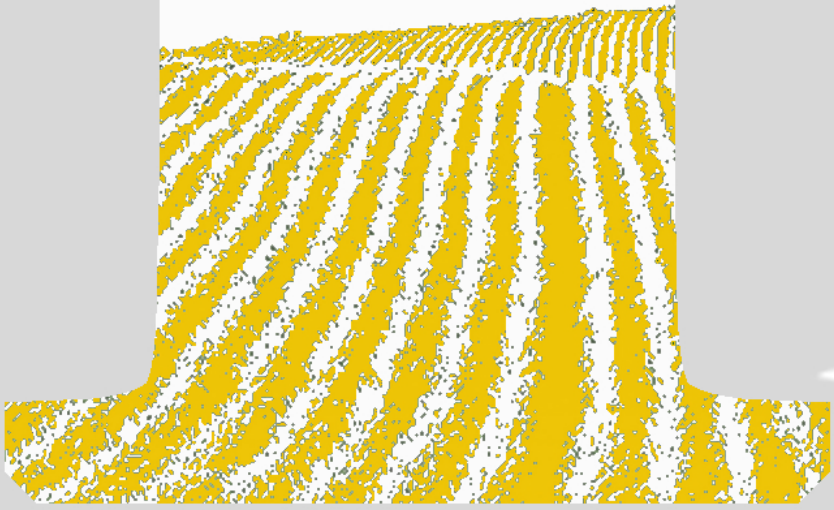
VOLUME 38



THE IOWA ORTHOPEDIC JOURNAL

2018

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

THE IOWA ORTHOPEDIC JOURNAL

2018 • Volume 38

Erratum: The article titled "The Surgical Incidence to Publication (SIP) Index: A Novel Equation Used to Focus Future Research Efforts" in the 2017 edition of the Iowa Orthopedic Journal included a misprint that excluded the last two words in the title. This has been corrected. We apologize to Dr. Kraeutler and his team and appreciate their contribution to the previous volume of the Iowa Orthopedic Journal.

INSTRUCTIONS FOR AUTHORS, 2018 EDITION

https://medicine.uiowa.edu/orthopedics/education/iowa-orthopedic-journal

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.

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

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 https://medicine.uiowa.edu/orthopedics/education/iowa-orthopedic-journal or by e-mailing the Iowa Orthopedic Journal at ioj@uiowa.edu.

2018 IOJ EDITORS' NOTE

From left to right: Dr. Sean Sitton/2018 Resident Editor, Dr. Jose Morcuende/Staff Advisor, Dr. Lawrence Marsh/Staff Advisor, Dr. Kyle Hancock/2018 Resident Business Manager, Dr. S. Blake Dowdle/2018 Resident Editor

Continued growth and quality of the articles published have been the staples of the 38th edition of the The *Iowa Orthopedic Journal* (IOJ). As in previous years, submissions were made from all across the globe including submissions from across the United States, to Central and South America, Europe, Africa and Asia. Additionally, the objective impact of the IOJ has continued to grow over the last 15 years. Where the impact factor once measured 0.16 in 2000, the impact factor now measures 1.0. With this continued recognition we are hopeful that the impact of the journal will continue to grow with the increased readership and quality of the articles published in the IOJ.

We would like to recognize and thank our parting senior residents, Drs. Chike Akoh, Nicolas Bedard, Jessica Hanley, Jacob Elkins, Elizabeth Fitzpatrick and Joseph Gholson. They have consistently provided excellent leadership and mentorship throughout all 5 years of their training. Each of them successfully matched at very high quality fellowships and we wish them all the best on their continued training and throughout the rest of their careers.

The publication of the IOJ would not be possible without the assistance of several individuals. Specifically, Teagan Von Seggern has been instrumental in the organization, formatting and preparation of this year's journal and she deserves special recognition and thanks for all of her efforts. Kyle Hancock has also worked tirelessly to obtain corporate sponsorship for which he deserves acknowledgment. We would also like to thank these sponsors for their generous support of the IOJ. Lastly, Jose Morcuende has provided his expertise in the form of a faculty advisor.

It has been an honor to serve as the editors for the IOJ for 2018. The University of Iowa is a special place, steeped in orthopedic tradition, and we feel privileged to have trained here and contributed to its legacy. We are excited for the future of the department, and hope that the readership enjoys this year's publication of our journal.

S. Blake Dowdle, MD
Sean E. Sitton, MD
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

2018
S. Blake Dowdle
Sean Sitton

2018 DEDICATION OF THE IOWA ORTHOPEDIC JOURNAL

DR. CHARLES R. CLARK

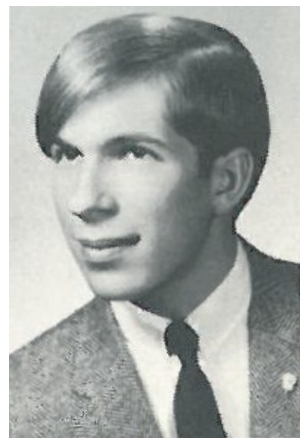
Excellence in Education and Leadership in Orthopedic Surgery

S. Blake Dowdle, MD and Sean E. Sitton, MD

Charles R. Clark, MD

Each year, as we prepare to publish the Iowa Orthopedic Journal, we have the opportunity to honor and dedicate the journal to an individual who has contributed to and made a profound impact on the Department of Orthopedics and Rehabilitation and resident education at the University of Iowa. It is our pleasure to make this dedication to Dr. Charles Clark.

Charles "Chuck" Richard Clark was born on September 11, 1950 and raised in Detroit, Michigan. His father, a World War II veteran and medic in the Philippines, worked as a tool and dye maker, and his mother was an accountant. His parents were very influential and provided him with the work ethic to accomplish greatness. His father worked long hours, sometimes up to 14-16 hours per day, to save money so that Chuck and his brother Bob would have the opportunity to attend the best Universities. His mother was a constant reminder of hard work and instilled in him the mantra, "always keep yourself busy and you will succeed." After graduating from high school, Chuck had a desire to make a difference in others' lives and entered the seminary for a short time. After some reflection and the influence of his father's service as a medic in the military, Chuck thought that he could make more of an impact in the field of medicine. He applied and was accepted to Notre Dame University as the first person in his family to attend college. He was joined shortly thereafter by his brother, Bob. While at Notre Dame, Chuck excelled in academics and graduated Summa cum laude with a Bachelor of Science degree. He then returned to his home state of Michigan to attend medical school at the University of Michigan. His time spent at Notre Dame has remained near and dear to his heart and he remains a fierce supporter and passionate for the University. He continues to contribute to the University and holds season tickets to the Fighting Irish football games. "Go Irish".



Charles Clark, Notre Dame Freshman Yearbook, 1968-69

Chuck continued to excel academically in medical school. He was elected to the Alpha Omega Alpha (AOA) medical honors society. He also became involved in biomechanics research with Dr. Larry Matthews in the Department of Orthopedics. Dr. Matthews was an amazing mentor and had great influence on Chuck pursuing a career in academia and orthopedics. Dr. Charles Clark graduated from the University of Michigan in 1976 with academic distinction and was accepted to a residency position at Yale University. At Yale, Dr. Clark worked very closely with Dr. Wayne Southwick. Dr. Southwick, the chairman of orthopedics at Yale University and credited with several landmark articles in orthopedics, saw great potential in Chuck and persuaded him to enter the academic world following residency. He was also influential in Dr. Clark's involvement in manuscript editing with The Journal of Bone and Joint Surgery for which he continues to serve as a current deputy editor.

Following his graduation from residency at Yale University in 1980, he was recruited to The University of Iowa Department of Orthopedics by Dr. Reginald Cooper. Per Dr. Clark, his plans were to stay here at Iowa for a year or two and then move on. At that time the department was in need of both a spine and arthroplasty surgeon, and Dr. Clark filled those roles without hesitation. He has spent the last 38 years as faculty in the department serving his patients and maintaining leadership roles within the hospital system. He proudly calls Iowa his home.

During his early years as faculty at Iowa, Dr. Clark was awarded the prestigious American British Canadian Traveling Fellowship. He credits this time as an ABC fel-

Dr. Charles Clark with Ruth Bonfiglio, wife of Dr. Michael Bonfiglio, upon receiving the Professorship in his name

low for creating long-lasting friendships as well as providing him with additional opportunities to serve in national leadership positions. In 2002, Dr. Clark was awarded the Dr. Michael Bonfiglio Professorship in Orthopedics. This prestigious distinction is given to a faculty member who exemplifies excellence in and dedication to teaching, research and patient care. Dr. Clark was honored to be awarded this distinction as Dr. Bonfiglio was one of his closest mentors from the time he arrived in Iowa.

Dr. Clark has provided teaching, mentorship and leadership at every level within orthopedics. From 1st year medical students to senior orthopedic residents and even previously serving on several Ph.D. candidate thesis committees, he has strived to make orthopedic education a priority throughout his career. He is known amongst the residents and his peers as an excellent educator and a wonderful faculty member to work with. He continues to serve as the clerkship director for Iowa medical students.

On a national level, Dr. Clark has served on several committees and in many leadership roles. He has served as the president of the Cervical Spine Research Society and Association of Bone and Joint Surgeons. He has been actively involved in both the American Academy of Orthopedic Surgeons and American Orthopedic Association, serving on the board of directors of both organizations. He has always enjoyed serving in these positions, but he has always found the most fulfillment giving back to his community, including teaching and philanthropy. An example of his desire to give back and promote education was the establishment of the Barbara S. and Charles R. Clark medical student scholarships at Carver College of Medicine.

Outside of his professional life, Dr. Clark has been married to his sweet wife Barbara for 35 years. They are the proud parents of 2 daughters and have 4 wonderful grandchildren. Dr. Clark has exemplified professionalism, patient advocacy, leadership and mentoring throughout his career. Congratulations, Dr. Clark on your fantastic career and a sincere thank you for all that you have given to orthopedics and the University of Iowa.

2018-2019
DEPARTMENT OF ORTHOPEDICS AND REHABILITATION
SCHEDULE OF LECTURESHIPS AND CONFERENCES

Carroll B. Larson Shrine Memorial Lecture
June 1, 2018

Larson Conference Room, 01090 JPP
University of Iowa Hospitals and Clinics
Department of Orthopedics and Rehabilitation

Michael Vitale, MD, MPH
Ana Lucia Professor of Pediatric Orthopedic Surgery and Neurosurgery
Vice Chair, Quality and Strategy, Orthopedic Surgery
Columbia University Medical Center
New York, NY
Spring 2019 to be arranged. Contact Nancy Love @ (319) 356-1872

2018 Senior Residents' Day
June 15-16, 2018

Urmila Sahai Seminar Room
University of Iowa
Medical Education Research Facility

James P. Stannard, MD
Hansjörg Wyss Distinguished Chair in Orthopaedic Surgery
Chairman, Department of Orthopaedic Surgery
Medical Director, Missouri Orthopaedic Institute
University of Missouri
President, AO North America

Terrance D. Peabody, MD
Chair, Department of Orthopaedic Surgery
Edwin Warner Ryerson Professor of Orthopaedic Surgery
Professor of Orthopaedic Surgery
Northwestern University Feinberg School of Medicine

34th Annual Hawkeye Sports Medicine Symposium
December 6-7, 2018

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

2019 Senior Residents Day
June 14-15, 2019

Discussants to be arranged. Contact Jessica Dorsman @ (319) 353-6747

Department of Orthopedics

Timothy Brown, 2017-present
Joseph Buckwalter V, 2017-present
Philip Chen, 2017-present
Jesse Otero, 2017-present
Brendan Patterson, 2017-present
Roberty Westermann, 2017-present
Timothy Fowler, 2016-present
Andrew Pugely, 2016-present
Lindsey Caldwell, 2015-present
Cassim Igram, 2015-present
Heather Kowalski, 2014-present
Eric Aschenbrenner, 2012-present
Apruva Shah, 2012-2015
Melissa Willenborg, 2012-2016
Mederic Hall, 2011-present
Carolyn Hettrich, 2011-present
Ryan Ilgenfritz, 2011-2014
Matthew Karam, 2011-present
Matthew Bollier, 2010-present
Benjamin Miller, 2010-present
Christina Ward, 2008-2009
Heather Bingham, 2008-present
Phinit Phisitkul, 2008-2017
Nicolas O. Noiseux , 2007-present
Robert Yang, 2007-2010
Ericka Lawler, 2006-present
John E. Femino, 2005-present
Joseph D. Smucker, 2005-2014
Jin-soo Suh, 2004-2005
Neil A. Segal, 2004-2014
Brian Wolf, 2003-present
Michael O'Rourke, 2003-2007
Sergio Mendoza, 2003-2015
Jose Morcuende, 2001-present
Annunziato Amendola, 2001-2015
Joseph Chen, 2000-present
Todd McKinley, 1999-2012
R. Kumar Kadiyala, 1998-2004
Leon Grobler, 1996-1999
Brian Adams, 1993-2014
Charles Saltzman, 1991-2005

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, 1962-2016
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 IV, 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, 1990-2018

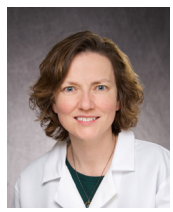
The University of Iowa
Roy J. and Lucille A. Carver College of Medicine

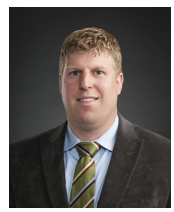
DEPARTMENT OF ORTHOPEDICS AND REHABILITATION STAFF 2017-18


Dr. John Albright


Dr. Donald Anderson


Dr. Eric Aschenbrenner


Dr. Heather Bingham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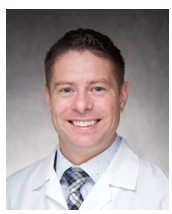
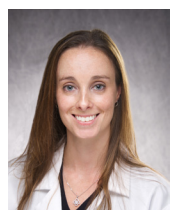
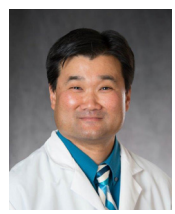
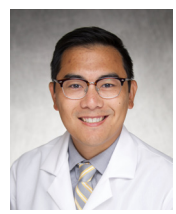
Dr. Timothy Brown


Dr. Joseph Buckwalter


Dr. Joseph Buckwalter V


Dr. Lindsey Caldwell


Dr. Joseph Chen


Dr. Philip Chen


Dr. Charles Clark

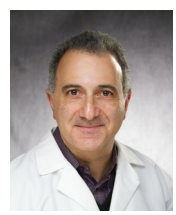

Dr. Mitchell Coleman


Dr. John Femino


Dr. Timothy Fowler

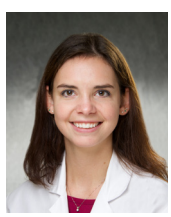

Dr. Jessica Goetz

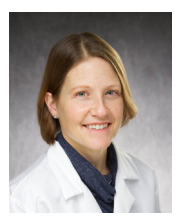

Dr. Mederic Hall

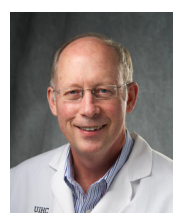

Dr. Cassim Igram


Dr. Matthew Karam


Dr. Valerie Keffala


Dr. Heather Kowalski


Dr. Ericka Lawler


Dr. J. Lawrence Marsh


Dr. James Martin

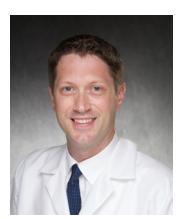

Dr. Benjamin Miller


Dr. Jose Morcuende

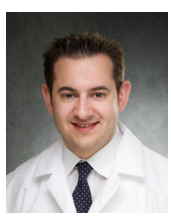

Dr. James Nepola


Dr. Nicolas O. Noiseux

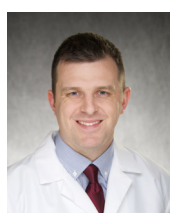

Dr. Jesse Otero

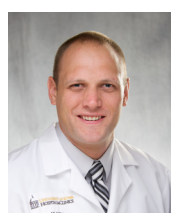

Dr. Brendan Patterson


Dr. Chester Pelsang


Dr. Andrew Pugely


Dr. Stuart Weinstein


Dr. Robert Westermann


Dr. Michael Willey


Dr. Brian Wolf

1. Timothy Brown, MD
2. Jesse Otero, MD
3. John Albright, MD
4. Stuart Weinstein, MD
5. Nicolas Noiseux, MD
6. Brendan Patterson, MD
7. Brian Wolf, MD
8. Charles Clark, MD
9. Christina Hajewski, MD
10. J. Lawrence Marsh, MD
11. Elizabeth Scott, MD
12. John Femino, MD
13. Sean Sitton, MD
14. Tyler CarlLee, MD
15. Jacob Elkins, MD, PhD
16. Sarah Schippers, MD
17. Joseph Buckwalter IV, MD
18. Matthew Karam, MD
19. Lindsey Caldwell, MD
20. Nicholas Bedard, MD
21. James Nepola, MD
22. Brandon Wilkinson, MD
23. Benjamin Miller, MD
24. Heather Kowalski, MD
25. Cassim Igram, MD
26. Jose Morcuende, MD
27. Blake Dowdle, MD
28. Jocelyn Compton, MD
29. Timothy Fowler, MD
30. Chris Anthony, MD
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38. Emily Connor, MD
39. Karthikeyan Chinnakkannu, MD
40. Ericka Lawler, MD
41. Jessell Owens, MD
42. Christopher West, MD
43. Craig Akoh, MD
44. Don Anderson, PhD
45. Nicholas Beck, MD
46. David DeMik, MD
47. Christopher Lindsay, MD

2018 GRADUATING ORTHOPEDIC RESIDENTS

Craig Chike Akoh, MD

Dr. Craig Chike Akoh was born on March 13, 1987 in Pullman, Washington to two Nigerian parents. His father Casimir Akoh, a distinguished food science professor at the University of Georgia and mother Celine Akoh, a retail pharmacist, moved to Pullman soon after their marriage so that Chike's father could pursue a PhD in Food Science. During his early years, Chike and his family lived in Mississippi, Texas, and Alabama before settling in Athens, Georgia at the age of 4.

Georgia provided a nurturing environment for Chike to cultivate his several talents. Chike was an avid cellist during elementary and middle school, and during his high school years at Cedar Shoals, Chike developed his love for basketball and was a starter for the Number 2 ranked basketball team in the state of Georgia. Being the captain for his high school team during his senior year helped cultivate his leadership skills. Chike was also an integral part of the 2005 high school state championship track and field team where he participated in the triple and long jump.

Chike also excelled academically throughout high school and was awarded the Foundation Fellowship Academic Scholarship to attend the University of Georgia. Through the fellowship, he was given the opportunity to study abroad in Italy, Argentina, Bosnia, the Netherlands, Australia, and Egypt. He graduated from the University of Georgia with a dual degree in Cellular Biology and Psychology. Throughout college, Chike developed his passion for medicine while shadowing several orthopaedic surgeons in his local town. Chike completed his medical school training at the Medical College of Georgia in 2013, and with the guidance of several orthopaedic mentors was fortunate to be given the opportunity to match at the University of Iowa for Orthopedic Surgery.

During his residency, Chike was involved with several foot and ankle research studies. He has been a part of radiographic foot deformity studies and received an AOFAS research grant to study the effects of ankle range of motion and distraction on arthroscopic ankle accessibility. He hopes to correlate radiographic location of ankle cartilaginous defects with intraoperative arthroscopic accessibility in order to predict the appropriate arthroscopic approach.

Chike will first pursue a Sports Medicine Fellowship at the University of Wisconsin and then a Foot and Ankle Fellowship at Duke University. Chike would like to thank his parents as well as his younger siblings Emeka, Chioma, and Ugonna for being a loving and supportive family. He would also like to thank his mentors in Georgia, Drs. Emory Alexander and Alonzo Sexton for exposure to Orthopaedic Surgery. Lastly, Chike would like to thank the entire University of Iowa orthopaedic family as well as the class of 2018 (Jake, Jessica, Elizabeth, Joe, and Nic) for a wonderful experience.

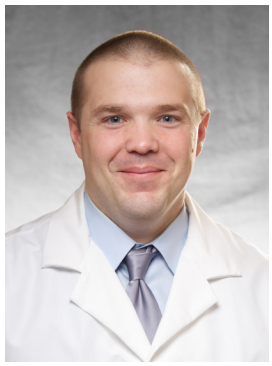
Nicholas Bedard, MD

Nic grew up in Cedar Rapids, IA with his two younger siblings (Joe and Abby) and his parents Tony and Marcia Bedard. He graduated from Xavier High School in 2005 and continued his education at Creighton University in Omaha, NE, where he majored in Exercise Science. While at Creighton, Nic was fortunate enough to graduate Summa Cum Laude in 2009 and was named Outstanding Exercise Science Major of the Year.

After college, Nic married the love of his life Katie Hall, and the two of them headed to Iowa City, IA where Nic started medical school at the University of Iowa. During medical school, Nic took an early interest in orthopaedic surgery after getting involved in orthopaedic research with his mentor Dr. John Callaghan during the first year of medical school. Nic graduated medical school in 2013 and was inducted into the Alpha Omega Alpha Honor Medical Society.

Throughout his residency training, Nic continued to work with Dr. Callaghan performing research on hip and knee replacements. His research has focused on long term follow-up of these total hip and knee replacements, use of large databases to evaluate pre-operative care of hip and knee arthritis, and evaluation of trends in hip and knee arthroplasty care. His success in research and experiences during residency ultimately led him to pursue a career in academic total joint arthroplasty. In July, Nic will be moving with his family (Ruby - 6 yrs, Isabel – 4 yrs, Penelope – 1 yr) to Rochester, MN for his Adult Reconstruction Fellowship at Mayo Clinic. Following fellowship, he plans to pursue a career in academics with a practice of complex primary and revision hip and knee arthroplasty, as well as, perform research in these areas.

Nic has many friends and family that he needs to thank for their support over the years. His wife, Katie, has always provided endless love and encouragement over their nearly nine years of marriage. Without her support and many sacrifices not a single success of Nic's would have been possible. Katie and Nic have been blessed with three beautiful little girls. Ruby, Izzy and Polly are his continual motivation and bring him so much joy and happiness. Nic's parents, Tony and Marcia, are who he credits with teaching him to never give up, never let anyone out work you and to never lose faith. Nic would also like to thank his brother Joe for keeping him grounded and teaching him not to stress about the small things in life and his sister, Abby, for teaching him to always put the needs of others before your own. Lastly, Nic would like to thank his co-residents and faculty at the University of Iowa Department of Orthopedics for an amazing five years of residency. He has learned so much from everyone in the department and is grateful for the opportunity to learn from such great people.



Jacob Elkins, MD, PhD

Jacob (Jake) Elkins was born in Las Cruces, NM, the second of three children to Ned and Cindy Elkins. Despite considering Carlsbad, NM home, he moved around the southwest frequently as a child, eventually moving to Las Vegas, NV where he attended high school and eventually met and fell in love with his future wife, Jaymie.

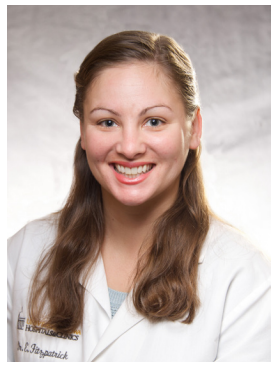
He initially wanted to become an oceanographic engineer, but eventually settled on nuclear engineering for a career. He dual-majored in chemical engineering and physics at the University of Nevada. However, after a couple of summer internships, he realized that while he loved the science, a career in nuclear engineering was not what he wanted. Thinking he might like to become a small-town family doctor, he volunteered at his local VA hospital where there was an apparent shortage of leg-holders in the OR. Within a week, he was scrubbing total hips and knees, and knew at that time he wanted to be an arthroplasty surgeon. He graduated the following summer, but still needed his medical school pre-reqs. He took a job at the VA as a scrub-tech, and also began a Master's degree in chemical engineering. Over the course of the next year – being in the OR each morning and in the lab each night – he realized he wanted to combine both to become an orthopaedic surgeon-engineer. He attended the University of Iowa Medical Scientist Training Program to study under Dr. Thomas Brown, earning a combined MD/PhD in Biomedical Engineering. He was blessed to stay at Iowa for residency in orthopedic surgery.

At Iowa, he luckily fell under the mentorship of John Callaghan, where he was fortunate enough to be involved in many research projects, mainly focused on computational modeling of total joint replacement.

During his stay in Iowa, he has been blessed with four amazing children: Madelyn (9), Tessa (7), Matthias (3) and Dorothy (18 months).

Following residency, Jake will be doing a fellowship in joint replacement at Colorado Joint Replacement in Denver, CO. After fellowship, he wishes to enter academics to continue his research in the biomechanics of joint replacement.

None of this would be possible without the amazing support he has received from family and friends. He credits his parents for instilling ambition, drive, and the importance of hard work. He thanks Drs. Tom Brown and John Callaghan for being incredible mentors and role models. And of course, he thanks his amazing wife Jaymie, for her endless support and devotion, and all past, present, and future success in his life.



Elizabeth Fitzpatrick, MD

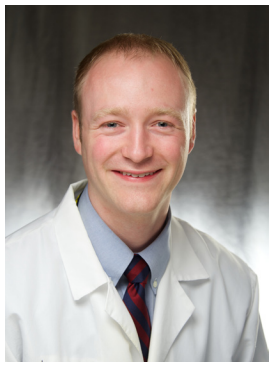
Elizabeth was born the fifth of six kids in a small town in Michigan. Growing up in a large family, there was never a dull moment. At the age of 10, Elizabeth and two of her siblings moved to California in hopes of becoming movie stars.

Her interests shifted from the limelight to the library once she entered high school. Her interest in science was triggered by the unfortunate passing of her mother during her sophomore year of high school. It was not until she attended a summer program at Brown University the summer prior to her senior year that she decided medicine was the path she wished to pursue.

Elizabeth attended the University of Southern California for her undergraduate studies, obtaining a Bachelor's of Science in Biology and a Bachelor's of Arts in Neuroscience. She then attended the University of California: San Diego for medical school where she was exposed to orthopedics in her first year and made the decision to pursue the specialty shortly after.

Entering residency with an open mind, Elizabeth was unsure which area of orthopedics she wished to pursue. She had always been drawn to hand surgery since it was her entre to the field, but she was hesitant to commit prior to exposure to all fields. It was not until her third year rotations at the VA when she looked forward to seeing the upper extremity complaints over any others that she decided on hand surgery. After residency, Elizabeth will be staying in Iowa City to pursue a hand fellowship at the University of Iowa.

Elizabeth could not have survived the transition from California sunshine to Iowa winters if it were not for her co-residents, especially those who have come before her. She is grateful to all the staff and patients who gave her the opportunity to learn. The highlight of her time here in Iowa is meeting and marrying the fireman of her dreams. The couple have two silly, slobbery English bulldogs and one perfect son named William. They are looking forward to a lifetime of adventures to come.



J. Joseph Gholson, MD

Joe Gholson grew up in a humble but proud coal mining town in Southern Illinois. He went to Southeast Missouri State on the Governor's Scholarship, where he was president of the student government senate, founded a charitable organization that raised over $75,000 for children's medical care, and was on the executive board of the Lambda Chi Alpha Fraternity for which he was named the International Man of the Year. While at Southeast Missouri State he was voted Greek Man of the Year, and he was awarded the University' highest student honor, the President's Award for the Spirit of Southeast, for his contribution to the campus and community through service and scholarship.

Joe's life changed for the better when he met his better half at a leadership conference in college, Le Gholson, who has been a constant source of inspiration and encouragement. Her encouragement led him to spend half a year volunteering in Southeast Asia and Oceania where he cemented his aspirations to become a physician and got hands-on experience providing medical care on the USNS Mercy Hospital ship.

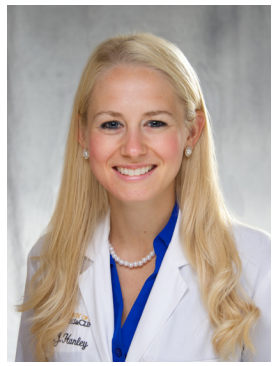
He later spent a semester with NASA at the Marshal Space Flight Center in Alabama before graduating at the top of his college class, and getting a scholarship to Harvard Medical School.

While at Harvard, Joe met Dr. Don Bae and Dr. Peter Waters who inspired him to pursue a career in orthopaedics. At Harvard, he was one of only five students to graduate his class magna cum laude, and was awarded the Henry Asbury Christian Clinical Research Award for his research study, "Scaphoid Fractures in Children and Adolescents: Contemporary Injury Patterns and Factors Influencing Healing," which was published in the Journal of Bone and Joint Surgery and has been named a classics article in hand surgery.

Joe's life took a turn for the better when he moved with his wife to Iowa City and started a family including a Bernese Mountain Dog named Lucy, and the pride and joy of his life—a beautiful daughter named Charlotte. While at Iowa he initially became interested in the long term follow-up of congenital hand conditions. For his senior research project Joe completed a comprehensive follow-up study of preaxial polydactyly patients treated by Dr. Adrian Flatt more than 35 years after surgery. He received the Andrew J. Weiland American Foundation for Surgery of the Hand Grant to support the project, he gave a podium presentation at the 72nd annual meeting of The American Society for Surgery of the Hand, and publication is pending in the Journal of Hand Surgery.

Despite a strong background in pediatric hand surgery research, Joe found his true calling while rotating at the VA Medical Center, where he found himself most fulfilled performing total hip and total knee arthroplasties in appreciative veterans. He quickly became involved with and inspired by the living legends of arthroplasty at the University of Iowa, including Dr. John Callaghan, and has since published more than 10 peer-reviewed articles including six articles in the Journal of Arthroplasty. He is the previous editor of the Iowa Orthopedic Journal and is a reviewer for the Journal of Arthroplasty.

Joe will be completing an Adult Reconstructive Hip and Knee Fellowship at Midwest Orthopaedics at Rush University, where he will work with Dr. Della Valle, Dr. Paprosky, Dr. Sporer, Dr. Rosenberg, Dr. Berger, Dr. Gerlinger, Dr. Nam, Dr. Levine, and Dr. Jacobs. He would like to thank Dr. Callaghan, Dr. Johnston, Dr. Clark, Dr. Noiseux, Dr. Brown, and Dr. Otero for their support and encouragement after deciding to become an arthroplasty surgeon. Joe looks forward to honing his clinical skills and research efforts during his fellowship at Rush next year, and to welcoming a second daughter to his family this May.



Jessica Hanley, MD

Jessica grew up in Canton, MI as the daughter of June and Bill Hanley and the middle child between two brothers, Brian and Billy. Growing up, she played pretty much any and every sport she could, even trying to convince her father to play football in high school. Needless to say, that didn't go over so well…

Jess graduated from Father Gabriel Richard High School in 2005 and went on to attend the University of Michigan (Go Blue!) for college. She majored in Neuroscience and graduated with highest honors in 2009. After graduation, she headed to Milwaukee, WI for medical school at the Medical College of Wisconsin.

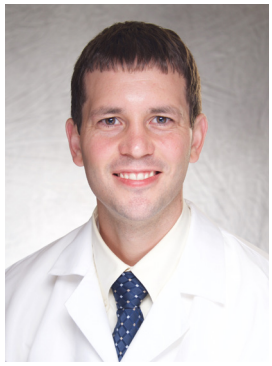
It was in her first few months of medical school, that Jessica started shadowing an orthopaedic surgeon. From there, her interest in ortho peaked and she started doing research in the orthopaedic biomechanical engineering lab. Jess graduated with honors in 2013 and was awarded the Bruce J. Brewer Endowed Stu- dent Award in Orthopaedic Surgery for the most outstanding senior medical student pursuing a career in orthopaedics.

Jessica was ecstatic to match at the University of Iowa, to become a resident in the greatest orthopaedic program in the world. Throughout her residency training, Jess has developed an interest in improving orthopaedic resident education and surgical skills. She has been a part of several projects that have focused on identifying ways that residents can become more efficient in understanding and using radio- graphs to assist with fracture reduction and operative fixation.

Jess has chosen to pursue a career in hand and upper extremity surgery, and she is thrilled to be moving east after residency to complete a fellowship at Harvard/Brigham-Womens in Boston. She will then happily return to the Midwest after fellowship to join her husband, Tony, in Milwaukee, WI. Jessica plans to continue to research and educate throughout her career, taking the strong surgical training, values and lessons she's learned at Iowa with her wherever she goes. She is extremely proud and grateful to have trained under some of the greatest orthopaedic surgeons in the world and worked side by side with amazingly talented residents and friends.

Jess has many amazing people in her life that she would like to thank for their unconditional love and support: her parents June and Bill, who have sacrificed so much to allow her to be where she is today. They have supported her every step of the way, teaching her the value of hard work and keeping her grounded in what's truly important. Jess also wants to thank her brothers, Brian and Billy, who have always kept her on her toes and pushed her to be the best version of herself. Her husband, Tony, deserves an award for his infinite understanding, steadfast commitment, and unwavering love and support of whatever crazy dreams Jess may have. Finally, a special thanks to her co-residents, who make good days great and the bad days tolerable. Jess is certain she wouldn't have survived residency without them. They have become more than simply colleagues to her, but lifelong friends.

2018 GRADUATING FELLOWS



Nicholas Beck, MD

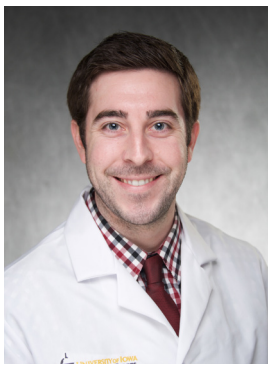
Dr. Nicholas Beck is an orthopaedic surgeon currently in fellowship training in hand surgery. As a fellow, he is receiving additional training in microsurgery, trauma, arthroscopy, arthritis, congenital differences, and reconstruction of the upper extremity.

Dr. Beck grew up in Baker, Montana. He obtained a B.S in Chemical and Biological Engineering and an Honors Degree with Distinction at Montana State University in Bozeman. After graduating medical school in Philadelphia at the University of Pennsylvania, he completed his orthopaedic surgery residency in the Twin Cities at the University of Minnesota. Once his fellowship training is complete, Dr. Beck plans to return to home to practice in Billings, Montana.

Karthikeyan Chinnakkannu, MD

Karthik is the current foot and ankle fellow for the 2017-2018 year. He grew up in Mettur Dam in the state of Tamil Nadu and he obtained his medical degree from Madras Medical College, Chennai, India. He completed his orthopedic residency from Lokmanya Tilak Municipal Medical College and General Hospital, Mumbai, India and he worked as an attending orthopedic surgeon at an academic institute before moving to the US.

He would like to appreciate the able mentorship and guidance of Dr. Femino throughout the year. He is very grateful to work with the amazing staff of this hospital. He is very happy to be a part of the University of Iowa orthopedic family.



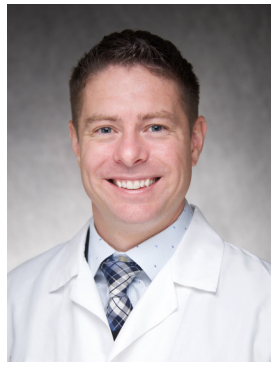
Andrew Freese, MD

Drew grew up in Dallas, Texas. He received his undergraduate degree in Biomedical Engineering at the University of Texas in Austin in 2008. He then graduated from the University of Texas Medical Branch at Galveston with his MD in 2012. He then moved to Indianapolis where he completed residency training in Orthopedic Surgery at Indiana University. He then joined the University of Iowa in August 2017 as an Orthopedic Sports Medicine Fellow working with Iowa Athletics. He is joined by his wife Krista. They have enjoyed their time in Iowa City and are grateful for the relationships forged over the past year.

NEW ORTHOPEDIC FACULTY

Timothy Brown, MD

Dr. Timothy S. Brown is a Clinical Assistant Professor at the University of Iowa in the Department of Orthopedics and Rehabilitation. He is an adult joint reconstruction surgeon that treats conditions of the hip and knee. Dr. Brown is a Texas native, and completed his orthopaedic residency at the University of Texas Southwestern Medical Center in Dallas, Texas. He did further fellowship training in complex adult lower extremity reconstructive surgery at The Mayo Clinic in Rochester, Minnesota. He treats patients with hip and knee arthritis, hip dysplasia, post-traumatic deformity, failed hip and knee replacements, and infected hip and knee replacements. His research interests include appropriate opiate use following hip and knee replacement and the interaction between mental health, opiate use, and satisfaction following hip and knee replacement.



Joseph Buckwalter V, MD

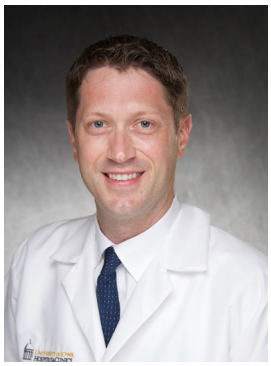
A fifth generation Iowan, Jody Buckwalter was born at University of Iowa Hospitals & Clinics and raised in Iowa City, graduating from Iowa City West High School in 1996. Dr. Buckwalter obtained his B.S. in Biological and Cognitive Psychology with concentration in Neuroscience at Duke University followed by his Ph.D. in Neuroscience at the University of Iowa. He received his M.D. at the University of California San Diego School of Medicine, and completed his Orthopedic Surgery Residency at the University of Iowa followed by a Hand and Upper Extremity Fellowship at the Washington University School of Medicine in the Department of Orthopedic Surgery. Dr. Buckwalter returned to his hometown to practice at the University of Iowa Hospitals and Clinics in 2017.

Philip Chen, MD

Dr. Philip Chen is from eastern Iowa, growing up in the Cedar Rapids area. He completed medical school at the University of Iowa, where he met his wife, and then completed Physical Medicine and Rehabilitation residency at the University of Michigan, where he also served as chief resident. He completed a one year non-interventional spine fellowship at the University of Iowa Spine Clinic, followed by a Spinal Cord Injury fellowship at the University of Michigan, Department of PM&R. He is now one of 4 ABPMR Spinal Cord Injury Medicine board certified physicians in the state of Iowa. He recently returned to Iowa City with his wife and 2 year old son to be near family, and with aspirations of growing the Physical Medicine and Rehabilitation services in the health system and region.

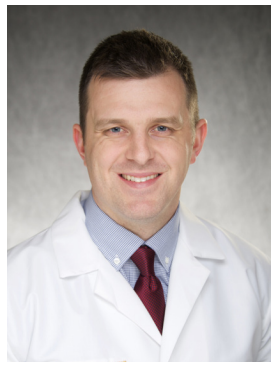
Jesse Otero, MD

Jesse Otero was born and raised in Albuquerque New Mexico. There, he met his wife, Emily. They graduated together from Stanford University in 2004 and traveled to St. Louis, Missouri, where Jesse completed medical school and earned a PhD from Washington University in St. Louis. While in St. Louis, they began their family of three children, Gentry, Samantha, and Leyla. They fell in love with Iowa during residency at the University of Iowa hospitals and clinics. Jesse completed a fellowship in adult hip and knee reconstruction at OrthoCarolina in Charlotte, North Carolina in 2017. The Otero family settled down back in Iowa as Jesse joined the faculty in the orthopedic department at UIHC.



Brendan Patterson, MD

Dr. Brendan Patterson joined the shoulder service in September, 2018. Dr. Patterson received his undergraduate degree from the University of Washington and his Masters in Public Health from St. Louis University. He earned his medical degree from Washington University School of Medicine in St. Louis. Dr. Patterson completed his orthopedic residency at the University of North Carolina and later returned to St. Louis for fellowship training in shoulder and elbow surgery at Washington University. Dr. Patterson treats patient with degenerative and traumatic shoulder and elbow conditions.



Robert Westermann, MD

Dr Robert Westermann is an Assistant Professor and Team Physician at the University of Iowa. He treats athletic related injuries to the hip, knee and shoulder. Dr Westermann completed residency at the University of Iowa and a Sports Medicine Fellowship at the Cleveland Clinic. He received advanced training in Hip Arthroscopy at Washington University in St Louis, University of Michigan and Minneapolis, MN. He treats patients with pre-arthritic hip conditions with arthroscopy, and also performs arthroscopic surgery on the knee and shoulder. He is involved in basic science research on cartilage biology and biomechanics as well as clinical outcomes research.

The 2018 Michael Bonfiglio Award for Student Research in Orthopaedic Surgery

The 2018 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 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.

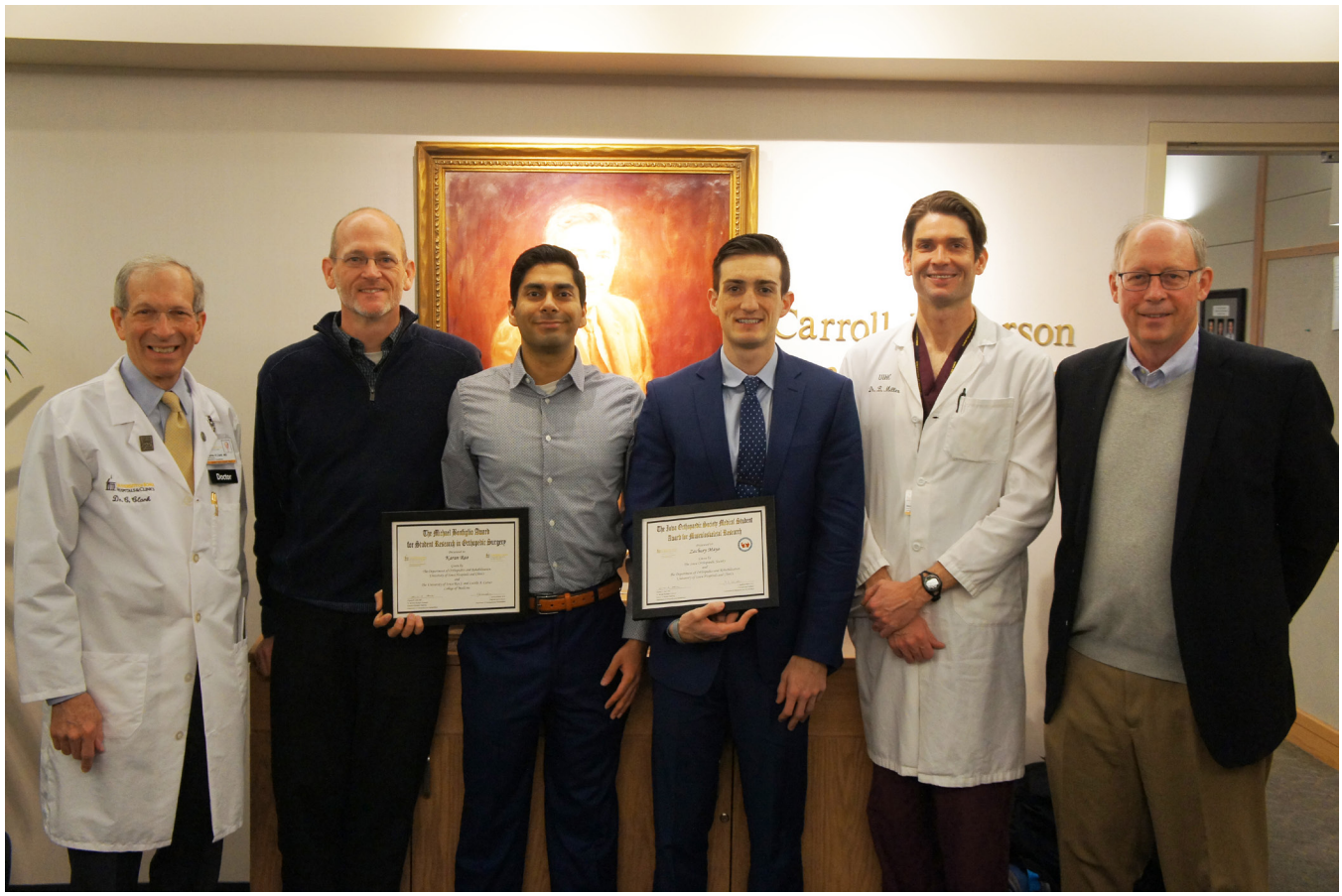
The Iowa Orthopaedic Society Medical Research Award for Musculoskeletal Research is an award for a student in the Carver College of Medicine who completes a research project involving orthopedic surgery during one of his or her first three years of medical school. The award consists of a $2000 stipend, $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, Timothy Brown, Joseph Buckwalter, Timothy Fowler, Cassim Igram, Jose Morcuende and Lynn Nelson. They recommended that Karan Rao, M3, receive the 2018 Michael Bonfiglio Student Research Award. Karan's award was based on his project, "Fracture Energy Correlates to the Sanders Classification for Evaluation Fracture Severity, but Does Not Predict Progression to Post-Traumatic Osteoarthritis." His advisors were Dr. J L Marsh and Dr. Donald Anderson.

The selection committee recommended that the Iowa Orthopaedic Society Medical Student Research Award be given to Zachary Mayo, M3, for his research titled "What Is the Clinical Importance of Incidental Findings on Staging CT Scans in Patients With Sarcoma?" His advisor was Dr. Benjamin Miller.

