, we know that the average length of stay in many orthopaedic procedures has decreased over time.[7,8] None of these studies, however, have identified what are the individual comorbidities and patient characteristics which can be used to target reductions in length of stay across all subspecialties of orthopaedic surgery.

University of Iowa Hospitals and Clinics
Department of Orthopaedics and Rehabilitation
200 Hawkins Drive
Iowa City, IA 52242
E-mail: james-gholson@uiowa.edu

Source of Funding:
No source of funding was utilized to perform this study.

Table I. Demographic Data

Category	Description	Number of Patients
Sex	Male	37610
	Female	54464
Race	White	72295
	Non-white	19971
Anesthesia	General	55642
	Other	36624
Diabetes	Yes	13736
	No	78530
Smoking	Yes	10736
	No	81530
Alcohol use	Yes	1386
	No	90880
DNR Code Status	Yes	196
	No	92070
COPD	Yes	3545
	No	88721
CHF	Yes	313
	No	91953
BMI Class	Underweight (BMI < 18.5)	876
	Normal Weight (BMI 18.5-24.9)	15610
	Overweight (BMI 25.0-29.9)	29020
	Obese Class I (BMI 30.0-34.9	23493
	Obese Class II (BMI 35.0-39.9)	13403
	Obese Class III (BMI >40)	9864
Procedure	Total Knee Arthroplasty	46428
	Total Hip Arthroplasty	29534
	Total Shoulder Arthroplasty	2545
	Total Ankle Arthroplasty	106
	Below Knee Amputation	316
	IM Nail of Femoral Shaft Fracture	428
	IM Nail of Tibial Shaft Fracture	468
	ORIF of Femoral Neck Fracture	3062
	ORIF of Distal Radius Fracture	786
	ORIF of Scaphoid Fracture	132
	ORIF of Bimalleolar Ankle Fracture	1411
	Primary ACL Reconstruction	2488
	Primary Rotator Cuff Repair	1898
	Laminotomy and Decompression of Lumbar Spine	2664

This study was completed by analyzing the American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP®) database, a large multicenter database with sufficient power to analyze complex hypotheses in a multivariate fashion. The ACS NSQIP® database is the leading nationally validated, risk-adjusted, outcomes-based program to measure and improve the quality of surgical care in hospitals. A model for outcomes-based quality improvement, ACS NSQIP collects clinical, risk-adjusted, 30-day outcomes data in a nationally benchmarked database. In addition to collecting information on patient's demographics and comorbidities, length of stay is available for each of the patients that are included in the NSQIP database.

We present a large, multi-center, multivariate analysis of the impact of patient comorbidities on hospital length of stay for a variety of common orthopaedic procedures representative of the major orthopaedic sub-specialties. The purpose of our study was to precisely determine the impact of comorbidities on hospital length of stay across the field of orthopaedic surgery, thus providing normative data to appropriately adjust expected hospital length of stay after an orthopaedic operation. We further sought to identify trends in length of stay over the 6 year study period. Finally, we suggest a targeted approach for addressing patient comorbidities and demographic risk factors which we identify to increase length of stay. We hypothesize that length of stay has decreased over time and that we would identify multiple modifiable risk factors which could be orthopaedic surgeons and their patient care teams to reduce length of stay in the future by targeting newly identified risk factors.

PATIENTS AND METHODS

The American College of Surgeons (ACS) National Surgical Quality Improvement Program (NSQIP) database of patients having surgery between 2006 and 2012 was utilized in this study to identify a cohort of 130,182 patients with common medical comorbidities, having one of fourteen common orthopaedic procedures. Patients with rare medical comorbidities likely to confound our analysis were excluded from the study, resulting in a final cohort of 92,266 patients. Demographic data for the cohort can be found in Table 1.

Fourteen common procedures in orthopaedic surgery, representative of each of the major orthopaedic subspecialties, were included in the analysis. We began by examining trends in length of stay over the six year study period for total hip arthroplasty and total knee arthroplasty, utilizing a linear regression model. We then utilized a generalized linear model to identify patient comorbidities which significantly influenced hospital length of stay in a multivariate manner. Comorbidities

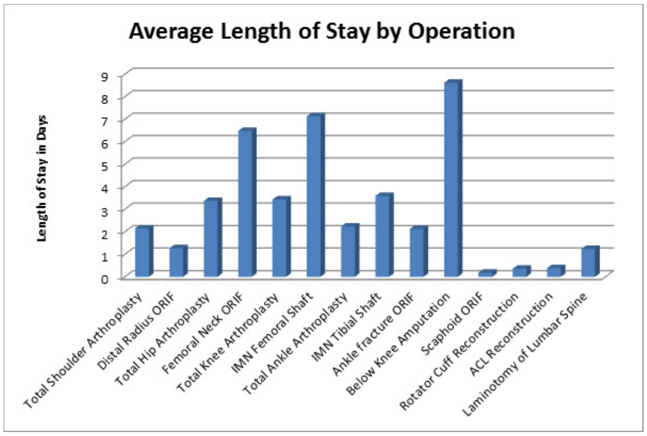


Figure 1: The average length of stay for the 14 procedures included in this study is demonstrated. Patients having a below knee amputation had the longest length of stay, followed by patients having open reduction or intramedullary nailing of various fractures common in trauma patients. Patients having a total joint arthroplasty had an average length of stay between 2-3 days. Patients having a hand, sports, or spine procedures included in the cohort had an average length of stay between 0-1 days.