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: Dr. Charles Clark/Director, Dr. Donald Anderson/Advisor of MB recipient, Karan Rao/MB recipient, Zachary Mayo/IOS recipient, Dr. Benjamin Miller/Advisor of IOS recipient, Dr. J L Marsh/Advisor of MB recipient

LELAND G. HAWKINS, MD – HIS LIFE AND ORTHOPAEDIC LEGACY: TALUS FRACTURES AND THE HAWKINS CLASSIFICATION

Molly A Day, MD; Jocelyn T. Compton, MD; Joseph A. Buckwalter V, MD

ABSTRACT

The long history of excellence and continued success of the University of Iowa Department of Orthopedics and Rehabilitation is due to the dedication and talent of generations of faculty, residents and staff. Many former Iowa Orthopedic residents have made significant contributions and become leaders in Orthopedic surgery. An orthopedic surgeon and scholar with roots at the University of Iowa deserving of tribute is Dr. Leland Greene Hawkins. His seminal investigation and interest in fractures of the talus established the well-known Hawkins Classification for talar neck fractures, which revolutionized treatment and quantified the risk of progression to avascular necrosis, earning him attention and respect worldwide.

Keywords: talus, iowa orthopedics, talar neck fractures, hawkins classification

INTRODUCTION

The long history of excellence and continued success of the University of Iowa Department of Orthopedics and Rehabilitation is due to the dedication and talent of generations of faculty, residents and staff. Many former Iowa orthopaedic residents have made significant contributions and become leaders in orthopaedic surgery. An orthopedic surgeon and scholar with roots at the University of Iowa deserving of tribute is Dr. Leland Greene Hawkins. His seminal investigation and interest in fractures of the talus established the well-known Hawkins Classification for talar neck fractures[1], which revolutionized treatment and quantified the risk of progression to avascular necrosis, earning him attention and respect worldwide.

Dr. Hawkins completed his orthopaedic surgery residency at the University of Iowa from 1961 to 1965. During his time in Iowa, his interest in talus fractures sparked a senior research project involving a retrospective evaluation of patients with talar neck fractures treated at the University. This project, which Dr. Hawkins later completed and published while a junior faculty member at the University of Colorado, became a landmark, highly cited paper (>755 citations, see Bibliometric Analysis)[1] in the world of orthopedic trauma, with a well-known, often-used classification system still commonly employed throughout the world. Dr. Hawkins demonstrated compassion for his patients and was dedicated to resident education, teaching orthopedic surgery residents at the University of Colorado and later family medicine residents in Cedar Rapids, Iowa, where he finished his career.

His mentors included Drs. Carroll Larson, Reginald Cooper, Adrian E. Flatt, Michael Bonfiglio, Carl Gillies, and Ignacio Ponseti (Figure 1). Dr. Hawkins was well-known for his tireless attitude, inquisitive nature, enthusiasm for the outdoors (Figure 2), friendly demeanor, dedication, and loyalty to his patients. His career significantly contributed to the growth of orthopedics in Iowa and beyond with his work as a skilled orthopedist, scholar, and teacher.

BIOGRAPHY

Leland Grene Hawkins was born on October 11, 1933 in Los Angeles, California, where he spent the majority of his childhood. His father was Dr. Leland Potts Hawkins, born on June 24 in Nebraska (d. 1985), a well-respected general practice physician in Los Angeles. His mother was Kathryn Greene (1903–1997), who grew up in Beloit, Wisconsin prior to moving to Los Angeles with her husband (Figure 3). Dr. Hawkins obtained his bachelor's degree at Beloit College in Beloit, Wisconsin from 1952 to 1956, where his two sisters (Elizabeth and Linny) also attended college. It was in Beloit that Dr. Hawkins met his future wife, Kathleen (Kate) Foster (Figure 4). After completing his pre-medical requirements, he was accepted and started medical school at the University of

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We have no conflict of interest to declare.

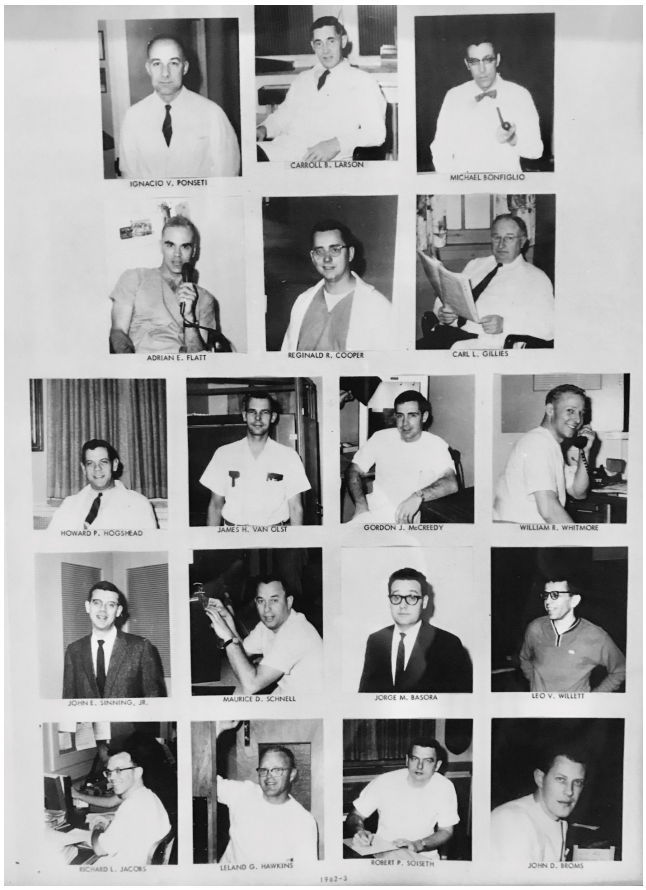

Figure 1. University of Iowa Orthopedic Surgery residency 1962

Figure 2. Leland Hawkins hiking in California (roughly age 20)

Figure 3. The Hawkins Family. Leland Hawkins with mother (Kathryn Hawkins), father (Leland Potts Hawkins), and son (Leland Foster Hawkins) (1964)

Figure 4. Dr. Hawkins with wife Kate (1990)

Chicago, School of Medicine in the fall of 1956. He married Kate on June 15, 1957 in Rockton, Illinois after his first year of medical school, and she joined him in Chicago, where she worked as a primary school teacher. In medical school, Dr. Hawkins studied tirelessly, working hard to achieve good grades, and he overcame adversity with learning and vision difficulties that stemmed from an accident with a BB gun as a child. His work ethic and personality made him stand out and excel in his clinical years. Dr. C. Howard Hatcher mentored him during his freshman and sophomore years of medical school; he described Leland as an "attractive young fellow who is industrious, shows good judgment in all respects, and his work was always well done" (personal communica-

Figure 5. Hawkins and wife (Kate) at medical school graduation, University of Chicago School of Medicine (1960)

tion from Dr.C. Howard Hatcher to Dr. Carroll Larson, 1960). Dr. Joseph Ceithaml, the Dean of Students at the University of Chicago, School of Medicine, described Dr. Hawkins as a "tall, well-proportioned young man, standing 6' in height and weighing 180 lbs. He is a conscientious, industrious individual who takes his duties almost too seriously. His personal character is excellent, and he possesses many fine, unsophisticated qualities. He makes a very good impression, and he holds the respect and the confidence of both his peers and his superiors. In his clinical work, he displayed poise and confidence in his work with patients" (personal communication from Dr. Joseph Ceithaml to Dr. Carroll Larson, 1960). He served as an assistant to an orthopedic surgeon in Rockford, Illinois for one month in the summer on 1959 between the end of his junior year and the beginning of his senior year of medical studies.

Following his graduation from the University of Chicago, School of Medicine in June 1960, Dr. Hawkins went to the Los Angeles County Hospital for his internship (Figure 5). He was amazed and challenged by the array of injury and disease he encountered while in Los Angeles, but had a strong desire to return to the Midwest for residency. Following his internship, he applied to orthopedic surgery residency at the University of Iowa, where he was a resident from 1961 to 1965. Dr. Reginald Cooper described Dr. Hawkins as an "outstanding resident who was obviously interested in clinical investigation" (personal communication from Dr. Reginal Cooper, 1965). While he was a resident at the University of Iowa, Dr. Hawkins completed a Master's thesis on the thrombotic mechanism in fat embolism under the supervision of Dr. Michael Bonfiglio.[2] His other research interests included articular cartilage matrix composition

Figure 6. The Hawkins family on vacation in Colorado (1971)

structure and degeneration. However, influenced by the previous works of Dr. Arthur Steindler, for his senior resident research project Dr. Hawkins focused on his special interest in talus fractures. He accumulated and reviewed a large series of patients with a history of talus fractures, publishing his first article his senior year of residency, 1965, on a review of 13 cases of lateral process fractures of the talus.[3] His interest in talus fractures led him to continue to review all review all talus fractures treated at the University of Iowa from 1943 to 1967, which ultimately comprised the bulk of material for his landmark publication on talar neck fractures.[1]

After residency, Dr. Hawkins completed an additional year at the University of Iowa as a junior faculty member to hone his abilities and experience in teaching and research, with the idea of continued pursuits in academic medicine. He then moved to Colorado with his wife and family (Figure 6), where he spent seven years on faculty of the University Hospitals and Denver General Hospital. His research interests were vast, publishing on topics

Figure 7. Dr. Hawkins posing with hand sculpture at a park in California, demonstrating his strong interest in orthopedic surgery of the upper extremity

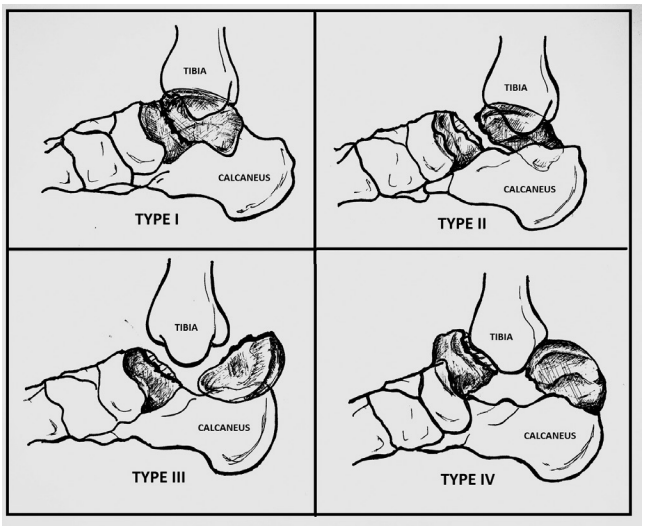

Figure 8. The Hawkins Classification for talar neck fractures

ranging from Pasteurella multocida infections[4], bites of the hand[5], the use of a Bier block for upper extremity fractures and dislocations[6], and systemic and local complications of intra-arterial injection of street drugs into the upper extremity[7]. He was promoted to the rank of Associate Professor of Orthopedic Surgery at the University of Colorado in 1971 and later became the Chief of the Division of Orthopedic Surgery at the University of Colorado and Head of Orthopaedics at County Hospital. He often wrote to his mentor, Dr. Larson, at the University of Iowa, who provided advice regarding administrative challenges and gaining departmental status within the university system, which was eventually accomplished.

After seven years in academics at the University of Colorado, in 1973, Dr. Hawkins decided to return to his roots in Iowa and finish his career in private practice in Cedar Rapids. During their tour of the practice Dr. Hawkins would later join, Kate and Leland drove by a beautiful stone home in Cedar Rapids and fell in love. Dr. Hawkins informed his future colleagues, "If we can get the house, we will come" (recounted by Kate Hawkins regarding Lee Hawkins decision to move to Iowa in 1973). They purchased the property from Arthur Collins and made a home in Iowa where they raised their two children, Leland Foster and Sarah (Figure 6). In Cedar Rapids, his practice was dedicated to hand surgery (Figure 7). He continued his passion for teaching and was in charge of the teaching program for orthopedics in the family residency program for Mercy Medical Center and St. Luke's Hospital. He was President of the Iowa Medical Clinic in Cedar Rapids, and a member of St. Luke's Hospital and Mercy Hospital Medical staff. He also returned to the University of Iowa several times for speaking engagements. Nationally, he contributed as an examiner on the American Board of Orthopaedic Surgery.

Dr. Hawkins had an inquisitive nature with many interests beyond orthopedics. His love for nature included interests as a beekeeper, sawyer, and farmer. His enthusiasm for the outdoors and commitment to his community facilitated the start of the beekeeping program at the Indian Creek Nature Center in Cedar Rapids. He died after a sudden illness at the age of 58 (1991) in his home in Cedar Rapids, Iowa.

ORTHOPAEDIC IMPACT & LEGACY

The Hawkins Classification System

Descriptions of talus injuries, their associated mechanisms, and management were widely published in the early 1900s, with note of high complications rates.[8,9] It wasn't until the 1970s that Dr. Hawkins correlated the rate of avascular necrosis with specific fracture patterns.[10] In his landmark paper, Dr. Hawkins described a series of 57 talar neck fractures in 55 patients with the intent to discuss the incidence of avascular necrosis and to suggest a plan of treatment for the patient who develops avascular necrosis after talar neck fracture.[1]

Dr. Hawkins originally presented a classification system that grouped three distinct talar neck fracture

patterns.[1] This classification system has been updated over the years: In 1978, Canale and Kelly included a fourth group[11], Williams et al. proposed a "Type 0" that includes anterior talar body fractures that are minimally displaced less than 2 mm[12], and Vallier et al. identified two subtypes of the original second grouping[13] (Figure 8). The classification utilizes plain radiographs to assess the severity of the fracture pattern and associated subluxations or dislocations. Group I describes a vertical fracture of the neck that is non-displaced and the talar body maintains its normal position, and the tenuous blood supply to the talus is not disrupted. Group II describes displaced vertical neck fracture with associated subtalar joint disruption, and has two subtypes (IIa and IIb) that predict development of osteonecrosis. Group III describes a vertical fracture of the neck of the talus with both tibiotalar and subtalar joint dislocations. Group IV includes vertical talar neck fractures that are associated with subtalar, tibiotalar, and talonavicular dislocation. Dr. Hawkins described the subsequent rates of avascular necrosis in each group: The non-displaced Group I fractures did not develop avascular necrosis, whereas Group III fractures went on to avascular necrosis in 22 patients (91%). He stated that Group II patterns were most difficulty to predict, as 24 patients (42%) subsequently developed avascular necrosis; he posited that satisfactory reduction of Group II fractures could prevent avascular necrosis development. His foresight into this issue was later clarified by Vallier et al. when they described two subtypes of Group II based on development of subsequent osteonecrosis.[13]

Dr. Hawkins also proposed treatment plans for patients sustaining these injuries. Initially, he advocated for closed reduction and plaster casting in all Group I fractures. In Group II fractures, closed reduction and casting was possible in only 40% of patients, with 60% of patients requiring open reduction through an anteromedial incision with adjunct pinning to maintain the reduction. He also advocated for acute bone grafting in these patients if needed. For Group III fractures, 25 of 27 patients required open reduction and adjunct pin fixation. He noted mild loss of subtalar motion and dorsiflexion routinely for all subtypes. For patients who went on to develop avascular necrosis, no single treatment was uniformly successful. The series reported bone grafting, fusion, and talectomy as possible treatment options; however, most patients had persistent pain.

The Hawkins classification system developed from his study served to clarify an otherwise confusing and controversial management of talus injuries. Studies regarding talus fractures are particularly difficult to interpret due to lack of specificity for talar neck fractures versus other complex fractures of the talar body. In a systematic review of talar neck fractures, Halvorson et al. identified 21 published articles that specifically address talar neck fractures. Of these 21 studies, 16 used the Hawkins classification system.[14] The Hawkins classification system furthermore underscored the relative risk of development of avascular necrosis in these patients, and it has been utilized to guide both initial and subsequent treatments. Due to the risk of development of avascular necrosis, urgent or emergent open reduction and internal fixation of talar neck fractures has been the prevailing paradigm of initial treatment for Group II–IV fractures. Although recent literature suggests that delayed timing to reduction may not affect overall rates of osteonecrosis development[13,15], many orthopedic traumatologists advocate for urgent reduction within 24 hours of injury due to this specific complication[16], and urgent reduction is always indicated in cases of neurovascular compromise of threatened skin[15].

The Hawkins Sign

Dr. Hawkins' study was also the first to identify a radiolucent subchondral band in the dome of the talus that signifies re-vascularization and healing of the talar body, known presently as the "Hawkins Sign"[1]. Disruption of the blood supply to all or a portion of the talar dome results in absence of the Hawkins sign (subchondral sclerosis), indicated underlying avascular necrosis[17]. The Hawkins sign has proven to be a highly reliable indicator of talus vascularity at 6–8 weeks after injury and it may be more sensitive than MRI for detection of revascularization.[18-21] The Hawkins sign indicates that there is sufficient vascularity in the talus, which is therefore less likely to develop avascular necrosis later .[8,12] The use of this radiographic sign has been applied beyond injuries of the talar neck to include talar body fractures and any injury pattern that is concerning for development of avascular necrosis,[18-21] and it aids in predicting long-term outcomes as well as the need for further surgical intervention.

Bibliometric Analysis

Utilizing the database of the Science Citation Index managed by Clarivate Analytics, we performed a bibliometric analysis of Dr. Hawkins' classic publication. Performing a query using the topic "talus fracture," we identified 1, 373 articles published between 1900 and 2018. Dr. Hawkins' publication on talar neck fractures is cited 263 times in the literature, second only to the original description of Osteochondritis Dissecans (OCD) of the talus in 1959.[22] The subsequent revision of the Hawkins classification by Canale and Kelly[11] has been cited 206 times, and the publication of outcomes of talar neck fractures by Vallier et al.[23] has been cited 102 times. If we refine the topic search "talus fracture" to include

publications that include "Hawkins" in the title, we identify over 30 articles[10,12,13,18,19,24-50] that comprise studies specifically focused on the Hawkins classification or the Hawkins sign. These findings highlight the significant impact Dr. Hawkins' senior orthopaedic resident project has had in the sphere of talus fractures and orthopaedic trauma.

CONCLUSION

Dr. Hawkins was a thoughtful, intelligent, and compassionate orthopedic surgeon who epitomized the characteristics of an Iowa orthopaedic resident. He was influenced by great many great orthopaedic figures and produced a senior resident project that changed the orthopaedic description and management of talus fractures forever. Although talar neck fractures represent less than 1% of orthopedic injuries, patients with talus fractures deal with significant complications and poor functional outcomes.[51] Due to the work of Dr. Hawkins, the risk of avascular necrosis with talar neck fractures is highly emphasized in the orthopedic literature and in orthopedic education. His description of the Hawkins sign has helped generations of surgeons evaluate the restoration of the vascular supply to the talus, which has improved clinical communication of expected outcomes. Moreover, the Hawkins sign, has proven to be a sensitive predictor even with the advent of more advanced imaging.

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THE ECONOMIC BURDEN OF RESIDENCY INTERVIEWS ON APPLICANTS

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ABSTRACT

Background: The residency match is increasingly competitive. The interview is an essential component, yet little has been documented about the costs applicants incur during the interview process and it is unclear how they manage these expenses.

Objective: The purpose of this study was to define the economic burden of residency interviews for United States (U.S.) allopathic students participating in the 2016 Main Residency Match. We hypothesized that the financial burden of residency interviews varies based on specialty and plays a role in the applicant's ability to participate in all desired interviews.

Methods: A 26 question electronic survey was developed following pilot study of applicants to a single residency program. Following validation, the survey was distributed to administrative officials at all U.S. allopathic medical schools for circulation to senior students. Results were pooled for statistical analysis.

Results: We received responses from 759 U.S. allopathic seniors. A single interview most commonly costs $250 - $499. Most applicants incurred substantial interview related costs. Sixty-four percent of respondents spent at least $2,500, while 13% spent $7,500 or more. Specialty competitiveness was predictive of higher interview costs. Seventy-one percent of respondents borrowed money to fund interview costs, and 41% declined interviews for financial reasons.

Conclusions: Senior medical students incur substantial costs to participate in residency interviews, often adding to already burdensome educational debt. We encourage residency programs, especially those in competitive specialty fields, to pursue cost reduction strategies. Additionally, medical schools should provide financial counseling to allow students to anticipate interview costs.

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INTRODUCTION

Each year, thousands of medical students apply for post-graduate training through the National Resident Matching Program's (NRMP) Main Residency Match. Despite modest increases in available PGY-1 positions, the number of applicants continues to outpace the number of available positions. In the 2016 Match, 24% of all active applicants went unmatched to PGY-1 positions.[1]

The interview is an essential component of the matching process. An interview is required for applicants to include a program on their rank order list, and thus potentially match there. Analysis of recent match data demonstrates a direct correlation between the number of programs an applicant ranks and their probability of matching. For example, in 2016 the mean number of contiguous ranks of matched U.S. allopathic seniors was 12, compared to only 4 for unmatched applicants.[2] Thus, there is incentive for applicants to participate in as many interviews as possible. The interview is also critical in the evaluation process. In 2016, residency program directors reported interactions with faculty and house staff during the interview as the first and third most important factors when ranking applicants.[3]

Table I. Residency Interview Costs Survey

1. Gender: __Female __Male

2. Age: _____

3. What best describes your marital status?
__Single __Married __Divorced __Widowed

4. Do you have children? __Yes __No

5. If yes, how many children do you have? _____

6. In what state is your medical school located? _____

7. What is the approximate population of the town/city where your medical school is located?
__<100,000 __100,000 – 499,000 __500,000 – 999,000 __>1,000,000

8. How would you evaluate the financial guidance your medical school provided to you when planning residency interviews?
__Exceeded expectations/needs __Met expectations/needs
__Fell short of expectations/needs __I received no financial guidance

9. Have you ever applied for residency through the National Residency Match Program ("The Match") prior to the 2016 Main Residency Match?
__Yes __No

10. What specialties did you apply to in the 2016 Main Residency Match (select all that apply)?
__Anesthesiology __Child Neurology __Dermatology __Diagnostic Rad.
__Emergency Med. __Family Medicine __General Surgery __Internal Medicine
__Internal Medicine/Pediatrics __Neurosurgery __Neurology
__Obstetrics and Gynecology __Orthopedic Surg. __Otolaryngology
__Pathology __Pediatrics __PM & R __Plastic Surgery
__Psychiatry __Rad. Oncology __Vascular Surgery

11. How many TOTAL residency programs did you apply to? _____

12. What was your target number of residency interviews? _____

13. How many interviews did you complete? _____

14. Approximately how much money did you spend interviewing for residency (this includes all costs associated with travel, e.g. flights, car, hotels, food, etc., and does NOT include the cost of applying for residency)?
__<$1,000 __$1,000 - $2,499 __$2,500 - $4,999
__$5,000 - $7,499 __$7,500 - $9,999 __≥ $10,000

15. How does your pre-interview budget compare to your actual total expenses?
__I spent more than I expected __I spent about what I expected __I spent less than I expected

16. What was your average expense for a single interview? (factor in all travel expenses, including flight, lodging, car rental, gas, etc.)
__< $50 __$50 - $99 __$100 - $249 __$250 - $499 __> $500

17. For all interviews combined, what did you spend the most money on?
__Flights __Car rental/taxi/gas __Lodging __Other:_____

18. Did you turn down any interviews for financial reasons? __Yes __No

19. If yes, how many interviews did you decline due to financial constraints? _____

20. How did you finance the costs for interviews? (select all that apply)
__Federal student loan __Private student loan __Loan from family/friend
__Gift from family/friend __Personal savings/earnings __Other: _____

21. Estimate your TOTAL education debt (including undergraduate and graduate education) when you applied for residency. (do not include additional sources of debt, such as car or credit card debt)
__$0 __<$50,000 __$50,000 - $99,999
__$100,000 - $149,999 __$150,000 - $199,999 __≥ $200,000

22. Did any residency programs offer video conferencing (e.g. Skype) or phone interviews? __Yes __No

23. Did you complete any interviews via video conferencing (e.g. Skype) or over the phone? __Yes __No

24. Which method of interviewing would you prefer for residency interviews?
__In person, face-to-face interviews __No preference __Video conferencing or phone interview

25. Approximately how many days of medical school did you miss for residency interviews?_____

26. Do you agree or disagree with the following statement: The residency interview process, separate of application cost, is too expensive.
__Strongly agree __Agree __Neither agree or disagree
__Disagree __Strongly disagree

The 26 question survey tool was developed in response to feedback on a small scale pilot study measuring interview costs incurred by orthopaedic surgery applicants, and subsequently underwent expert validation.

Table II. Accrued Educational Debt and Total Interview Costs

Total Cost of Interviews		Total Accrued Educational Debt	
69 (9%)	<$1000	115 (15%)	No Educational Debt
206 (27%)	$1,000 - $2,499	46 (6%)	<$50,000
259 (34%)	$2,500 - $4,999	36 (5%)	$50,000 - $99,999
120 (16%)	$5,000 - $7,499	74 (10%)	$100,000 - $149,000
50 (7%)	$7,500 - $9,999	152 (20%)	$150,000 - $199,999
51 (7%)	>$10,000	334 (44%)	>$200,000
4 (.5%)	Undisclosed		

Respondents documented their estimated total accrued educational debt, as well as the total cost of attending interviews, not including application costs.

Interviewing is time consuming and financially taxing for applicants. Because students are responsible for all expenses associated with the interview, such as transportation and lodging, costs accumulate rapidly. Recent literature has attempted to define interview costs within specific specialties. Our group recently found that most applicants to our orthopaedic surgery program spent over $7,000 on interviews.[4] This figure was similar to interview costs documented for neurosurgery and urology applicants.[5-7] Aside from these few studies, there is a paucity of information on the variance in interview costs by specialty, and even more, how applicants balance the cost of interviewing with the competition of matching into residency. The primary purpose of this study was to define the economic burden of the residency interview process for U.S. allopathic seniors participating in the 2016 Main Residency Match. Secondary objectives were to determine how applicants finance this expense and if specialty type impacted the cost of interviewing. We hypothesized that the financial burden of residency interviews varies based on specialty and influences applicants' ability to complete desired interviews.

MATERIALS AND METHODS

Study Participants and Survey Administration

A 26 question survey of interview costs and applicant demographics [Table 1] was developed following administration of a pilot survey of a single specialty at our institution.[4] The survey subsequently underwent validation by three attending physicians (KW, APS, and LMN), with attention to representativeness, clarity, relevance, and distribution strategy.[8,9] The survey (Survey Monkey, Palo Alto, CA) was e-mailed to administrative officials at every allopathic medical school in the contiguous U.S. with requested distribution to senior students. The voluntary and anonymous survey was open for completion for one month before and one month after Match Day 2016. This study received exemption status from our Institutional Review Board.

Data Collection and Analysis

Upon conclusion of the survey period, data was pooled for analysis. Chi-square tests were used for categorical comparison. Comparison across specialty groups and tiers was performed using non-parametric Kruskal-Wallis tests with follow-up Dwass, Steel, Critchlow-Flinger multiple comparison analysis. ANOVA was used to identify differences in average application characteristic across tiers. A Tukey-Kramer test was used to assess group differences while controlling for Type I experiment wise error rate.

RESULTS

Descriptive Statistics

Seven-hundred-fifty-nine U.S allopathic students responded to the survey. Respondents included 392 women (52%) and 367 men (48%) attending medical schools in 22 states and applying to 21 different specialties. Most (696, 92%) were applying for residency for the first time. Applicants applied to a mean 45 programs (SD 28.4), and completed an average 13 interviews (SD 4.9). A single interview most commonly cost $250 - $499. Total cost of interviews as well as total educational debt is reported in Table 2. To fund these expenses, 540 applicants (71%) utilized loans while 203 (27%) used gifts and/or personal savings. Airfare was the greatest expense for 65% of respondents, followed by lodging (21%) and car/taxi/gas (13%).

Three-hundred-nine applicants (41%) turned down an average 3 (IQR 2-4) interviews for financial reasons. Six-hundred-thirty-eight (84%) respondents either strongly agreed or agreed that interview costs are too expensive and 407 (54%) reported receiving less than expected or no financial guidance from their medical school. An average of 12 school days were missed for interviews, although many used discretionary or vacation time or simultaneously participated in online courses. Only 54 (7%) respondents were offered a videoconference or phone interview and 31 (4%) actually completed one. Meanwhile, 652 (85%) of respondents noted that they prefer in-person interviews.

Statistical Analysis

To determine the potential impact of a specialty's competitiveness on interview costs, applicants were grouped into quartiles based on their chosen specialty's mean 2014 USMLE Step 1 score of matched U.S. seniors[10] [Table 3]. On average, respondents who applied to Tier 1 (i.e. most competitive) specialties applied to significantly more programs than respondents represented by Tiers 2,

Table III. Interview Characteristics Across Specialty Tiers

	Tier 1 (n=89) Otolaryngology (248/14)* Dermatology (247/15) Orthopedic Surgery (245/48) Plastic Surgery (245/6) Neurosurgery (244/6)	Tier 2 (n=131) Diagnostic Radiology (241/35) Radiation Oncology (241/7) Vascular Surgery (237/5) Internal Med/Peds (233/22) General Surgery (232/62)	Tier 3 (n=271) Internal Medicine (231/137) Pathology (231/11) Anesthesiology (230/45) Emergency Medicine (230/61) Neurology (230/17)	Tier 4 (n=245) Child Neurology (229/3) Obstetrics & Gynecology (226/74) Pediatrics (226/74) Physical Medicine & Rehabilitation (220/11) Psychiatry (220/31) Family Medicine (218/52)	p-value
Gender					
Female	18 (20.2%)	66 (50.4%)	122 (45.5%)	177 (72.2%)	
Male	71 (79.8%)	65 (49.6%)	149 (55.5%)	68 (27.8%)	<0.0001
Number of Completed Applications (mean, SD)	90.0 (31.98)	48.66 (23.49)	38.08 (21.42)	34.44 (18.86)	<0.0001
Number of Interviews Targeted (mean, SD)	15.15 (6.42)	15.42 (5.27)	13.11 (3.76)	12.94 (3.86)	<0.0001
Number of Interviews Completed (mean, SD)	14.61 (5.56)	15.11 (5.43)	12.89 (4.51)	12.62 (4.42)	<0.0001
Turned Down Interview For Financial Reasons	22 (24.7%)	59 (45.0%)	122 (45.0%)	96 (39.2%)	0.01
Number of Interviews Turned Down For Financial Reasons	2 (IQR 1-4)	3 (IQR 2-4)	3 (IQR 2-4)	2 (IQR 2-4)	0.45

Specialties were grouped into quartiles based on 2014 mean USMLE Step 1 scores[10] for matched U.S. Seniors and ranked according to competitiveness, where Tier 1 = "most competitive." Applicants applying to more than one specialty were categorized by the specialty with the higher mean Step 1 score. To look for differences in the average number of residency programs to which respondents applied, the target number of interviews, and the number of interviews completed across tiers, an ANOVA was performed. A non-parametric Kruskal-Wallis Test was used to look for differences in the number of interviews turned down for financial reasons across each tier.

3 and 4 (adjusted p<0.05) [Table 3]. Similarly, those who applied to Tier 1 or 2 specialties targeted and completed significantly more interviews compared to Tiers 3 and 4 (adjusted p<0.05). Respondents who applied to more competitive specialty areas spent significantly more on interview costs than their counterparts in less competitive tiers (p<0.0001) [Figure 1].

Lastly, survey respondents were grouped by specialty type [Table 4]. Respondents pursuing primary care (n=255) spent significantly less than many of their peers, including those selecting radiologic specialties (n=42; adjusted p<0.0001), surgical specialties (n=115; adjusted p<0.0001), emergency medicine (n=61; adjusted p=0.03), and "other" specialty areas (n=37; adjusted p<0.001). Respondents who selected neurology or psychiatry (n=51) also spent significantly less on interview costs than those pursuing radiologic specialties (n=42; adjusted p=0.03).

DISCUSSION

The purpose of this investigation was to gain insight into the expense residency interviews pose to graduating medical students. Because an applicant's chance of matching directly correlates with their number of contiguous ranks, applicants feel obligated to complete as many interviews as possible.[2] According to NRMP data, 13 interviews corresponds to a match rate of greater than 90% for all specialties except neurosurgery. Nonetheless, in our study, applicants targeted an average of 14 (SD 4.6) interviews and even applicants to tier 4 (i.e. least competitive) specialties set a target of an average of 13 interviews (SD 3.9).

Total interview costs were substantial for the majority of applicants: 64% spent at least $2,500 while 13% incurred costs of $7,500 or more. These costs are comparable to those described in prior studies.[4-7] Considering that the median accrued educational debt for graduating medical students is $170,000, interviewing costs represent a meaningful addition to already burdensome debt.[11]

Respondents who applied to more competitive residencies as determined by mean USMLE Step 1 scores targeted and completed significantly more interviews and spent significantly more than their peers applying to less competitive specialties. Furthermore, those applying to surgical, radiological, and emergency medicine specialties spent significantly more than those applying to primary care specialties. While we believe all residency

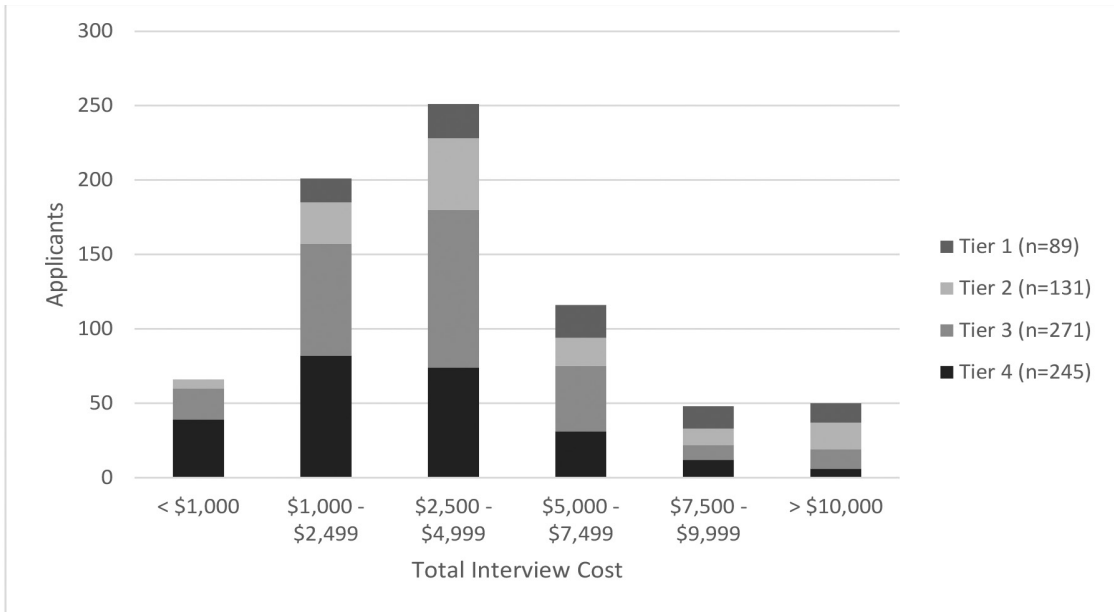

Figure 1. Total Interview Cost Across Specialty Tiers
To determine if respondents from any specialty tiers spent significantly more on interview costs, a non-parametric Kruskal-Wallis Test was performed. A DSCF multiple comparison analysis was then conducted to look for specific group differences. Respondents who applied to more competitive specialty areas spent significantly more money on interview costs than their counterparts in lower tiers ($p<0.0001$). Tier 1 respondents spent significantly more than those in Tier 3 (adjusted $p<0.0001$) or Tier 4 (adjusted $p<0.0001$). Similarly, Tier 2 respondents spent significantly more than those in Tier 3 (adjusted $p=0.03$) or Tier 4 (adjusted $p<0.0001$). Tier 3 respondents also spent significantly more on interview costs than Tier 4 respondents (adjusted $p=0.01$).

programs should consider cost reducing strategies, those in more competitive fields should be particularly sensitive to this financial burden on applicants.

Lastly, we found that an overwhelming majority (84%) of respondents either strongly agreed or agreed that interview costs were too expensive. Forty-one percent of applicants turned down an interview for financial reasons. If cost can limit a candidate's ability to attend an interview, it is imperative that students receive appropriate financial guidance from their medical school. With the ability to anticipate interview costs, students can weigh the benefits of an additional interview against the cost of attending.

Since interviews are an indispensable part of the application process, the focus should be on cost-saving strategies, and this begins with understanding how applicants spend their money. In our study, 65% noted airfare to be the largest expense, while 21% cited lodging. A logical option then is replacing traditional in-person interviews with videoconferencing or phone interviews. When University of New Mexico's Urology program trialed web based interviews, they documented a nearly 50% reduction in applicant costs, as well as a reduction in medical school days missed by applicants.[12] Similarly, a family medicine residency program found that videoconference-based interviewing not only saved applicants money, but also saved the program over $5,000 in direct cash and indirect salary savings.[13]

Despite the potential savings, only 7% of our respondents were offered a videoconference or phone interview. Perhaps more importantly, though, 85% stated they prefer in-person interviews. The obvious drawback to "virtual" interviews is that applicants don't meet faculty and residents or tour the program's facilities. To this point, one study that trialed videoconferencing saw no difference in applicant's costs when factoring in the subsequent site visits most applicants independently scheduled.[14] Videoconferencing or phone interviews may therefore be best utilized as a preliminary assessment tool to identify a smaller pool of candidates to invite for a visit.

Another option that reduces applicant cost while maintaining the in-person interviewing format is co-locating interviews, where representatives from several programs convene at a single location to interview all applicants. This strategy was previously trialed in the Canadian Urology match, and while savings were demonstrated, once again these savings did not account for subsequent program visits by many of the interviewees.[15] Additionally, co-located interviews pose substantial logistical challenges. While the Canadian Urology Fair only involved nine programs and 28 candidates, the 2014

Table IV. Total Interview Cost Across Specialty Areas

	Primary Care (n=285)	Surgical (n=215)	Anesthesiology (n=45)	Neurology & Psychiatry (n=51)	Radiology & Radiation Oncology (n=42)	Emergency Medicine (n=61)	Other (n=37)
	Family Medicine (n=52) Internal Medicine (n=137) Internal Medicine/ Pediatrics (n=22) Pediatrics (n=74)	General Surgery (n=62) Neurourgery (n=6) Obstetrics & Gynecology (n=74) Orthopedic Surgery (n=48) Plastic Surgery (n=6) Otolaryngology (n=14) Vascular Surgery (n=5)		Child Neurology (n=3) Neurology (n=17) Psychiatry (n=31)	Diagnostic Radiology (n=35) Radiation Oncology (n=31)		Dermatology (n=15) Pathology (n=11) PM & R (n=11)
< $1,000	49 (17.2%)	5 (2.3%)	2 (4.4%)	5 (9.8%)	0 (0.0%)	5 (8.2%)	0 (0.0%)
$1,000 - $2,499	100 (35.1%)	49 (22.8%)	10 (22.2%)	13 (25.5%)	6 (14.3%)	13 (21.3%)	10 (27.0%)
$2,500 - $4,999	87 (30.5%)	70 (32.6%)	22 (48.9%)	21 (41.2%)	16 (38.1%)	27 (44.3%)	8 (21.6%)
$5,000 - $7,499	39 (13.7%)	37 (17.2%)	7 (15.6%)	8 (15.7%)	10 (23.8%)	6 (9.8%)	9 (24.3%)
$7,500 - $9,999	3 (1.1%)	28 (13.0%)	1 (2.2%)	4 (7.8%)	3 (7.1%)	5 (8.2%)	4 (10.8%)
> $10,000	7 (2.5%)	25 (11.6%)	2 (4.4%)	0 (0.0%)	7 (16.7%)	4 (6.6%)	5 (13.5%)
No Response	0 (0.0%)	1 (0.5%)	1 (2.2%)	0 (0.0%)	0 (0.0%)	1 (1.6%)	1 (2.7%)

Respondents were divided into groups based on specialty likeness. A non-parametric Kruskal-Wallis Test was performed to determine if respondents from any of the specialty areas spent significantly more on interview costs. A follow-up DSCF multiple comparison analysis was then conducted to look for specific group differences. Respondents pursuing a primary care specialty spent significantly less on interview costs than those who selected radiology or radiation oncology (adjusted p<0.0001), surgical specialties (adjusted p<0.0001), emergency medicine (adjusted p=0.03), and other specialty areas (adjusted p<0.001). Respondents who selected neurology or psychiatry also spent significantly less on interview costs than those who selected Radiology or Radiation Oncology (adjusted p=0.03).

internal medicine match, for example, included over 9,300 applicants. Simply put, coordinating and hosting wide participation by so many applicants and residency programs may prove to be too difficult.

An alternative and more practical option then is a city or region-based approach. If programs in the same area were to schedule their interviews on sequential days, students could travel to a city or region once rather than several times.

One easily implemented cost saving technique utilized by our own residency program is to interview any visiting student at the end of their rotation. Although away rotations are not required, they are common amongst applicants, with a reported 67.4% of all applicants performing at least one visiting rotation and 21.7% performing 3 or more.[16,17] Routinely interviewing an applicant at the end of their rotation saves the students a return trip and is also convenient for the residency program. We estimate that we save our rotating students $344 with this practice.[4]

There are several limitations to this study. Respondents attended medical schools in only twenty two of the forty three states (51.5%) in the contiguous U.S. with graduating seniors. It is unclear why there were no responses from schools in twenty one states, and why many of these schools were in the Pacific region. It is possible the lack of Western participants skewed our data, but it is unclear if these applicants would have less, equal, or greater interview costs than our respondents. Our goal was to distribute our survey to as many senior allopathic medical students as possible. However, because many school officials did not communicate their willingness or refusal to participate, we are unable to accurately calculate the response rate. There was an overrepresentation of applicants to Tier 1 and 2 programs when compared to NRMP match data,[7] but this was not statistically significant. This may be related to both participation and recall biases inherent to any questionnaire based study, as students who chose to participate may have had particularly negative or positive experiences, making them more inclined to respond. Since the distribution of responses amongst individual specialty choice and demographics is similar to published NRMP data,[7,18] we feel our data set is representative of the graduating class in general.

CONCLUSION

This study examined residency interview costs incurred by U.S. allopathic medical students and the potential implications of these costs. A single interview most commonly cost $250 - $499 and total cost was $2,500 or greater for 64% of applicants. Costs were significantly higher for those pursuing more competitive specialties. A majority of students borrow money for interviews and four in ten decline interviews for financial reasons. We encourage residency programs, especially those in more competitive fields, to utilize cost reducing strategies and for medical schools to become more active in counseling students.

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MYCOBACTERIUM TUBERCULOSIS MONOARTHRITIS OF THE KNEE IN CHILDREN: A CASE REPORT

Christopher N. Carender, MD*, Craig Chike Akoh, MD, Heather R. Kowalski, MD

ABSTRACT

Mycobacterium tuberculosis monoarthritis is a rare form of TB, occurring in 1-2% of cases in the United States. Delays in definitive diagnosis and subsequent treatment are common. While case reports of tuberculous arthritis have been presented in international literature, there is a relative paucity of literature from within the United States. Given the difficulty in diagnosis and adverse outcomes of delayed diagnosis, we present the case of an 11-year-old otherwise healthy male with isolated monoarticular TB septic arthritis of the right knee. A discussion, including review of current literature, regarding presentation, diagnosis, and treatment of tuberculous monoarthritis follows. The emerging role of arthroscopy as a diagnostic and treatment modality for tuberculous monoarthritis of the knee is discussed.

Level of Evidence: VI

INTRODUCTION

Tuberculosis (TB) is a systemic disease that is endemic in many countries outside of the United States.[1] The annual incidence of TB in the United States is reported to be 9,287 cases, compared to 10.4 million cases worldwide.[2] Within the United States, there is a significant difference the incidence of TB between pediatric (0.5 to 1.2 per 100,000) and adult populations (3.0 per 100,000).[3]

Myocbacterium tuberculosis, the causative organism of TB, can manifest in a variety of ways. A remote history of fever is the most common clinical manifestation of primary tuberculosis, occurring in 70% of symptomatic cases.[4] Pulmonary symptoms, including cough, pleuritic chest pain, and shortness of breath are present in 60-80% of pediatric TB infection.[4-9] Overall, over 90% of older children and adults exposed to TB do not develop overt clinical symptoms.[9] In contrast, children under the age of two have an increased risk (60-80%) of developing clinical TB.[9]

Tuberculosis monoarthritis is a rare form of TB, occurring in 1-2% of cases of cases in the United States.[5, 10-13] Most cases of monoarthritis TB are a result of reactivation of latent disease, marked by a latency period of 1-3 years.[9] Hip and knee monoarticular arthritis accounts for 30% of all cases of skeletal tuberculosis in children.[14, 15] Interestingly, systemic symptoms are present in only one-third of patients with skeletal tuberculosis.[9] Septic arthritis secondary to TB is often indolent and may be indistinguishable from much more common etiologies of knee pain and inflammation in children, such as juvenile idiopathic arthritis (JIA).[7, 10, 13] Given the lack of systemic symptoms and indolent disease course, delays in definitive diagnosis and subsequent treatment of monoarthritis secondary to TB are common.[5, 6, 10, 11, 16] Delayed diagnosis of monoarticular TB arthritis can lead to synovial erosion, formation of draining sinuses, osteomyelitis, and pathologic fracture of the bone.[6, 7, 13] Additionally, articular cartilage erosion and joint space narrowing may occur in late-stage disease.[7, 17]

While case reports of tuberculous arthritis have been presented in international literature,[10, 18-20] there is a relative paucity of literature from within the United States. Given the difficulty in diagnosis and adverse outcomes of delayed diagnosis, we present the case of an 11-year-old otherwise healthy male with isolated monoarticular TB septic arthritis of the right knee.