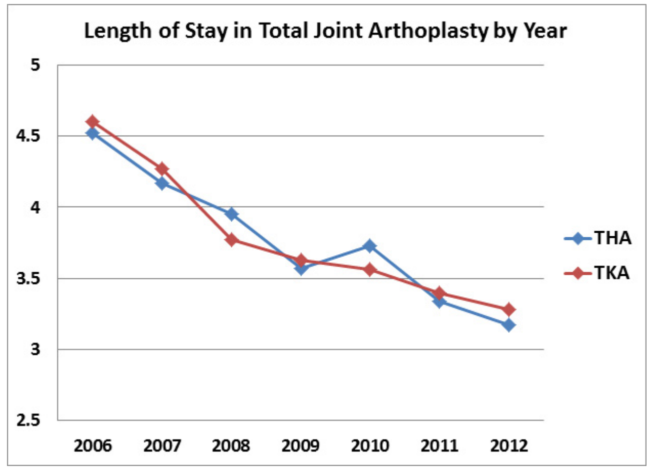


Figure 2: The average length of stay for total hip arthroplasty or total knee arthroplasty based on the procedural year is demonstrated. There was a significant decrease in length of stay for both total hip arthroplasty ($p < 0.001$) and total knee arthroplasty ($p < 0.001$) over time.

included in the analysis included: age, sex, race, anesthesia technique, body mass index (BMI), diabetes, smoking, alcohol use (EtOH) greater than 2 drinks per day, do nor resuscitate (DNR) status, history of chronic obstructive pulmonary disease (COPD), history of congestive heart failure (CHF), and hypertension (HTN). The list of comorbidities significantly increasing length of stay was compiled, with a p-value ≤ 0.05 used to define significance. The effect of BMI was studied by dividing patient into the categories of underweight (<18.5), healthy weight (18.5-24.9), overweight (25.0-29.9), obese class 1 (30-34.9), obese class 2 (35-39.9), and obese class 3 (morbid obesity) (≥40.0).

RESULTS

Length of stay for the 14 orthopaedic procedures varied substantially by the operation performed. The longest length of stay was seen in patients having a below knee amputation, at 8.6 days. The average length of stay for trauma patients were as follows: 7.1 days in patients having intramedullary nailing of a femur fracture, 6.4 days in patients having open reduction internal fixation of a femoral neck fracture, 3.6 days in patients having an intramedullary nail of a tibia fracture, and 2.1 days in patients having open reduction internal fixation (ORIF) of an ankle fracture. In total joint arthroplasty, the average length of stay for total hip arthroplasty was 3.4 days, total knee arthroplasty was 3.4 days, total shoulder arthroplasty was 2.2 days, and total ankle arthroplasty was 2.2 days. Other elective procedures in sports, hand, and spine each had average lengths of stay of approximately 1 day or less. (Figure 1)

We then considered how length of stay might have changed during the study period by considered the average length of stay in patients having total hip arthroplasty or total knee arthroplasty based on the year the procedure was performed. Utilizing a multivariate linear regression model we found a significant decrease in length of stay from 2006 to 2012 for patients having both total knee arthroplasty ($p < 0.001$) and total hip arthroplasty ($p < 0.001$). The average length of stay for patients having total hip arthroplasty in 2006 was 4.52 days, while the average length of stay in 2012 was 3.17 days. Similar results were seen in patients having total knee arthroplasty, with a length of stay of 4.60 days in 2006 compared to an average length of stay of 3.28 days in 2012. (Figure 2)

Finally, we turned our attention to identifying which factors significantly influence length of stay across all orthopaedic procedures. A total of nine separate patient comorbidities and demographic factors were found to independently increase hospital length of stay. The greatest increase in hospital length of stay was seen in patients with congestive heart failure, with an increased length of stay of 1.46 days. The second largest increase in length of stay was seen in patient classified as underweight (BMI < 18.5), with an increase in length of stay of 1.01 days. Other factors increasing length of stay included non-white race at 0.69 days, chronic obstructive pulmonary disease at 0.50 days, diabetes mellitus at 0.25 days, morbid obesity at 0.23 days, general anesthesia at 0.19 days, and hypertension at 0.10 days. Increased patient age was also found to significantly increase length of stay, with a 0.02 day increase in stay for every 1 year