CASE REPORT

KF is an 11-year-old healthy Chinese-American male who initially presented to orthopaedic clinic with a several-month history of intermittent right knee pain, swelling and difficulty bearing weight. He denied any recent fevers, chills, cough, weight loss, or pulmonary symptoms. The patient had recently travelled to China on multiple occasions, and noted that he had received previous treatment for his knee pain in China, including

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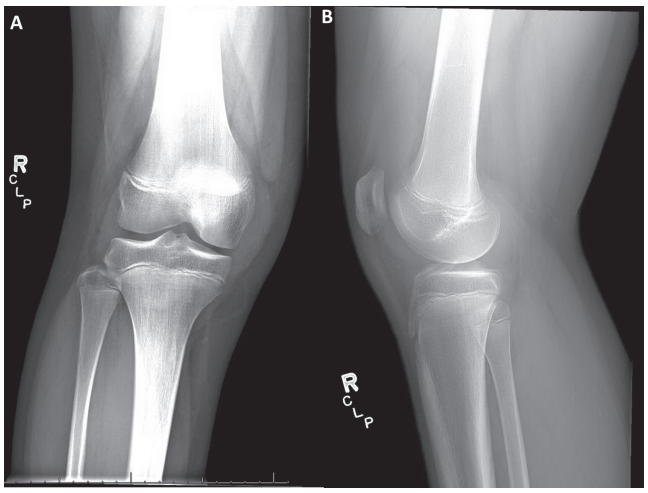

Figure 1 (a,b) – AP (a) and lateral (b) radiographs of the right knee. Overall alignment is anatomic, with the presence of a knee effusion. No osseus pathology observed.

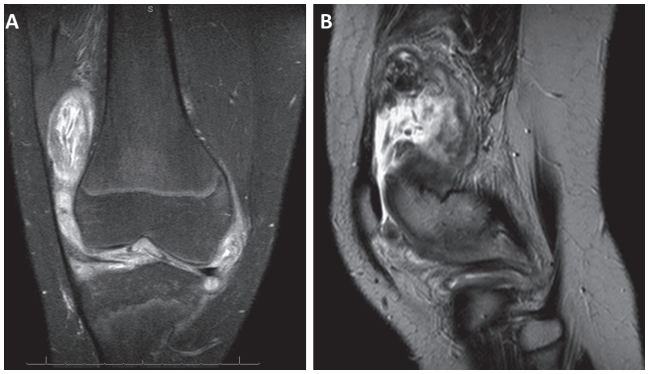

Figure 2 (a,b) – Coronal section of T2-weighted MRI (a) and sagittal section of T2-FS weighted MRI of the right knee demonstrating diffuse synovitis and free intra-articular bodies.

intra-articular steroid injections, knee aspirations, and hyaluronic acid injections. On physical examination, patient had a moderate effusion of the right knee joint without noticeable erythema. He was able to bear weight on the affected extremity in clinic and was afebrile. He also had limited range of motion, with active knee range of motion from 15° of flexion to 100° of flexion. The remainder or the physical examination was unremarkable.

Plain radiographs of his right knee revealed a large knee effusion but were unremarkable for any bony erosion or joint space narrowing (Figure 1). An MRI of the right knee with and without contrast was obtained and demonstrated a large effusion of the right knee joint with the presence of diffuse synovitis throughout the knee joint (Figure 2). Additionally, multiple intra-articular loose bodies were identified. Laboratory workup included an elevated erythrocyte sedimentation rate (27 mm/Hr [reference range 0-15 mm/Hr]), C-reactive protein (1.0 mg/dL [reference range ≤0.5 mg/dL]), and platelet count (502 x 10^3/mm^3 [reference range 150-400 x 10^3/mm^3]). His complete blood count was normal without evidence of leukocytosis.

Given his elevated inflammatory labs and knee effusion, a knee aspirate was performed in clinic. Synovial fluid aspirated from the joint was turbid and red, but contained only 7568 total nucleated cells/mm^3, with 2043 total polymononuclear cells/mm^3. His initial intra-articular gram stain, aerobic cultures, anaerobic cultures, and acid-fast bacilli culture were negative. We elected to obtain a comprehensive infection workup, including a Manotoux tuberculin skin test (PPD), QuantiFERON TB-gold serum test, and HIV test. Although his antibody assays for HIV-1 and HIV-2 were negative, his PPD test was remarkable for a site of skin reaction 20 mm in diameter. His follow-up QuantiFERON TB-gold serum testing was read as indeterminate.

In the setting of a positive PPD test and inconclusive knee aspiration assay, the decision was made to perform a diagnostic knee arthroscopy, tissue biopsy, and repeat right knee joint aspiration to improve our diagnostic yield. We elected to hold intraoperative antibiotics until cultures were performed. Prior to our diagnostic arthroscopy, we performed a repeat intra-articular knee aspirate. This aspirate yielded 15 ml of brown-tinged synovial fluid without evidence of gross purulence. During our diagnostic arthroscopy, the patient was noted to have diffuse nodular synovitis as well as numerous circular rice bodies (Figure 3). Multiple soft tissue samples were obtained for microbial culture as well as histologic examination. Tissue samples taken intraoperatively were positive for acid-fast bacilli. Histologic examination of soft tissue biopsy demonstrated granulomatous synovitis with focal necrosis (Figure 4). Synovial fluid cultures from the knee aspirate were positive for *Mycobacterium tuberculosis*. Repeat QuantiFERON TB-gold testing was positive for TB.

The patient was diagnosed with monoarticular TB infection, and he was initiated on a multi-drug treatment for TB by the infectious disease team. The treatment regimen included rifampin, isoniazid, pyrazinamide, and ethambutol. Speciation and sensitivity results of cultures demonstrated the bacterium to be resistant to isoniazid, with susceptibility of fluoroquinolones. The patient was then initiated on levofloxacin after discontinuation of the isoniazid. At the patient's four month follow up appointment, he was doing well, with marked improvements in knee stiffness and swelling. Physical examination demonstrated a 5° flexion contracture in the affected

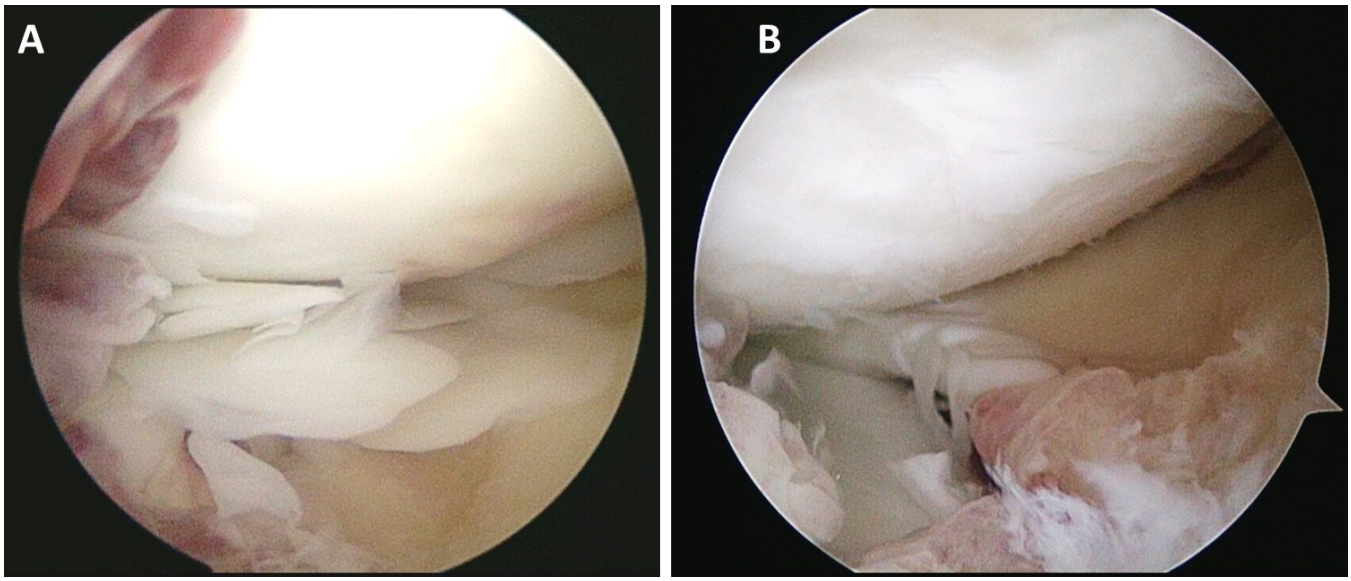

Figure 3 (a, b) – Intra-operative photographs demonstrating synovitis (a,b) and free-floating articular bodies (a).

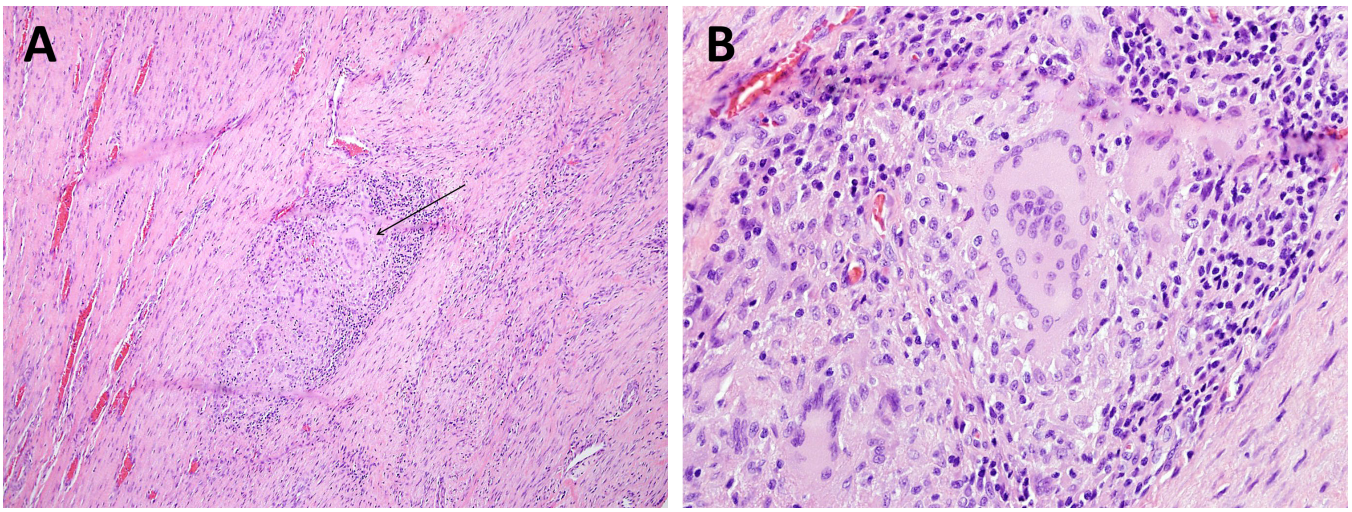

Figure 4 (a,b) – a. Histopathology slide (100x power) of resected synovial tissue demonstrating granulomatous synovitis with central focal necrosis (black arrow). Histopathology slide (400x power) re-demonstrating granuloma with focal necrosis.

knee, but was otherwise unremarkable. He is currently scheduled for a 9 month course of antibiotic treatment.

DISCUSSION

The clinical case above illustrates the history and physical exam findings in an adolescent male with tuberculous arthritis of the knee. Previously undiagnosed disseminated tuberculosis that presents as isolated monoarticular arthritis is rare, with an estimated incidence of 1-2% within the United States.[5, 10-13, 16] Risk factors for developing TB in the United States include being foreign born, having a foreign born parent, and living outside of the United States for greater than two months.[21] A history of close contact with infected persons or travel to endemic areas may be difficult to establish, or may be absent entirely in up to 16% of patients.[10, 13] Our subject had a recent travel to China and was born in China (as were both of his parents); both of these are identifiable risk factors for developing septic TB of the knee. According to the World Health Organization (WHO) annual report in 2016, China had 804,163 cases of TB with an annual incidence of 67 cases per 100,000 and a mortality rate of 2.6 cases per 100,000.[1] China's annual expenditure for TB prevention and treatment was

Table 1

Stage	Radiographic Findings
I	Localized osteopenia, no bone lesions, +/- soft tissue swelling
II	One or more areas of osseus erosion, without narrowing of the joint space
III	Narrowing of the joint space without gross anatomical disorganization
IV	Narrowing of the joint space with gross anatomical disorganization

Table 1 – Kerri and Martini Classification

$372 million USD per year.[1] Another well-described cohort at an increased risk of developing symptomatic TB are children with juvenile rheumatoid arthritis patients on immunomodulating agents, such as tumor necrosis factor-alpha.[22, 23] Often times patients with presumed juvenile rheumatoid arthritis are treated with intra-articular steroids.[10] The patient in our case report did not have a prior history of juvenile rheumatoid arthritis or immunomodulating agents.

Our case of monoarticular tuberculosis presented with knee pain, swelling, stiffness, and decreased range of motion 6 months after foreign travel. In a recent case review, Rosenberg et al. found that only approximately 15% of children present with erythema and joint effusion that would be suggestive of a septic arthritis.[9] Bone pain proximal or distal to the joint and mechanical locking of the knee have also been reported.[10,13] These indolent findings are in stark contrast to the clinical presentation of a child with a bacterial septic arthritis secondary to a more common pathogen (i.e. *Staphylococcus aureus*). Common pathogenic organisms for bacterial septic arthritis in children include *Staphylococcus aureus*, *Kingella kingae*, *Neisseria gonorrhoeae*, and *Haemophilus influenza* type B.[24] Fever, pain, and swelling are common clinical symptoms of these organisms.[24]. Transient synovitis may also present in a similar manner to septic arthritis with pain and swelling of the affected joint.

Plain radiographs are often the first imaging modality employed to evaluate children with knee pain, swelling, or decreased range of motion. These radiographs may be unremarkable in the acute phase of TB.[6, 25] In later stages, joint effusion, osteopenia, widening of the intercondylar notch, osseous erosion and cortical defects, bone cysts and peri-articular lytic lesions represent common findings of monoarticular TB arthritis. A unique finding of monoarticular TB is its ability to cross the epiphysis into the joint space. This trans-epiphysial spread of TB osteomyelitis is not characteristic of other causes of septic arthritis.[26] In young children, the epiphysis may not be ossified and joint destruction is often underestimated. The epiphysis can also appear inappropriately mature for the patient's age secondary to hyperemia as a result of the infection.[19] Involvement of the epiphysis, often as a result of the spread of infection from a metaphyseal nidus, may manifest as epiphyseal widening.[6,19,26] Periosteal reaction may be present or absent.[27] In chronic cases, radiographic joint space narrowing can occur.[11,12,15] Phemister's triad, first described by D.B. Phemister in 1924, encompasses the classical radiographic findings of mycobacterial septic arthritis: periarticular osteoporosis, erosion of subchondral bone, and joint space narrowing indicative of destruction of articular cartilage.[28] Kerri and Martini developed a classification system that placed patients into one of four stages based on radiographic findings (Table 1).[25] Numerous studies have demonstrated that radiographic stage at the time of presentation is predictive of overall functional outcome of the affected knee.[7,8,25] Our patient would fall into stage I based on the Kerri and Martini classification, and therefore would be predicted to make near to full recovery in terms of knee motion and function.[7, 8, 25] Ultrasound may be helpful in identifying the presence of a joint effusion.[26] Advanced imaging, including CT and MRI, may be useful for identifying the extent of bone destruction as well as synovial and soft tissue involvement.[26] MRI may also be useful for identifying free-floating bodies within the joint, including rice bodies, which may be seen in tuberculous arthritis, as was the case in this patient.[29] Although imaging of the affected joint may reveal the presence of a pathologic process within the joint, findings are often not specific enough for a concrete diagnosis, and further laboratory workup is often necessary.

Pediatric patients presenting with knee pain, swelling, and erythema often undergo numerous laboratory assays including complete blood counts with differential, ESR, and CRP. If clinical suspicion is high, more specific tests for tuberculosis (PPD skin testing, QuantiFERON TB-gold serum testing) may be warranted. Several case series have shown than ESR is often elevated above 20 mm/Hr in 80-96% of children with TB monoarthritis.[11,23] CRP and platelet count were not frequently reported in the reviewed studies, but were elevated in the case of KF. Mantoux skin testing is frequently positive (≥10mm) in immunocompetent patients with TB, ranging from 87%-97% in recent case series.[7, 8, 13, 30] Examination with QuantiFERON TB-gold serum was not widely reported, but was indeterminate in this case. Cell count from synovial fluid in tuberculous arthritis is often less than more traditional cases of septic arthritis, ranging from 5,000-20,000 total cells with a predomination of polymorphonuclear leukocytes (PMNs).[10, 12, 13]

The gold standard for diagnosing TB arthritis is isolating the causative bacterium on tissue culture or histological study.[6,7,10] Needle biopsy of synovium and bone has been established as an effective method of obtaining material for culture and histopathologic examination as described above, with the advantage of being much less invasive than an open synovial or bone biopsy.[7,12,31] However, the synovial aspirate may yield a negative result, especially in the earlier stages of the disease potentially due to a lack of an early immune response.[6,7,12] Culture-negative intraarticular tissue samples during arthroscopy may undergo histologic evaluation, and more often yields a definitive diagnosis.[8,10,20,24,25] Characteristic histologic findings from open biopsies include caseating granulomas and the presence of giant cells.[6-8,10]

Recently, arthroscopy has been proposed as an alternative to needle biopsy for the diagnosis of tuberculous arthritis in older children.[13,24,25] Arthroscopy of affected joints remains minimally invasive relative to open biopsy, and synovial tissue from multiple sites within the joint may be collected for culture and histopathology. Guo et al. reported a recent series of 41 patients with tuberculous arthritis of the knee, in which the diagnostic yield of arthroscopy was >90% of its cohort.[32] Additionally, direct visualization of the affected synovium has diagnostic value, and is not accomplished with needle biopsy. Synovial projections described as "tongue-like" or "nodular" may be observed in TB arthritis.[32] Additionally, free-floating rice bodies described previously may be observed, retrieved, and sent for histopathologic examination.[29] Arthroscopy has the added benefit of being therapeutic in addition to diagnostic, the ability to debride and resect inflamed synovium and free-floating bodies within the joint.[29,31,32] Multiple studies have reported rapid and sustained improvement in knee range of motion following arthroscopy.[31,32] Arthroscopic arthrolysis has been well-described as an effective long-term treatment of arthrofibrosis, as may be seen following ACL reconstruction and total knee arthroplasty.[33,34] We believe that arthroscopy may play a similar role in the treatment of tuberculous arthritis, especially in cases of delayed presentation with prolonged periods of inflammation and decreased knee range of motion. Restoration of range of motion early in the disease course and post-operative physical therapy have also been proposed as adjunct treatments aimed at preserving range of motion. [31,32]

Chemotherapeutic regimens often involve three to four drugs (isoniazid, rifampin, pyrazinamide, and ethambutol) for an extended period of time (e.g. ≥12 months).[6,8,35,36] In a recent sudy, the Treatment Action Group demonstrated that worldwide TB research funding has increased from $358 million USD in 2005 to $676 million USD in 2013, with 38% of the total expenditure related to drug therapies.[35] The use of this three to four drug regimen has increased substantially in the United States from 40.3% of TB patients in 1993 to 84.7% in 2015.[3] Additionally, treatment monitoring is advocated by the CDC, with 92.1% of patients undergoing treatment monitoring in 2013.[3] Although the rate of multi-drug resistant TB has remained stable in the United States at 1.1% (37 persons) in 2015, foreign-born individuals represent over 86% of these cases. Additionally, the World Health Organization (WHO) 2016 report shows a significantly higher rate of multi-drug resistant TB in China (5.1 cases per 100,000) when compared to the United States.[1]

Timing of intervention directly influences patient outcomes in TB arthritis. Early initiation of antibacterial therapy has been shown to yield improved ROM and function in children with monoarticular TB.[6-8] Recurrence of infection does occur in patients treated with medical and surgical management, with rates estimated to be as high as 29% in adult population in endemic countries.[37] Recurrence is often due to drug-resistant strains of tuberculosis, and usually occurs within the first 6 months following completion of the initial course of therapy. End stage arthritis secondary to late-stage monoarticular TB can be treated with a total knee arthroplasty after the completion of antituberculosis medication.[38, 39] Antituberculosis medication is often continued after surgery. Unfortunately, re-infection rates following total knee arthroplasty secondary to monoarticular TB infection ranges from 14-31%.[38, 39] Arthrodesis remains an option for patients that fail treatment with arthroplasty, offering pain relief and joint stability.[39]

CONCLUSION

Tuberculosis monoarthritis of the knee in children, while rare in the United States, remains a difficult condition to diagnose and treat. A high clinical index of suspicion coupled with a comprehensive history, physical examination, and diagnostic workup is required to make a timely and accurate diagnosis. Consistent follow-up during a protracted treatment course with both orthopedic and infectious disease physicians is necessary to ensure treatment efficacy, and to identify treatment failures or complications in their early stages. Knee arthroscopy has a developing and increasing role in both the diagnosis and treatment of tuberculous monoarthritis.

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BONE MINERAL DENSITY T-SCORES DERIVED FROM CT ATTENUATION NUMBERS (HOUNSFIELD UNITS): CLINICAL UTILITY AND CORRELATION WITH DUAL-ENERGY X-RAY ABSORPTIOMETRY

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ABSTRACT

Background: Clinical computed tomography (CT) studies performed for other indications can be used to opportunistically assess vertebral bone without additional radiation or cost. Reference values for young women are needed to evaluate diagnostic accuracy and track changes in CT bone mineral density values across the lifespan. The purpose of this study was to determine reference values for lumbar trabecular CT attenuation (Hounsfield units [HU]) and determine the diagnostic accuracy of HU T-scores (T-score$_{HU}$) for identifying individuals with osteoporosis.

Methods: We performed a retrospective single-center cohort study of patients undergoing CT of the lumbar spine. Reference values for lumbar spine Hounsfield units were determined from a reference sample of 190 young women aged 20-30 years undergoing CT scan of the lumbar spine. A separate sample of 252 older subjects undergoing CT and dual-energy X-ray absorptiometry (DXA) within a 6-month period that served as a validation cohort. Osteoporosis was defined by T-score$_{DXA}$ ≤ -2.5. Reference values were determined for lumbar HU from L1 to L4 from the reference cohort (24.0 ± 2.9 years). T-score$_{HU}$ was calculated in the validation cohort (58.9 ± 7.5 yrs). Receiver operating characteristic (ROC) curves were used to assess sensitivity and specificity of T-score$_{HU}$ for this task.

Results: Reference group HU ranged from 227 ± 42 at L3 to 236 ± 42 at L1 (P < 0.001). Validation group T-score$_{DXA}$ was -0.7 ± 1.5 and -0.9 ± 1.2 at lumbar and femoral sites respectively. Mean T-score$_{HU}$ was -2.3. T-score$_{HU}$ of -3.0, corresponding to 110 HU, was 48% sensitive and 91% specific for osteoporosis in the validation group. ROC area under the curve ranged from 0.825 to 0.853 depending on lumbar level assessed.

Conclusions: Although lumbar trabecular HU T-scores are lower than DXA T-scores, thresholds can be selected to achieve high sensitivity and specificity when screening for osteoporosis. Patients with a lumbar T-score$_{HU}$ ≤ -3.0 should be referred for additional evaluation. Further research into HU T-scores and clinical correlates may also provide a tool to assess changes in vertebral bone and the relationship to fracture risk across the lifespan.

Keywords: screening, computed tomography, dual-energy x-ray absorptiometry, osteoporosis

INTRODUCTION

In 2009, 10% of the U.S. population underwent computed tomography imaging (CT), accounting for 75 million scans.[1] In addition to established clinical indications, CT imaging is actively being investigated as a screening tool for conditions such as colorectal polyps, lung cancer, coronary artery disease, and metabolic bone disease. Clinical CT exams, such as for evaluation of trauma patients, contain unused quantitative information that could provide an opportunity to screen large numbers of patients for metabolic bone disease at no additional radiation exposure and little cost when CT studies have been ordered for other indications.[2-6]

Osteoporosis is a condition of low bone mineral density and poor bone quality resulting in increased risk of fracture.[7] Among women ≤ 65 years old with osteoporo-

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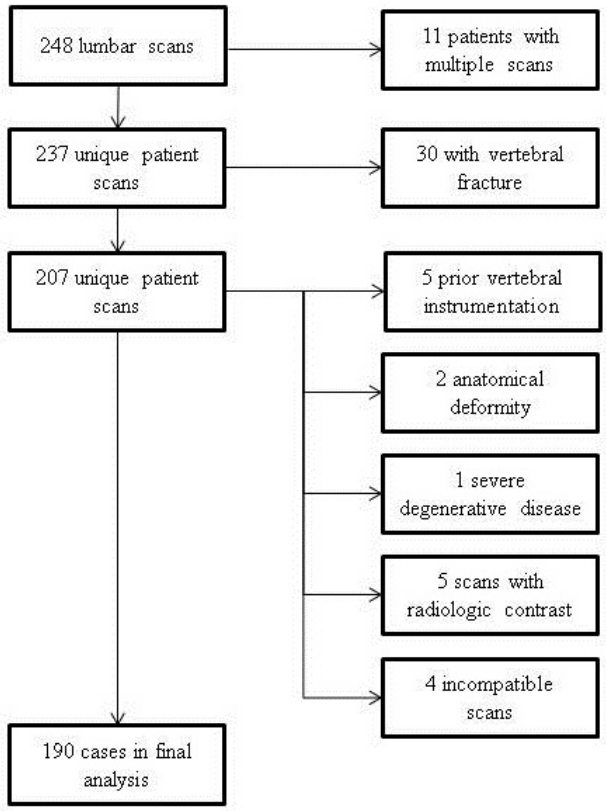

Figure 1. Flow diagram demonstrating frequencies of exclusions by criteria.

sis without prior vertebral fracture, 28% will experience vertebral fracture within 15 years.[8] Still, osteoporosis is underdiagnosed and undertreated.[9] The current standard of bone mineral density (BMD) assessment, dual-energy X-ray absorptiometry (DXA), is based upon a person's BMD T-score at the hip and lumbar spine.[10,11] These T-scores ($T\text{-score}_{DXA}$) are calculated as the difference between the individual's BMD and a reference population mean, divided by the standard deviation of the reference population. Osteoporosis is operationally defined by World Health Organization as a BMD 2.5 SD or more below the reference population mean, i.e. a T-score ≤ -2.5, whereas osteopenia is a state of low bone mass defined by a BMD T-score between -1 and -2.5.

Although World Health Organization diagnostic criteria apply only to DXA measures at the femoral neck and lumbar vertebrae, CT densitometry of the spine is equal to or superior to DXA for assessing vertebral fracture risk.[12] One explanation for this is the ability to exclude cortical bone and vertebral posterior elements, which contribute less to vertebral compressive characteristics than trabecular bone but may change measured BMD due to degenerative changes or when deformity is present.[13,14] CT attenuation numbers or values, measured in Hounsfield units (HU), can be attained prospectively or retrospectively from all clinical CT studies and can be used to estimate BMD without added costs or radiation.[2] Traditionally, this required bone mineral phantoms and dedicated software to assess bone density. Recently, multiple studies have reported excellent reproducibility and strong accuracy identifying osteoporosis with simple CT attenuation measures of the spine, obviating the need for bone mineral reference phantoms or dedicated software.[2-4,15,16] Appropriate HU reference values for 20 to 30 year old women have been reported from a relatively small sample.[2] Expansion of this reference population could provide more robust CT reference intervals, thus improving CT-based screening for metabolic bone disease.

We hypothesized that vertebral CT attenuation, in HU, could identify individuals at risk for metabolic bone disease using T-scores based upon CT attenuation ($T\text{-score}_{HU}$). To this end, we tested the reliability of vertebral HU measures and then measured a cohort of young women to create a reference standard in order to compare it to other HU measures. We gathered data from a second cohort that had undergone both DXA screening (the "gold standard" for osteoporosis screening and diagnosis) and abdominal CT to examine the diagnostic accuracy of $T\text{-score}_{HU}$ based upon $T\text{-score}_{DXA}$.

PATIENT SAMPLE

This retrospective cohort study was approved by a major U.S. academic medical center Institutional Review Board and exempted from informed consent. Records were identified by querying our picture archiving communication and storage (PACS) database. The reference cohort was identified by searching for lumbar CT scans performed on women aged 20 to 30 years, performed between January 2001 and July 2012. We identified 248 records in this cohort, with 58 subsequently excluded; exclusions included eleven repeat scans, 30 pre-existing vertebral fracture, five prior vertebral surgery, five radiologic contrast dye, two anatomical deformity, one severe degenerative disease, and four incompatible scan parameters (figure 1). This left 190 unique cases in the final reference cohort.

A separate validation cohort consisted of 252 older subjects undergoing CT colonography who also underwent DXA bone study within six months.

Sample size estimation was based on attaining enough precision for mean HU, measured as the width of the 95% confidence interval. Based on previously reported lumbar HU standard deviation of 38 HU, we predicted 95% confidence intervals of ± 5 HU for a sample of 225 subjects and ± 6 HU for 157 subjects, respectively (4). Therefore, our goal was 225 subjects for the reference cohort.

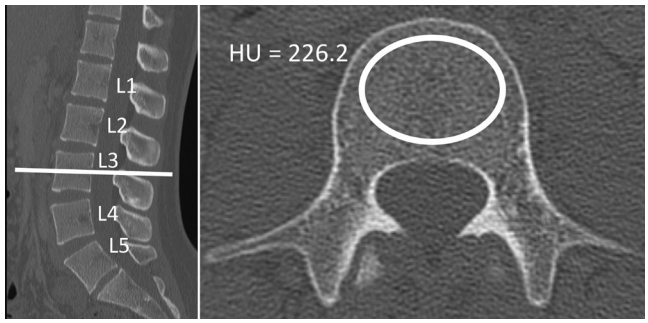

Figure 2. CT attenuation was measured by first locating the mid-vertebral body in the sagittal plane. Axial click-and-drag elliptical ROI were manually placed to be as large as possible while safely avoiding the cortical shell and vertebrobasilar complex. The picture archiving software reported the average CT attenuation of the ROI in Hounsfield units (HU)

METHODS

Imaging

Lumbar CT was performed using helical sixty four-channel CT scanner with automated exposure control, previously demonstrated to approximate trabecular bone mineral density (Light Speed Series, GE Healthcare).[2] CT parameters included slice thickness of 1.25 mm with a 0.625 mm interval, tube voltage of 120 kVp, automated exposure control tube current of 300 mA (Smart mA/ Auto mA range, 150 to 750), and a bone reconstruction algorithm (window width/window level, -3000/300).

CT images were retrospectively analyzed using a commercially available picture archiving and communication system (McKesson, San Francisco, California). Two-dimensional reconstructions were obtained in the axial and sagittal planes (figure 2). CT attenuation was measured in Hounsfield Units (HU) by placing a click-and-drag elliptical region of interest (ROI) within axial sections of vertebral trabecular bone. ROI were made as large as possible while avoiding vertebrobasilar complex, mild degenerative changes, and cortical surfaces. For the reference cohort three axial measures were included for each vertebra: inferior to cranial endplate, mid-body, and superior to caudal endplate. Dynamic oblique multiplanar reformatting (MPR) was used to align ROI parallel to the vertebral endplates in the sagittal plane. Cranial and caudal ROI were measured approximately 4 mm from the vertebral endplate. Lumbar vertebrae from L1 through L4 were assessed. L5 vertebrae were also measured, but were not reported due to potential difficulties that might arise when attempting to measure mid-body ROI without MPR reformatting due to lumbar lordosis and possible sacralization of the L5 vertebral body. HU measures in the older validation cohort were measured at a single mid-vertebral axial ROI without MPR reformatting, as these methods have been evaluated and shown to produce similar reliability.[16]

Dual-energy x-ray absorptiometry was performed using standard techniques on Lunar Prodigy densitometers (GE Healthcare, Waukesha, WI). Central DXA BMD T-scores were recorded from the lumbar spine and hip. Subjects were categorized as having osteopenia ($T\text{-score}_{DXA}$ between -1.0 and -2.5 SD) or osteoporosis ($T\text{-score}_{DXA} \leq$ -2.5 SD) based upon the lowest $T\text{-score}_{DXA}$ from either femoral or vertebral region.

Intra-rater and Inter-rater Reliability

Reliability of HU measures was assessed on a random sample of 20 subjects. Two separate readers performed HU measures from L1 to L3 at cranial, mid-body and caudal sections. Rater A, a research fellow, performed each measure on two separate occasions separated by more than one week and a rater B, an orthopaedic surgery resident, performed each measure once. Intra- and inter-rater reliability of HU measures was assessed using intraclass correlation coefficients (ICC) with an absolute agreement definition. ICC greater than 0.75 was considered excellent.[17]

Statistical analysis

Results are reported as mean ± standard deviation (SD), unless noted otherwise. A Wilcoxon rank-signed test was used to compare attenuations at different vertebral levels. Threshold for statistical significance was set at two-sided alpha = 0.05. Reference values including mean, SD and confidence intervals were calculated from the reference cohort.

Our goal was to assess whether T-score based on vertebral CT attenuation ($T\text{-score}_{HU}$) is in close agreement with conventional DXA-derived T-scores ($T\text{-score}_{DXA}$), considered here as the gold standard. To this end, we had access to both the CT and DXA data from Pickhardt et al., 2011.[4] The trabecular CT attenuation at L1 through L4 were converted into T-scores by subtracting the reference mean and dividing the result by the reference standard deviation,

$$T\text{-score} = (HU - \mu ref)/\sigma ref \quad \text{(equation 1)}$$

where *HU* represents CT attenuation in Hounsfield Units, and μref and σref are the mean and standard deviation of the reference values calculated from the reference cohort, respectively. T-score histograms were obtained at each level for both HU and DXA to assess whether these were approximately normally distributed.

$T\text{-score}_{HU}$ was plotted against central $T\text{-score}_{DXA}$ using the lower of two DXA T-scores measured at the lumbar spine and hip. The coefficients of determination (R^2) and correlation (ρ) were obtained from regression analyses to

Table I.
Reference CT attenuation reference values (Hounsfield units) from lumbar CT scans

	n	mean	std. dev	95% CI	-1 SD	-2.5 SD
L1	187	236.3	41.8	230.3, 242.3	194.5	131.8
L2	188	234.3	42.1	228.3, 240.3	192.2	129.1
L3	189	227.3	42.0	231.1, 243.9	185.3	122.3
L4	188	229.7	42.6	223.6, 235.8	187.1	123.2
L1 to L4Avg	184	232.4	40.7	226.5, 238.2	192.0	129.6

Table 1. CT attenuation measures (Hounsfield units) are reported from single-slice mid-body trabecular ROI taken from lumbar CT scans performed on 190 20 to 30 year old women comprising our reference cohort. Column one lists the respective lumbar vertebral levels. Hounsfield unit values corresponding to T-scores of -1 and -2.5 are listed in the columns labeled -1 SD and -2.5 respectively.

Table II.
CT attenuation values (Hounsfield units) from lumbar CT scans of validation cohort

	mean	std. dev
L1	152.9	38.3
L2	143.1	39.3
L3	130.5	38.6
L4	133.2	38.3

Table 2. Lumbar CT attenuation measures (Hounsfield units) from validation cohort of 239 women and 13 men aged 59 ± 7.5 years. Column one lists the respective lumbar vertebral levels.

Table III. Validation cohort T-scores from DXA and CT measures

	CT T-score	vertebral DXA T-score	femoral DXA T-score
L1	-2.0 ± 0.9	-0.7 ± 1.5	-0.9 ± 1.2
L2	-2.2 ± 0.9		
L3	-2.4 ± 0.9		
L4	-2.3 ± 0.9		

Table 3. CT measures were based upon single-slice mid-body regions of interest. Regression analysis performed between externally validated lumbar trabecular CT T-score and the lowest DXA T-score from either the lumbar or femoral region, as well as between CT T-score and lumbar DXA T-score.

assess the degree of linear association between T-score$_{HU}$ and T-score$_{DXA}$. This same analysis was then repeated comparing T-score$_{HU}$ to T-score$_{DXA}$ from the lumbar spine to assess for changes in relationship when both T-score$_{HU}$ and T-score$_{DXA}$ are based on the same anatomical region. To assess the ability of T-score$_{HU}$ at different lumbar levels to identify osteoporosis, receiver operating characteristic (ROC) curves were obtained, and the area under the curve (AUC) was calculated.

RESULTS

The reference cohort included 190 women in the third decade of life. The validation cohort included 239 women and 13 men. Mean age of the validation cohort was 58.9 ± 7.5 years.

Intra-rater and Inter-rater Reliability

Intra-rater reliability of lumbar HU measured at cranial, mid-body, and caudal ROI in 20 reference cohort subjects was excellent, with ICC exceeding 0.98 at each location measured within the L1 to L3 vertebral bodies (i.e. cranial, mid-body and caudal). Inter-rater reliability was also excellent, exceeding 0.98 at the mid-body locations. Cranial and caudal measures demonstrated more inter-rater variability than mid-body measures, as ICC ranged from 0.8 and 0.9.

Reference cohort

Mean lumbar CT attenuation from the reference cohort ranged from 229.7 at L3 to 236.3 HU at L1 (table 1). The L1 to L4 mean HU value was 232.4 ± 40.7 (95% CI for mean: 226.5, 238.2). HU were significantly higher at L1 and L2 compared to L3 and L4 ($P<0.001$).

Validation cohort

The mean T-score$_{DXA}$ in the validation cohort was -0.7 ± 1.5 for vertebral DXA (min -3.4, max 4.5) and -0.9 ± 1.2 for femoral DXA (min -3.6, max 3.7) (table 2). Mean lumbar T-score$_{HU}$ was -2.3 and ranged from -2.0 ± 0.9 at L1 to -2.4 ± 0.9 at L3. Similar to the reference cohort, lumbar CT attenuation was lowest at L3 and highest at L1 in the validation cohort.

All T-scores were approximately normally distributed, although large positive T-scores were slightly more likely than large negative T-scores. T-score$_{HU}$ was more negative than T-score$_{DXA}$, with a difference in T-score

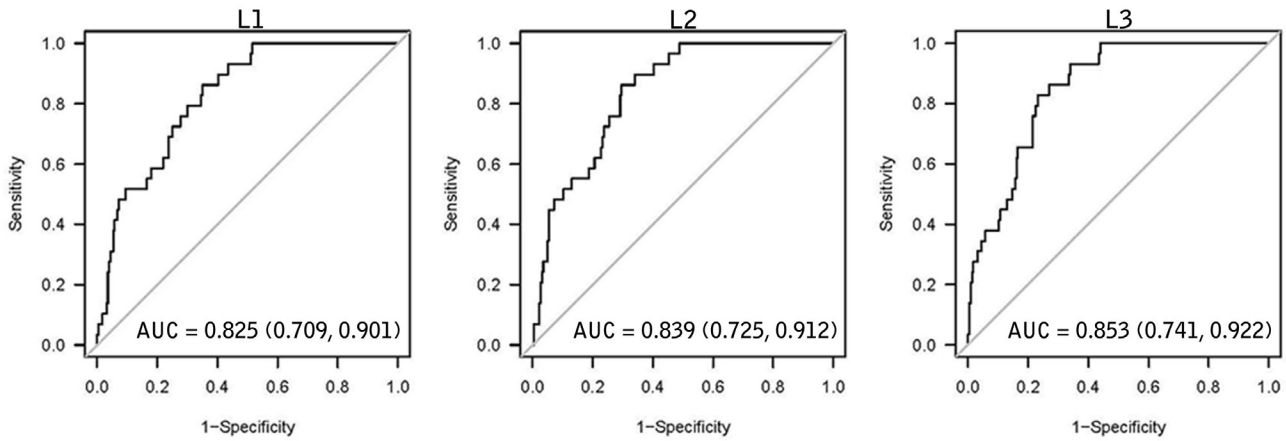

Figure 3. Receiver operating characteristic (ROC) curves assessing performance of lumbar spine Hounsfield Unit T-score (T-score$_{HU}$) to identify subjects with osteoporosis as diagnosed by DXA BMD T-score (T-score$_{DXA}$). Each point along the ROC curve represents the relationship between sensitivity (true positive rate) and the quantity 1-specificity (false positive rate). More negative T-scores occur closer to the origin. At the first lumbar vertebrae a T-score$_{HU}$ of -3.0 (110 HU) was 90% specific and 48% sensitive for osteoporosis, while a T-score$_{HU}$ of -2.0 was 50% specific and 93% sensitive for osteoporosis as classified by DXA.

of -1.1 to -1.6 depending on the anatomical region of interest compared (table 3). Regression analysis of T-score$_{DXA}$ compared to T-score$_{HU}$ resulted in coefficients of determination (R^2) ranging from 0.32 to 0.36. Correlations between T-score$_{DXA}$ and T-score$_{HU}$ were similar for CT attenuation measured regardless of vertebral body measured from L1 to L4 (range 0.57-0.60). Comparing T-score$_{HU}$ to vertebral T-score$_{DXA}$ did not increase the correlation coefficient compared to using the lower of either vertebral or femoral T-score$_{DXA}$, as is used in standard DXA osteoporosis screening.

ROC analysis to assess the diagnostic accuracy of T-score$_{HU}$ for identifying individuals with osteoporosis resulted in area under the curve (AUC) ranging from 0.825 [0.709, 0.901] at L1 to 0.853 [0.741, 0.922] at L3 (reported as AUC [95% confidence interval]) (figure 3). L1, a T-score$_{HU}$ of -3.0 is 90% specific and 48% sensitive for osteoporosis, as defined by World Health Organization criteria of T-score$_{DXA}$ equal to or more negative than -2.5. For L1, a T-score$_{HU}$ of -2.0 is 50% specific and 93% sensitive for osteoporosis. These T-score$_{HU}$ values correspond to L1 HU thresholds of 110 and 153 HU, respectively.

DISCUSSION

Our findings further validate previous publications applying CT modalities to opportunistic screening of metabolic bone disease. CT studies performed about the abdomen, pelvis, or lumbar spine can be used to assess bone density using Hounsfield Units to indicate patients for further assessment of metabolic bone disease.

Fundamental differences exist between DXA and CT vertebral densitometry, resulting in differences in bone density measures: DXA produces planar measures obtained in the anteroposterior plane and includes cortical bone, posterior elements, vascular calcification, and degenerative changes, potentially leading to spuriously elevated bone mineral density without correlating increase in vertebral body strength, and making DXA less sensitive to changes in fracture risk.[18,19] Degenerative and arthritic changes in the posterior elements may reduce the sensitivity of DXA scans to decreases in trabecular bone density, at least partially explaining the greater absolute T-scores seen with DXA as compared to trabecular Hounsfield unit T-scores. These differences also help explain the low correlation between the two T-scores, with R^2 only reaching 0.32. These issues may lead to significant false negative rates using DXA: Pickhardt et al. reported that 50% of subjects with moderate or severe radiographic vertebral fractures had non-osteoporotic T-score$_{DXA}$ and the majority of self-reported fractures in the National Osteoporosis Risk Assessment study were among women with non-osteoporotic T-score$_{DXA}$.[16,22] Helical CT technology produces volumetric measures and allows selective placement of regions of interest which greatly reduce the impact of these confounding factors. Thus, CT provides better accuracy and precision for measuring metabolically active trabecular BMD and monitoring changes over time.[20,21]

Our L1 to L4 average of 232 ± 41 HU is similar to previously reported lumbar HU values of 248 ± 52 and 222 ± 36 HU in similar aged women.[2,23] Pickhardt et al. reported HU thresholds for L1 allowing clinicians to screen for osteoporosis with > 90% sensitivity and specificity using screening thresholds of 160 HU and 110 HU, respectively [16]. Our data uses subjects undergoing both DXA and CT measures to link these HU thresholds to T-scores

based upon reference intervals from young women similar in age to those used in constructing the NHANES reference intervals for assessing DXA T-scores.[10] T-scores have become a widely accepted parameter for diagnosis and treatment of osteoporosis. However, T-score$_{DXA}$ thresholds are not applicable to CT-based measures because DXA scans include cortical bone and posterior vertebral elements. Similar to previous reports, we found T-score$_{HU}$ was more negative than T-score$_{DXA}$. In concordance with our results, previous comparisons of DXA and QCT T-scores found QCT T-score of -3.3 equal in sensitivity to spinal DXA for predicting vertebral fracture risk.[12] Our data suggest that a T-score$_{HU}$ of -3.0 is highly specific for osteoporosis, meaning a high proportion of non-osteoporotics are correctly identified as such. Therefore, we recommend patients with T-score$_{HU} \leq$ -3.0 be referred for further evaluation of metabolic bone disease. Likewise, a T-score$_{HU}$ of -2.0 was highly sensitive, meaning a high proportion of osteoporotics are correctly identified as such (figure 3). Based on these results, we recommend against referring patients with T-score$_{HU} \geq$ -2.0 for additional workup, unless otherwise indicated by established screening guidelines or clinical presentation. ROC analysis, which is a comparison of sensitivity (true positive rate) and the quantity [1-specificity] (false positive rate), showed similar AUC for L1, L2, and L3 suggesting that T-score$_{HU}$ has good accuracy for discriminating between osteoporotic and non-osteoporotic bone regardless of which lumbar vertebrae is measured.

In addition to allowing calculation of T-scores from vertebral HU, our reference values provide insight into the distribution of vertebral CT attenuation in young women and allows for comparison with other cohorts at increased risk of fracture. These reference values are also a starting point for estimation of age-adjusted risk profiles that may allow future inclusion of vertebral HU as an input for predicting clinical fracture risk and informing treatment decisions.

The small geographic region sampled and a lack of demographic information for the women included in our analysis is a significant limitation to general applicability of these results. Our results are further limited by not screening subjects for conditions that can affect bone mineral density, including menopausal status. We selected reference cohort subjects undergoing lumbar CT independent of the clinical indication with the expectation that this would be a relatively heterogeneous cross-section of the regional population. These reference values should be expanded to include young women from other geographical regions and should be evaluated in prospective studies to determine age-adjusted fracture risk and response to treatment based upon trabecular spinal HU measures. Furthermore, we recognize the potential harm from radiation exposure and do not recommend CT analysis for the sole indication of osteoporosis screening, but rather recognize the clinically relevant information available in CT imaging acquired in appropriate clinical scenarios.

Our findings corroborate previous publications supporting the use of various CT modalities for screening subjects for metabolic bone disease. While it is not recommended for replacing central DXA as the standard of bone density assessment, T-score$_{HU}$ opportunistically measured from routine clinical CT studies is a time and cost efficient tool for identifying subjects who are likely to have metabolic bone disease and may benefit from additional studies or treatment.

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OVERUSE OF MAGNETIC RESONANCE IMAGING IN THE DIAGNOSIS AND TREATMENT OF MODERATE TO SEVERE OSTEOARTHRITIS

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ABSTRACT

Background: MRI in the evaluation of end-stage knee joint osteoarthritis (OA) is usually unnecessary when radiographic and clinical evidence of gonarthrosis is clear. The purpose of this study was to assess the prevalence of MRI scans ordered in patients with radiographically obvious gonarthrosis and to examine the characteristics of health care providers who ordered these imaging studies.

Methods: We retrospectively identified 164 patients diagnosed with moderate to severe OA who were referred for total knee replacement (TKA) over a one-year period. The percentage of patients who had an MRI scan with or without X-ray, within the preceding 3 months prior to referral, were calculated. Subgroups were analyzed to identify characteristics that may influence the decision to order an MRI, including K-L grade, provider type, level of training, and practice location.

Results: Of 145 patients, 19 (13.1%) presented with an MRI scan. Between the number of MRI scans ordered, there was a significant difference when comparing physicians versus non-physicians, with physicians ordering less MRI scans (p=0.018). There was a significant difference when comparing non-academic versus academic, with academic providers ordering less MRI scans (p=0.044). There was no significant difference with fellowship training or provider proximity to our academic institution.

Conclusions: In this study, 13.1% of patients with radiographically obvious knee OA obtained an MRI prior to referral for TKA. Non-physicians and non-academic physicians were more likely to order MRI scans. Improved education for referring providers may be necessary to decrease overuse of MRI in the diagnosis of moderate to severe arthritis.

Level of Evidence: Level II

Keywords: magnetic resonance imaging; testing and procedures; osteoarthritis; gonarthrosis

INTRODUCTION

The disease burden of knee osteoarthritis (OA) affects an estimated 27 million people.[1] More than 600,000 of these patients undergo total knee arthroplasty (TKA) annually in the United States.[2,3] With such a high prevalence of disease and surgical treatment, it is critical to identify cost-effective strategies for accurately diagnosing and managing moderate to severe OA. Health care expenditures continue to increase and the overuse of diagnostic imaging including magnetic resonance imaging (MRI) is a significant contributor to costs.[4,5]

Clinical examination of the patient with plain radiography is 91% sensitive and 86% specific for diagnosing knee OA.[6] The diagnostic accuracy of this combination increases with worsening severity of OA. One meta-analysis calculated that the sensitivity and specificity of MRI for making the diagnosis of arthritis to be 61% and 82%, respectively.[7] While MRI has the ability to visualize abnormalities in OA patients not present on radiography – including bone marrow lesions, ligamentous damage, and meniscal tears[8-12] – the clinical relevance of these findings and implications for surgical treatment in severe OA are not well understood. For example, MRI can detect meniscal tears, but these are frequent findings in patients with radiographic evidence of OA, with no difference in prevalence among those with and without symptoms.[13-15] Similarly, the presence of undiagnosed ACL tears among patients with OA is not associated with increased pain or functional instability.[16,17] Therefore, MRI has little to no role in the initial evaluation of pa-

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Table I. Subgroups of providers with the amount of patients presenting with an MRI vs. without an MRI

	MRI	Without MRI	Total
Physician	15	121	136
Non-Physician	4	5	9
Academic	1	34	35
Non-Academic	18	92	110
Fellowship Trained	4	23	27
Non Fellowship	15	103	118
≥40 miles	11	54	65
<40miles	8	72	80

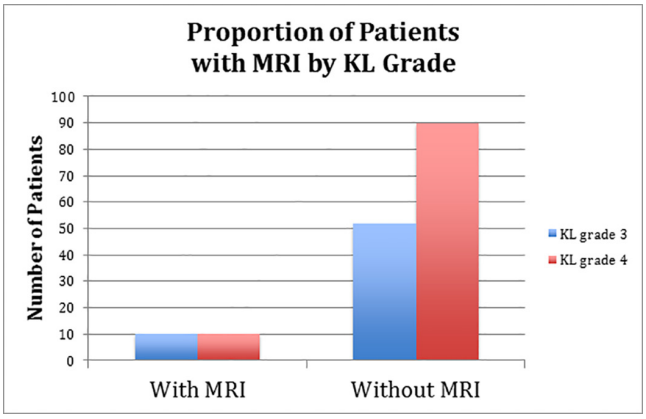

Figure 1. Graph shows that there was no difference between KL grade with the patients who presented with an MRI.

tients with radiographic evidence of moderate to severe arthritis, and similarly minimal role in the pre-surgical planning or decision making prior to TKA.

Previous studies have demonstrated MRI overuse for the diagnosis and treatment of shoulder and foot and ankle pathology.[18,19] Our goal was to examine MRI overuse in patients with moderate to severe knee OA referred to our institution for TKA. Additionally, we sought to examine the characteristics of the providers who ordered these MRI scans. Our hypothesis was that many providers order MRI for evaluation of OA prior to referring to an orthopedic surgeon, and that providers with higher levels of training are less likely to order these imaging studies.

METHODS

With Institutional Review Board approval, we retrospectively examined the records of consecutive patients referred for TKA to one high-volume arthroplasty surgeon at a large academic institution over a 12-month period. All new patients with an ICD-9 code for OA (715) were identified. Knee radiographs were graded in severity using the Kellgren-Lawrence (KL) scale taking into account osteophyte formation, joint space narrowing, and subchondral sclerosis.[20] Patients with a KL grade 3 (moderate) or 4 (severe) in any compartment were included in the analysis. Exclusion criteria consisted of: 1) recent trauma, 2) history of systemic inflammatory disorder, and 3) previous ipsilateral knee arthroplasty. We next identified all patients within this cohort who had a knee MRI ordered by their referring provider within the 3 months prior to the index surgical consultation.

Subgroup analysis evaluated for characteristics which may have influenced the decision to order an MRI prior to referral. These included: Kellgren-Lawrence grade (III versus IV), physician versus non-physician (physician assistant or nurse practitioner) provider, non-academic versus academic physician, fellowship trained versus non-fellowship trained physician, and distance of referring provider from our institution.

Statistical analysis consisted of applying Fisher's exact test to compare characteristics between those presented with MRI versus those who did not, with statistical significance set at $p < 0.05$.

RESULTS

Of the 164 patients identified who met study criteria, 19 patients were excluded because no referring provider was listed. Subgroup analysis was therefore performed on a total of 145 patients (19 patients presenting with MRI (13.1%), 126 patients presenting without MRI). Provider demographic information can be found in Table 1. There were a total of 94% patients referred from a physician and 6% referred from a non-physician. There were 24% referred from academic providers and 76% from non-academic providers; 20% of the physicians were fellowship trained and 80% were non-fellowship trained. A total of 45% of the patients were referred from a provider greater than 40 miles from our academic institution.

Subgroup analysis demonstrates that a greater proportion of patients with KL grade 3 presented with MRI compared to those with KL grade 4 (16.1% vs. 10.0%, p=0.32) with no statistical difference found between the groups. (Figure 1)

Out of the 9 patients who were referred from a non-physician provider, 44% presented with an MRI. Of the 136 patients referred from a physician provider, 11% presented with an MRI. The unequalized odds ratio of non-physicians ordering an MRI in our population was 6.45. When comparing physicians versus non-physicians,

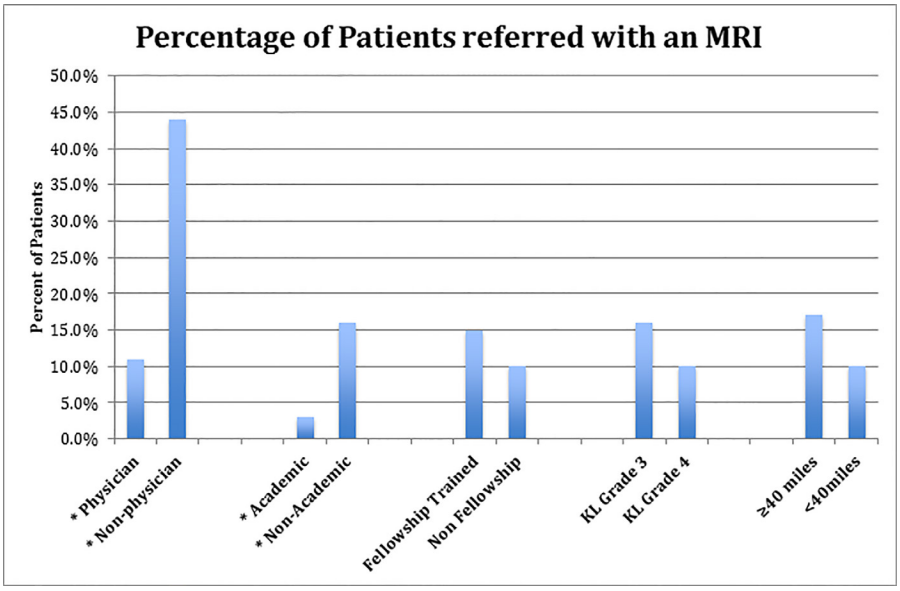

Figure 2. Characteristics of the percentage of patients referred with an MRI. * indicates significant difference p < 0.05. Physician vs. Non-physician: p < 0.018; Academic vs. Non-academic: p < 0.044.

there was a statistically significant difference between the number of MRIs ordered based on provider type (p=0.018) (Figure 2).

Only 3% of the patients who were referred from an academic provider presented with an MRI as compared to 16% referred from non-academic providers. The unequalized odds ratio of non-academic providers ordering an MRI in our population was 6.65. When comparing non-academic providers to academic providers, there was a statistically significant difference between the number of MRI orders based on academic affiliation (p=0.044).

Of the 27 patients referred from a fellowship trained physician, 14% presented with an MRI as compared with 10% of the 109 patients referred from a non-fellowship trained physician. When comparing fellowship trained versus non-fellowship trained there was no statistical significance in the number of MRIs ordered based on the physician fellowship status (p=0.50).

Out of the 65 patients who presented from a provider greater than 40 miles from our academic institution, 17% presented with an MRI as compared to 10% patients who presented from a provider within 40 miles from our academic institution. When comparing the number of MRIs ordered based on provider distance, we found no statistical significance (p=0.32) between the groups.

DISCUSSION

The financial burden of MRI imaging in the diagnosis and evaluation of pathologic orthopaedic conditions is well recognized.[21-23] We examined the incidence of MRI imaging ordered for patients with radiographically obvious OA prior to referral to an academic arthroplasty surgeon. We found that 13.1% of patients referred for knee arthroplasty had a MRI scan despite knee radiographs demonstrating K-L grade III-IV OA. Non-physician and non-academic providers were more likely to order MRI scans when compared with physicians or academic providers.

As more non-physicians are engaged in the initial management of patients, cost savings from using non-physicians may be overcome by the increased use of imaging, such as knee MRI scans.[24] We did not find that MRI use differed by referring physician specialty, or by referring physician fellowship training. More studies may shed light on the relationship, if any, between the incidences of knee MRI scans between providers with different levels of training.

Referring providers employed by the academic institution itself were less likely to order MRI (27%). It is possible that early communication between providers may have clarified what type of imaging was preferred at the time of referral. Such communication is often easier amongst providers within the same institution or setting via electronic medical records or more direct methods of interaction. Providers from an outside institution often do not have the liberty and freedom to easily access the tertiary specialist to whom they refer.

No patient referred with knee OA was felt to require a MRI for diagnosis, at least when evaluated by the orthopaedic surgeon. Knee MRI scans are usually reserved

Table II. Referral characteristics of patients in the specifically defined population

	With MRI	Without MRI
KL Grade 3	50.0%	37.0%
KL Grade 4	50.0%	63.0%
Age	65.68	63.49
Average Distance	55.96	53.39
Prop MU physician	9.0%	0.27*
Prop fellowship trained	21.1%	18.3%
Physician specialty		
Family Practice	47.0%	64.0%
Internal Medicine	11.0%	20.0%
Orthopedic Surgery	16.0%	7.0%
Other	5.0%	5.0%
Non-Physician	21.0%	0.04*
Unavailable	1	18

* = statistically significant
prop = proportion

for younger patients without radiographically apparent OA, in whom the diagnosis is unclear. Bernstein et al. found that 45% of the knee MRI scans ordered by physicians outside the orthopedic specialty (non-orthopedic surgeons) were normal or showed only OA, compared to 27.6% of the scans ordered by orthopedic surgeons.[25] These results suggest that non-orthopedic physicians may use knee MRI scans to screen painful knees for a diagnosis more often than orthopedic surgeons.[26]

Song et al. found a pre-obtained knee MRI rate of 27% in 185 of 680 patients. Their results suggest a "useful MRI" rate was assessed in sports-related injury (84%) than in degenerative joint disease (18%). The study, however, does not contain practice patterns of referring physicians.[27]

There are several limitations to this study. Our study was limited to the patients referred to one surgeon and it is possible the findings may have been different if patients referred to other arthroplasty surgeons were included. Also, the academic center was in a semi-rural community with many referrals from adjacent rural clinics; the average distance travelled by the patients in this study was 53.7 miles. Referring physicians may have ordered knee MRI scans simply to expedite treatment and reduce the burden of travel on their patients. We did not identify any differences between the distances travelled by patients with and without knee MRI scan prior to referral (Table 2). Further studies may identify if patient convenience and expediency of treatment are related to referring physician readiness to order a knee MRI prior to evaluation by a surgeon.

At our institution, outside imaging is brought by the patient to the visit, and the images are uploaded to the electronic record. Since some patients may not have brought pre-referral imaging with them, it is possible that the incidence of MRI scans was underestimated in the patient cohort studied. Since only 9.7% of referred patients had knee imaging (X-rays or MRI) performed before the first visit with an arthroplasty surgeon, some pre-referral imaging studies may have been missed in our analysis.

Our study showed that 13.1% of patients with moderate-to-severe knee OA (KL grade 3 and grade 4, respectfully) presented to our arthroplasty surgeon with an MRI ordered by the referring provider. Non-physician providers and non-academic providers were more likely to order knee MRI scans in patients with radiographically identifiable knee OA. While prospective clinical data is needed to corroborate these observations, provider education in the appropriate use of MRI scans in patients with radiographically obvious OA may be a cost-effective strategy.

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EVALUATION OF ORTHOPAEDIC TRAUMA FELLOWSHIP WEB SITES AND AN ASSESSMENT OF 21 CONTENT DOMAINS

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ABSTRACT

Background: A program's web site can attract or deter fellowship applications. It can also impact applicants' final rank lists. Web-based information may allow applicants to apply more selectively, decreasing interview costs for themselves and programs. The accessibility and content of program web sites for several orthopaedic subspecialties have been analyzed for inadequacies. The goal of this study was to perform an analysis for the web sites of orthopaedic trauma fellowships.

Methods: A list of accredited orthopaedic trauma fellowships was obtained from the Orthopaedic Trauma Association (OTA) Fellowship Directory. Web site accessibility was determined by presence of a functional hyperlink in the directory and the web site's searchability using Google®. Web site content was evaluated based on 21 criteria.

Results: 53 programs were identified, offering 84 positions. 27 had web sites accessible through the OTA fellowship directory via functioning links. 19 additional web sites were accessible using Google®. Seven programs lacked web sites entirely. Web site content varied between programs. Over half of the web sites lacked information for 13 of the 21 content criteria. A complete list of results can be located in Table 1.

Conclusions: Inadequacies exist in the accessibility and content of OTA accredited Orthopaedic Trauma Fellowship web sites. We draw attention to 21 standard content areas pertinent to applicants that could be considered by the OTA and individual programs to include on their respective web sites. Standardization across web sites may allow for a more direct comparison between programs and improve the match process.

Level of Evidence: Review Article

Keywords: analysis, website, fellowship, trauma, orthopaedic

INTRODUCTION

Postgraduate medical trainees across all specialties utilize the Internet to gather information and compare training programs. Online information, as a first line of information, can influence which programs they look more heavily into, thus potentially affecting their decision to apply to certain programs and how they compose their rank list.[1-5] Web-based information has been specifically reported to influence the decisions of fellowship applicants.[6-8]

Specific to orthopaedics, some hand fellowship applicants valued a program's web site over the opinions of their mentors and family.[8] Therefore, fellowship programs may attract more applications by providing accessible and comprehensive online information that is important to applicants. Alternatively, adequate online information may allow applicants to apply more selectively early in the match process, decreasing interview costs for both themselves and programs.[8-10] A recent survey of orthopaedic fellowship applicants found that information pertaining to operative experience, fellow autonomy, program prestige, and program faculty are valued most by applicants when forming their final rank list.[9] Both applicants and programs could benefit from accessible and quality web sites that help limit unnecessary interview expenditures and optimize a fellow-program match that is conducive to the satisfaction of both parties' expectations and objectives.

Several orthopaedic subspecialties web sites have been analyzed based on their accessibility and content.[6, 11-14] To the best of our knowledge, no such analysis has been performed for the web sites of Orthopaedic Trauma

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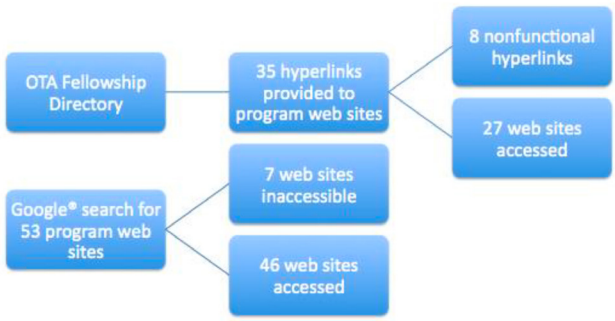

Figure 1. Flowchart detailing the accessibility of orthopaedic trauma fellowship web sites using Orthopaedic Trauma Association (OTA) Fellowship Directory and Google®.

Association (OTA) accredited trauma fellowships. The goal of the study herein was to determine the accessibility of orthopaedic trauma fellowship web sites and objectively evaluate their content.

METHODS

This study was exempt from institutional review board (IRB) approval. Initial data collection and web searches were performed on January 27, 2017. A follow-up analysis was performed in August 2017. The accessibility of each program's web site was assessed using the following criteria: the presence of a direct hyperlink in the OTA Fellowship Directory to the program's web site, functionality of this link, and web site searchability using Google®.[15-16] A hyperlink was determined to be functional if it routed the web browser to a web page where fellowship information could be accessed within two clicks. Google® search phrases were "program name + orthopaedic trauma fellowship" and "program name + orthopaedic surgery + trauma + fellowship." Only the first page of search results was viewed.

The criteria chosen to evaluate web site content was originally established by a program director and fellowship applicant in the sports medicine match.[12] These criteria have been refined and expanded by several subsequent web site reviews into more specific data points, allowing for tailored and more objective data collection.[6, 9, 11-14] The list utilized herein is a culmination of the criteria used in the original list and subsequent web site reviews. Individual program web sites were objectively evaluated for the inclusion of any information pertaining to the following 21 criteria: research opportunities, research requirements, current or past research performed by fellows, rotation schedules, on-call expectations, journal clubs, case descriptions (case logs), intra-institutional meetings (i.e. grand rounds), conferences or meetings sponsored by program (i.e. national and societal conferences), teaching responsibilities, list of current fellows, list of previous fellows, previous education of current fellows (i.e. medical school and residency), alumni career choices, list of orthopaedic trauma faculty, description of the application process, program director's and coordinator's contact information, salary, and a program description. After performing separate web site reviews, two authors reached collective agreement when discrepancies arose in the data collected.

RESULTS

Fifty-three fellowship programs were identified on the official Orthopaedic Trauma Association (OTA) web site.[15] The number of annual fellowship positions varied by program with 60.38% of programs offering one position, 22.64% offering two positions, 11.32% offering three positions, 3.77% offering five positions. The number of positions offered by one program could not be found. The sum of these reported positions was 84.

Concerning the accessibility of program specific web sites, the OTA Fellowship Directory contained hyperlinks to 35 (66.04%). However, eight of these hyperlinks were non-functional. The Google® search identified web sites for 46 (86.79%) of the programs. Nineteen web sites were identified using Google® that were not accessible using the directory. All web sites that were accessible through the directory were also accessible through Google®. Overall, seven programs did not have web sites accessible through the directory or Google®. (Figure 1)

The content of the 46 program specific web sites varied across programs. None of the programs had web sites with data pertaining to all 21 criteria. Thirteen criteria were more likely than not to be missing from more than 50% of web sites. The most common data points found on program web sites included: program description (46; 100.00%), research opportunities (38; 82.61%), description of application process (34; 73.91%), and faculty involved (33; 71.74%). The least accessible data found on program web sites included: previous education of current fellows (7; 15.22%), list of current or previous research conducted by fellows (9; 19.57%), journal club (11; 23.91%), and alumni career choices (13; 28.26%). Complete results for the 21 criteria is found in Table 1. The follow-up analysis revealed no changes in content contained in fellowship programs' web sites.

DISCUSSION

Investigations into the accessibility and content of pediatric orthopaedics, sports medicine, spine, shoulder and elbow, and hand fellowship web sites have been performed with the common goal of uncovering their inadequacies and improving the match process for each subspecialty.[6,11-14] The study herein aimed to determine if inadequacies existed among the web sites of orthopaedic trauma fellowship programs. The findings of this analysis

Table I. Content Included on OTA Fellowship Directory and Program Specific Web Sites

	OTA	Individual Pages
Number of Programs %(n)	**n=53**	**n=46**
Program Description	49.06% (26)	100.00% (46)
Research Opportunities	28.30% (15)	82.61% (38)
Description of Application Process	3.77% (2)	73.91% (34)
Attending Faculty	92.45% (49)	71.74% (33)
Case Descriptions	94.34% (50)	69.57% (32)
Coordinator Contact Info	98.11% (52)	67.39% (31)
Institutional Meetings	81.13% (43)	67.39% (31)
Research Requirements	13.21% (7)	63.04% (29)
Teaching Responsibilities	15.09% (8)	43.48% (20)
Out-Patient Clinic Expectations	7.55% (4)	43.48% (20)
Rotation Schedules	22.64% (12)	39.13% (18)
Previous Fellows	0% (0)	39.13% (18)
Fellow Salary	90.57% (48)	36.96% (17)
On-Call Expectations	71.70% (38)	34.78% (16)
Director Contact Info	90.57% (48)	32.61% (15)
National Meetings Sponsored	33.96% (18)	32.61% (15)
Current Fellows	0% (0)	32.61% (15)
Career Choice of Previous Fellows	0% (0)	28.26% (13)
Journal Clubs	20.75% (11)	23.91% (11)
Current and Previous Research	3.77% (2)	19.57% (9)
Medical School and Residency of Current Fellows	0% (0)	15.22% (7)

Table 1. Depiction of the informative content provided in the Orthopaedic Trauma Association (OTA) Fellowship Directory and on the program specific web sites.

identified a wide variation among the accessibility and content of OTA accredited trauma fellowship web sites. It also revealed that between January and August of 2017, the presence or absence of content criteria in fellowship web sites did not change, demonstrating a lack of continued maintenance and improvement of resources valuable to applicants.

The Orthopaedic Trauma Fellowship Match was established in 2008. The SF Match Residency and Fellowship Matching Service facilitates the match process, and the OTA sponsors the match and enforces its guidelines.[17] The match was formalized to coordinate appointments and avoid forced early commitments by either party. However, programs and applicants now spend a significant amount of time and money searching for their ideal match counterpart. Multiple surveys have found that orthopaedic fellowship applicants spend upwards of $5,000 and miss an average of 11 days of residency during the interview process.[9-10] A study exploring the effects of the interview process on fellowship programs, reported that hand fellowship programs incurred 65 hours in opportunity cost and $4,572 in monetary cost while interviewing applicants.[8] The fellowship interview process also impacts the residency programs of applicants as over 60% of orthopaedic residency program directors viewed resident absences during interview season as "extremely disruptive" to their program.[10] By selectively applying to programs that exhibit attributes desired by the applicant, fellowship programs, applicants, and residency programs could potentially avoid unnecessary expenditures and disruptions in clinical duties.

Easily accessible online information may foster a more selective application process by providing prospects with information about the program, possibly precluding the need for an interview. The survey by Meals and Osterman indicated that program web sites were of equal or greater value than peer recommendations when forming a rank list, leading the authors to encourage programs to offer comprehensive, online information.[8] Neisen et al. also discussed the importance of accessible online information, which could lead to selective applying.[9] Statistics show that orthopaedic residents who apply to eight to ten programs and interview at seven to eight programs have a 99% chance of matching.[18] However, the average number of applications per applicant in the orthopaedic trauma match ranged from 14 to 21 between 2010 and 2016.[16]

This study objectively analyzed the accessibility of orthopaedic trauma fellowship web sites. More web sites could be accessed using Google® than the OTA Fellowship Directory; however, several programs lacked web sites entirely. The inability to easily and reliably identify web sites or the complete lack of web sites could hinder applicants who rely solely on the OTA directory from comprehensive access to program information. A solution would be for programs without web sites to develop cheap, cost-effective web sites and for programs with established web sites to routinely update their hyperlinks in the OTA directory and check their functionality.[19] The twenty-one content domains can serve as a useful guide for included content in the creation and improvement of fellowship web sites, not only for Orthopaedic Trauma, but also other fellowships.

Critical information was frequently missing from trauma fellowship web sites. In the OTA article, "Tips for Applicants," it was encouraged for applicants to consider if the fellowship training program will include pelvic, soft-tissue, spine, and/or hand trauma.[20] While operative experience and program faculty are valued highly

by orthopaedic fellowship applicants nearly 40% of the web sites lacked any description of cases (or case logs) and almost 30% lacked a list of the program's attending faculty. Although many programs indicated their number of faculty in the directory, the names of the faculty are not available, which hinders applicants from easily researching these potential instructors. On the other hand, the directory successfully reports a descriptive case log for 94% of the programs. The case descriptions, however, were inconsistent between programs. For example, significant variability existed in which programs listed acetabular and pelvic ring cases. This information should be central in the decision-making process for potential applicants. The OTA requires a case log for all OTA accredited fellowships and these case logs should be made available to the applicants to assist in their decision-making process. The findings from this analysis, in addition to the OTA "Tips for Applicants" publication, provides further support that programs should make their case logs more comprehensive and available on their web sites.[20]

The OTA also encourages applicants to consider how important research is to their career goals in their "Tips for Applicant" article.[20] More available online information concerning each program's research agenda, support, and resources may help applicants select programs based on their desired career path. Information about research opportunities was available on 83% of fellowship web sites, but a smaller proportion included any information on research requirements and current or previous research performed by fellows. Whether or not a program has journal clubs may also be important to an applicant depending on their desired educational objectives, but few of the web sites contained information on this topic. The OTA also encourages applicants to inquire about various aspects of each fellowships' rotations, call experience, out-patient expectations, teaching roles, experiences of past fellows, career choices of past fellows, and opportunities to attend academic meetings.[20] Rather than contacting each program or scheduling expensive interviews to make such inquiries, applicants could easily access this information on the programs' web sites. Unfortunately, the study herein determined that online information pertaining to each of these above topics was sparse. Even if applicants were to attempt to contact each program to inquire about this information, several programs did not provide coordinator or director contact information in the directory, and many web sites also lacked this information.

Prior to beginning the application process, both applicants and programs involved in the orthopaedic trauma fellowship match, as well as other fellowship matches, could benefit from the data presented in this study. Applicants could benefit by increasing their vigilance when browsing for online information because the accessibility of web sites is dependent on search medium. Programs who update their web sites to include each of the criteria assessed in this study would likely provide prospective applicants with valued information, improve their recruitment, and selectively draw interviewees whose objectives are in line with that of the program. Moreover, personnel involved in other subspecialty matches could benefit from reviewing this analysis of the OTA Fellowship Directory, which has been offered as an exemplary solution to web site inadequacies in other subspecialties.[14] However, we found that there is also room for improvement among the content provided in the directory.

Although the scope of this study is focused on individual program web sites. We should mention that we were the first to assess the relatively new American Academy of Orthopaedic Surgeons (AAOS) Fellowship Directory, which strives to provide program specific information such as: director's name and contact information, fellow salary, and program characteristics.[21] However, we found that there were only 39 listings for orthopedic trauma fellowship programs, and several of these listings were not formally listed in the OTA Fellowship Directory. This discrepancy may serve as evidence that applicants may not be able to rely on the current state of this database for adequate vetting of their fellowship options. Moreover, the AAOS Directory is accessible only to eligible members or for purchase to the public, inherently limiting its usefulness to some applicants. On the other hand, the directory may be developed into a sufficient informative resource for applicants if its management were to consider the roster discrepancies and important criteria suggested in this study.

There were several limitations to this analysis. First, the content evaluation was based on the objective presence of information and not based on its quality. Further studies into the usefulness and accuracy of the provided information would be beneficial. Second, the web site evaluations were performed during a fixed time period. Programs could, and hopefully will, update the accessibility and content of their web sites, changing the data presented in this study. Third, there is a chance of human error during web site content review, as reviewers may have missed present content.

In conclusion, the web sites of accredited orthopaedic trauma fellowships lack comprehensive accessibility and information. While this study pertained particularly to orthopaedic trauma fellowships, the information obtained and assessment of specific content domains is relevant for all subspecialties in and outside of orthopaedics. Both programs and their prospective applicants may be at risk

of accruing unnecessary opportunity and monetary costs that could be avoided by providing adequate information early in the application process, fostering more selective applications. Both parties could benefit if all programs offered adequate online information, leading to more ideal fellow-program matches and improved career directed educational experiences.

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UNINTENTIONAL FIREARM INJURIES REMAIN PREVALENT OVER A 12 YEAR EXPERIENCE AT A RURAL MIDWESTERN LEVEL 1 TRAUMA CENTER

Brian Guetschow, MD, Michele Lilienthal RN, MA, CEN, Michael Willey MD

ABSTRACT

Recently, firearm injuries in the United States have taken center stage in political debates and in the media. Much of the past epidemiological research on firearm injuries has focused primarily on the urban landscape. This study was undertaken to highlight the unique spectrum of firearm injuries seen at a rural level 1 trauma center to provide insight into prevalence, mechanism of injury, and seasonal variation. An IRB-approved retrospective study was performed of the trauma registry at a rural Level 1 hospital to identify all patients with firearm injuries from January 2002 to May 2014. Data obtained for each patient included demographics, injury date, a brief injury summary, and results of drug/alcohol screening. Chart review was performed to confirm accuracy of the database and descriptive statistics were calculated to compare subgroups. During the 12 year study period, 408 patients with firearm injuries were treated at our hospital. There were 360 males and 48 females. Ages ranged from an infant to 90 years. Handguns were the most common type of firearm (49%). Mortality in this series was 19%. The median age for fatal and non-fatal wounds was 44 and 27 years, respectively. The three main causes of injury were accidental (36%), self-inflicted (33%), and assault (26%). Alcohol and drugs were commonly present. Hunting incidents accounted for 26% of accidents and most of these occurred while deer hunting in November and December. The demographics and mechanism of firearm injuries vary across the urban-rural continuum and it is important to identify these subgroups so targeted interventions can be pursued.

Keywords: firearm inuries, rural trauma center

BACKGROUND

Recently, firearm injuries in the United States have taken center stage in political debates and in the media. This discussion often focuses on violent crimes and law enforcement, but fails to highlight unintentional injuries that are often seen in a rural community. Much of the past epidemiological research on firearm injuries has focused primarily on the urban landscape.

One may expect firearm death rates in urban areas to dwarf that of rural areas, but multiple studies have shown that population adjusted mortality rates are nearly equivalent in both settings.[1] This phenomenon is not limited to the adult population, as shown by Nance et al., who found that this trend also persists in the pediatric population.[2] However, the mechanism of injury differs, with the adjusted death rate in rural areas predominated by self-inflicted injuries and unintentional injuries, whereas homicide is the dominant factor in urban areas.[1] The rural setting is unique, and unintentional injuries account for a significant proportion of gun related injuries.[3]

This study was undertaken to highlight the unique spectrum of firearm injuries seen at a rural Midwestern level 1 trauma center to provide insight into prevalence, mechanism of injury, and seasonal variation. Our goal is to identify characteristics of preventable firearm injuries to guide firearm education and public policy.

METHODS

Data was gathered from a 730 bed facility located in a rural Midwestern hospital. It is the only dual certified Level 1 Adult and Level 1 Pediatric trauma center in the state.[4] The facility is located in a small Midwestern town which predominantly serves a rural population in a state with a large population of hunters.

After institutional review board approval, hospital admission records following emergency department (ED) admission were retrospectively reviewed to include patients in the trauma registry at our institution. This registry was reviewed for record identifiers indicating a firearm related injury as outlined by the International

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Table I. Demographics of patients with fatal and non-fatal injuries

	Fatal	Non-Fatal	
	N= 79 (19%)	N= 329 (81%)	
Sex			
Male	71 (90%)	289 (88%)	p=0.701
Female	8 (10%)	40 (12%)	
Age (Mean/Median)	44 / 44	31 / 27	p<0.0001
Race			
White	60(76%)	240 (73%)	p=0.671
Black	6 (8%)	59 (18%)	p=0.025
Other	13 (16%)	30 (9%)	
Type of Firearm			
Handgun	52 (66%)	146 (44%)	p=0.0007
Shotgun	7 (9%)	65 (20%)	p=0.02
Rifle	10 (13%)	30 (9%)	p=0.40
Air Gun	2 (3%)	42 (13%)	p=0.007
Other/Unknown	8 (10%)	46 (14%)	p=0.461
Toxicology (tested)	34 (43%)	247 (75%)	
ETOH	12 (35%)	88 (36%)	
Illicit Drugs	3 (9%)	25 (10%)	
ETOH+Illicit Drugs	2 (6%)	22 (9%)	

Classification of Disease version 9 (ICD-9). ICD-9 utilizes the prefix "E" for external causes of injury. The firearm related E-Codes 922, 955, 965, 970, and 985 relate to accident, suicide, assault, legal intervention, and cause undetermined, respectively. Each of these codes has subsets which specify the type of weapon used in the act. Air guns are typically excluded in analyses of gunshot wounds (GSW) due to their perceived innocuous nature; however, they are included in our report to highlight their potential for significant injury. E-codes were collected from the trauma registry for the 12 year period from January 2002 to May 2014.

Data obtained for each patient included demographics, injury date, a brief injury summary, and an Abbreviated Injury Scale (AIS) score for each body region. The results of drug and alcohol screening tests were recorded. These tests were performed when the results were deemed relevant for patient care. This decision was made by the treating trauma surgeon. Additionally, the number of blood products received, intensive care unit (ICU) days, ventilator days, and hospital length of stay (LOS) were captured in addition to the ultimate incidence of in hospital mortality for the patient population. Discharge location from the hospital was also recorded for each patient. Chart review was performed to confirm accuracy of the database.

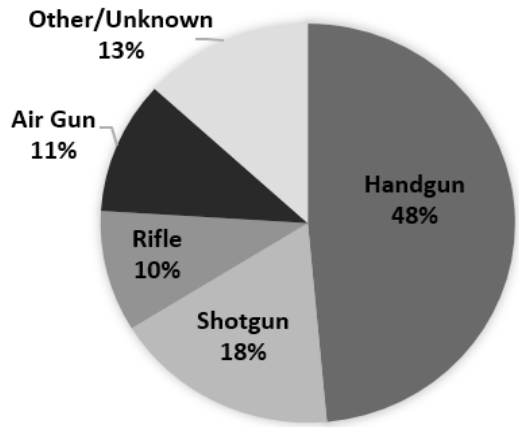

Figure 1: Type of firearm (408 patients)

Descriptive statistics were calculated to compare subgroups in the analysis. Two-tailed T-tests were used for comparisons between groups with continuous variables and Fisher's Exact test for comparisons between groups with categorical variables. Significance was considered $p < 0.05$.

RESULTS

Demographics

During the 12 year period ranging from January 2002 to May 2014, 408 patients with firearm injuries were treated at our institution. There were 360 (88%) males and 48 (12%) females. Ages ranged from infancy to 90 years, with a mean age of 33.6 years and median of 29 years. Mortality in this series was 19% (79 patients). The median age for fatal wounds was 44 years and was significantly higher than the median age for non-fatal wounds, which was 27 years (p<0.0001). 300 (74%) patients were Caucasian (non-Hispanic), 65 (16%) were African-American, 15 (4%) were Hispanic, and 28 (7%) were Asian/other. (Table 1)

Type of Firearm

The firearm involved was a handgun in 198 (48%) cases, a shotgun in 72 (18%) cases, a rifle in 40 (10%) cases, an air gun in 44 (11%) cases, and a different type of weapon (other than the aforementioned; categorized as "Other") or an unspecified weapon in 54 (13%) cases (Fig. 1). Assault was the mechanism of injury in 83% (39/47) of cases where the type of weapon was unknown.

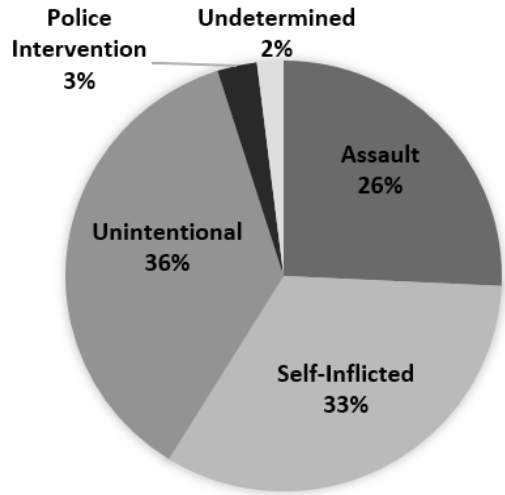

Figure 2: Mechanism of Injury (408 patients)

Handguns accounted for 66% of the fatal wounds and 44% of non-fatal wounds. Fatal injury was more commonly related to handgun injuries ($p<0.001$). (Table 1)

Mechanism of Injury

The cause of injury was unintentional in 148 (36%) cases, self-inflicted in 135 (33%) cases, assault in 105 (26%) cases, police intervention in 12 (3%) cases, and undetermined in 8 (2%) cases (Fig. 2). Upon further analysis of the 148 cases that were classified as unintentional, 38 (26%) occurred while hunting.

Unintentional injuries, self-inflicted injuries, and assaults accounted for 95% of all cases. Table 2 provides a breakdown of demographics among these mechanisms of injury. Males represent the majority of cases in all mechanisms of injury, but a higher rate of females were injured in cases of assault compared to other mechanisms. The mean and median age for accident and assault are in the mid to upper 20s, while the median age for self-inflicted injury is significantly higher at 44 years ($p<0.0001$). Caucasian individuals accounted for the majority of unintentional injuries and self-inflicted wounds with 84% and 86% of cases, respectively, while 46% of African-American individuals were assault victims. Over 93% of unintentional wounds and assaults resulted in non-fatal injuries, while nearly half of self-inflicted injuries (47%) resulted in death.

The ages for the 135 self-inflicted injuries ranged from 9 to 90 years old with a mean age of 44 years. Caucasian males accounted for the majority of these injuries (105 patients, 78%). Toxicology tests were performed on 83 self-inflicted cases (61%) and of those tested, 32 individuals (39%) were positive for alcohol, 23 (28%) had illicit drugs, and 9 patients (11%) had a combination of both illicit drugs and alcohol. In comparison, toxicology tests in those 117 patients (79%) with unintentional firearm injuries who were tested indicated that 32 individuals (27%) were positive for alcohol, 34 (29%) had illicit drugs, and 10 patients (9%) had both illicit drugs and alcohol.

Injury location

The locations of the GSWs were characterized as head/neck, face, chest, abdomen, extremities, and skin. In 153 patients (38%) there were multiple locations of injury. There was a single injury location in the other 255 cases (63%), with extremity injuries accounting for 77 cases, 51 cases of skin injuries, 47 cases of head injuries, 42 cases of facial injuries, 21 cases of abdominal injuries, and 17 cases of chest injuries. The primary location of injury was evaluated for rifle, shotgun, and handgun injuries by recording the body location with the highest AIS score. (Table 4) The head/neck region was the most common primary site of injury in handgun (43%) and rifle (40%) wounds, with p values of $p<0.001$ and $p=0.05$, respectively, when compared to shotgun wounds. Extremity injuries were the most common primary injury location in shotgun wounds (39%).

Medical Utilization

As seen in Table 3, multiple metrics outlining hospital resource utilization including total LOS, ICU LOS, blood product utilization, and ventilator days were captured and analyzed. In total, 372 (91%) of patients were admitted, including over 90% of victims within the three mechanistic subsets. The LOS for self-inflicted wounds was significantly greater than assault and unintentional victims, $p<0.002$ and $p<0.0001$, respectively. Blood products were administered to 130 (32%) patients and more self-inflicted wounds received blood than all other modalities combined. Patients with self-inflicted injuries received blood products in 50% of cases and were significantly more likely to receive blood than the other injury modalities (vs. assault $p=0.0037$ & vs. unintentional $p<0.0001$). Overall, 179 (44%) patients were admitted to an ICU. Self-inflicted injuries were the most likely to result in ICU admission as seen 97 patients (72%) ($p<0.0001$). There was not a significant difference between the injury cause with respect to the number of blood products received, ICU LOS, or ventilator days (all $p>0.05$).

Temporal Association and Hunting

As seen in Figure 3, the months of November and December account for 34% of all unintentional injuries, while the months of January, February, May, and June show slightly higher rates of self-inflicted injuries (Fig. 3). Figure 3 depicts the incidence of hunting accidents

Table II. Demographics based on mechanism of injury

	Mechanism of Injury				Significance of Association		
	Assault	Self-Inflicted	Unintentional		Assault vs. Self-Inflicted	Assault vs. Unintentional	Self-Inflicted vs. Unintentional
	N= 105 (26%)	N= 135 (33%)	N= 148 (36%)	**Hunting** N=38 (26%)			
Sex							
Male	81 (77%)	123 (91%)	138 (93%)	37 (97%)	p=0.003	p=0.0003	p=0.515
Female	24 (23%)	12 (9%)	10 (7%)	1 (3%)			
Age - Mean (Median)	29 (27)	44 (44)	28 (24)	35 (33)	p<0.0001	p=0.75	p<0.0001
Race							
White	43 (41%)	116 (86%)	125 (84%)	35 (92%)	p<0.0001	p<0.0001	p=0.741
Black	48 (46%)	5 (4%)	9 (6%)	-	p<0.0001	p<0.0001	p<0.0001
Other	14 (13%)	14 (10%)	14 (9%)	3 (8%)			
Type of Firearm							
Handgun	55 (52%)	86 (64%)	42 (28%)	-	p=0.087	p=0.0001	p<0.0001
Shotgun	10 (10%)	25 (19%)	36 (24%)	27 (71%)	p=0.07	p=0.003	p=0.25
Rifle	1 (1%)	19 (14%)	20 (14%)	9 (24%)	p=0.0002	p=0.0001	p=1
Air Gun	-	1 (1%)	42 28%)	-			p<0.0001
Other/Unknown	39 (37%)	4 (3%)	8 (5%)	-			
Outcome							
Fatal	7 (7%)	64 (47%)	6 (4%)	1 (3%)	p<0.0001	p=0.395	p<0.0001
Non-Fatal	98 (93%)	71 (53%)	142 (96%)	37 (97%)			
ISS (Med)	14 (9)	21 (25)	9 (4)	-			
Toxicology (tested)	89 (85%)	83 (61%)	117 (79%)	24 (63%)			
ETOH	41 (46%)	32 (39%)	32 (27%)	11 (46%)			
Illicit Drugs	25 (28%)	23 (28%)	34 (29%)	10 (42%)			
ETOH + Illicit Drugs	7 (8%)	9 (11%)	10 (9%)	4 (17%)			

by month. Hunting firearm injuries occurred primarily while deer hunting (22/38; 58%). The other unintentional hunting accidents were associated with pheasant (8), raccoon (1), waterfowl (1) and 6 were undetermined.