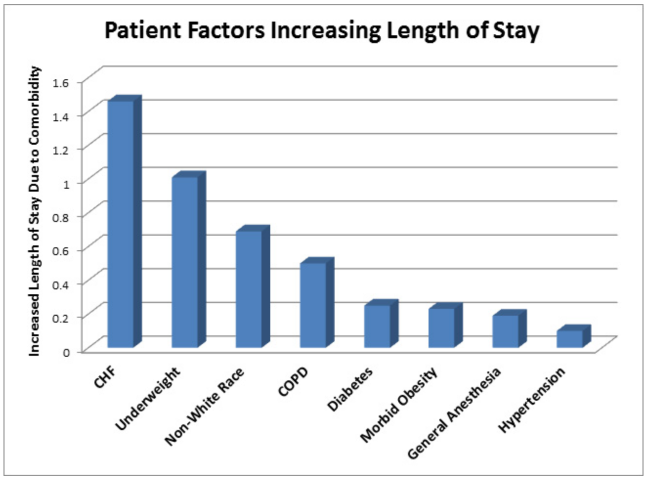


Figure 3: Multivariate analysis of patient factors which independently increase hospital length of stay. Pre-operative optimization of the listed comorbidities represents an opportunity for decreasing length of stay. Age (not included in graph) was also found to significantly increase length of stay by 0.02 days with each increasing year.

increase in age. Factors which did not significantly influence length of stay included: sex, smoking status, alcohol use, DNR code status, overweight, obesity class 1, and obesity class 2. (Figure 3)

DISCUSSION

The cost of medical care in the Unites States continues to increase at an alarming rate, with an overall cost estimate of $2.9 trillion in 2013, representing 17.3 % of our GDP, which is significantly greater than any other country in the world.[9] The average cost of a 1 day increase in patient length of stay varies by hospital, with a recent cost estimate of $2000 per day for orthopaedic surgery patients at a major level I trauma center.[10] With increasing numbers of orthopaedic operations in the United States each year, and more than 620,000 primary total knee arthroplasty procedures in 2009,[11] the cost savings from decreasing length of stay by even small amounts are tremendous. The results of this study demonstrate that patients with significant medical comorbidities can expect to have prolonged hospitalization, and therefore, increased consumption of medical resources. Factors increasing length of stay can be broken down into patient comorbidities that can optimized or modified pre-operatively, patient comorbidities which can be addressed systematically through protocols in the peri-operative setting, and patient demographics that can be targeted with pre-operative planning and patient education.

The results of this study make it clear that pre-operative optimization of cardiac, endocrine, and pulmonary function has the potential to result in significant decreases in patient length of stay. Patients with poor nutritional status also represent a significant area for pre-operative optimization, as patients that were underweight had an increased length of stay greater than 1 day. By focusing on optimizing specific high yield comorbidities including congestive heart failure, nutritional status, COPD, and diabetes prior to surgery, there is potential for improved patient care and outcomes as well as decreased medical costs through reduction in hospital length of stay. Pre-operative optimization of medical conditions by partnering with colleagues in medicine represents a significant opportunity to systematically decrease length of stay, and continuing this partnership into the peri-operative setting with protocols for treatment of identified comorbidities represents an additional opportunity for improvement.

Another area of focus for decreasing hospital length of stay can be seen in the differential length of stay found between Caucasian and non-Caucasian patients. The reasons for the difference in length of stay between Caucasians and the rest of the population are unclear. It has been demonstrated previously, however, that there is decreased access to patient care in the non-white population, and orthopeadic surgeons do not mirror the diversity seen in their patient population.[12,13] Some of the differences observed in length of stay may be attributable to cultural expectations following surgery, representing an area where improved communication pre-operatively may significantly improve length of stay. Another potential reason for the differences in length of stay may be related to socioeconomic status, as this variable was not available for patients in the NSQIP database, and patient race may be a partial surrogate for this measure. Nevertheless, pre-operative education of all patients regarding the expected post-operative course and rehabilitation expectations prior to surgery has the potential to further decrease length of stay, especially among groups that might be less familiar with the modern US healthcare system.

We found a marked decrease in length of stay in the total hip arthroplasty and the total knee arthroplasty population over a relatively short study period of six years. The average length of stay for each of these operations was reduced by more than 1.3 days over the study period. This represents a significant cost savings, and suggests that many orthopedics centers are already beginning to find ways to improve their length of stay metric. This study provides definable risk factors for increased length of stay, which allows both orthopaedic surgeons and hospital systems to target reduction in length of stay by addressing these now known risk factors. Further studies on length of stay should focus on making specific interventions to address the known risk factors, and to identify the cost-effectiveness of each of these interventions.