Firearm injuries associated with hunting accounted for 38 (26%) of the unintentional cases. This subset exhibits notable variations from the data set as a whole. Demographically, 37 of the patients (97%) were male, 35 (92%) were Caucasian, and age ranged from 15 to 68 years with a mean of 35 years and median of 33 years. The type of firearm implicated in hunting injuries was a shotgun in 27 cases (71%) and a rifle in 9 (24%) cases. Toxicology tests were performed on 24 (63%) of the patients, and of those tested, 11 individuals (46%) had alcohol, 10 (42%) had illicit drugs, and 4 patients (17%) had a combination of both illicit drugs and alcohol. In 8 hunting cases (21%) there were multiple locations of injury. There was a single injury location in the other 30 incidents, with extremity injuries accounting for 26 cases.

Discharge Disposition

Disposition for admitted patients was analyzed in the data set and 218 (59%) patients were discharged home with no assistance, while 94 (25%) patients required higher level care (Table 3 and 4). Victims of unintentional injuries and assaults were dispositioned home with no assistance in 80% and 67% of cases, respectively, which was significantly more often than victims with self-inflicted wounds (32%) (p<0.0005). Shotgun injuries resulted in admission 90% of the time, which was significantly more than handgun (p=0.003) and rifle (p=0.05) injuries. The majority of handgun, shotgun, and rifle injuries went home with no assistance. Shotgun injuries had the largest cohort (45%) which required additional

Table III. Hospital resource utilization

	Total Patients N=408	Mechanism of Injury			Significance of Association		
		Assault N=105	Self-Inflicted N=135	Unintentional N=148	Assault vs. Self-Inflicted	Assault vs. Unintentional	Self-Inflicted vs. Unintentional
Resource Utilization							
Total Length of Stay							
Admitted (%)	372 (91%)	97 (92%)	126 (93%)	134 (91%)	p=0.80	p=0.66	p=0.514
Mean / Median LOS (days)		6.5 / 4	11.5 / 4	5.3 / 3	p<0.002	p=0.25	p<0.0001
Blood Products							
Packed Red Blood Cells, patients (%)	130 (32%)	33 (31%)	68 (50%)	29 (20%)	p=0.0037	p=0.39	p<0.0001
Mean / Median (units per patient)		8.1 / 3	6.9 / 4	5.6 / 4	p=0.56	p=0.36	p=0.55
Intensive Care Unit							
Admitted to ICU (%)	179 (44%)	49 (47%)	97 (72%)	33 (22%)	p=0.0001	p<0.0001	p<0.0001
Mortality (%)		6 (12%)	43 (44%)	5 (15%)			
Mean / Median LOS (days)		3.7 / 2	4.2 / 2	6.3 / 3	p=0.63	p=0.14	p=0.20
Ventilator (patients)	155 (42%)	35 (36%)	89 (71%)	23 (17%)			
Mean / Median (days)		3.7 / 1	3.2 / 1	5.3 / 2	p=0.70	p=0.40	p=0.21
Disposition (if admitted)							
Home, no assistance	218 (59%)	65 (67%)	26 (21%)	118 (80%)	p<0.0001	p=0.00014	p<0.0001
Additional Healthcare Assistance	94 (25%)	27 (28%)	40 (32%)	23 (17%)	p=0.558	p=0.074	p=0.009
Skilled Nursing Facility/ Rehab/Acute							
Care Hosp.	50 (13%)	19 (20%)	16 (13%)	15 (11%)			
Home, w/ home health	28 (8%)	8 (8%)	9 (7%)	8 (6%)			
Inpatient Psychiatry	13 (3%)	-	12 (10%)	-			
Home Hospice	3 (<1%)	-	3 (2%)	-			
Other							
Jail/Prison	15 (4%)	5 (5%)	5 (4%)	-			
Left AMA	2 (<1%)	1 (<1%)	-	1 (<1%)			

healthcare assistance compared to handgun (p=0.06) and rifle (p=0.02) injuries.

Age of Patient

Analysis of the data by age highlighted trends in mechanism of injury, sex, race, and mortality rate. Unintentional injuries are most common in the 2nd and 3rd decades of life, while self-inflicted injuries are most common between the 3rd and 6th decades of life, peaking in the 5th decade. Furthermore, self-inflicted injuries accounted for 73% of cases after the age of 59. The data indicates assaults are common among young people with 87% of cases occurring between the 2nd and 4th decade of life.

DISCUSSION

Firearm violence in this country is increasingly highlighted in the media, stirring social activism, and has become a contentious debate in national politics. This public focus on gun violence requires a detailed look at the entire spectrum of these unique injuries in various regions of the country. The variability in firearm injuries between urban and rural areas has garnered increasing interest over the past decade. Reports have looked at this problem through a number of different lenses to include urban-rural differences in unintentional fatalities, pediatric fatalities, intentional fatalities (suicide and homicide), and other trends at a national level. Fatalities from firearm injuries do not capture the majority of injuries and only represent 19% of the cases in our data set,

Table IV. Demographics based on type of firearm

	Total Patients N=408	Firearm			Significance of Association		
		Handgun N=198	Shotgun N=72	Rifle N=40	Handgun vs. Shotgun	Handgun vs. Rifle	Shotgun vs. Rifle
Primary Injury Location							
Head/Neck		86 (43%)	18 (25%)	16 (40%)	p<0.001	p=0.73	p=0.05
Face		10 (5%)	6 (8%)	1 (3%)	p=0.38	p=0.70	p=0.42
Chest		22 (11%)	8 (11%)	4 (10%)	p=1	p=1	p=1
Abdomen		17 (9%)	4 (6%)	2 (5%)	p=0.61	p=0.75	p=1
Extremity		42 (21%)	28 (39%)	12 (30%)	p=0.005	p=0.22	p=0.41
Skin		21 (11%)	8 (11%)	5 (13%)	p=1	p=0.78	p=1
Disposition							
Admitted	372 (91%)	146 (74%)	65 (90%)	30 (75%)	p=0.003	p=1	p=0.05
Home, no assistance	218 (59%)	91 (62%)	33 (51%)	23 (77%)	p=0.13	p=0.15	p=0.02
Additional Healthcare Assistance	94 (25%)	45 (31%)	29 (45%)	6 (20%)	p=0.06	p=0.28	p=0.02
Skilled Nursing							
Facility/Rehab/Acute Care Hosp.	50 (13%)	25 (17%)	11 (17%)	3 (10%)			
Home, w/ home health	28 (8%)	9 (6%)	16 (25%)	-			
Inpatient Psychiatry	13 (3%)	9 (6%)	1 (2%)	3 (10%)			
Home Hospice	3 (<1%)	2 (1%)	1 (2%)	-			
Other							
Jail/Prison	15 (6%)	9 (6%)	3 (5%)	-			
Left AMA	2 (<1%)	1 (<1%)	-	1 (3%)			

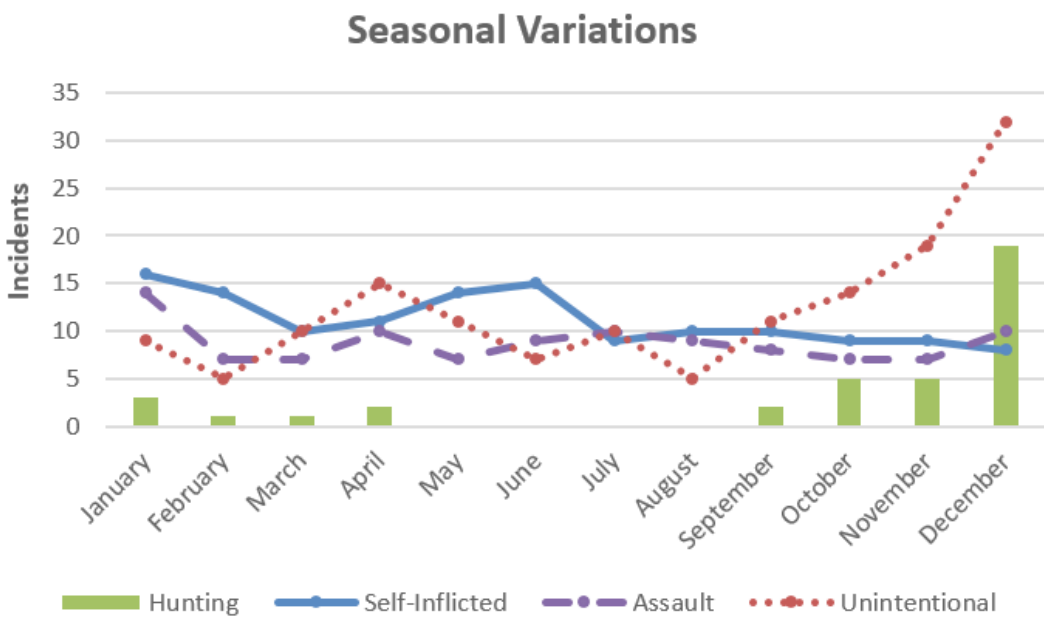

Figure 3: Seasonal variation based on mechanism of injury

20-36% in other rural data sets, and 33% on the national level.[3,5] Thus, comparison across studies reporting solely on fatalities is problematic and using this viewpoint as a measure of this public health problem can greatly underestimate the magnitude of the issue.

Demographic and Regional Variation

As highlighted in our data set, the predominant mechanism of injury varies between urban and rural settings. Additionally, the demographics and firearms also vary among mechanism of injury. Few studies have looked at this issue from the perspective of a rural trauma center. This snapshot into firearm injuries at our institution may not be directly generalizable at a national rural level, as highlighted by Fowler et al. who showed that significant geographic variation is present nationally, with 46% of firearm fatalities occurring in the south compared to approximately 20% in the Midwest and Western U.S., respectively.[5] As such, our analysis of rural Midwest firearm injuries at a level 1 trauma center provides valuable insight into this issue and, to our knowledge, stands alone as the only report of its kind.

Similar to other studies, our data showed a disproportionate male predominance representing 88% of total cases, which is consistent with numerous previous studies across both rural and urban settings.[5-7] However unlike other studies, females in our environment were disproportionally more at risk for assault. Compared to a national study conducted by Fowler et al. in 2010-2012 which noted 11% of assaults were perpetrated against females, our rural data set recorded a value more than double that at 23%.[5] This was also more than another rural analyses, which noted 14% of assault victims were female.[7]

One study at a rural level 2 trauma center demonstrated that long guns resulted in injury in 60% of cases but in our population handguns were the most common type of firearm, representing 48% of cases and accounting for 66% of fatalities.[3] Other rural analyses in North Carolina and Washington also demonstrated handguns as the predominate firearm used in fatal cases, however at a lower level of 51% and 53%, respectively.[8] This data shows that handgun violence is not restricted to urban inner city environments since it was common and often lethal in our series.

Drug and Alcohol Association

Our data indicates drug and alcohol use are commonly associated with firearm injuries in a rural environment. Of those individuals tested, our data set indicates 71% of hunters and 55% of patients with self-inflicted injuries had alcohol and/or drugs in their system. Alcohol was present in 39% of tested patients with self-inflicted injuries. Alcohol and drug use have widely been accepted as lubricants to unintentional trauma. However, at a national level, Loder et al. evaluated a dataset of 1.8 million firearm injuries and found alcohol involvement in 6.7% of non-hunting cases and 1.5% of hunters.[9] Branas et al. explored the relationship with firearms and noted an association between acute alcohol consumption and higher incidence of firearm suicide.[10] Nationally, the CDC reported that nearly 35% of homicide and suicide victims in 2007 tested positive for alcohol.[11]

Medical Utilization

Self-inflicted firearm injuries accounted for over a third of the patient in our series. Injuries caused by this mechanism required higher medical resource utilization by multiple metrics. These patients had more blood transfusions (50%), more likely to be admitted to the ICU, and had a longer hospital length of stay. This significant difference compared to patients that suffered unintentional injuries or assaults can be accredited to the fact that these injuries more likely involved critical body areas including the head or chest.

Unintentional Injuries

Unintentional injuries are the most common type of firearm injury in our rural dataset. However, this mechanism represents the smallest fatality rate amongst the three mechanisms of injury at 8%. Dresang et al. also noted this trend in their series, highlighting that 3% of fatalities in a rural setting were unintentional.[8] Fowler et al. on a national level also found that unintentional firearm injuries account for 2% of urban fatalities.[5] The months of November and December had a spike in incidents which accounted for over one-third of all accidents, with 47% of those cases related to hunting. Data from the 2014 International Hunter Education Association shows that Iowa has the highest percentage of firearms accidents nationally as a function of total license holders.[12]

Hunting Injuries

Hunting accidents were common in our series and are often associated with long guns, similar to previously reported series.[3] Hunting and sport shooting beyond being merely a recreational activity are a way of life in many rural parts of the country, as evidenced by 13.7 million hunters across the United States in 2011.[13] Residents of a metropolitan area greater than 1 million hunted at a rate of 3% compared to 18% of those in cities of less than 50,000.[13] Successful completion of a hunter's safety course is a state requirement for a hunting license in Iowa, which many individuals complete in their teenage years. However, the median age of hunting accidents from our data was 32 years old, which suggests that an impactful public health intervention could include a requirement for a refresher course and warnings for hunters in an effort to reduce complacency and reinforce safe practices later in life.

Diversity

Demographically, our region lacks the racial and ethnic diversity that one would expect to find in an urban environment. Data from the 2010 census for the county in which our institution resides estimated the population as 83% Caucasian, 7% Asian, 6% African American, and the remaining 4% as Other.[14] As shown in Table 2, the rates of unintentional and self-inflicted injuries align with the demographic data from the census bureau and are dominated by Caucasian individuals. However, African American individuals are more commonly victims of assault. These demographic correlations among the three mechanistic categories were also found in a rural North Carolina investigation with comparable demographics.[7]

Gun deaths by suicide have topped those via homicides over the past 30 years, with 61% of gun deaths in 2010 attributable to suicide.[11] Self-inflicted injury, as a percentage of total fatalities, was a common mechanism in our series, accounting for 81% of the fatalities, which was higher than 59% in another rural data set and 64% nationally.[5,7] However, the mortality of self-inflicted injuries in our series was only 47% compared to 85% of suicides by firearm nationally.[5] Our data did not show significant seasonal variation of suicides or annual variation correlated with economic downturns.

Unknown Firearm Type

One weakness of our series is the substantial number of cases that had an unknown firearm type. There were 47 cases that despite further chart review we were unable to determine the type of firearm. The majority (39/47 cases) were from assaults where the perpetrator's weapon was not noted. We can assume that handguns were the predominant weapon used given that 83% of assaults with a known weapon type were with a handgun.

CONCLUSION

Unintentional firearm injuries are common in rural Midwestern hospitals. A higher percentage of firearm injuries are unintentional compared to urban centers and there are significant modifiable risk factors unique to this region that could have an impact on the incidence of these costly injuries. This series highlighted the seasonal variation of firearm injuries seen at these centers associated with hunting season. Unintentional injuries occurred most commonly in the fourth decade of life and refresher hunting courses and warnings may be beneficial later in life for hunters. The danger of combining drugs and alcohol use with firearms is strongly highlighted in this series. The over representation of African-American individuals and women as the victims of assault emphasizes the need for interventions for these high risk groups. We hope this information will be used to identify avenues for improved firearm safety in rural environments.

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DO ORTHOPEDIC TRAUMA SURGEONS ADHERE TO AAOS GUIDELINES WHEN TREATING DISTAL RADIUS FRACTURES?

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ABSTRACT

Background: The American Academy of Orthopedic Surgeons (AAOS) has provided Clinical Practice Guidelines (CPG) and Appropriate Use Criteria (AUC) regarding management of distal radius fractures. The purpose of this study was to evaluate current practices in management of distal radius fractures among orthopedic trauma surgeons and to examine adherence to the AAOS criteria.

Methods: An online survey was posted and distributed via the Orthopaedic Trauma Association (OTA) website. Information collected included demographics, injury management, and case based questions. For all cases, surgeons were asked to select their treatment of choice given the same fracture in a 25-year-old patient and a 65-year-old patient. Results were compared between surgeons with < 10 years of practice experience and those with > 10 years of experience.

Results: There was a total of 51 survey respondents. 45% had <10 years in practice, while 55% had > 10 years in practice. All respondents reported routine use of preoperative radiographs, while 26% reported routine use of preoperative computed tomography (CT) scans. 73% of respondents reported that they perform operative adjunct fixation of associated ligamentous injuries at the time of distal radius fracture fixation. No one used wrist arthroscopy or fixed associated ulnar styloid fractures. 69% did not allow any range of motion in the immediate postoperative period, while the remainder allowed active and/or passive ROM. 20% routinely used Vitamin C for Complex Regional Pain Syndrome (CRPS) prophylaxis postoperatively. 59% routinely used physical and/or occupational therapy postoperatively. For case-based scenarios, respondents generally tended towards operative fixation in younger patients compared to older patients with the same fracture type. Surgeons with < 10 years in practice and those with > 10 years in practice varied significantly in terms of preoperative imaging and operative fixation of associated ligamentous injuries at the time of fracture fixation.

Conclusions: When compared to the AAOS CPG and AUC, orthopedic trauma surgeons generally followed accepted treatment guidelines. Differing practices between surgeons with <10 years in practice compared to those with >10 years in practice may be reflective of what is taught in residency training programs.

Keywords: distal radius fracture, clinical practice guidelines, appropriate use criteria, american academy of orthopaedic surgeons

INTRODUCTION

Management of distal radius fractures varies widely depending on patient factors and fracture characteristics. The American Academy of Orthopedic Surgeons (AAOS) has provided guidelines regarding management of distal radius fractures. According to the AAOS Clinical Practice Guidelines (CPG), operative fixation of distal radius fractures is recommended with shortening > 3mm, radial tilt > 10 degrees, or intra-articular displacement or stepoff >2 mm.[1] The CPG did not recommend any specific type of fixation. The Appropriate Use Criteria (AUC) were later developed based on the Clinical Practice Guidelines to provide a case-based decision approach to treatment of distal radius fractures.[2] The AUC considers AO/OTA fracture type, mechanisms of injury, activity level of pa-

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The authors have no conflicts of interest. Dr. Lisa K. Cannada reports she is a member of the Board of Directors of the American Academy of Orthopaedic Surgeons and the Mid America Orthopaedic Association.

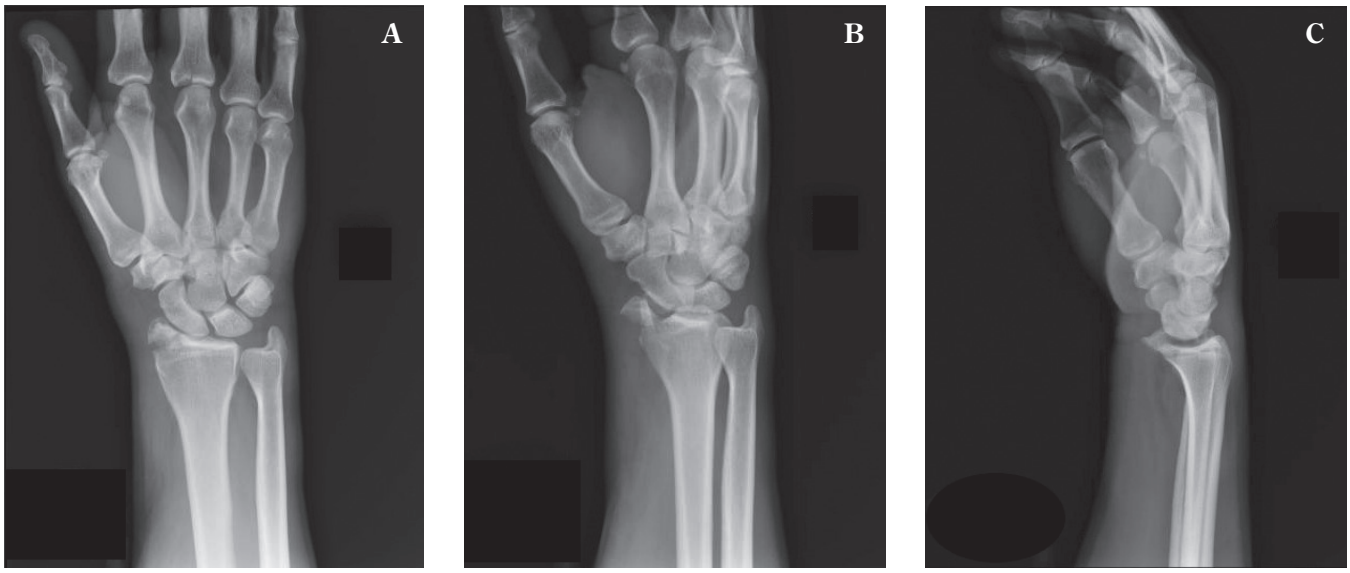

Figure 1: Case 2 in survey - a displaced radial styloid fracture. A. AP View B. Oblique view C. Lateral view

tient, patient health, and associated injuries to formulate recommendations for treatment. These criteria are not absolute and the surgeon should use his or her own discretion when deciding on treatment.

There are numerous controversies surrounding distal radius fractures beginning with fracture assessment to post operative treatment regimens. These also include surgical and non surgical controversies.[3] Often, the method of treatment and postoperative management is dependent on surgeon preferences. The purpose of this study was to evaluate current practices in management of distal radius fractures among orthopedic trauma surgeons and to examine adherence to the AAOS Guidelines.

METHODS

An online survey was posted via the OTA website. Practicing orthopaedic trauma surgeons who were interested could participate. The data collected included demographic information, general management questions, and five case-based patient scenarios.

The first portion of the survey consisted of surgeon

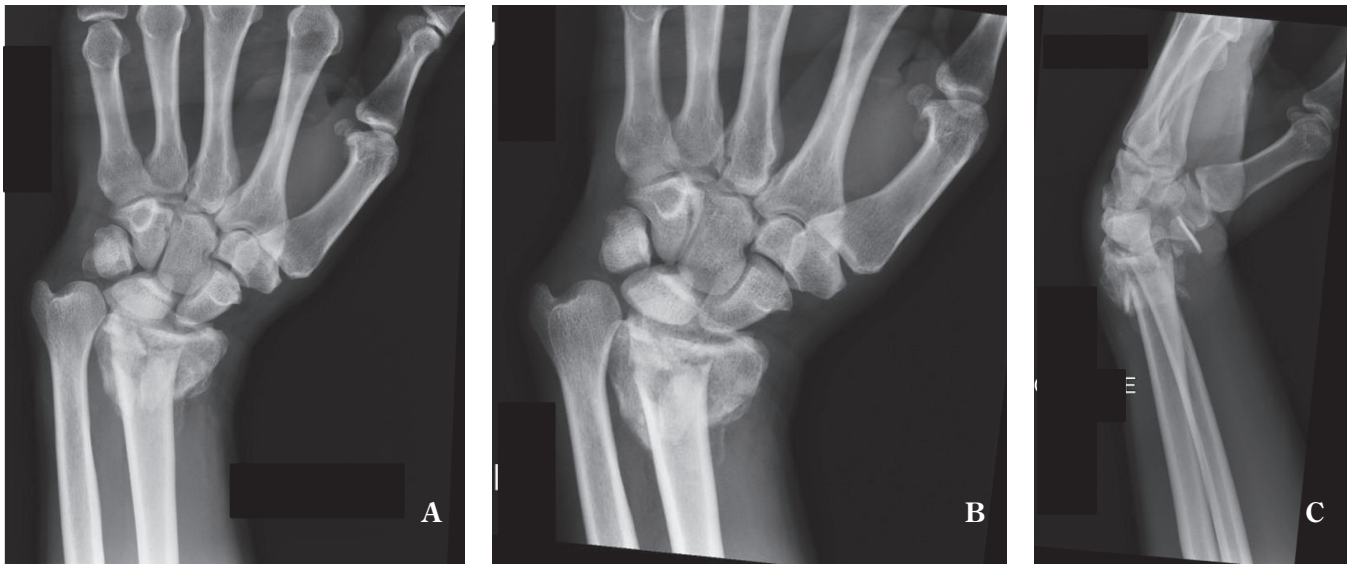

Figure 2: Case 3 in survey - a comminuted intra-articular distal radius fracture with radiocarpal subluxation. A. AP View B. Oblique view C. Lateral view

demographics, including years in practice, fellowship training details, practice setting, and monthly case volume of distal radius fractures. The second portion of the survey consisted of general management questions such as imaging, immobilization, and criteria for operative fixation. The third portion of the survey inquired about the surgeons' postoperative management protocol weight bearing restrictions, Complex Regional Pain Syndrome (CRPS-also known as Reflex Sympathetic Dystrophy Syndrome) prophylaxis, and use of physical/occupational therapy.

The fourth portion of the survey consisted of five case scenarios. Antero-posterior (AP), oblique and lateral views were provided for each case. Case 1 was an extra-articular distal radius fracture with apex volar angulation. Case 2 (Figure 1), was a displaced radial styloid fracture. Case 3 (Figure 2), was a comminuted intra-articular distal radius fracture with radiocarpal subluxation. Case 4 was an intra-articular distal radius fracture with dorsal comminution. Case 5 was a die punch intra-articular distal radius fracture. For all cases, surgeons were asked to give their treatment of choice for the specific fracture in a 25-year old patient and a 65-year old patient. They were given the following treatment options: removable splint, closed reduction and casting or splinting, closed reduction and percutaneous pinning, ORIF with volar plate, ORIF with dorsal plate, fragment specific plate fixation, external fixator, and dorsal bridge plating.

The cases were also analyzed using the Appropriate Use Criteria Guidelines web-based application.[1] All fractures were assumed to be low energy fractures, except for Case 3 which was designated a high-energy fracture. The 25-year-old patient was assumed to have a high functional demand activity level, and the 65-year-old patient was assumed to have a normal activity level. Patients were assumed to be ASA class < 3 and have no other associated injuries. The recommendations are given on a 9-point scale, with an appropriate treatment having a rating of 7-9, maybe appropriate being 4-6, and rarely appropriate being 1-3.

Statistics

Using Chi-square and Fisher exact tests, the survey results were compared between surgeons who had < 10 years of practice and those who had > 10 years of practice. Statistical significance was defined as $p<0.05$.

RESULTS

Surgeon Demographics

There was a total of 51 survey respondents. 45% of the respondents had <10 years in practice, while 55% had > 21 years in practice. 41% were employed in an academic setting, 29% were private practice, and 29% were hospital employees. 43% treated up to 5 distal radius fractures per month while 57% treated more than 5 distal radius fractures per month.

Treatment Practices

100% of respondents reported routine use of preoperative radiographs, while 26% reported routine use of preoperative computed tomography (CT) scans, and 2% reported routine use of preoperative magnetic resonance imaging (MRI). 100% reported routine use of postoperative radiographs, while 4% reported routine use of postoperative CT scan, and 2% reported routine use of postoperative MRI. Most commonly, the initial fracture reduction for displaced distal radius fractures was performed by either a resident physician or emergency room (ER) physician. 39% reported initial immobilization of a nondisplaced distal radius fracture with a sugartong splint, while 49% reported initial immobilization with a short arm cast, and 12% reported initial immobilization with a removable brace. In terms of definitive immobilization for a nondisplaced distal radius fracture, 82% reported use of a short arm cast, while 10% utilized a removable brace, 4% utilized a long arm cast and 4% utilized a sugartong splint. For displaced distal radius fractures, 59% utilized a sugartong splint for initial immobilization after reduction and 37% utilized a short arm cast for initial immobilization. For evaluation of associated ligamentous injuries, 41% of respondents reported use of preoperative advanced imaging, 31% utilized a stress exam, and 35% utilized stress radiographs. Table 1 provides a summary of treatment practices.

Trends in Operative Management

73% of respondents reported that they perform operative adjunct fixation of associated ligamentous injuries at the time of distal radius fracture fixation. No respondents reported routine use of wrist arthroscopy for intra-articular distal radius fractures. 4% reported routine use of bone graft or bone graft substitute for operative fixation of distal radius fractures. No respondents reported routine operative fixation of associated ulnar styloid fractures.

Postoperative Course

In terms of restrictions of range of motion in the immediate postoperative period, 69% reported that they do not allow any range of motion, while the remainder reported allowance of active and/or passive ROM. Of those who did not allow immediate range of motion, 77% reported initiation of range of motion within 2-4 weeks postoperatively, 20% reported initiation of range of motion within 4-6 weeks postoperatively, and 3% reported initiation of range of motion within 6-8 weeks postoperatively. 59% reported utilizing a splint for immobilization in the immediate postoperative period, 23% utilized a removable brace, 4% utilized a cast, and 14% did not use any form

Table I.
Distal Radius Fracture Treatment Practices

Number of distal radius fractures treated per month	n	%
0-5	22	43
>5 but < 10	17	33
>10	12	24
Routine Preoperative Imaging		
X-ray	51	100
CT scan	13	26
MRI	1	2
Routine Postoperative Imaging		
X-ray	51	100
CT scan	2	4
MRI	1	2
Who performs initial reduction		
Resident	23	45
Physician Assistant or Nurse Practitioner	6	12
Emergency room physician	21	41
Attending	15	29
Method of initial immobilization of nondisplaced distal radius fracture		
Removable brace	6	12
Short arm cast	25	49
Long arm cast	0	0
Sugartong splint	20	39
Method of definitive immobilization of nondisplaced distal radius fracture		
Removable brace	5	10
Short arm cast	42	82
Long arm cast	2	4
Sugartong splint	2	4
Method of immobilization after initial reduction of displaced distal radius fracture		
Removable brace	2	4
Short arm cast	19	37
Long arm cast	0	0
Sugartong splint	30	59
Method of evaluation of associated ligamentous injuries		
Preoperative advanced imaging	21	41
Stress exam	16	31
Post-operative advanced imaging	9	18
Stress radiographs	18	35

Table 1. Summary of treatment practices of survey respondents

of immobilization. 4% reported routine use of an edema control glove postoperatively. 20% reported routine use of Vitamin C for CRPS prophylaxis postoperatively. 59% reported routine use of physical and/or occupational therapy postoperatively.

Case Based Management

Table 2 provides results of the most common method of treatment for each patient scenario. For the first case, which was an extra-articular distal radius fracture with apex volar angulation, 45% elected to perform open reduction and internal fixation with a volar plate in a 25-year-old patient. In a 65-year-old patient, 39% elected to perform closed reduction and casting or splinting.

In the second case, which was a displaced radial styloid fracture, 41% elected to perform a plate and fragment specific fixation in a 25-year-old patient. 43% elected to perform closed reduction and percutaneous pinning in a 65-year-old patient.

For the third case, which was a comminuted intra-articular distal radius fracture with radiocarpal subluxation, 67% elected to perform open reduction and internal fixation with a volar plate in a 25-year-old patient. 43% who elected to perform open reduction and internal fixation with a volar plate in a 65-year-old patient.

The fourth case was an intra-articular distal radius fracture with dorsal comminution. In this scenario, 31% elected to perform open reduction and internal fixation with a dorsal plate in a 25-year-old patient, while 31% elected to perform closed reduction and casting or splinting in a 65-year-old patient.

In the fifth case, which was a die punch intra-articular distal radius fracture, 73% elected to perform open reduction and internal fixation with a volar plate in a 25-year-old patient. 57% elected to perform open reduction and internal fixation with a volar plate in a 65-year-old patient.

AUC web-based application

Table 3 shows the appropriate treatment options having the strongest ratings of 8-9 for each case scenario. For Case 1, the strongest treatment recommendation was a volar locking plate for a 25-year-old patient and closed reduction and immobilization for a 65-year-old patient. For Case 2, the strongest treatment recommendations were a volar locking plate or fragment specific fixation for a 25-year-old patient and fragment specific fixation, and volar locking plate for a 65-year-old patient. For Case 3, 4, and 5, the strongest treatment recommendations were a volar locking plate or fragment specific fixation in both a 25-year-old patient and a 65-year-old patient.

Surgeons with < 10 years of experience versus those with > 10 years of experience

43% of surgeons with >10 years of experience responded that they did perform operative fixation of

Table II. Most Common Method of Treatment of Distal Radius Fractures in Case Scenarios

Patient Age	Method of Treatment	Case 1		Case 2		Case 3		Case 4		Case 5	
		n	%	n	%	n	%	n	%	n	%
25 years	ORIF with volar plate	23	45			34	67			37	73
	ORIF with dorsal plate							16	31		
	Plate and fragment specific fixation			21	41						
65 years	Closed reduction and casting or splinting	20	39					16	31		
	CRPP			22	43						
	ORIF with volar plate					22	43			29	57

Table 2 Provides results of the most common method of treatment for each patient scenario.

associated ligamentous injuries at the time of fracture fixation compared to 9% of surgeons with < 10 years of experience (p=0.007). 54% of surgeons with >10 years of experience reported obtaining advanced imaging preoperatively compared to 26% of surgeons with < 10 years of experience (p=0.047). There was no difference found between the two groups regarding the management of the case-based scenarios.

DISCUSSION

Distal radius fractures are an Accreditation Council of Graduate Medical Education (ACGME) surgical milestone for orthopedic surgery residents. In the academic setting, both orthopedic trauma surgeons and hand surgeons may operate on distal radius fractures. Often, the treatment of distal radius fractures by orthopedic trauma surgeons can vary based on practice and referral patterns. Management of distal radius fractures can also vary based on factors such as patient age and fracture characteristics.

In patients older than 65 years with distal radius fractures, additional angulation can be accepted, and these patients may be better managed conservatively. Arora et al performed a randomized controlled trial which demonstrated improved radiographic outcomes but no significant difference in functional outcomes in elderly patients > 65 years old with distal radius fractures managed nonoperatively compared with locked plating.[4] The AAOS clinical practice guidelines were unable to recommend for or against operative treatment of distal radius fractures in patients > 55 years old.[1] In the case-based scenarios in our study, we found a trend of less aggressive management of the intra-articular and displaced distal radius fractures in a 65-year-old patient compared with a 25-year-old patient. We also found that the management choices of the respondents generally corresponded with the AUC recommendations.[2]

External fixation is rarely used in the management of distal radius fractures. It is typically used when dealing with a compromised soft tissue envelope or a comminuted fracture pattern that will not accommodate plate fixation. In our study, we found that no surgeons favored external fixation over open reduction and internal fixation in any of our case based scenarios. Grewal et al performed a randomized controlled study comparing 53 patients with distal radius fractures that failed

Table III. AAOS AUC Recommendations by Case Scenario

Patient Age	Case 1	Case 2	Case 3	Case 4	Case 5
25 years	• Volar locking plate (8)	• Volar locking plate (9) • Fragment specific fixation (8)	• Volar locking plate (9) • Fragment specific fixation (9)	• Volar locking plate (9) • Fragment specific fixation (9)	• Volar locking plate (9) • Fragment specific fixation (9)
65 years	• Reduction and immobilization (8)	• Volar locking plate (8) • Fragment specific fixation (8)	• Volar locking plate (9) • Fragment specific fixation (9)	• Volar locking plate (8) • Fragment specific fixation (8)	• Volar locking plate (8) • Fragment specific fixation (8)

Table 3 Shows the appropriate treatment options from AAOS AUC having the strongest ratings of 8-9 for each case scenario

closed reduction and casting who underwent treatment with either open reduction and internal fixation or external fixation and found better functional outcomes for patients treated with ORIF.[5] Williksen et al performed a prospective randomized controlled trial comparing volar locked plating to external fixation and found that patients who underwent volar locked plating of AO/OTA 23 C2 fractures had better clinical outcomes but 21% required hardware removal at 5 years.[6] Meta-analyses of randomized controlled trials comparing open reduction and internal fixation to external fixation have demonstrated improved Disability of the Arm, Shoulder, and Hand (DASH) scores, restoration of volar tilt and radial height, reduced infection rates, and improved forearm ROM with open reduction and internal fixation compared to external fixation.[7,8] The use of an external fixator was not the treatment of choice in our survey of comminuted distal radius fractures, although we did not provide a case with a compromised soft tissue envelope.

The literature has provided varying results regarding dorsal versus volar plating. In this study, we found that dorsal plating was the preferred treatment method for a distal radius fracture with dorsal comminution in a young patient. In the other scenarios in which operative fixation was chosen, volar plating was generally preferred. Volar locked plating has been found to provide adequate reduction of the articular surface.[9] Volar plating has also been cited as reducing the risk for extensor tendon rupture compared to dorsal plating. Rausch et al conducted a biomechanical study which found no significant difference in biomechanical properties between volar and dorsal locked plating.[10] A retrospective study found no significant difference in functional or radiographic outcomes when comparing dorsal and volar plating for management of distal radius fractures.[11] A study of intra-articular distal radius fractures found that volar plating had a significantly better Gartland and Werley score, as well as lower complication rates and a lower rate of volar collapse, when compared to dorsal plating. It did not find any difference in DASH score.[12] Lastly, Yu et al conducted a retrospective study comparing dorsal and volar plating and found that volar plating had a higher rate of neuropathic complications.[13] The AAOS CPG was unable to recommend for or against a specific type of fixation.[1] There are 216 scenarios in the AAOS AUC on distal radius fractures.[2] The AUC is also unable to support dorsal or volar plating as being superior.[2] In the high energy scenarios, there are more "Appropriate" ratings for volar versus dorsal plating.[2] Our results demonstrated the surgeons preferred dorsal plating in the 25 yo patient in the case scenario with dorsal comminution, but prefer volar plating for fixation in patients in the other scenarios in our survey. (Table 2)

In our study, we found that no respondents routinely performed fixation of associated ulnar styloid fractures. Gogna et al conducted a prospective study of 47 patients with distal radius fractures who underwent ORIF with volar locking plates and divided these patients into groups of those with and those without associated ulnar styloid fractures.[14] The ulnar styloid fractures were managed nonoperatively. They found no significant difference in radiologic or clinical outcomes between patients with and without ulnar styloid fractures. Fixation of ulnar styloid fractures has been recommended in the setting of an unstable DRUJ, particularly for fractures of the ulnar styloid base.[15] A prospective case-control study compared distal radius fractures treated with open reduction and internal fixation with or without fixation of the ulnar styloid and found no significant difference in clinical and radiographic outcomes.[16] Along these same lines, the AAOS CPG found insufficient evidence to recommend operative fixation of associated ulnar styloid fractures.[1] The orthopedic trauma surgeons responding to our survey did not routinely fix ulnar styloid fractures.

The role of wrist arthroscopy in reduction of intra-articular distal radius fractures has not been well elucidated. Although not considered standard, arthroscopic assisted reduction of distal radius fractures has been employed during operative treatment.[17,18] Proponents have found that wrist arthroscopy is useful in allowing a faster recovery time in comparison to ORIF,[19] identifying associated ligamentous injuries, visualizing the adequacy of the reduction, and removing debris from the joint.[20] A recent randomized controlled trial found no benefit of arthroscopic assisted reduction over conventional fluoroscopic guided reduction in the management of distal radius fractures.[21] At this time, there are no widely accepted indications for wrist arthroscopy in the operative treatment of distal radius fractures. None of our survey respondents reported routine use of wrist arthroscopy, and the AAOS CPG provided only weak evidence in support of its use for in treatment of intra-articular distal radius fractures.[1] In our survey, using wrist arthroscopy was not supported. However, it might be interesting to see orthopedic trauma versus hand surgeon's thoughts on this topic.

In terms of postoperative management, the majority (69%) of the survey respondents reported that they do not allow any range of motion postoperatively. This is consistent with the AAOS CPG, which provides a moderate strength recommendation that patients do not need to begin range of motion immediately postoperatively.[1] The current literature is not clear supporting post operative immobilization and effects on functional outcomes following volar plate fixation of distal radius fractures. One study demonstrated there was no loss in three

month range of motion following 6 weeks of immobilization compared to two weeks after volar plate fixation.[22] Interestingly, with solid plate fixation of fractures in a 25-year-old with good bone quality, there should be no reason why early mobilization could not be done. Perhaps this represent a further area of research.

While the AAOS CPG found moderate strength recommendation for the use of Vitamin C for CRPS prophylaxis, this practice was not performed by most survey respondents with only 20% reporting routine use of Vitamin C for CRPS prophylaxis postoperatively. The reported incidence of CRPS after distal radius fractures has ranged from 10.5-37%.[23] The reported benefit of Vitamin C in preventing development of CRPS has varied in the literature. Zollinger et al conducted a prospective randomized controlled trial which demonstrated that Vitamin C reduced the prevalence of CRPS in patients with wrist fractures.[24] They recommended a daily dose of 500mg Vitamin C for 50 days. Along these same lines, a recent meta-analysis showed a reduction in the prevalence of CRPS after wrist fractures with administration of Vitamin C.[22] On the contrary, Ekrol et al conducted a prospective randomized controlled trial demonstrating no benefit in reduction of the prevalence of CRPS with Vitamin C administration.[25]

Regarding the use of postoperative therapy, 59% of our survey respondents reported routine use of physical and occupational therapy postoperatively. The AAOS CPG provided a weak recommendation for the use of a home exercise program as an alternative to therapy, and a consensus recommendation for finger range of motion to avoid hand stiffness.[1] Some form of therapy appears to be beneficial although the extent and type of therapy is generally surgeon dependent, but may also be dependent upon patient insurance status and social issues.

When comparing surgeons with < 10 years in practice to those with > 10 years in practice, we found that they varied in terms of preoperative imaging and operative fixation of associated ligamentous injuries at the time of fracture fixation. Surgeons with > 10 years of practice had a significantly higher percentage who obtained advanced imaging preoperatively and a significantly higher percentage who performed operative fixation of associated ligamentous injuries. We cannot draw any definitive conclusions based on these findings, however. The AAOS CPG provided a weak recommendation for operative treatment of associated ligamentous injuries at the time of fracture fixation.

There are several limitations to our study. First, the data collected was based on the responses of the individuals who completed the survey. With any survey, the accuracy of the data is based on the responses provided by the participants, which can introduce a potential source of bias. In addition, this survey was administered via the OTA website, so only individuals who were members of the OTA or visited the OTA website were given the opportunity to participate. However, since this survey was administered to OTA members, we believe that the respondents are representative of the orthopedic trauma community. In addition, this survey included only orthopedic trauma surgeons since that was the intended target group. We realize that distal radius fractures are often managed by hand and general orthopedic surgeons as well.

CONCLUSIONS

When compared to the AAOS criteria, orthopedic trauma surgeons generally followed accepted treatment guidelines. Clinically, these guidelines should be used to guide decision-making in the management of distal radius fracture.

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THE TELESCOPING HIP PLATE FOR TREATMENT OF FEMORAL NECK FRACTURE: DESIGN RATIONALE, SURGICAL TECHNIQUE AND EARLY RESULTS

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ABSTRACT

Recent estimates suggest an annual incidence of greater than 125,000 femoral neck fractures. Surgical treatment is indicated for the majority of these fractures, which are estimated to double by the year 2050. Most displaced femoral neck fractures in elderly patients are treated with arthroplasty secondary to high complication rates associated with internal fixation. Traditional implants used for internal fixation, typically in elderly patients with stable fracture morphology and younger patients regardless of morphology, include the sliding hip screw (SHS), with or without a supplemental anti-rotation screw, and multiple cancellous lag screws.

Complications have been reported with both of these fixation techniques, especially as they apply to treating displaced femoral neck fractures in the elderly. Yet, complications of nonunion, loss of fixation and osteonecrosis, among others, still frequently occur in stable patterns of femoral neck fracture treated with internal fixation. Accordingly, additional implants have been designed recently to improve outcomes and avoid such complications in this population.

The Targon Femoral Neck Plate (Aesculap, Tuttlinger, Germany) has been used in Europe for the treatment of both displaced and nondisplaced femoral neck fractures by combining a side plate and multiple cancellous lag screws. Multiple studies have shown superior rates of both nonunion and osteonecrosis when compared to the SHS and multiple cancellous screws in both displaced and nondisplaced femoral neck fractures.

This article details the design rationale, surgical technique and early postoperative results of a new hybrid implant used for the treatment of both displaced and nondisplaced femoral neck fractures.

INTRODUCTION

Each year, greater than 250,000 hip fractures occur in the United States and are evenly divided between femoral neck and intertrochanteric fractures[1]. By 2050, this number is projected to double[2]. Surgical treatment is indicated for the majority of these fractures to optimize functional outcomes. In situ stabilization is usually performed for impacted or nondisplaced, stable femoral neck fractures. Displaced femoral neck fractures are treated with either open or closed reduction and internal fixation, hemiarthroplasty, or total hip replacement. Currently, most displaced femoral neck fractures in older individuals are treated with arthroplasty secondary to the high complication rates associated with internal fixation.

The traditional implants for fixation of a femoral neck fracture involve use of either a sliding hip screw (SHS) with or without a supplemental anti-rotation screw or multiple cancellous lag screws. Compared to a SHS, multiple cancellous lag screws can be inserted through a minimally invasive technique and a shorter operative time. Typically, three cannulated cancellous screws (6.5 mm, 7.0 mm, or 7.3 mm) are inserted in an inverted triangle configuration (inferior, posterosuperior, anterosuperior) with placement of the screws adjacent to the inferior (calcar) and posterior cortices. The inferior screw resists inferior displacement of the femoral head, while the posterior screw resists posterior displacement. A SHS may provide better fixation than cancellous screws for fixation of femoral neck fractures, particularly in cases where the fracture is oriented more vertically (Pauwels III) or in the basicervical region[3-7]. However, patients treated with a SHS are at increased risk for osteonecrosis compared to multiple cancellous lag screws, secondary to the insertion torque generated by the large diameter lag screw resulting in rotational malalignment[3-7].

Results reported using either a SHS or multiple cannulated screws have been disappointing for the treatment of both nondisplaced and displaced femoral neck fractures. In a series of 4,468 patients, Gjertsen et al reported an

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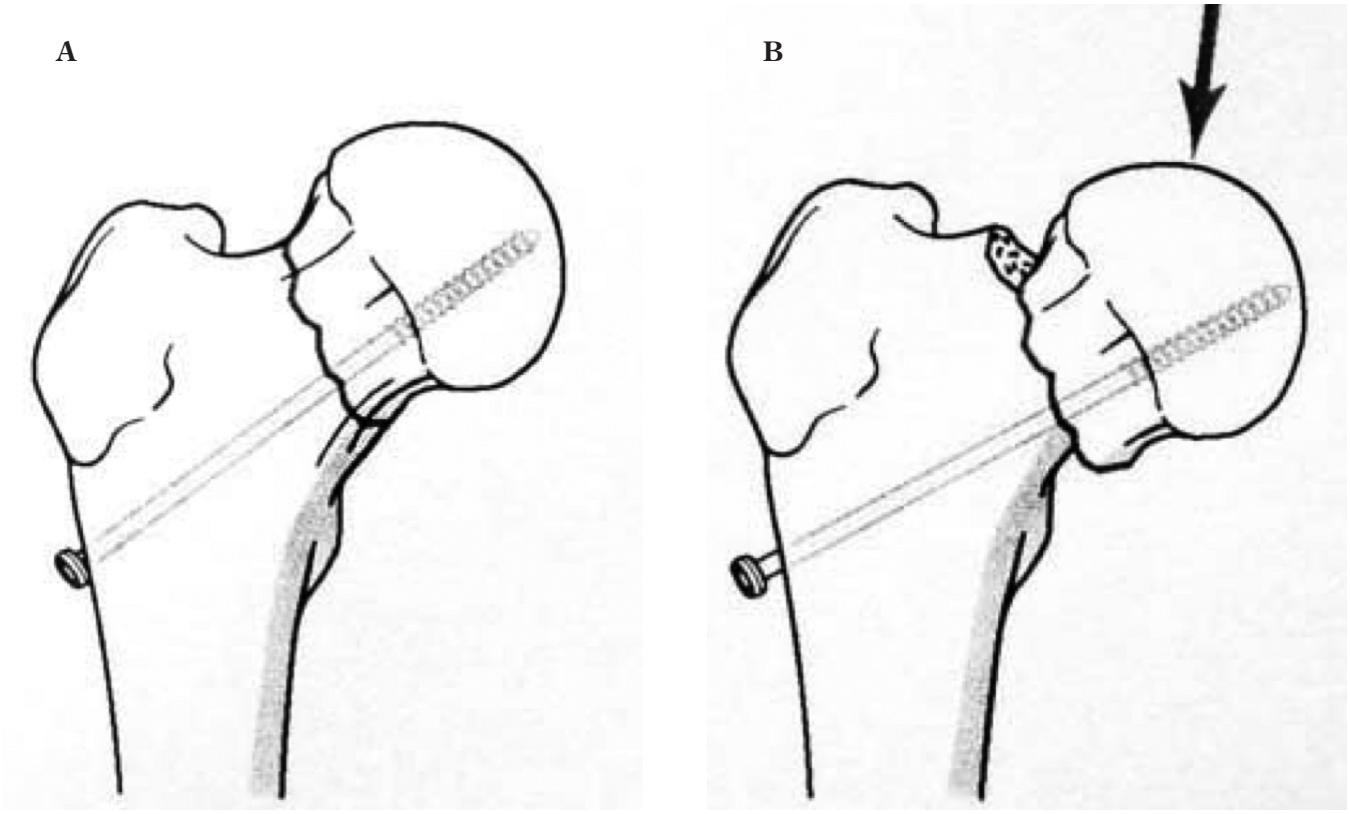


Figure 1a. This cancellous screw has support at the lateral cortex and the subchondral bone but no support in the femoral neck. 1b. With load, the fracture will displace until the screw has cortical support in the inferior femoral neck.

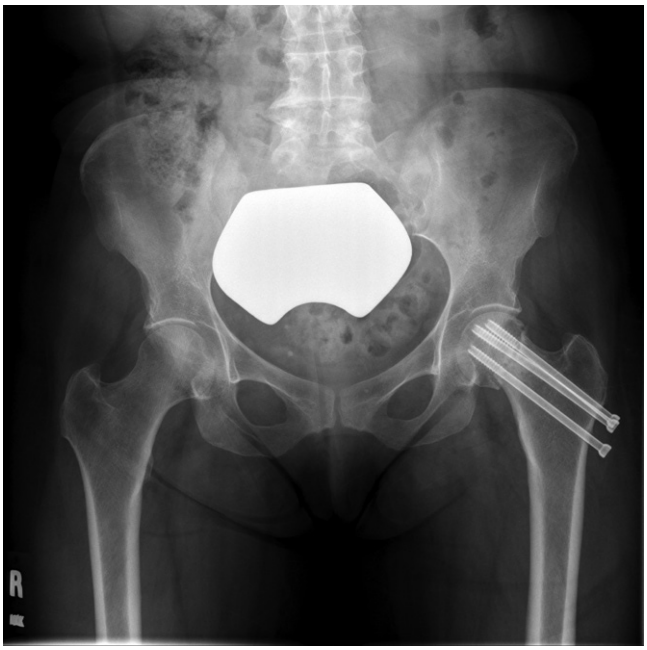


Figure 2. Lateral protrusion of the cancellous screws into the soft tissue as the fracture settles.

89% implant survival rate with use of cannulated screws for stabilization of nondisplaced femoral neck fractures at 1 year follow-up[8]. Conn and Parker reported an osteonecrosis rate of 8% and a nonunion rate of 6% in a series of 375 patients treated with multiple screw fixation for a nondisplaced femoral neck fracture[9]. Kain et al reported a revision surgery rate of 10% after cannulated screw fixation in a series of elderly patients (average age 80 years old) who sustained a Garden I or II femoral neck fracture at an average follow-up of 11 months[10]. Osteonecrosis, loss of fixation, nonunion, and subtrochanteric fracture were reported as the main reasons for revision.

Biomechanically, a sliding hip screw provides better fixation than multiple cancellous screws for stabilization of femoral neck fractures[5]. The side plate provides lateral support and prevents toggling of the cancellous screws in the femoral neck, resulting in inferior and posterior displacement of the femoral head relative to the femoral shaft (Figure 1). In a cadaveric femoral neck fracture model, a SHS provided more than twice the maximal strength and less displacement under physiologic loading than multiple screw fixation[5]. Stiasny et al compared a SHS to multiple cancellous lag screws for stabilization

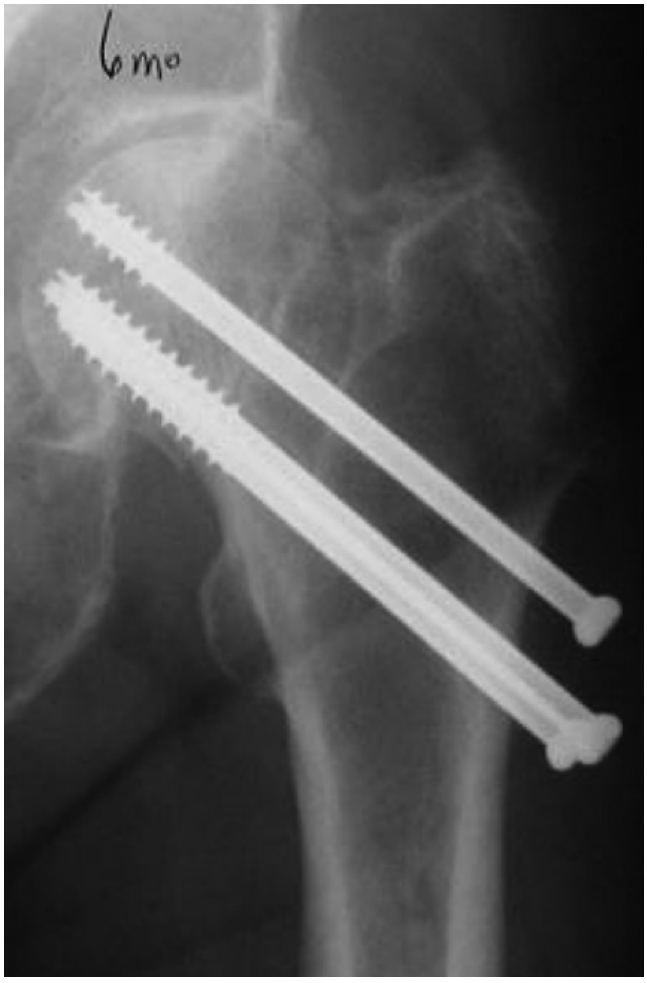


Figure 3. Shortening of the femoral neck with fracture healing.

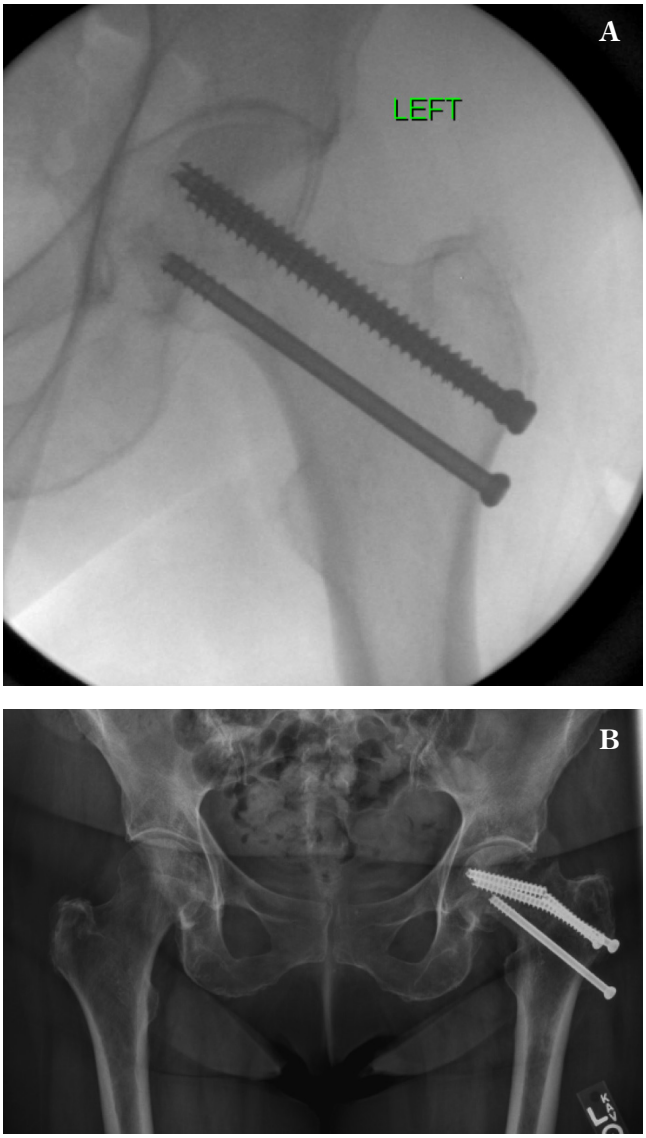


Figure 4a. Initial radiograph of a nondisplaced femoral neck fracture treated with length stable fixation. 4b. Follow up radiograph at 8 weeks, demonstrating failure of fixation.

of Garden type I and II fractures and reported a revision rate of 15% using cannulated screws and an overall 50% higher likelihood of revision[6]. The primary reason cited for revision was lateral soft tissue irritation by prominent cancellous screws that resulted from progressive femoral neck shortening. The same study also reported better patient outcomes when a sliding hip screw was utilized. However, Parker et al reported no advantage of either multiple screws or a SHS for treatment of femoral neck fractures in a meta-analysis of 28 trials (N=5547 patients) [11]. Bray reported that patients treated with a SHS had higher rates of osteonecrosis than multiple cancellous lag screws[12].

The results of both a SHS and multiple cancellous screws are much worse when used to stabilize displaced femoral neck fractures, with reported rates of loss of fixation, nonunion, and osteonecrosis approaching 33%[13-14]. A meta-analysis by Lu Yao et al[13] and more recently by Bhandari et al[14] reported a revision surgery rate over 35% secondary to complications after internal fixation of displaced femoral neck fractures. Parker et al reported a nonunion rate of 30% following fixation of displaced femoral neck fractures[15]. In a prospective randomized trial comparing internal fixation versus arthroplasty in 298 patients aged 60 or older, Keating et al reported fixation failure, defined as nonunion or osteonecrosis, in 37% of the internal fixation group.

Besides loss of fixation and osteonecrosis, other concerns with use of either multiple cancellous screws or a SHS for fixation of femoral neck fractures include: 1) lateral soft tissue irritation secondary to impingement of the lag screws as they protrude from the lateral

Figure 5. The Zimmer Biomet Telescoping Hip Plate.

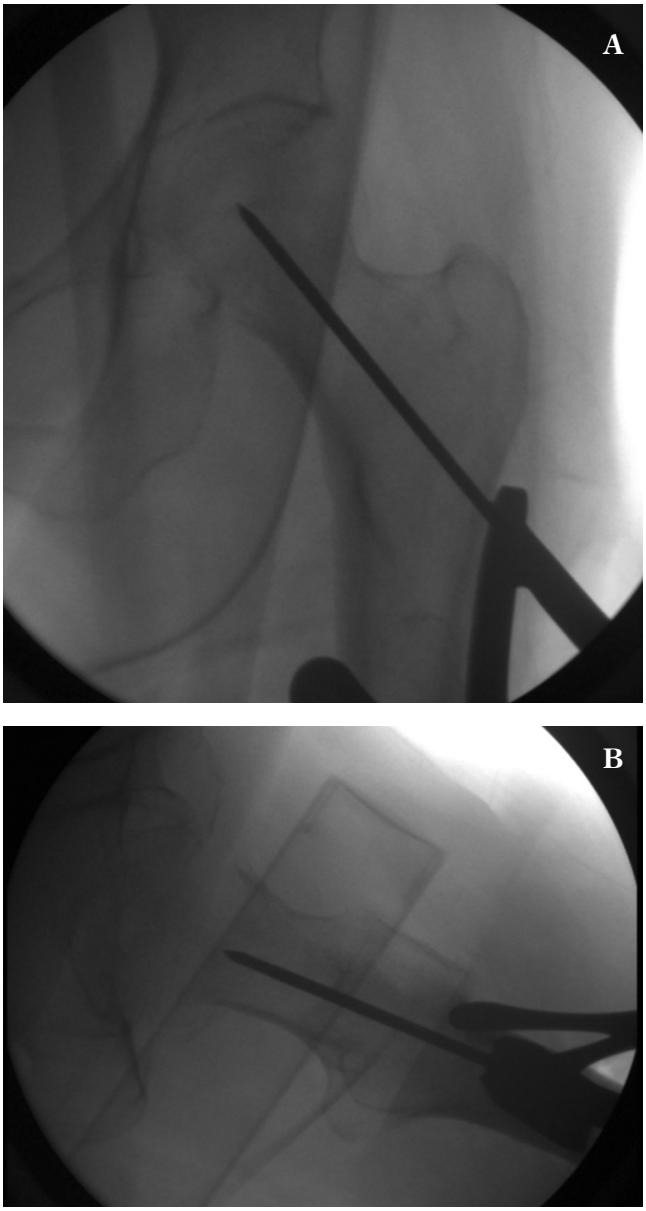


Figure 6. Use of a 130 degree angle guide to place a 3.0mm pin in the middle of the femoral neck and head on both the AP (a) and lateral (b) radiographs.

femoral cortex (Figure 2) and 2) uncontrolled collapse of the femoral neck leading to femoral neck shortening (Figure 3). Soft tissue irritation secondary to protrusion of the lag screws laterally is a common problem and can result in the patient experiencing lateral thigh pain and an inability to lie on the injured side. Although a rare occurrence, the patient may require a secondary surgery for removal of protruding hardware.

While historically a shortened and healed femoral neck fracture was an acceptable clinical result, recent studies focusing on femoral neck shortening and outcomes have reported a positive association between increasing amounts of femoral neck shortening and lower quality of life measures as well as higher revision rates[17]. Length-stable implants (fully threaded cancellous screws, divergent cancellous screws, and proximal femoral locking plates) have been proposed as solutions for minimizing the amount of femoral neck shortening to potentially improve postoperative outcomes, lower revision rates, and provide sufficient mechanical stability. However, one study reporting use of a length-stable proximal femoral locking plate to stabilize femoral neck fractures

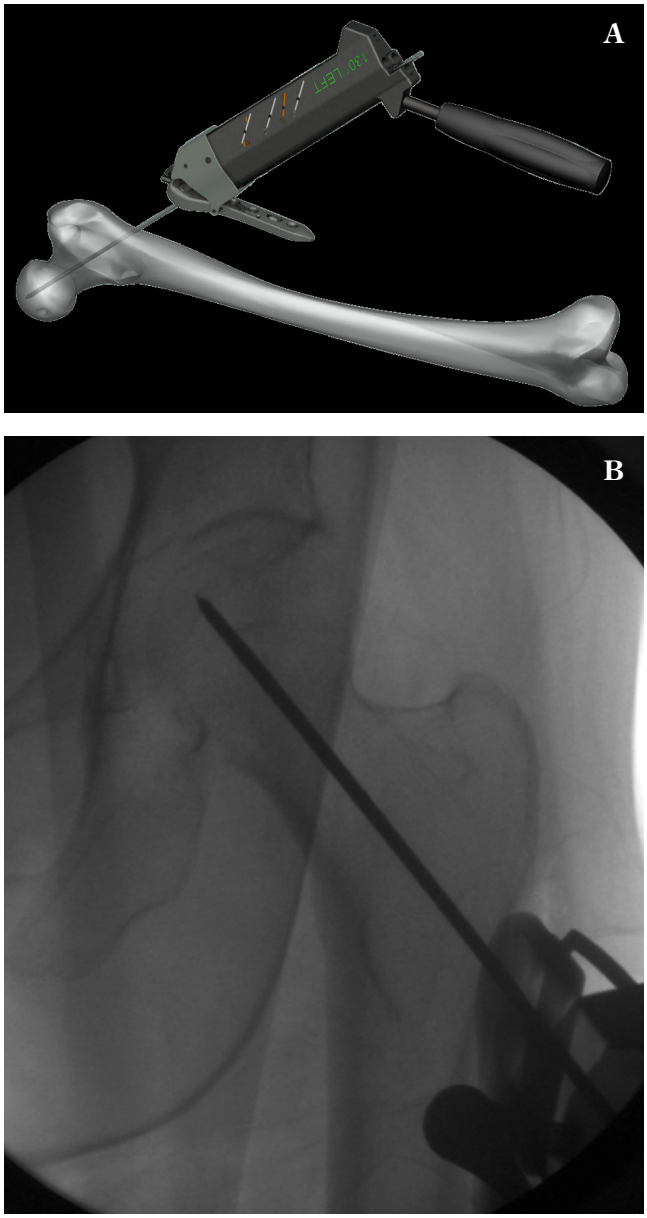


Figure 7. The THP is then placed over the guidewire (a) and pushed down to bone (b).

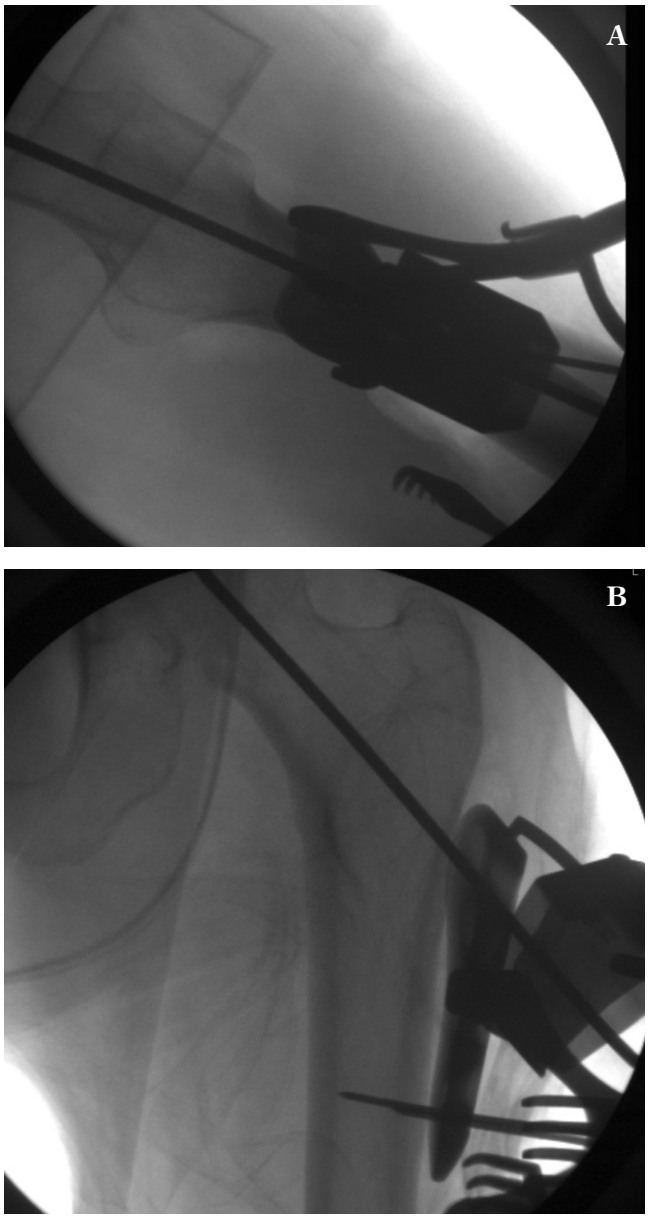


Figure 8. The plate is centered on the bone (a) and a pin used to hold the plate position (b).

reported an unacceptably high failure rate (36.8%) and recommended against use of this implant for managing femoral neck fractures[18]. The authors hypothesized that the stiffness of the implant precluded micromotion at the fracture site, which in turn transferred applied mechanical loads to the implant; this increased load resulted in fatigue failure of the plate or failure at the bone-screw interface. We have also found a high rate of implant related complications with use of length stable screw constructs when used for stabilization of femoral neck fractures (Figure 4).

A European implant (Targon Femoral Neck Plate, Aesculap, Tuttlinger, Germany) which has four smaller diameter cancellous screws that telescope within a barrel and lock to a side plate has shown promising potential for managing femoral neck fractures[19-21]. Parker et al reported a series of 320 patients who sustained a femoral neck fracture and were treated with this implant[19]. Minimum follow up was two years. In 112 nondisplaced fractures, three (2.7%) developed nonunion or loss of fixation and five (4.5%) developed osteonecrosis of the femoral head. In 208 displaced fractures, 32 (15.4%)

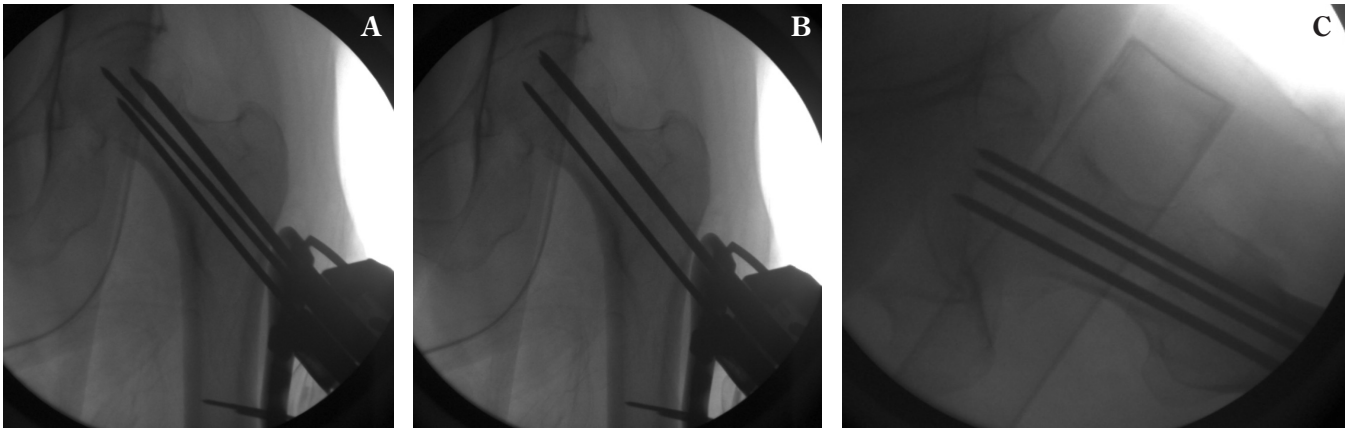


Figure 9. The 3 guidewires are inserted around the central pin (a) and advanced to within 1cm of the subchondral bone (b,c). The central guidepin can be removed at this time.

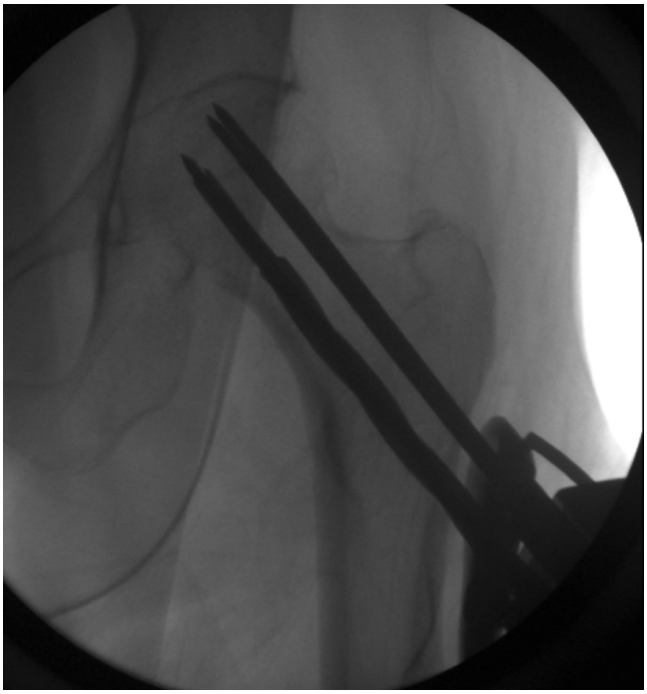


Figure 10. Reaming of the proximal femur over the guidepin.

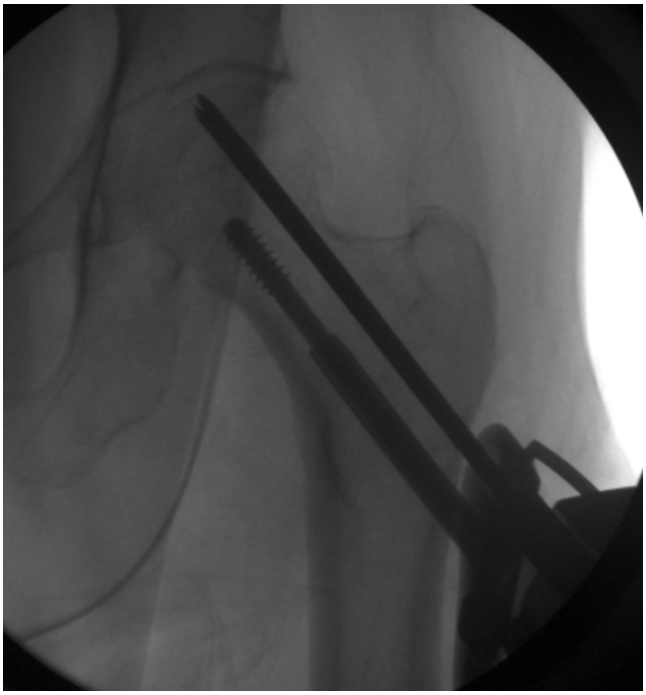


Figure 11. The telescoping screw is inserted fully collapsed and locked to the plate.

developed nonunion or loss of fixation and 23 (11.1%) developed osteonecrosis. The authors hypothesized that the lateral support combined with rotational stability may have resulted in a reduced incidence of complications compared to other contemporary fixation devices.

In a retrospective series of patients who sustained a displaced femoral neck fracture, Thein et al compared the results of the Targon femoral neck plate to multiple cancellous screws[21]. Seventy-eight patients were evaluated with a mean age of 54 years. The rate of nonunion with use of the Targon plate was 3.2% compared to 46.8% with use of cancellous screws. Multiple regression analysis showed that use of the Targon plate decreased the odds for overall complication by 77%. Eschler et al reported a series of 52 patients who sustained either a nondisplaced or displaced femoral neck fracture and were stabilized using the Targon plate or a SHS[20]. Mean follow-up was 15 months. The study reported less subsid-

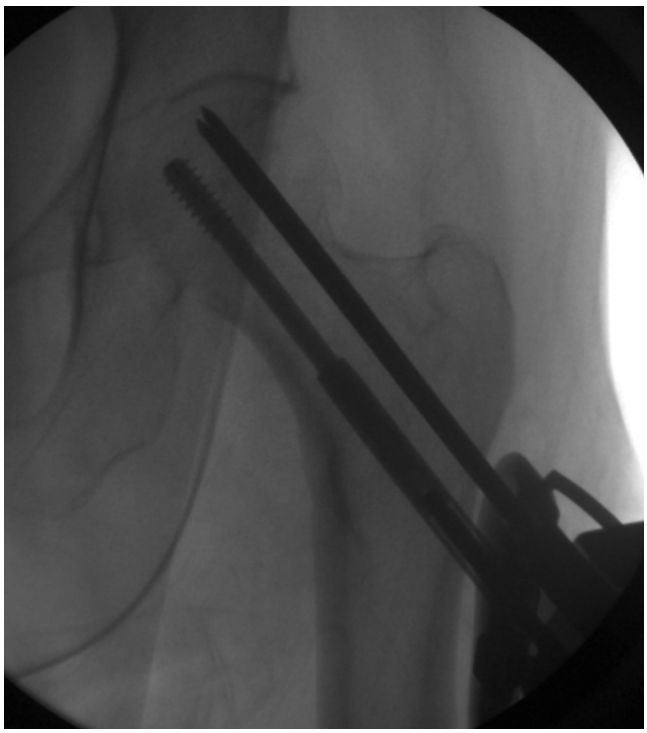
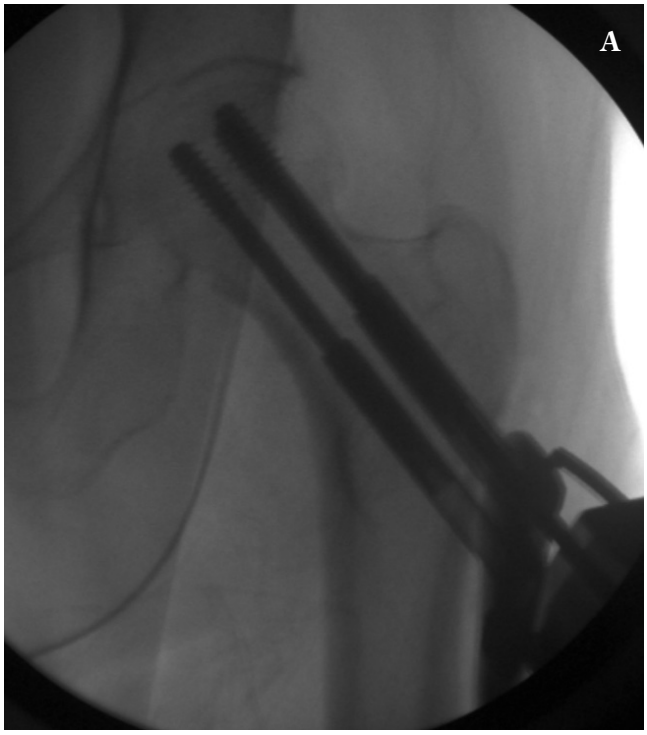


Figure 12. The screw is then advanced to its final position.



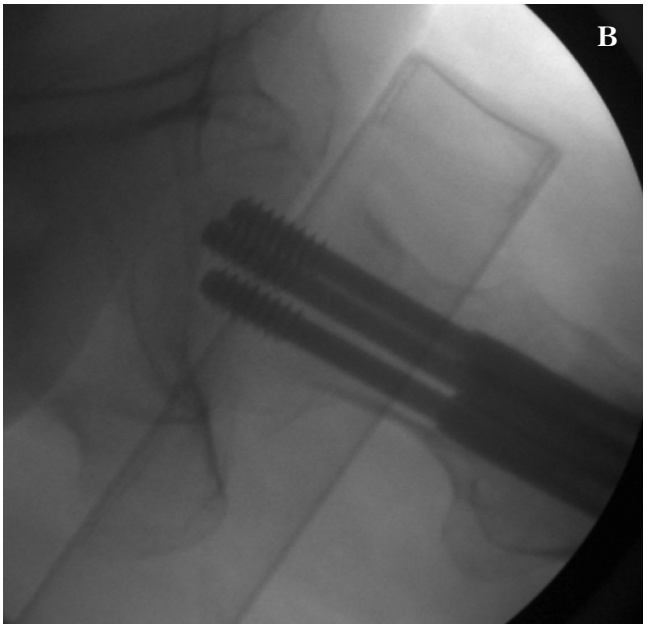


Figure 13. a,b. Insertion of all 3 telescoping screws.

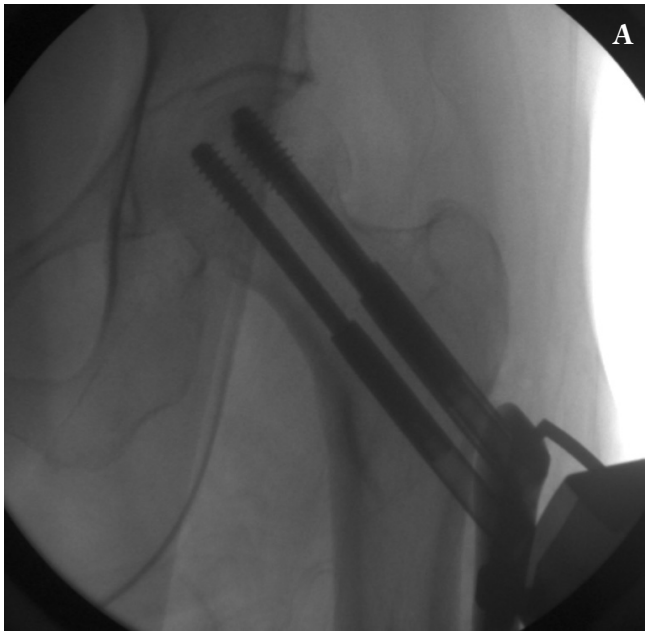
ence of the femoral head fragment, lower cut-out rates and lower rates of conversion to arthroplasty with use of the Targon plate.

The present paper reports the design rationale and surgical technique for a new hybrid implant, the Telescoping Hip Plate (Zimmer Biomet, Warsaw, IN), as well as our initial results using this plate when used to stabilize a consecutive series of femoral neck fractures.

DESIGN RATIONALE

The Telescoping Hip Plate (Zimmer Biomet, Warsaw, IN) (Figure 5) was designed to combine the best features of multiple cancellous screw and sliding hip screw fixation for stabilization of femoral neck fractures. This implant consists of three 7.5mm cancellous lag screws that telescope within a barrel which locks to a sideplate. The three titanium screws are oriented in an inverted triangular configuration at a 130 degree angle to the sideplate. The screw sliding occurs solely within the barrel, so that protrusion of the screws into the lateral soft tissue is prevented. Each of the screws has 20mm of available slide within the barrel when fully extended; multiple sleeve options are available which can be inserted into the barrel to limit the amount of screw collapse (5mm, 10 mm, 15mm or no collapse), if desired. The sideplate is available in two and four-hole lengths and has anterior offset from the proximal telescoping screw cluster for an anatomic fit.

The multiple cancellous screws provide rotational control of the head and neck, minimizing the risk of osteonecrosis, which has been reported with use of a single, large diameter lag screw. The side plate provides



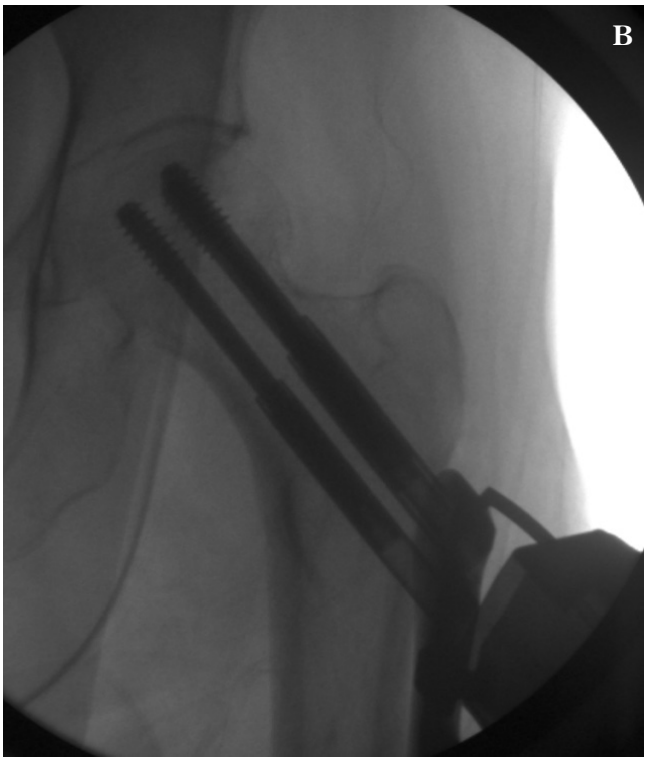


Figure 14. If the plate is off the bone (a), the plate holding pin is removed and the plate impacted to the lateral cortex (b).

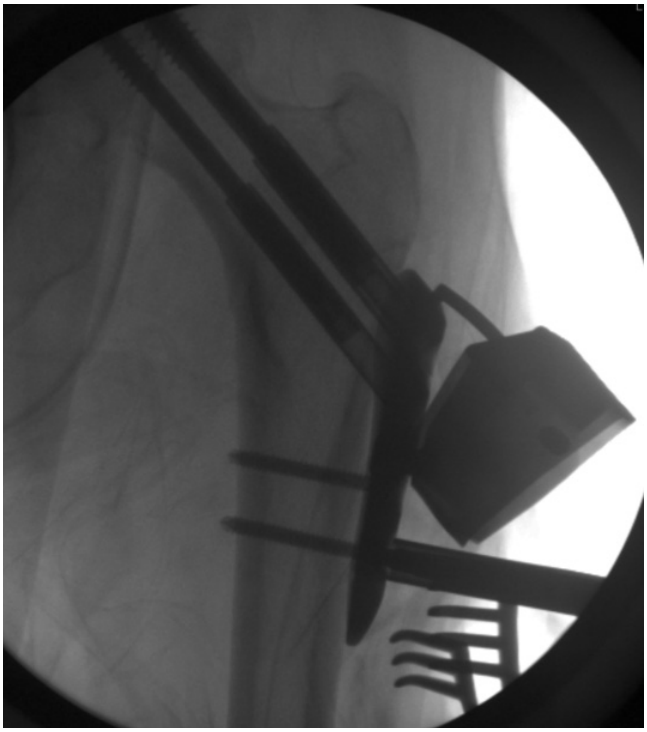


Figure 15. Insertion of the plate holding screws.

lateral support and prevents toggling of the cancellous screws and subsequent loss of fixation. The inverted triangular pattern has been shown to be the preferred configuration and is the standard of care for placement of the three cancellous screws; no advantage has been demonstrated for use of more than three screws for fixation of a femoral neck fracture. Placement of the cancellous screws within a barrel optimizes sliding. The amount of available slide for each screw when fully extended was set at 20mm to allow sufficient slide given a worst-case scenario of fracture collapse. The sleeve options were designed to prevent uncontrolled collapse while allowing surgeon options for controlled lag screw slide. The anterior offset was designed to accommodate the anterior offset of the femoral neck on the shaft.

The instrumentation was designed to allow a percutaneous or mini-open technique. The telescoping cancellous and plate holding screws are inserted through the targeting jig. Small diameter pins can be used to hold the plate to the shaft during screw insertion to minimize the need for soft tissue retraction.

SURGICAL TECHNIQUE

The two-hole plate is inserted through a 6cm skin incision while the four-hole plate is inserted through an 8cm skin incision. The iliotibial band is similarly incised in line with the skin incision exposing the vastus lateralis

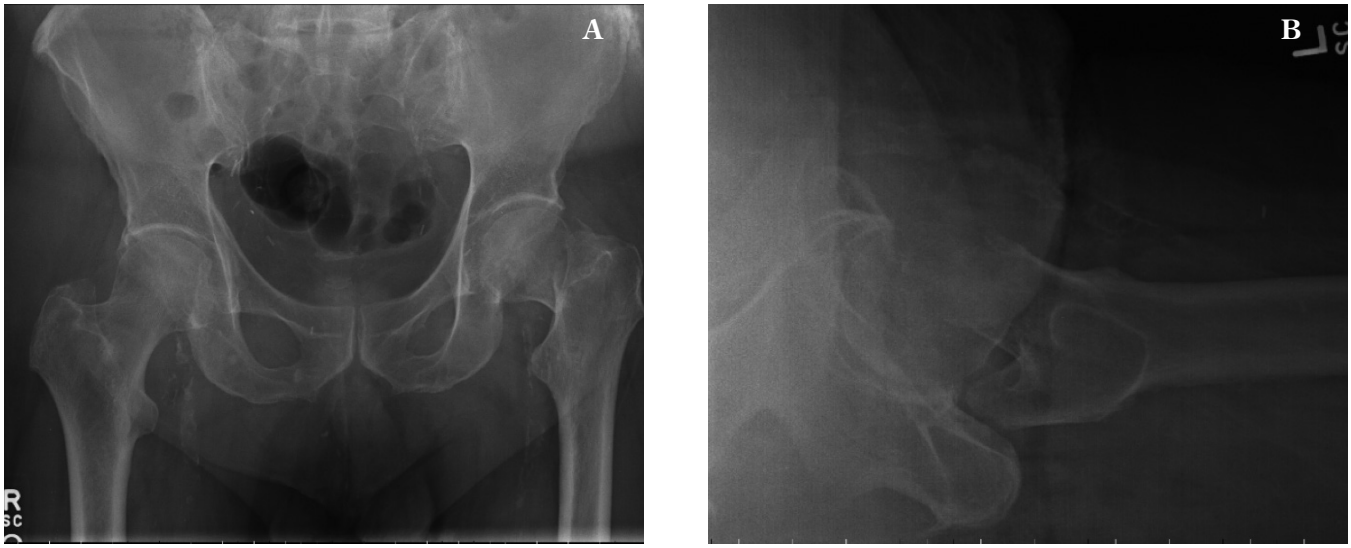


Figure 16. AP (a) and lateral (b) radiographs of a 60 year old male who fell, sustaining a displaced left femoral neck fracture.