There were a number of limitations to this study. First, the study is a retrospective study involving hospitals which have agreed to voluntarily collect patient comorbidity and length of stay data, and thus has potential inherent bias in its retrospective nature and may not be completely representative of non-participating hospitals. Second, the study includes a sampling of multiple orthopaedic procedures representative of the subspecialties looking at the effect of comorbidities and demographic data on hospital length of stay. Some of the procedures included in the analysis are generally outpatient in nature, and thus the effects of patient factors on length of stay may be less pronounced in the outpatient surgery population. Finally, patient socioeconomic information is not available in the NSQIP database, and this is likely a significant factor in length of stay, which might be more pronounced in the non-Caucasian population.

This study demonstrates that congestive heart failure, poor nutrition, non-white race, COPD, morbid obesity, general anesthesia use, increased age, diabetes, and hypertension each lead to significantly increased length of stay in orthopaedic surgery. Orthopaedic surgeons who wish to improve patient care, decrease medical costs, and improve individual provider metrics should focus on pre-operative optimization of these risk factors, peri-operative protocol development for management in the peri-operative period, and targeted patient education throughout all phases of care when seeking to decrease length of stay in the orthopaedic patient population.

REFERENCES

1. **Pugely AJ, Martin CT, Gao Y, Belatti DA, Callaghan JJ.** Comorbidities in patients undergoing total knee arthroplasty: do they influence hospital costs and length of stay? Clinical orthopaedics and related research. Dec 2014;472(12):3943-3950.
2. **D'Apuzzo MR, Novicoff WM, Browne JA.** The John Insall Award: Morbid Obesity Independently Impacts Complications, Mortality, and Resource Use After TKA. Clinical orthopaedics and related research. May 13 2014.
3. **Halawi MJ, Vovos TJ, Green CL, Wellman SS, Attarian DE, Bolognesi MP.** Preoperative Predictors of Extended Hospital Length of Stay Following Total Knee Arthroplasty. J Arthroplasty. Oct 25 2014.
4. **Nikkel LE, Fox EJ, Black KP, Davis C, Andersen L, Hollenbeak CS.** Impact of comorbidities on hospitalization costs following hip fracture. The Journal of bone and joint surgery. American volume. Jan 4 2012;94(1):9-17.
5. **Shah AN, Vail TP, Taylor D, Pietrobon R.** Comorbid illness affects hospital costs related to hip arthroplasty: quantification of health status and implications for fair reimbursement and surgeon comparisons. J Arthroplasty. Sep 2004;19(6):700-705.
6. **Chen LT, Lee JA, Chua BS, Howe TS.** Hip fractures in the elderly: the impact of comorbid illnesses on hospitalisation costs. Annals of the Academy of Medicine, Singapore. Sep 2007;36(9):784-787.
7. **Cram P, Lu X, Kates SL, Singh JA, Li Y, Wolf BR.** Total knee arthroplasty volume, utilization, and outcomes among Medicare beneficiaries, 1991-2010. Jama. Sep 26 2012;308(12):1227-1236.
8. **Joynt KE, Orav EJ, Jha AK.** Thirty-day readmission rates for Medicare beneficiaries by race and site of care. Jama. Feb 16 2011;305(7):675-681.
9. Center for Medicare & Medicaid Services. National health expenditure data. 2013; http://www.cms.gov/Research-Statistics-Data-and-Systems/Statistics-Trends-and-Reports/NationalHealthExpendData/NationalHealthAccountsHistorical.html. Accessed 12/14/2014, 2014.
10. **Hiza EA, Gottschalk MB, Umpierrez E, Bush P, Reisman WM.** The Effect of a Dedicated Orthopaedic Advanced Practice Provider in a Level I Trauma Center: Analysis of Length of Stay and Cost. Journal of orthopaedic trauma. Dec 1 2014.
11. **Losina E, Thornhill TS, Rome BN, Wright J, Katz JN.** The dramatic increase in total knee replacement utilization rates in the United States cannot be fully explained by growth in population size and the obesity epidemic. The Journal of bone and joint surgery. American volume. Feb 1 2012;94(3):201-207.
12. **Singh JA, Lu X, Rosenthal GE, Ibrahim S, Cram P.** Racial disparities in knee and hip total joint arthroplasty: an 18-year analysis of national medicare data. Annals of the rheumatic diseases. Dec 2014;73(12):2107-2115.
13. **Cai X, Cram P, Vaughan-Sarrazin M.** Are African American patients more likely to receive a total knee arthroplasty in a low-quality hospital? Clinical orthopaedics and related research. Apr 2012;470(4):1185-1193.


THE UNIVERSITY OF IOWA
DEPARTMENT OF ORTHOPAEDICS