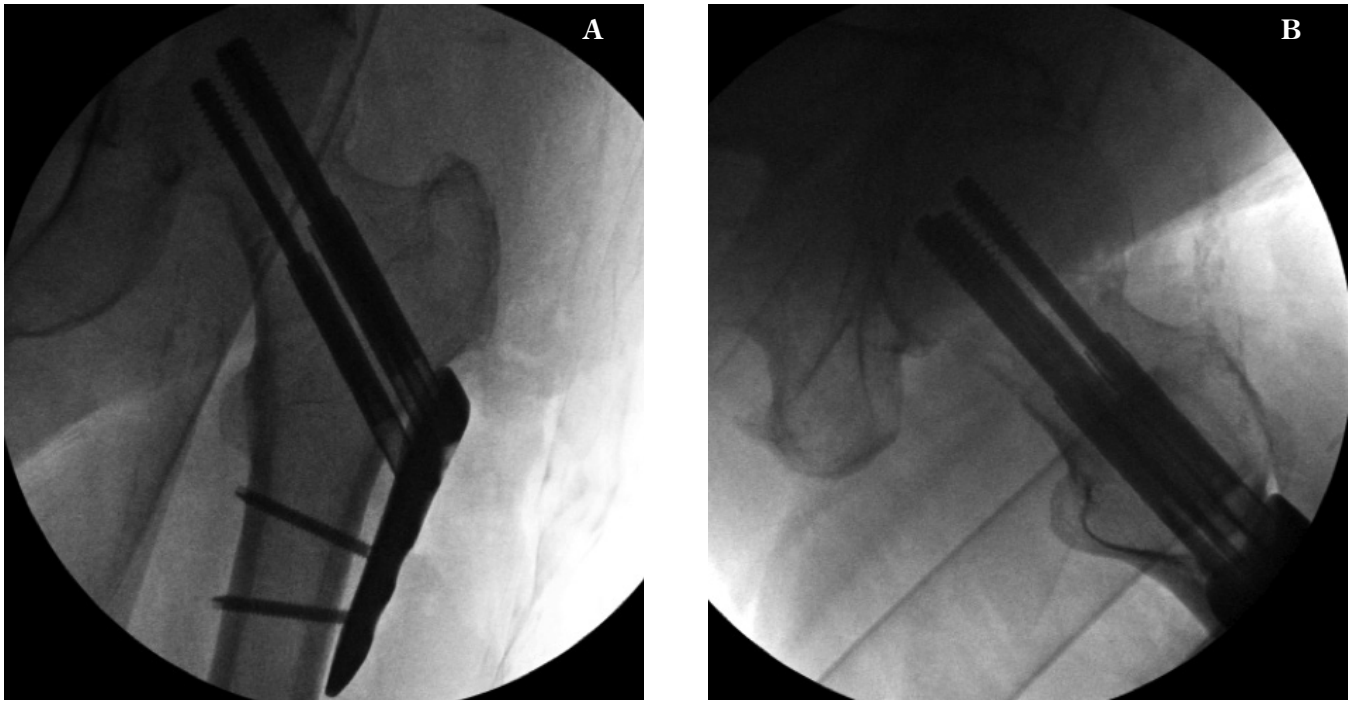


Figure 17. Initial AP (a) and lateral (b) radiographs after closed reduction and internal fixation using the THP.

muscle, which is subsequently elevated from the lateral femur. After exposure of the lateral femur, the plate and targeter or a 130 degree angle guide (Figure 6) is used to insert a 3.0mm guidepin into the femoral neck and head, centered on both the AP and lateral planes. If the angle guide is used to insert the pin, the plate is slid over the wire and pushed to bone (Figure 7). The plate is centered on the lateral femur and a small diameter pin is inserted to hold the plate in position (Figure 8). Three 3.0mm guidepins are then inserted through the targeter and plate, around the central pin, in an inverted triangular configuration. These 3.0mm guidepins are placed within 1cm of the subchondral bone (Figure 9). The central guidepin can then be removed. The pins are

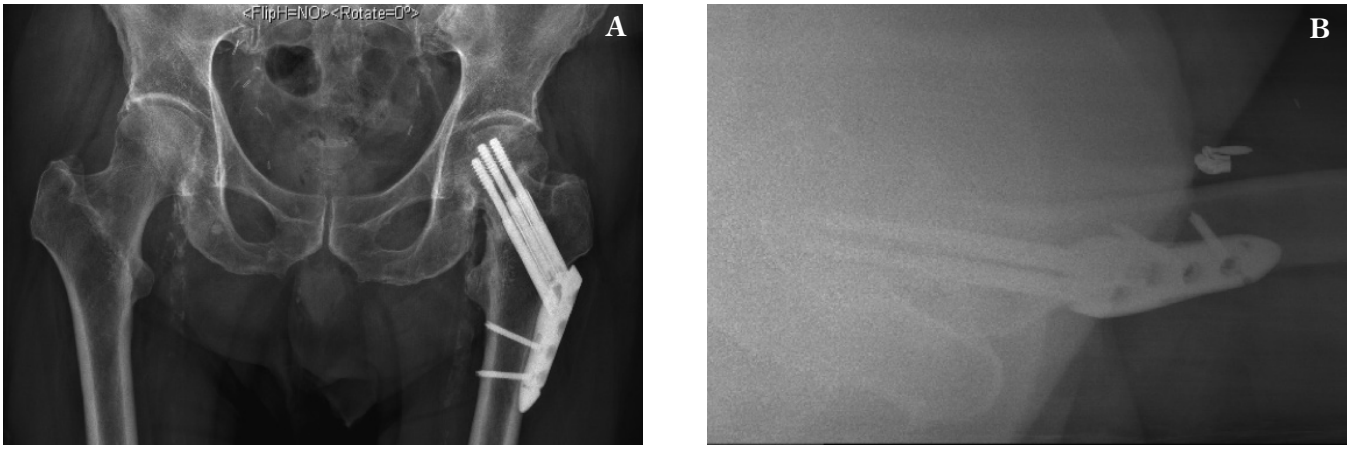


Figure 18. One year AP (a) and lateral (b) radiographs demonstrating a healed femoral neck fracture with minor shortening and no protrusion of the screws into the lateral soft tissue.

measured, the screw paths reamed (Figure 10) and the telescoping screws inserted. Each screw is inserted fully collapsed within the barrel and the barrel locked to the plate (Figure 11); the telescoping lag is then advanced to its final position (Figure 12). After all three telescoping screws are inserted (Figure 13), if the plate is situated off the bone, the plate-holding pin is removed and a tamp used to impact the plate until it contacts the lateral femur (Figure 14). The sideplate is then secured to the femur through the targeter using 5.0mm locked or nonlocked screws (Figure 15). Prior to releasing traction, sleeves of various lengths can be inserted into the barrels to limit the amount of screw collapse, if desired.

INITIAL RESULTS

Between April 2015 and April 2016, 44 patients who sustained a femoral neck were treated at our institution using the Telescoping Hip Plate. There were 15 men and 29 women with an average age of 70 years (range, 20-96 years). Forty-one fractures were the result of a ground level fall, while three were the result of high energy (MVA=1, GSW=1, pedestrian struck=1). Twenty-three fractures were nondisplaced or valgus impacted while 21 were displaced femoral neck fractures. All of the nondisplaced or valgus impacted fractures were stabilized in situ; 18/21 displaced femoral neck fractures (86%) were close-reduced while 3 (14%) were open-reduced using a Smith-Peterson approach. Forty-two fractures were stabilized using a two-hole side plate and two fractures received a four-hole plate. Thirty-eight fractures (86%) were allowed full telescoping screw slide, 5 fractures were limited to 5mm slide and 1 fracture was allowed no slide.

Eight patients (18%; 6 nondisplaced, 2 displaced fractures) were lost to follow-up, leaving 36 patients (82%) who had 6-month minimum follow-up (mean 9 months, range 6-16 months). In the nondisplaced fracture group (N=17), all fractures united with no loss of fixation or osteonecrosis. In the displaced fracture group (N=19), 18 fractures united (95%) (Figures 16-18) while one patient had loss of fixation with screw cut out at one-month follow-up. That patient was 96 years old and had surgery performed 2 days after hospital admission; she never had additional surgery secondary to severe medical comorbidities. In addition, one patient developed osteonecrosis at one-year follow-up and underwent conversion to a total hip replacement.

CONCLUSION

Our early results using the Telescoping Hip Plate are promising with very high union rates and low complication rates when used to stabilize both nondisplaced and displaced femoral neck fractures. Further studies with larger patient numbers and longer follow-up are required to determine the role for this new device in the treatment of both nondisplaced and displaced femoral neck fractures.

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SET IT AND FORGET IT: DIAPHYSEAL FRACTURES OF THE HUMERUS UNDERGO MINIMAL CHANGE IN ANGULATION AFTER FUNCTIONAL BRACE APPLICATION

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ABSTRACT

Objectives: To quantify radiographic changes observed in humeral shaft frctures throughout course of treatment with functional bracing.

Design: Retrospective cohort study.

Setting: Level 1 Trauma Center and affiliated Tertiary Care Center

Patients: 72 retrospectively identified patients with fracture of the humeral diaphysis

Intervention: Application of functional brace with radiographs obtained immediately after brace application and at 1 week, 2 weeks, 3 weeks, 6 weeks, 3 months, 6 months and 12 month follow-up.

Main Outcome Measure: Fracture angulation, measured in the coronal and sagittal planes.

Results: 522 radiographs from 72 patients were critically reviewed. All fractures were followed to healing. Sixty-six patients (92%) successfully healed their fractures with non-operative treatment. The average angulation on immediate post-brace X-ray was 12 degrees varus ad 7 degrees procurvatum. At final follow-up, average coronal angulation was 14 degrees and 4 degrees procurvatum. Fracture angulation changed a mean 2 degrees in the AP plane and 3 degrees in the sagittal plane over the course of care. Linear regression determined fracture angulation proceeds toward both varus and recurvatum at 0.01 degrees per day.

Conclusion: Humeral shaft fractures treated non-operatively heal with minimal change in angulation after brace application. If angulation on the post-brace radiograph is acceptable and there is no history of repeat trauma and no cosmetic deformity, radiographs may be utilized less frequently. Patients should be evaluated via history and physical exam at follow-up prior to the 6-week point, at which time regular radiographs (6 week, 3 month, 6 month, 12 month) should commence.

INTRODUCTION

Fracture of the humeral diaphysis is a common injury treated by orthopaedic surgeons. The injury accounts for 1-5% of all fractures in the United States and has an incidence of approximately 14.5 per 100,000 people.[1-3] Non-operative management remains the treatment of choice for the majority of these injuries owing to decreased cost of care, ability of the upper extremity to overcome moderate anatomic deformity, and reliable return to pre-functional status. Treatment requires placing the extremity in a well-molded splint with subsequent advancement to a functional brace at two weeks to allow primary callus formation. This algorithm was popularized in the 1970's when a report by Sarmiento et al. was published detailing 51 patients treated with functional bracing.[4] Functional bracing allows early introduction of functional activity by permitting full range of motion at the shoulder and elbow joints and reliably yields excellent outcomes.[5-15]

Functional bracing for humeral shaft fractures is particularly demanding for both patient and physician. Once the patient is transitioned to functional brace, some physicians opt to follow patients with weekly or bi-weekly plain radiographs for the first 3-6 weeks to ensure angulation remains within acceptable parameters. Despite extensive outcome investigations, no literature exists defining how these patients should be surveilled or what degree of change in fracture alignment is expected or acceptable on week to week surveillance. As such, it is difficult to define what early changes in angulation are allowable versus those which are alarming and require adjustment. If fear of progressive angulation after brace application is alleviated, physicians may opt to obtain radiographs less frequently which serves to diminish

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Institutional Review Board Approval:
This study was approved by the New York University School of Medicine Institutional Review Board

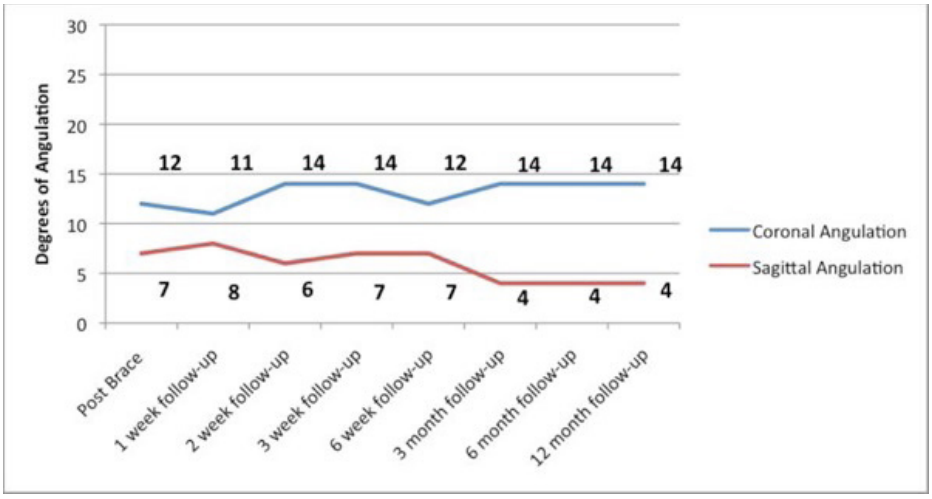

Figure 1. Mean Degrees of Angulation at Follow-up Intervals

patient radiation exposure and cost of care. This study aims to quantify radiographic changes observed in humeral shaft fractures throughout course of treatment with functional bracing. We hypothesize that no clinically significant change in fracture alignment would occur subsequent to application of the brace.

PATIENTS AND METHODS

Patients were retrospectively identified by querying medical records for ICD-9 codes pertaining to humeral shaft fracture treated by traumatologists in our department. Inclusion criteria were: non-operative treatment with functional bracing, isolated humeral shaft injury, X-rays (AP and trans-thoracic lateral) available for analysis on the picture archiving system (PACS), and minimum follow-up through clinical and radiographic union. We identified seventy-two consecutive patients who underwent non-operative management of seventy-two humeral shaft fractures. This cohort received a total of 522 radiographs during their treatment.

Fracture patterns were classified according to O/OTA-system.[16] Fracture angulation and displacement was measured in the coronal and sagittal planes on PACS (Siemens Erhlanger, Germany). In the coronal plane, a line was drawn down the long axis of the humeral shaft; varus angulation was defined by positive values and valgus angulation by negative values. In the sagittal plane, procurvatum was defined by positive values and recurvatum was defined by negative values. Images were evaluated post-brace application and at 1 week, 2 week, 3 week, 6 week, 3 month, 6 month and 12 month follow-up.

Mean coronal and sagittal angulation was calculated for each of the above radiographic intervals. A linear regression was performed for both coronal and sagittal angulation to model change over time.

RESULTS

Seventy-two patients met inclusion criteria and were included in the study cohort. All fractures were followed, at minimum, to fracture healing or decision for surgery. Average length of follow-up was 40 weeks (range 12-56 weeks). Sixty-six patients (92%) successfully healed their fractures with non-operative management in a mean of 15 weeks (range 8-32 weeks, SD 4.1 weeks). Six patients (8%) failed non-operative management and underwent surgical intervention.

The average angulation immediately after brace application was 14 degrees varus and 7 degrees procurvatum. Fourteen patients had a fracture with greater than 20 degrees of varus angulation after initial brace application, of which four (29%) were eventually indicated for open reduction and internal fixation. Mean coronal and sagittal angulation at follow-up are depicted graphically in Figure 1. Fracture angulation changed a mean of 2 degrees in the coronal plane and 3 degrees in the sagittal plane throughout the course of treatment. Clinical radiographs throughout the course of treatment are provided as an example (Figures 2a-2e).

Linear regression was performed investigating fracture angulation change as a function of time. Total days since initial brace application was the independent variable. Linear regression revealed $\beta = 0.01$ (progression towards varus) for coronal alignment and $\beta = -0.01$ (progression towards recurvatum) for sagittal alignment. These results demonstrate that fractures tend towards varus and posterior angulation at approximately 0.01 degrees per day. It should be noted that a standard convention of defining angulation was utilized to obtain these values (varus and anterior angulation defined as positive values, valgus and posterior angulation as negative values).

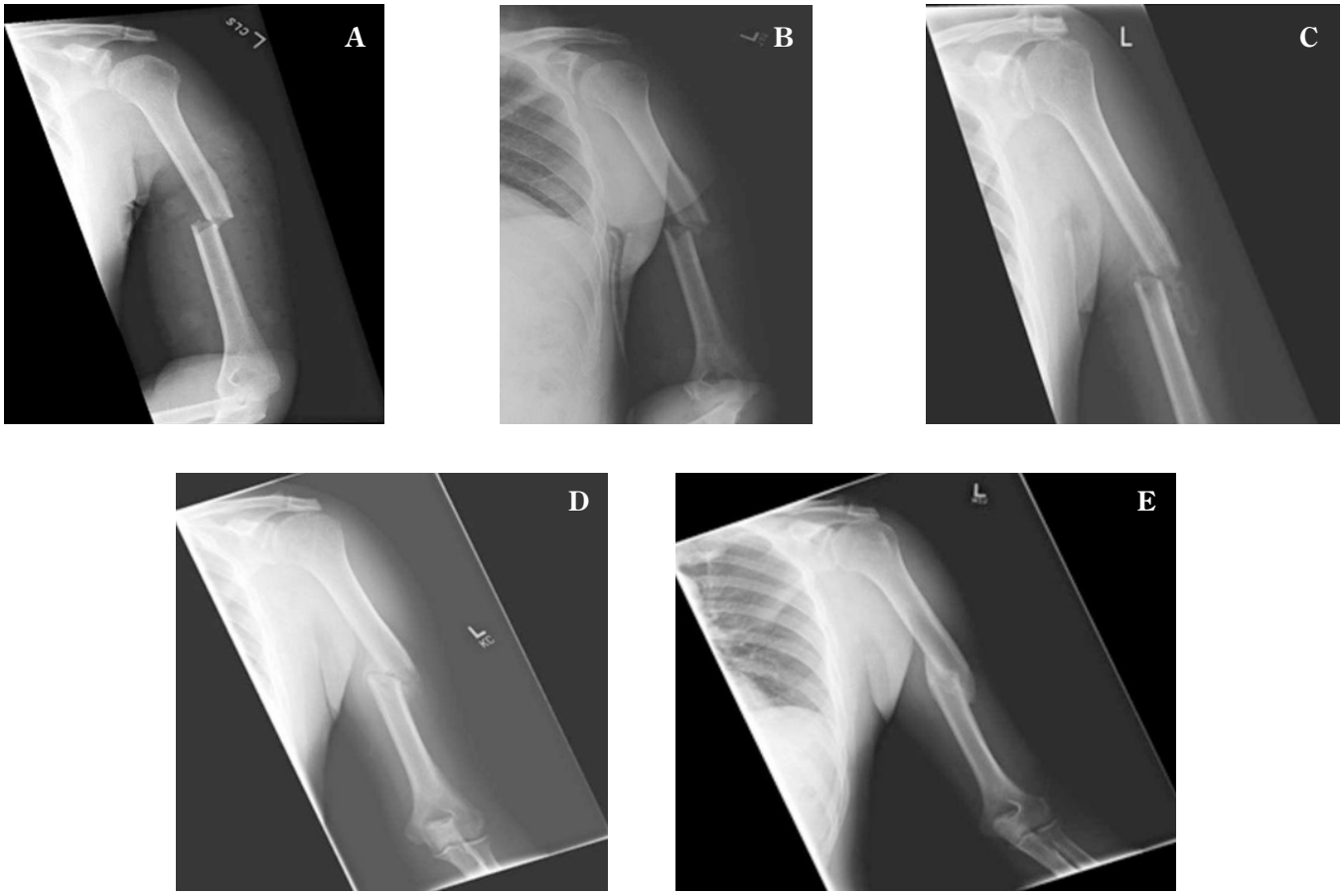

Figure 2 - a.) Immediate post-brace radiograph, b.) 2 week follow-up, c.) 3 week follow-up, d.) 6 week follow-up, e.) 1 year follow-up

Fourteen fractures remained in 20° or greater of varus after brace application. At one- and two-week follow-up, surgical intervention was offered to these patients on the basis of persistent angulation; four patients (29%) elected ORIF and ten patients opted to complete non-operative management. For the non-operative group (n=10), average post-brace angulation was 25° varus and 2° procurvatum. At union, which occurred at a mean of 20 weeks, average angulation was 20° varus and 3° procurvatum. No patient healed with clinical deformity despite radiographically significant angulation. An example is demonstrated in Figures 3a-c.

Six patients (8%) failed non-operative treatment and required surgical intervention. Four patients with significant clinical and/or radiologic coronal deformity noted after brace application, and which failed to improve at follow-up visits, opted for surgical intervention (ORIF) at the two-week time point. For this group (n=4), the mean coronal deformity was 21° varus on post-brace radiograph and 26° varus at two weeks (time of surgical indication). One patient presented at one-week follow-up with complaints of increased pain and obvious cosmetic deformity. She was found to have an acute worsening of angulation between brace application and one week follow-up (12° varus vs. 42° varus, respectively). She was indicted for ORIF. One patient proceeded to nonunion. There was no specific fracture pattern (AO/OTA system16) associated with failure of non-operative treatment.

DISCUSSION

These results demonstrate that humeral shaft fracture angulation changes minimally throughout course of treatment with a functional brace. While it is true that there is a tendency varus and posterior angulation, the overall change is clinically insignificant. Our results support two conclusions: First, fractures in unacceptable angulation should not be expected to significantly "self-correct" following initial application of functional bracing. Second, frequent radiographic evaluation in early stages of treatment is unnecessary since minimal change is expected.

It is commonly taught that active motion of the upper extremity permits realignment as muscles contract around the fracture.[17] Our results demonstrate that it is unlikely for fractures remaining in unacceptable clinical

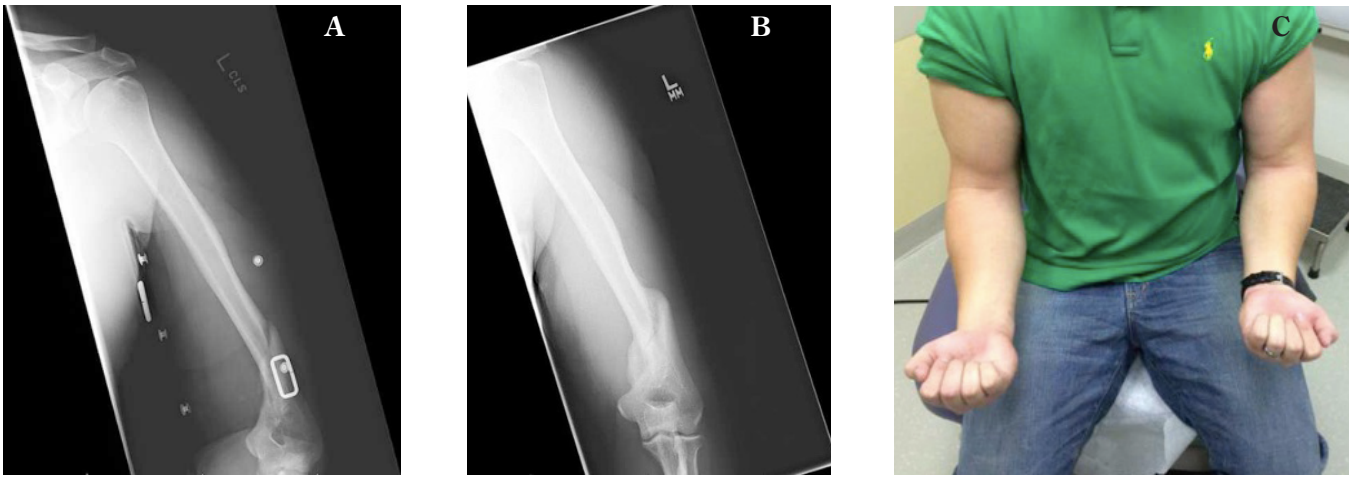

Figure 3 - a.) Post-brace radiograph demonstrating varus angulation > 20°. He opted to complete non-operative management , b.) Radiographs demonstrating healed fracture, c.) There was no clinical deformity despite radiographically significant angulation.

or radiographic angulation after application of the brace to self-correct over the course of treatment. While it is true that some degree of correction occurs in the sagittal plane (provided the fracture is angulated anteriorly), the rate of change is too small to result in significant clinical improvement by the time union occurs. In addition, varus angulation – the most common coronal deformity – may progress slowly throughout treatment rather than diminish.

Varus angulation greater than 20 degrees is an accepted indication for operative intervention, as this level of angulation is thought to result in cosmetic deformity and functional deficit.[2,17] Many studies report that functional bracing reliably yields acceptable results with regards to angulation[4-15] and our results confirm this notion. However, results of treatment appear contingent on radiographic alignment immediately following application of the brace. If the humerus is well aligned on the initial X-ray obtained after bracing, excellent results may be expected. Fractures remaining in unacceptable clinical or radiographic deformity after brace application should not be expected to significantly "self-correct" and operative fixation should be considered. This is supported by the high rate of conversion to operative treatment in our cohort of patients with greater than 20° of varus angulation following brace application (29%).

The cohort of 10 patients who opted to complete non-operative treatment despite persistent significant radiographic deformity represents a treatment "grey-zone" and highlights the need for open, comprehensive communication between orthopaedist and patient. For each patient, the risks of continued non-operative treatment (cosmetic deformity and functional deficit) were explained as well as the risks of surgery. When patients elected non-operative management, the need for strict follow-up was stressed to ensure a positive outcome. Physical examination – consisting of visual inspection for cosmetic deformity and range of motion (ROM) assessment while in the brace – was the mainstay of evaluation. With this method of follow-up, all patients were satisfied with their outcome despite suboptimal radiographs.

The minimal rate of change in fracture angulation suggests frequent radiographic evaluation in the early stages of treatment is unnecessary. Provided that adequate cosmetic and radiographic alignment is achieved immediately after application of the brace, the humerus can be expected to remain stable. Patients should still be seen by the physician at weekly intervals in the early stages of treatment but evaluation should rely chiefly on history and physical exam. So long as the patient has not experienced repeat trauma and shows no cosmetic deformity on physical exam, radiographs may be deferred until the usual 6-week time point. Increased radiographic evaluation is warranted in three particular instances: 1) when patients remain in 20° of varus angulation (or greater) after application of the brace and still opt for non-operative management 2) When there is history of repeat trauma to affected extremity 3) A cosmetic deformity or ROM deficit is appreciated in the physical exam.

While anatomic reduction is seldom achieved with non-operative management of humeral shaft fractures, this is rarely necessary to preserve function due to the range of motion provided by the gleno-humeral joint and elbow.[17] As mentioned previously, greater than 20-30 degrees of varus or sagittal angulation is historically accepted as the cutoff for operative intervention in fractures of the humeral diaphysis.[4,5,8-10,12,14,17,18] There has been little debate regarding the validity of these values ever

since 1966 when Klenerman published the observation that function is preserved within these measurements.18 The small rate of change in fracture angulation determined in this study suggests it is unlikely for patients with acceptable post-brace angulation to sustain functional impairment.

Our results for average post-brace angulation and final angulation are similar to those reported in the literature.[5,8,9,12,18] Nevertheless, this study should be interpreted in light of its limitations. First, it is rare for AP and lateral X-rays to be taken with the humerus in the exact same position from week to week. Inevitably, there is inconsistency in positioning of the humerus between each X-ray which may have led to minimal differences in measured angulation. It is possible that in some cases the true fracture angulation did not change and difference in humerus positioning created an apparent change in angulation. This may have resulted in less accurate results despite our best efforts to include only true AP and lateral radiographs. Nonetheless, inconsistency in humeral positioning between follow-up X-rays is common and will need to be navigated by the orthopaedist clinically. Second, the mean duration of follow-up is admittedly short (40 weeks). However, all fractures were followed to union, which occurred at a mean of 15 weeks. Given that angulation only occurs in the setting of an ununited fracture, and our mean final follow-up surpassed mean time to union, it is unlikely that our results were adversely impacted.

Functional bracing for humeral shaft fractures provides adequate fracture stabilization and results in minimal change in angulation throughout treatment once the brace is applied. Fracture stability mitigates the need for frequent radiographic evaluation early in the treatment period, and patients should be followed closely with history and physical exam for the first six weeks. Increased radiography is warranted in the case of significant post-brace angulation, repeat trauma or cosmetic deformity. Decreased overall reliance on X-rays will result in less patient radiation exposure and lessen the cost of care. Fractures remaining in unacceptable cosmetic or radiographic deformity after application of the brace should be considered for operative intervention.

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THE EFFECT OF DIFFERENT COMBINATIONS OF THREE STACKED HALF-HITCHES AND SUTURE MATERIALS ON AN ARTHROSCOPIC KNOT IN A DRY OR WET ENVIRONMENT

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Rosalee E. Zackula, MA[5]; Lisa N. MacFadden, PhD[3,4]; Daniel J. Prohaska, MD[2, 6]

ABSTRACT

PURPOSE: Evidence is lacking on the effect of different combinations of three stacked half-hitches and suture materials on the loop/knot security of an arthroscopic knot under cyclic loading conditions. The specific aim of this study was to identify variables, such as stacked half-hitch configurations, suture materials, and testing environments, that affect knot strength and loop security under cyclic loading conditions.

METHODS: Two suture materials (Orthocord and ForceFiber) were used to tie five differently stacked reversing half-hitches on alternating posts (RHAP) in an arthroscopic knot condition. All knots were evaluated in both dry and wet cyclic loading tests.

RESULTS: Knots tied with three identical half-hitches stacked on the same post (Conf #1) resulted in 100% knot slippage regardless of suture material in dry environment. In the wet environment this knot configuration performed slightly better (ForceFiber: 20% survived; Orthocord: 40% survived). With knots tied with one of the half-hitches in the RHAPs reversed, a significant improvement occurred in knot holding compared to Conf #1 ($p<0.05$). Knots tied with the last half-hitches in the RHAPs reversed using ForceFiber were 100% secure in both test environments; whereas those tied with Orthocord had 70% and 80% security rates in the respective environments. Knots tied with two half-hitches of the RHAPs reversed demonstrated the best overall performance.

CONCLUSION: Significant effects for both stacked half-hitch configurations and suture materials on the knot loop and knot security were observed. Caution should be used when tying the 3 RHAPs in a knot using standard arthroscopic techniques. This study may provide a solution that might improve the maximum failure loads observed between orthopaedic surgeons, and achieve better clinical outcomes.

CLINICAL RELEVANCE: The findings of this study indicate the importance of three reversing half-hitches on alternating posts in performing arthroscopic knot tying, and provide evidence regarding discrepancies of maximum clinical failure loads observed between orthopaedic surgeons leading to better surgical outcomes.

KEYWORDS: Arthroscopic; Cyclic loading; Knot tying; Half-hitches; Alternating post; Environment

INTRODUCTION

Arthroscopic sliding knots have been widely used for most arthroscopic reconstructive surgeries, and have become an essential skill for the practicing orthopaedic surgeon. A secure knot should not only provide optimal tissue apposition for healing,[1] but also shall withhold at submaximal loads (loads below the expected failure level) during the cyclic loading encountered during rehabilitation.[1-3] Most arthroscopic knots are comprised of initial stacks of slip knots followed by additional reversing half-hitches on alternating posts (RHAPs) to prevent slippage of the initial slip knot.[4-7] Potential complex

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Conflict of Interest Statement:
The authors received suture materials from Stryker (San Jose, CA) and DePuy-Mitek (Warsaw, IN) for this study. However, both Stryker and DePuy-Mitek had no role in the collection, analysis and interpretation of data, writing of the manuscript, or decision to submit the manuscript for publication. The authors also received no payments or other personal benefits or a commitment or agreements related to the subject of the research we conducted in the research.

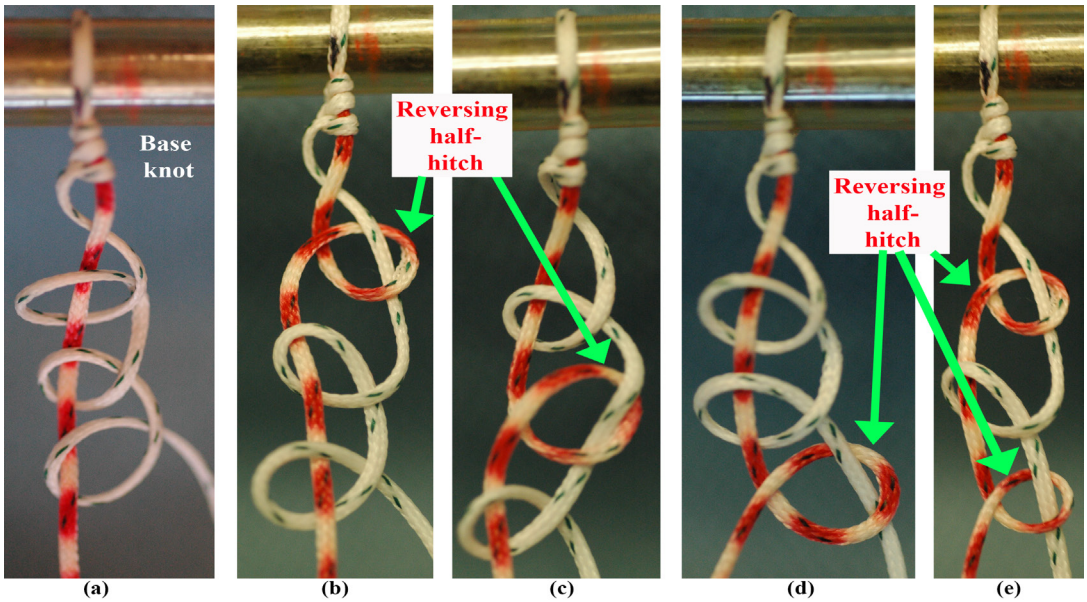

Figure 1. Five differently stacked three reversing half-hitches on alternating posts (RHAPs) evaluated. (a) Conf #1: Identical half-hitches on the same post; (b) Conf #2: Reversing half-hitch on 1st RHAPs; (c) Conf #3: Reversing half-hitch on 2nd RHAPs; (d) Conf #4: Reversing half-hitch on 3rd RHAPs; (e) Conf #5: Reversing half-hitch on 1st and 3rd RHAPs

surgical considerations underscore the importance of understanding the optimal methodology to tie sutures to provide the best knot and loop security. Arthroscopists must consider many factors, such as knot configuration, number of knots, suture tension, tying techniques, along with suture material and condition.

Several studies[4-7] have shown that at least 3 reversing half-hitches on alternating posts (RHAPs), after the placement of most types of sliding or nonsliding knots, are necessary for optimal knot integrity. Meier et al[8] and Chong et al[9], however, noted that when unintentional tension was placed on the wrapping suture limb, it could easily "flip" the half-hitch and convert a series of RHAPs into a series of identical half-hitches on the same post, thereby reversing the kinking effect created by alternating posts, producing insecure knots or suture loops. Evidence is lacking on the effect of different combinations of three stacked half-hitches and suture materials on the loop/knot security of an arthroscopic knot under cyclic loading conditions. Further evaluation of the experimental utility of wet versus dry testing would offer valuable information for determining not only the application of study results to practicing surgeons, but also to help determine if differences between wet and dry conditions are significant enough to justify the increased cost and effort of in vivo testing for future studies. The purpose of the study was to identify variables, such as stacked half-hitch configurations, suture materials, and testing environments, that affect knot strength and loop security under cyclic loading conditions. We hypothesize that 1) knots tied with one half-hitch in the RHAPs reversed will have better knot strength and loop security compared to knots tied with three identical half-hitches, but not as good as knots tied with two half-hitches in the RHAPs reversed; and 2) the Forcefiber suture will have better knot security and stronger knot characteristics when tied under a wet environment and tied with reversing half-hitches on alternating posts.

MATERIALS AND METHODS

This study compared the knot strength and loop security of two braided arthroscopy suture materials tied with five differently stacked RHAPs in arthroscopic knots. The two braided arthroscopy suture materials included ForceFiber (Stryker, San Jose, CA) and Orthocord (DePuy-Mitek, Warsaw, IN) which were #2 braided polyblend polyethylenes with an estimated length of 48 cm (19 inch). All knots in this study began by advancing 3 identical half-hitches stacked, and the five differently stacked three RHAPs were: Configuration (Conf) #1) identical half-hitches on the same post, Conf #2) reversing half-hitch on 1st RHAPs, Conf #3) reversing half-hitch on 2nd RHAPs, Conf #4) reversing half-hitch on 3rd RHAPs, and Conf #5) reversing half-hitch on 1st and 3rd RHAPs (Figure 1).

Knot characteristics were evaluated in two tying and testing environments. The first series of knots were tied and tested in dry conditions, and the second series were

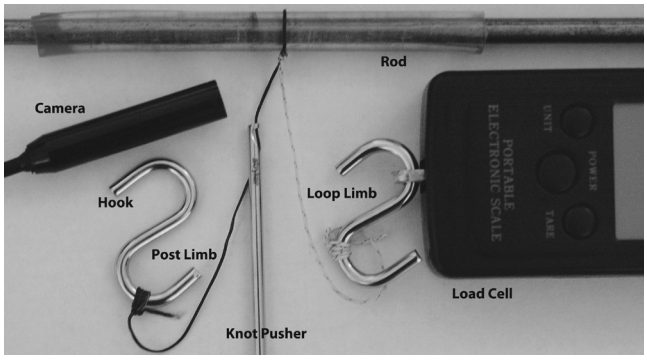

Figure 2. Arthroscopic knot tying apparatus

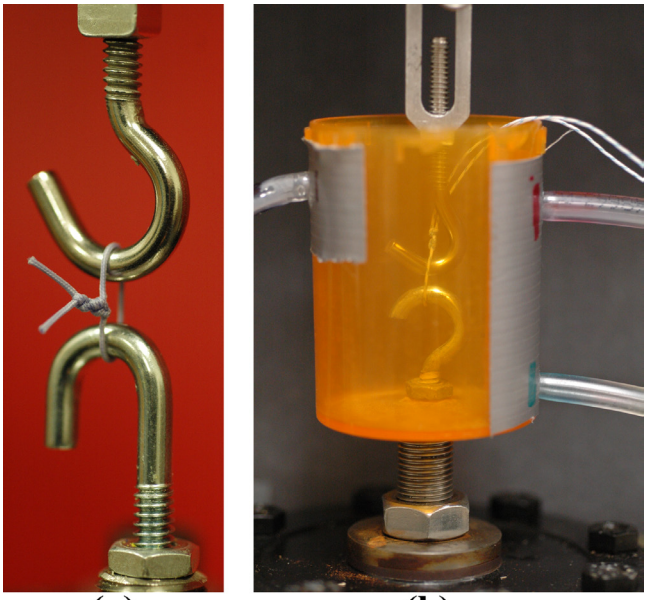

Figure 3. Cyclic loading experimental test setup. (a) Dry Condition; (b) Wet Condition

tied to simulate in situ (wet) conditions. For the second series, to replicate actual knot tying conditions the suture was pre-soaked for at least 5 minutes in normal saline solution at room temperature (23 °C) before being tied in the same simulated dry condition setup as the series of dry knots. After these knots were tied, they were soaked in the saline solution for a 24-hour period and then cycled in an experimental setup that continued to immerse the knot in room temperature saline throughout the entirety of cyclic load testing.

All knots were tied down to a standardized 30 mm circumference post using standard arthroscopic techniques with a single-hole knot pusher in a dry environment. This provided a consistent starting circumference for each knot and replicated the suture loop created during arthroscopic rotator cuff repair. A load cell (Protable Electronic Scale, China) was attached to standardize the strength used to tighten the half-hitches (Figure 2). Half-hitches were tightened manually to at least 45 N using an over-pointing/past-pointing technique; all knots were tied by a single orthopaedic surgeon. After each knot was tied over the post, the knotted suture loop was removed and trimmed, leaving approximately 6 mm length tags from the most distal end of the knot.

Servohydraulic Material Testing System instruments (MTS model 858 Mini Bionix, Eden Prairie, MN) were used to test the knot and loop security of each combination of knots and suture types. Two round hooks with a diameter of 3.9 mm were attached to the actuator and the load cell, with modification to allow for immersion in saline for wet testing (Figure 3). Loops were preloaded to 10 N to avoid potential errors produced from slack in the loops and stretching of the suture materials while also providing a well-defined starting point for data recording.

The cyclic loading test was carried out in both dry and wet testing conditions with ten samples of each suture/knot configuration for each mechanical testing type. Each suture loop was axially loaded at a frequency of 1 Hz across nine load levels (starting at a maximum load of 40 N and increased by 20 N for each level up to a maximum load of 200 N), for 2,000 cycles at each load level. This procedure is similar to previous studies such as Ilahi et al[10] and Barber et al[11] which used cyclic loading to characterize the knot and loop security. The maximum load of 200 N was selected based on the worst-case scenario of expected physiologic loads. During in situ cyclic loading testing, the suture loops were tested bathed in normal saline at room temperature.

The cross head displacement and applied loads were recorded every 5 cycles at maximum load. Previous studies have established that knot slippage to 3 mm (crosshead displacement) is the point where tissue apposition is lost.[2, 12-14] Based on this criterion, the study defines knot slippage of 3 mm (crosshead displacement) as a "clinical failure" which is supported by previously performed evaluations of different suture/knot combinations.[1, 4, 6, 7, 15-21] This study also defined "clinical failure load" when the knot maximum cyclic load was at least 100 N. This criterion was based on the estimated minimum required ultimate load per suture during a maximum muscle contraction.[22, 23]

STATISTICAL ANALYSIS

Data retrieved from each test configuration were analyzed for statistical difference among sutures and test conditions using z-tests and Fisher's Exact tests in IBM© SPSS© Statistics, version 23; Chicago, IL; $p<0.05$ denoted significant results.

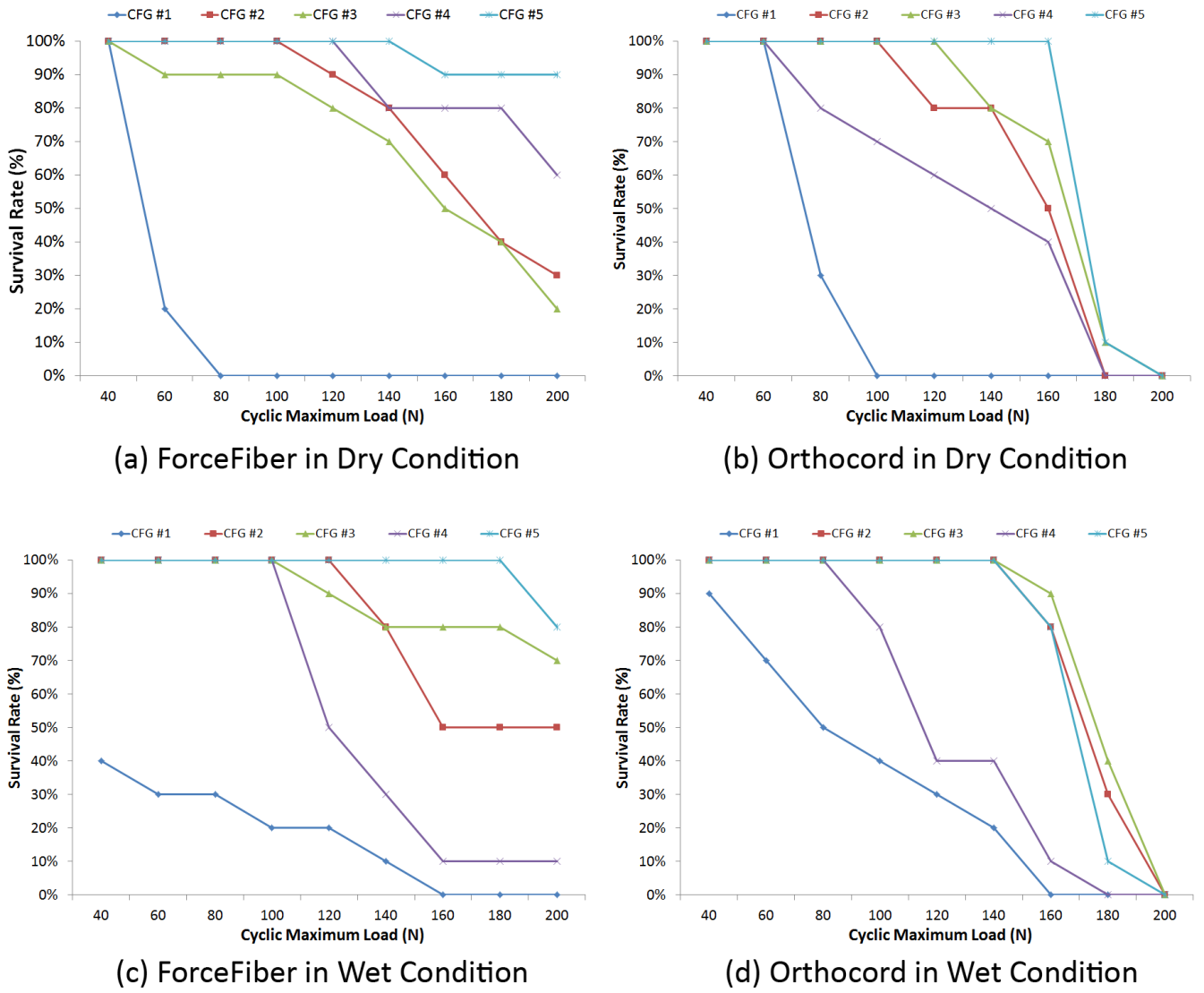

Figure 4. Survival rate of knots tied with five differently stacked reversing half-hitches on alternating posts (RHAPs) for two braided materials and in two testing environments

RESULTS

The survival rate of the five differently stacked three RHAPs configurations with two braided suture materials at different load levels and in two testing environments is shown in Figure 4. In the comparison of biomechanical performance (knot and loop security) under dry and wet conditions, no significant difference was observed across all knot configurations regardless of suture material ($p>0.05$).

Knots tied with three identical half-hitches stacked on the same post (Conf #1) resulted in 100% knot slippage when using either ForceFiber or Orthocord in the dry environment at clinical failure load (maximum cyclic load of 100 N). When in the wet environment, a low percentage of this knot configuration tied with different suture materials survived the 2,000 cycles at clinical failure load (ForceFiber: 20% and Orthocord: 40%). When compared with other knot configurations under both test environments, this knot configuration was the weakest in terms of biomechanical performance (Figure 4).

Knots tied with one of the half-hitch in the RHAPs reversed (Confs #2, #3, and #4) showed significant improvement in knot strength and loop security compared to Conf #1 regardless of test environment or suture material ($p<0.05$). All knots tied with either 1st or 2nd half-hitches in the RHAPs reversed (Confs #2 and #3) survived the 2,000 cycles at clinical failure loads regardless of suture material or tested environments. Knots tied with the last half-hitches in the RHAPs reversed (Conf #4) showed slightly ambiguous biomechanical perfor-

mance when tied with different suture types (ForceFiber dry & wet: 100% and 100% survival rate; Orthocord dry & wet: 70% and 80% survival rate).

Knots tied with two half-hitches of the RHAPs reversed (Conf #5) demonstrated the best performance (in survival rate) when compared to other configurations in both suture type and test environments. When tied with ForceFiber, there was a high survival rate even at 200 N maximum cyclic loads (dry: 90%; wet: 80%) for this knot configuration. When tied with Orthocord, this knot configuration could withhold up to 160 N ultimate cyclic loads (dry condition: 100%, wet condition: 80%).

DISCUSSION

The major findings of this study revealed that the orientation of these additional post switching half-hitches and braided suture materials have a significant effect on the knot loop and knot security. Other researchers have shown that at least three reversing half-hitches on alternating posts (RHAPs) after placement of most types of sliding or non-sliding knots are necessary for optimal knot integrity.[4-7] Kim and colleagues[5] performed a mechanical testing study (both dynamic cyclic loading and load-to-failure tests) to evaluate the optimal number of additional half-hitches needed to achieve optimal knot-holding capacity, and they concluded that with 3 or more additional half-hitches optimal security was achieved. Their dynamic cyclic loading test was performed at 30 N loads for 20 cycles at 1 cycle per seconds. Unfortunately, they did not mention how their 3 RHAPs were tied, and they could be tied with reversing half-hitch on 2nd RHAPs (Conf #3) or with reversing half-hitch on 1st and 3rd RHAPs (Conf #5). Furthermore, the testing load level and numbers of cycles in this study were low. The results of the current study, with a stepwise incremental cyclic loading pattern, higher load level (up to 200 N) and numbers of cycles (2,000 cycles for each load level), agreed with their results that with at least one of the half-hitches in the RHAPs reversed will withhold at submaximal loads during cyclic loading. This stepwise incremental cyclic loading pattern is optimal for representing postoperative stresses than single pull-to-failure methods.[24]

Chan and colleagues[25] described a technique for switching posts simply by alternating tension on the suture limbs, whereby the knot "flips" and the wrapping limb (or the loop limb) effectively becomes the post. Meier et al[8] and Chong et al[9] noted that unintentional tension placed on the wrapping suture limb on a seated and tightened half-hitch may inadvertently convert the RHAPs into a series of identical half-hitches on the same post. During our experiment, we observed that over tensioning (> 50N) during knot tying using either past-pointing or over-pointing could also potentially "flip" the previously seated and tightened half-hitch in the base knot without noticing. Unfortunately, there is no convenient tool, such as a small portable load cell, that can be used by a surgeon to indicate if they have unintentionally "flipped" the tightened half-hitch down at the base knot. There is, however, a technique described as "Reverse Flipping Technique" by Chong and colleagues[9], which purposely "flips" the half-hitch down at the main knot, and once confirms the half-hitch is in the direction intended to be placed, then the half-hitch can be retightened using either a past-pointing or over-pointing technique. This technique is strongly recommended as it can ensure that the half-hitch is tightened in the direction intended.

Research has shown that half-hitches tied on the same post will create insecure knots or suture loops that most likely to fail by slippage, whereas half-hitches tied with RHAPs are unlikely to fail by slippage, but rather failure by rupture of the suture material itself.[4, 26] The outcomes of this research agree with these prior studies.

Arthroscopic knot security not only depends on the coefficient of friction, ductility, handling properties, solubility, and diameter of the suture material,[1, 4, 7, 10, 16, 21-23, 27-29] but is also affected by tissue fluids or tissue reaction to suture material.[30-32] Dinsmore[33] emphasized the need to simulate in vivo conditions when determining knot security. He also advocated the use of the loop method to test for knot security. Pietschmann and colleagues[34] evaluated the influence of the dry and wet condition on knot security of sliding and nonsliding knots with 5 suture materials and observed differences between wet and dry conditions across different suture material and knot types and suggested that biomechanical testing might be more realistic in a wet environment. The findings in the present study contradict these previous results. This difference may be due to the stacked half-hitches of the RHAPs placed after a base knot. Technical errors can occur, especially in wet condition. For example, an unintentional tension applied to the wrapping limb can reverse the kinking effect created by alternating posts and result in the incorrect 3 RHAPs configuration. In this study, we also observed that the unintentional tensile strength greater than 10 N might "flip" a seated and tightened half-hitch in a knot during arthroscopic procedures. Results also demonstrated that different braided suture materials used in arthroscopic procedures required different minimum tensile strength to revert a tightened half-hitch in an arthroscopic knot.

One important factor affecting the tendency of knot slippage might be the suture surface characteristics and suture construction. Several studies have determined that braided non-absorbable polyblend sutures now commonly used for arthroscopic knots have better strength profiles and less potential for slippage.[1, 17, 18, 21,

[27, 35-38] Herculine and Ultrabraid suture material comprise braided, nonabsorbable polyethylene fibers without a longitudinal core, which is present in FiberWire and Orthocord. Both Ultrabraid and ForceFiber are made with braided ultrahigh-molecular-weight polyethylene (UHMWPE) and have just a few variations in weave patterns. FiberWire is made of braided polyethylene and polyester fibers coated with a proprietary coating. Orthocord comprises dyed-absorbable polydioxanone core, an undyed-nonabsorbable polyethylene sleeve, and a polyglactin coating. Some of these sutures are made of similar materials, but with varying designs, and have been reported to have different mechanical and handling properties. These authors concluded that a surgeon choosing arthroscopic repair techniques should be aware of the differences in suture material and the variation in knot strength afforded by different knot configurations, as suture material is one important aspect of loop security. Our findings agree with these studies, showing that suture materials having an effect on knot security especially on a series of 3 RHAPs which also aligns with the theory that these RHAPs should minimize suture friction, internal interference, and slack between loops of the knot, which emphasizes the effect of material selection. Our findings also agree with a previous study[18] that suture materials with a core in the design (Orthocord) have higher prevalence of knot slippage compared to suture materials without a core in the design (ForceFiber).

Our experimental design had certain limitations. First, tying a knot on a standardized rigid aluminum post (30 mm in circumference) differed from what is performed clinically. This setup does not account for the variability seen in clinical practice, especially as suture loop did not pass through any soft tissue, turn acute angles, risk abrasion on suture anchors, or rub over bony surfaces. Second, the metal hooks used in this study were not compressible and did not interpose in the substance of the knot as soft and hard tissues do in the clinical setting. Third, knots were tied with no tension against the sutures, whereas clinically knots are tied under tension as tissues are pulled together in reconstructions. Fourth, all arthroscopic knots were tied with a single knot pusher, whereas in the clinical setting different techniques, through a cannula, may cause knots not similar to those in the laboratory setting. Fifth, this study was performed in room temperature saline solution environment, whereas a joint fluid environment with varying temperature (body temperature of 37°C) might affect the effectiveness of knots. Given the available research models, we feel that our data are valid. Further evaluation in patients is required to support our findings.

CONCLUSIONS

Significant effects for both stacked half-hitch configurations and suture materials on the knot loop and knot security were observed indicating that caution should be use when tying the 3 RHAPs in a knot using standard arthroscopic techniques. Caution should be used when tying the 3 RHAPs in a knot using standard arthroscopic techniques, as the results of this study demonstrated the best performance when a knot tied with two half-hitches of the RHAPs reversed. This study may provide a solution that might improve the maximum failure loads observed between orthopaedic surgeons, and achieve better clinical outcomes.

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GANGLION CYST AS A RARE COMPLICATION OF HIP ARTHROSCOPY RESOLVED WITH THA: A CASE REPORT

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ABSTRACT

Background: A rare complication of hip arthroscopy is the development of a ganglion cyst. These cysts can affect structures surrounding the hip joint. In some cases, the femoral artery may be involved, leading to claudication or a pulsatile mass that can resemble an aneurysm.

Case Description: We present the case of a 62 year-old male who complains of 3 months of right hip pain. Workup reveals a degenerative labrum with cam impingement. After a discussion of various treatment options, the patient elected for arthroscopy to correct the impingement. An anterior capsulotomy was created to establish access to the joint. Cam decompression was indicated to address the impingement. The patient developed a recurring ganglion cyst following the procedure that was not permanently prevented with cyst aspiration. Total hip arthroplasty with ganglion cyst decompression resolved the ganglion cyst and resolved the hip pain.

Conclusions: This is the first case report that describes the development of a ganglion cyst following hip arthroscopy. Arthroplasty and ganglion cyst decompression in the presence of degenerative joint disease presents a viable treatment option for these cysts. Additionally, this case suggests interportal capsulotomy closure may prevent ganglion cyst development and should be considered when performing hip arthroscopy.

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Conflicts of Interest:

John Callaghn: Royalties and Consultant (DePuy – for intellectual property transfer of hip and knee implant designs).
Royalties (Wolters Kluwer – for books edited)
Board Membership (Journal of Arthroplasty, OREF, International Hip Society, Knee Society)

All other authors have no disclosures.

Key words: Ganglion cyst; hip; arthroscopy; arthroplasty

INTRODUCTION

A ganglion cyst is a soft-tissue mucinous capsule communicating with the adjacent joint commonly found in the wrist or ankle, but occasionally occurring in the hip. Cysts of the hip are usually associated with hip disorders such as trauma, avascular necrosis of the femoral head, osteoarthritis, rheumatoid arthritis, and total hip arthroplasty (THA)[1]. We report a case of a large ganglion cyst of the hip located anterior to the hip joint and overlying the femoral artery following an arthroscopy procedure indicated for a right hip labral tear with cam impingement.

CASE HISTORY

Written informed consent was obtained by the patient for publication of this case. A 62-year-old male presented with 3 months of right hip pain. The pain was deep within the joint, aggravated by hip flexion and the patient reported catching symptoms. Radiographs of the hip were relatively unremarkable with some moderate osteoarthritis, mild joint space narrowing, and osteophyte formation (Figure 1). An MRI of the joint showed a degenerative labrum. In addition, there were articular cartilage changes in the superior acetabulum with some evidence of cam impingement. Right hip arthroscopy was performed to resect the labrum and shave the degenerated articular cartilage. To gain access to the hip, an anterior interportal capsulotomy was created. During the procedure, the articular cartilage of the superior dome was noted to be delaminated down to the bone. Additionally, there was some degeneration of the superolateral femoral head. The cartilage was debrided and microfracture was performed. A cam decompression was completed without complication and the capsulotomy was left unclosed. One month following arthroscopy, the pre-operative pain resolved. Some mild groin discomfort was noted with complete range of motion.

Over the course of the next month, the patient had increasingly severe right groin pain and focal anterior hip swelling. The pain worsened with flexion and activity. An ultrasound (US) of the right hip was obtained. US revealed an 8.0 x 3.3 x 3.1 cm well-circumscribed cystic mass overlying the hip anteriorly. There was no evidence

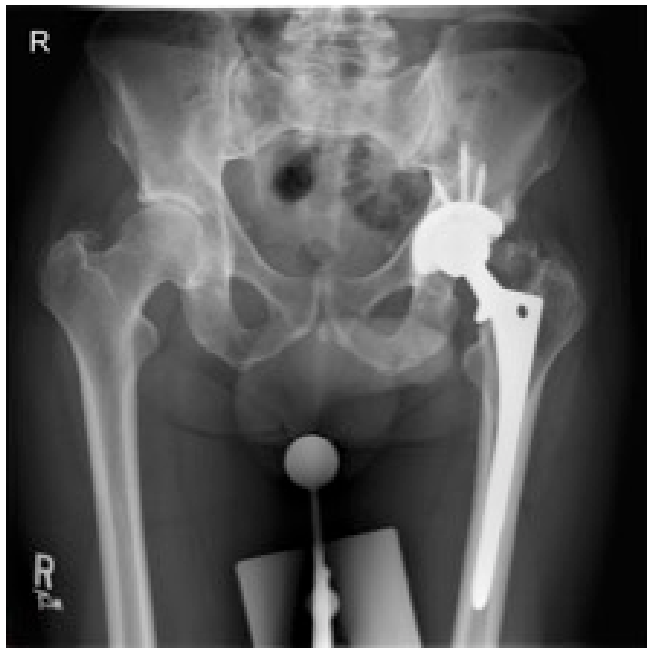

Figure 1. AP radiograph of hip demonstrates mild degenerative changes at the pubic symphysis and right hip with joint space narrowing and peripheral osteophyte formation.

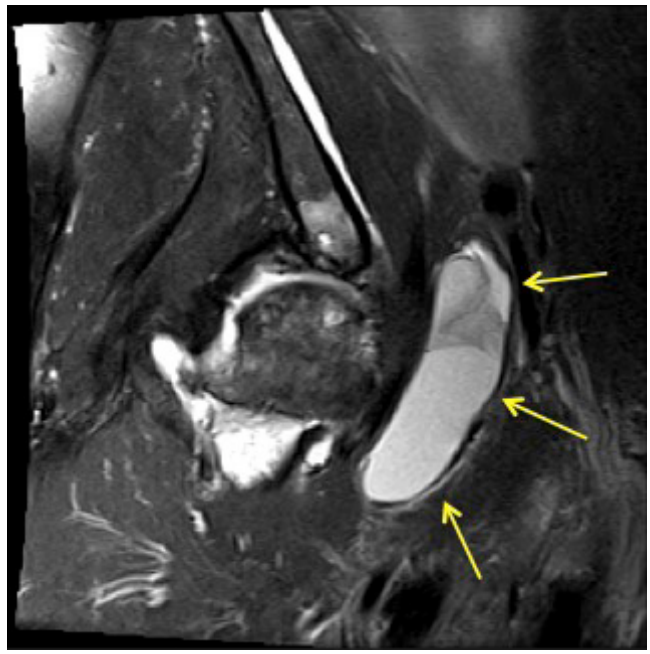

Figure 3. Coronal T2 fat saturated pulse sequence of right hip after arthrogram following arthroscopy. This image shows a large multiloculated right hip joint cyst (yellow arrows) that has a narrow neck anterior inferiorly and the cyst extends anteromedially in relationship to the hip joint and superiorly underneath the iliacus muscle into the iliacus fossa.

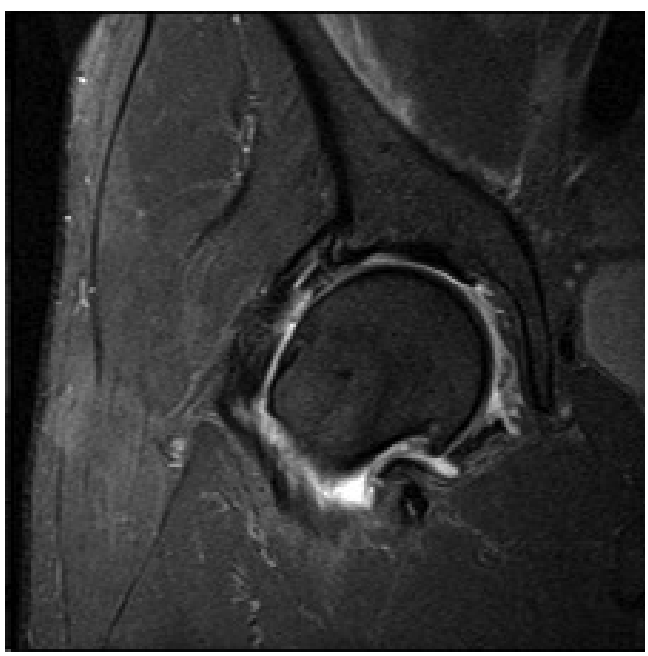

Figure 2. Coronal T2 fat saturated pulse sequence of right hip after arthrogram prior to arthroscopy. This image shows the femoral head with some degenerative changes, including inferior osteophytes. There is no cystic lesion present.

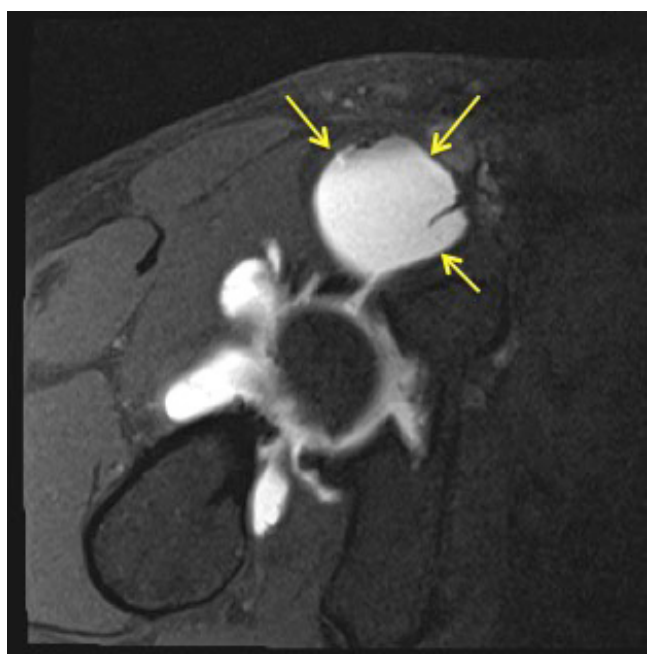

Figure 4. Oblique axial T1 fat suppressed imaging of right hip without contrast shows ganglion cyst (yellow arrows).

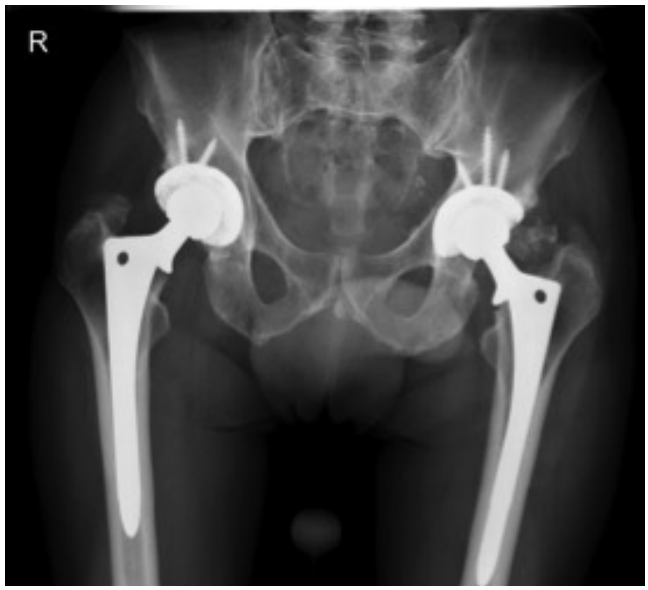

Figure 5. AP radiograph of pelvis following right hip arthroplasty without complication shows stable prosthesis.

of flow within the mass. US imaging was consistent with a large ganglion cyst arising from the hip joint. The cyst was aspirated and fluid was sent for analysis to rule out infection. No injection was performed during this US procedure. Final cultures were negative. Aspiration of the cyst successfully relieved the patient's swelling and pain in the hip for a few weeks, but the cyst eventually re-accumulated and the patient's symptoms returned. At that point a MRI arthrogram of the hip was obtained.

MRI of the hip was compared to pre-operative MRI of the hip (Figure 2) and demonstrated a large ganglion cyst that was not present pre-operatively. The cyst arose from the anterior aspect of the hip joint with a narrow stalk and extended anteromedially and superiorly underneath the iliacus muscle into the iliacus fossa (Figure 3, Figure 4). The cyst measured approximately 14 cm in height and 4.3 x 2.6 cm in transverse diameter. Additionally, the MRI demonstrated moderate osteoarthritis of the right hip with joint space narrowing, minimal cartilage thinning, and peripheral osteophyte formation, which was largely unchanged from an MRI obtained pre-operatively. After discussion with the patient, it was decided that conservative management was the best option at this time with observation and aspiration as needed.

Over the next year and one half, the patient had four cyst aspirations and received one corticosteroid injection in the joint that provided mild relief but failed to offer a permanent resolution of his symptoms. The patient's pain in the hip continued to worsen and he elected to undergo arthroplasty with a plan of removing the cyst during the operation.

The patient underwent primary total hip arthroplasty via a posterior approach. Intra-operatively the cyst was identified and completely decompressed. The surgery was uneventful and there were no complications during the recovery period. The patient was last seen at four years following total hip arthroplasty and at that time the patient had no complaints, was very satisfied with the procedure and had no recurrence of the ganglion cyst or pain (Figure 5).

DISCUSSION

We present a case of a symptomatic ganglion cyst of the hip following arthroscopy. Arthroscopy was indicated in this 62-year-old male after the arthritis was determined to be moderate, the duration of symptoms short, and the patient's desire to avoid arthroplasty. The cyst and symptoms persisted despite conservative measures of time and repeated US-guided aspirations. The cyst was located proximal to the femoral artery and the arterial flow over the cyst was appreciable on physical exam and ultrasound imaging. Arthroplasty was indicated due to the degenerative joint disease and a successful decompression of the cyst was completed during the procedure.

Ganglion cysts around the hip joint are not uncommon findings. There are 15 synovial-lined bursae around the hip joint with the largest being the iliopsoas bursa. It is thought that cysts occurring at the anterior of the hip could be due to inflammation of this bursa or herniation of the anterior capsule caused by increased intra-articular pressure and an intrinsically weak capsule secondary to underlying inflammatory or degenerative joint disease[2-4]. Moderate osteoarthritis and an anterior capsulotomy provide a setting for formation of a ganglion cyst in this patient.

There are reports of mass effects around the hip secondary to ganglion cysts. Structures around the hip that have been affected include the femoral nerve[5], the sciatic nerve[6], and the femoral and iliac vessels in rare instances resulting in thrombosis[7]. Compression of lymphatics, bladder, ureters, and colon have been reported although these are less common[1]. The pulsation of neighboring femoral vessels may conduct through the ganglion and resemble an aneurysm. A snapping phenomenon has been reported from the psoas tendon slipping over the pubis. Occasionally, symptoms of ganglion cysts may mimic a vascular disease with intermittent claudication. Although there was no evidence of neurovascular compression in this case, we did observe close proximity to the femoral artery such that an aneurysm was considered during the initial workup.

Arthroscopy in older patients is becoming increasingly common, with a 200% increase in patients older than 60 years from 2007 to 2011[8]. Recently, research has focused on determining which factors predict poor

outcomes after hip arthroscopy. A number of recent systematic reviews and retrospective studies report that age, duration of symptoms and presence of arthritis predict worse outcomes following the procedure[9-11]. In the first prospective study looking at long-term outcomes of hip arthroscopy with 10-year follow-up, the presence of arthritis was the major determining factor of worse outcomes, while age and duration of symptoms were not predictive[12]. While end stage osteoarthritis should be treated with total hip arthroplasty, arthroscopy may be considered in patients with moderate osteoarthritis and an associated tear to relieve pain and catching[13]. Ultimately, counseling for hip arthroscopy, as was done in the described case, should include both risks and benefits of the procedure as well as patient-specific considerations.

A ganglion cyst is an uncommon complication of arthroscopy. There are no reported cases of arthroscopy of the hip leading to the formation of a ganglion cyst. There are, however, cases of ganglion cysts developing after knee arthroscopy[14], lumbar fixation[15], PCL and ACL repairs[16,17]. Complications associated with hip arthroscopy that have been reported include chondral or neurovascular structural damage, infection, DVT, avascular necrosis of the femoral head, adhesions, heterotopic ossification, trochanteric bursitis and iliopsoas tendinitis. The overall complication rate of arthroscopy reported by a systematic review of 6962 cases was 4.0%[18].

After reviewing the operative notes of the case, the authors wondered if closure of the capsulotomy site could have helped to prevent formation of the ganglion cyst. Although there is nothing in the literature that links failure of closure of a capsulotomy site to development of a ganglion cyst, release has been demonstrated to increase risk of subluxation and instability within the hip joint[19]. Additionally, the presence of capsular defects is a reported reason for revision arthroscopic surgery[20]. This issue needs to be further explored to determine if a link exists between capsular release and ganglion cyst genesis.

The treatment of ganglion cysts varies depending on the presentation. Benign cysts are generally treated by observation. Larger, symptomatic cysts can be treated with nonsteroidal anti-inflammatory medications, application of heat, and physical therapy. Moreover, needle aspiration with application of local anesthetic and/or corticosteroids may also be considered. When neurovascular structures are compromised or there is potential for compression of arterial or venous structures, aspiration of the cyst or surgical excision may be indicated. While surgical excision is associated with lower recurrence rates relative to needle aspiration, the first treatment choice remains needle aspiration because it is less invasive[1]. This is the first case in which hip arthroplasty and ganglion decompression has been shown to completely relieve symptoms of a ganglion cyst.

SUMMARY

This case describes a ganglion cyst as a unique complication of hip arthroscopy. The presenting symptoms included anterior focal hip swelling and pain with flexion. US revealed a cystic structure that resembled an aneurysm with femoral artery involvement. Following failure of cyst aspiration, right hip arthroplasty with ganglion cyst decompression was deemed the appropriate treatment option for this patient and completely resolved the persistent ganglion cyst. The cyst likely stemmed from the capsulotomy used to gain access to the hip; perhaps closure of this interportal capsulotomy could have prevented this complication. In the setting of ganglion cyst development following hip arthroscopy in the setting of significant hip arthritis, total hip replacement and ganglion cyst decompression can provide permanent relief of symptoms without recurrence of the ganglion cyst.

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DOES CLOSURE OF THE CAPSULE IMPACT OUTCOMES IN HIP ARTHROSCOPY? A SYSTEMATIC REVIEW OF COMPARATIVE STUDIES

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ABSTRACT

Introduction: Arthroscopic management of the hip capsule has become a topic of debate in recent literature. Few comparative studies exist to help establish clear treatment recommendations.

Methods: Utilizing the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, a systematic review of the literature was conducted using PubMed, CINAHL, EMBASE, sportDiscus (EBSCO) and Cochrane Central Register of Controlled Trials databases by two independent investigators. Comparative studies evaluating outcomes after two or more distinct treatment approaches to capsule management were included.

Results: The review yielded 7 articles that met inclusion criteria. Outcomes included in the review include patient reported outcome measures (mHHS, HOS, NASH) in 5 articles, return to sport in 1 article, and formation of postoperative heterotopic ossification (HO) in 1 article. In two articles evaluating the outcomes of revision hip arthroscopy, plication was associated with > 10 point improvements in HOS-ADL and mHHS scores when compared to no plication. The literature is inconclusive regarding routine hip capsule closure in primary arthroscopy, with one study supporting the practice, and one study showing no difference; capsular closure may help accelerate return to sports and improve outcomes while decreasing revisions in cases of borderline dysplasia. Closure does not influence HO rates after surgery.

Conclusion: There is insufficient evidence in the present literature to suggest routine closure of inter-portal capsulotomies after primary hip arthroscopy impacts patient outcomes. Capsular closure or plication should be given strong consideration in revision cases. Complete closure or plication may influence outcomes in patients with borderline dysplasia, for athletes wishing to return to sport, and in cases of extensile capsulotomies, although the data are inconclusive. Prospective, high level studies are indicated to create evidence-based treatment recommendations for capsular management in hip arthroscopy.

Keywords: sports medicine, outcomes, illiofemoral ligament, hip capsule, hip arthroscopy

INTRODUCTION

Arthroscopic management of the hip capsule has gained significant interest and is a topic of much debate.[1,2] Capsulotomy allows for improved arthroscopic access to the joint and facilitates better visualization and treatment of cam deformities, which is important as uncorrected deformity is the most common indication for revision hip arthroscopy.[3-5]

The hip capsule is an important soft tissue stabilizer of the femoroacetabular joint and is comprised of the iliofemoral, pubofemoral, and ischiofemoral ligaments. The zona orbicularis and iliocapsularis are intimately associated and play an important role in maintaining hip stability. From a biomechanical and anatomic prospective, the hip capsule has been extensively studied.[6-9] A capsulotomy connecting the anterolateral portal to the anterior portal results in near-complete transection of the iliofemoral ligament (the thickest portion of the capsule), important in resisting anterior hip translation and external rotation.[6,7] If these capsulotomies are repaired, cadaveric data suggest normal hip stability can be re-approximated[6,8,9].

Outcomes following hip arthroscopy for femoroacetabular impingment (FAI) using inter-portal capsulotomies have historically been favorable without capsular closure.[10] Despite this, the popularity of routine capsu-

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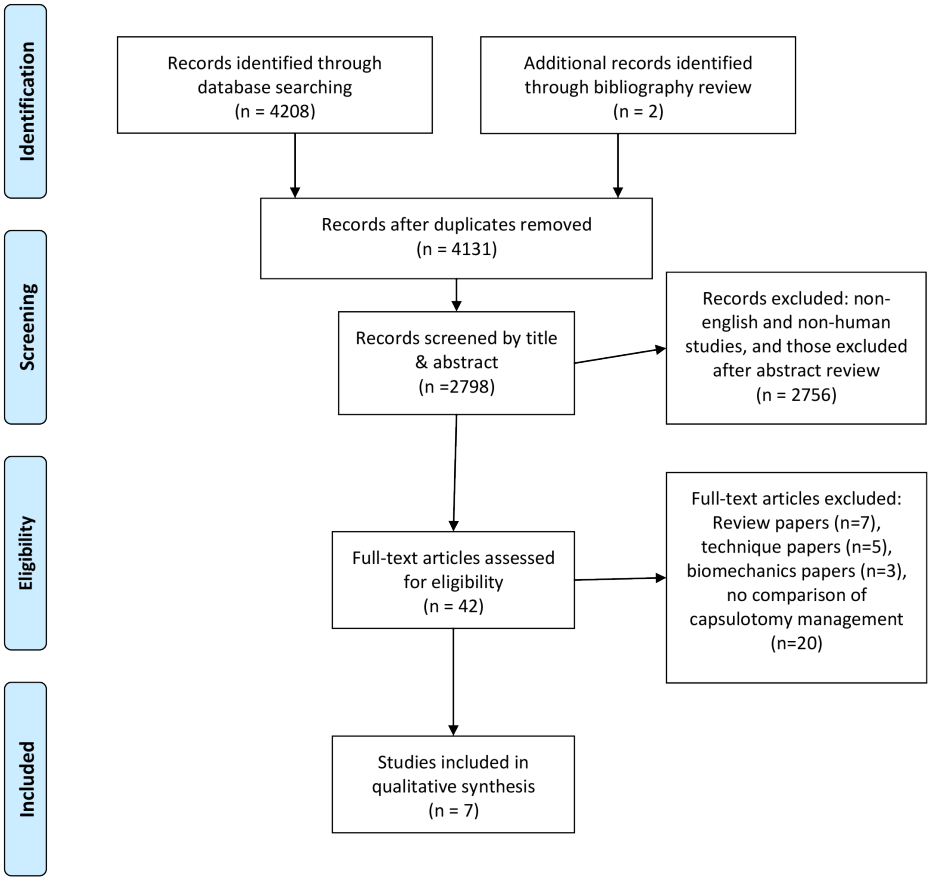

Figure 1: Systematic Review flowchart. There were 4131 unique articles identified using our search criteria; after application of inclusion and exclusion criteria, 7 studies were included in the qualitative analysis.

lar closure has increased in the absence of high level evidence.[1] There is significant debate in the literature regarding the influence capsular closure has, if any, on patient reported outcomes.[11, 12] The purpose of this review was to systematically evaluate the available literature for comparative studies of different hip capsule management techniques (including plication, full, partial, or no closure) to determine if specific capsular management strategies influence outcome. We hypothesized that cases of borderline dysplasia would have improved outcomes with closure or plication and routine inter-portal closure of capsulotomies would not be associated with patient reported outcomes.

METHODS

A systematic review of the literature was performed on December 2, 2016 by two independent reviewers (RWW and MCB) according to Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines.[13, 14] Databases queried included PubMed, CINAHL (EBSCO), Embase (Elsevier), Sport Discus (EBSCO), and Cochrane Central Register of Controlled Trials (Wiley). Searches were performed without filters for all public databases except for EMBASE where conference abstracts were excluded. In the event of a disagreement between reviewers, the lead author decided on paper inclusion.

Inclusion Criteria

English language studies published between 1980 and December 2016 on human subjects treated with hip arthroscopy were considered if they compared outcomes (patient reported outcomes (PROs), return to sport, heterotopic ossification, reoperation) between two different capsular management techniques. These include but were not limited to "complete versus partial closure", "closure versus no closure" and "plication versus closure or no closure".

Exclusion Criteria

Studies reporting outcomes after hip thermal capsulorrhaphy and those that did not compare outcomes between two different capsule management strategies in a given manuscript were excluded.

Quality Appraisal

Two independent non-blinded reviewers (RWW and MCB) assessed the quality of the included studies according to the modified Coleman Methodology Score (MCMS).[15] The quality of studies was compared between groups with respect to the cohort studied (primary FAI, revision FAI, dysplasia, etc). Comparisons were made using 2-sample Student t tests; significance was set at $p < 0.05$.

RESULTS

Seven studies met inclusion criteria after review.[11, 12, 16-20] [Figure 1]. Validated patient reported outcome instruments were used to compare patients treated with different capsular management techniques in 5 studies; [11, 12, 18-20] of these, 2 studies focused on outcomes after primary hip arthroscopy for FAI,[11, 12] 2 studies evaluated the influence of capsular repair in revision FAI settings[18, 20], and one studied capsular management in a dysplastic cohort.[19] Other primary outcomes were the ability to return to sport[17] and the development of heterotopic ossification after hip arthroscopy[16].

Primary Hip Arthroscopy

Two studies evaluating cohorts undergoing primary hip arthroscopy were identified that compared complete capsular closure with either partial or no closure using revision rates and validated outcome instruments as outcomes.[11, 12] Frank, et al., compared PROs between those who underwent partial closure (closure of the vertical aspect of the T capsulotomy) versus complete closure (including the horizontal component). They determined that there were more revision hip arthroscopies in the partial repair group (13%, 4/32) compared to the complete closure group (0%, 0/32), although it not stated whether the difference is statistically significant. There were statistically and clinically relevant differences in early outcomes (6 months and 1 year), with the complete closure group having superior hip outcome score sports specific subscale (HOS-SS) scores; however, no differences were observed in the modified Harris Hip Score (mHHS) or the hip outcome score activities of daily living subscale (HOS-ADL) scores at final follow-up. No multivariate analysis was used to control for patient factors contributing to these differences. Domb, et al., compared the outcomes of patients with no closure of an inter-portal capsulotomy to those who had between 50-100% of their capsulotomy closed. The authors performed a multivariate analysis and determined that capsular closure did not predict the outcome of patients using the instruments measured (HOS-ADL, HOS-SSS, and non-arthritic hip scores (NAHS)). [Table 1]

Borderline Hip Dysplasia

Larson, et al., evaluated the outcomes of patients with borderline hip dysplasia treated with all-arthroscopic procedures. They found that capsular repair or plication coupled with labral repair was associated with lower failure rates when compared to all other patients (18% with labral repair and capsular repair/plication versus 40% without, p=0.03). When evaluating patients treated with labral repair, there were no clinically relevant or statistically significant differences in outcomes between those who underwent capsular plication and those who did not (p=0.06 – 0.13). [Table 1]

Revision Hip Arthroscopy

Two studies[18, 20] compared outcomes of revision arthroscopy according to capsular management. Newman et al., prospectively evaluated the outcomes of 179 patients undergoing revision hip arthroscopy; 106 cases underwent capsular plication and 73 did not. The HOS-ADL scores were compared pre- and post-operatively and patients who had demonstrated clinically important differences (minimal clinically important difference (MCID), >10 points) were more likely to have undergone plication of the capsule compared to those who did not (69% versus 44%, p=0.001).[20] Larson et al.,[18] evaluated the outcomes of patients undergoing revision hip arthroscopy and determined that capsular repair or plication was associated with greater changes in the mHSS preoperative to final follow-up when compared to no closure (14.8 vs 26.4; p=0.032). This difference in scores was both statistically significant and met minimum clinically important differences for the outcome measure. [Table 1]

Return to Sport/ Sport-specific PRO

Two studies[12, 17] evaluated sports participation after hip arthroscopy by comparing capsular management. Domb et al., evaluated patients who were able to return to sport and those who were not. They reported 54/82 (65.85%) patients were able to return to sport after hip arthroscopy with capsular repair/plication compared to 39/76 (51.31%) who were not repaired.[17] This difference was not found to be statistically significant. Meanwhile, Frank et al., evaluated sports participation using the HOS-SS,[12] which determines the amount of difficulty patients have running one mile, jumping, landing, cutting and performing other sports-related tasks. When comparing partial repair of a T-capsulotomy (inter-portal capsulotomy equivalent) to complete repair, the complete repair group demonstrated a statistically significant increase in HOS-SS scores compared to the partial repair group. These differences were clinically relevant and statistically significant at 6 month and 1 year time points. At 2.5 years,

Table I. Included studies and toucomes according to capsular management

Author	Journal	Cohort	Year	Study Design	LOE	Number of Patients (Number of Hips)	Average Age (Years)	Females	Capsule Management Comparison (Number of Patients per Group)	Difference in Outcome	p value
Domb	JHPS	Athletes	2016	Retrospective Case Series	4	148 (158)	30.6 (range 13-61)	61%	Capsular repair or plication (82) vs no closure (76)	a: 54 Patients (65.85%) with repair/plications returned to sports b: 39 Patients (51.31%) without repair/plications returned to sports	a: 0.0635 b: 0.096
Larson	AJSM	Dysplasia	2016	Retrospective Cohort	3	77 (88)	33.9	71%	Capsular repair (37) vs Capsular plication (35) vs no closure (16)	Patients with capsular plication AND labral repair had better good/excellent results* (a: 73% vs 53%), higher mHHS scores at final follow-up (b: 85 vs 77), and fewer failures (c: 18% vs 40%) when compared to all others.	a:0.06 b:0.13 c: 0.03
Newman	AJSM	Revision FAI	2016	Prospective Cohort	2	246 (246) Revisions; 492 (492) Primaries	32.1 ± 9	59%	Capsular plication (106) vs no plication (140) within revision cohort	Revision patients with increase in HOS-ADL >10 points more likely to have undergone capsular plication (75) vs no plication (31)	0.001
Amar	Arthroscopy	Primary FAI	2015	Retrospective Comparitive Study	3	100 (100)			Capsular closure (50) vs no closure (50)	Heterotopic ossification seen in 14/50 (28%) cases after capsular repair vs 22/50 (44%) cases without repair	0.764
Domb	Arthroscopy	Primary FAI	2015	Retrospective Case Series	4	403 (403)	36.9	58%	Capsular repair (168) vs no closure (235)	After multivariate analysis, no difference was found in NAHS, HOS-ADL, HOS-SSS, and mHHS scores.	
Frank	AJSM	Primary FAI	2014	Retrospective Cohort	3	64 (64)	32.8 ± 9.9	63%	Partial repair (32) vs complete repair (32) of T-capsulotomy	a: 13% Revision after partial repair vs 0% after complete repair. b: HOS-SS favored complete repair @ 6, 12, and 30 months c: Finals satisfaction better after complete repair (8.6) vs partial repair (8.4) d: No difference in HOS-ADL and mHHS	a: NA b: 0.039, 0.006, <0.001 c: 0.025 d: NS
Larson	AJSM	Revision FAI	2014	Retrospective Cohort	3	79 (85) Revisions; 220 (220) Primaries	29.5 (range 16-59)	56%	Capsular plication (23) vs repair within revision corhort (62)	Greater increase in mHHS with capsular plication (26.4) vs repair (14.8)	0.032

*** Good and excellent results defined as mHHS >80**
**** Failure is <70 or osteotomy or THA**

however, differences in the HOS-SS scores between the complete and partial repair groups did not meet the minimum clinically important difference (MCID) for the outcome instrument (9 points)[21]. [Table 1]

Heterotopic Ossification

One study evaluated the development of heterotopic ossification as an outcome comparing capsular repair to no repair.[16] Amar et al., determined that the rate of heterotopic ossification without capsulotomy closure was 44% compared to 28% after routine capsular closure, though this difference was not statistically significant (p=0.764). [Table 1]

Quality Appraisal

Overall, the quality of studies comparing outcomes by capsular management were deemed to be low by MCMS scoring. The MCMS is graded on a scale of 0-90 with 90 representing studies of the highest quality. Overall, the quality of studies comparing outcomes by capsular management were deemed to be low by MCMS scoring (range 36-59, mean 45.6). There were no differences in MCMS scores for revision hip arthroscopy (50) compared to primary hip arthroscopy (48) return to sport (39), borderline dysplasia (48) and heterotopic ossification (36), p=0.84. Of the studies included, the level of evidence was graded '2' in one study, 4 studies were given a level 3 grade and two were graded level 4.

DISCUSSION

Despite the increasing popularity of routine capsular closure in hip arthroscopy[1, 2], there are limited applications supported by high level evidence in the present literature. The strongest available literature in the field (Level 2 and 3 evidence) supports capsular repair or plication in a revision hip arthroscopy setting. Clinically important differences in patient outcomes are not seen with complete closure after primary hip arthroscopic treatment of FAI at final follow up. Capsular repair may help patients after primary arthroscopy for FAI for surgeons who use a T capsulotomy, but no such differences are seen after inter-portal-only access. This review suggests capsular repair may aid in early return-to-sport for athletes but further studies are needed to prove or refute this hypothesis. Capsular closure does not appear to prevent the development of HO. Several of the findings in this literature review warrant further discussion.

Primary hip arthroscopy

The present literature is inconsistent regarding the influence of capsular closure on outcomes after primary hip arthroscopy. Domb et al[11] evaluated the influence of capsular repair on outcomes after primary hip arthroscopy. Cases that were left unrepaired were older (42.3 vs 29.4; p<0.001) had higher BMIs (26.8 vs 22.9; p<0.001) and were more commonly male (p<0.001). Prior to surgery, they had more chondral damage (p<0.0081) and lower baseline patient reported outcomes. When univariate analysis was performed, it appeared that hip capsular repair yielded greater HOS-ADL and NAHS scores compared to those left unrepaired. Importantly, the study was adequately powered for a multivariate analysis in order to account for these potential confounders, and when proper statistical models were applied, capsular repair did not change any outcome. Frank, et al., retrospectively evaluated differences in outcomes after partial and complete closure of a T-capsulotomy after primary hip arthroscopy for FAI. They found no clinically important differences in HOS-ADL or mHHS; however, patients who underwent complete repair had improved early HOS-SS scores after surgery.[12] It should be recognized that T-capsulotomies[12] are much more extensile (extending to or through the zona orbicularis) than inter-portal[11] capsulotomies. There may be a role for complete capsular closure for extensile capsulotomies in the primary setting in active patients, however further prospective studies are needed.

Return to Sport

When an athlete sustains a hip injury such as a labral tear and continues to stress the joint with both axial and rotational forces, the hip capsule is thought to be subjected to more tensile loading[22, 23] once the suction-seal is lost due to a lesion in the acetabulum[24]. Athletes, therefore, should be examined for micro instability at the time of arthroscopy. Early return to sport may be improved with complete closure of the capsulotomy in athletes. It appeared that more athletes were able to return in a retrospective review by Domb et al[17], however the study was not powered to detect a significant difference. In the report by Frank et al[12], the sports-specific subscale of the HOS was significantly better and met MCID for the first 6-12 months after surgery for those that underwent complete repair as opposed to partial repair, suggesting earlier return to activities. It has been suggested that hip injuries and labral tears in athletes can lead to focal instability with elongation of the iliofemoral ligament; this may be most pronounced in hip injuries with participation in football, golf, baseball, gymnastics and martial arts.[23] With repetitive loading and rotational stress, injuries can occur including labral tears and iliofemoral ligament redundancy, resulting altered joint biomechanics.[22, 23] Level 3 evidence suggests complete capsular repair after hip arthroscopy is associated with earlier return to activity and capsular closure should be considered in athletic populations with FAI and labral pathology.

Revision Hip Arthroscopy

The highest level evidence (Level 2 and 3) supports capsular repair or plication in a revision hip arthroscopy setting[18, 20]. Larson et al compared a cohort of revision patients to those undergoing primary hip arthroscopy for FAI. They determined that capsular plication in a revision setting was associated with a pre- to post-operative difference in the mHHS of 26.4 points, which was significantly greater than the 14.8 point difference seen without plication.[18] In their prospective study, Newman et al, found that capsular plication was more likely to meet MCID in HOS-ADL scores compared to no plication and this this difference was statistically significant (p=0.001).[20] Furthermore, repair in a primary setting has been suggested to be associated with lower rates of revision surgery[12, 19].

It should be recognized that inherent bias is present in retrospective studies with revision surgery as an outcome. While ACL graft failure or an infected joint arthroplasty are indications for re-operation in many settings, surgeons who are treating patients with persistent pain after hip arthroscopy with an un-closed capsulotomy may have a lower threshold to recommend revision in part to close their capsulotomy despite a clear association between their symptoms and previous treatment. Patients undergoing revision arthroscopic surgery of the hip do so for a wide array of indications. It has been demonstrated that patients with micro-instability after primary hip arthroscopy do improve with revision and capsular plication.[25] The current literature suggests surgeons should have a low threshold for repairing or plicating the hip capsule in a revision setting most importantly if there is a concern for micro-instability contributing to symptomatology.

Heterotopic Ossification

Heterotopic ossification is a known complication of hip arthroscopy with an incidence between 5-36%[16, 26]. Heterotopic ossification is more commonly seen postoperatively in males when a large osteoplasty is performed.[26] Furthermore, there is some retrospective evidence that suggests postoperative indomethacin is associated with decreased rates of heterotopic ossification. In a study by Bedi et al, the rate of HO was 1.8% when indomethacin was administered after surgery compared to 8.3% in the absence of prophylaxis. The rate of heterotopic ossification was found to be much higher in the study identified in our review.[16] Capsular closure did not alter rates of heterotopic ossification following arthroscopic surgery for FAI.

Limitations

This review does have some limitations. First, comparative groups were not uniform across the identified studies that met inclusion criteria; they included partial versus complete closure of different types of capsulotomies and plication versus no closure. Further, capsular repair and plication were not always clearly defined and occasionally used interchangeably. Outcomes were not uniform or granularly reported; these shortcomings in the present literature prevented a quantitative meta-analysis as the data could not be pooled cleanly. The majority of studies evaluated comprised of level 3 evidence and multivariate analysis controlling for important patient factors was rarely utilized in this body of literature. Finally, several studies reported outcomes with small sample sizes and reported "no difference" in their selected outcome after capsular closure. These small studies, without the use of an a priori power analysis, may potentially be under-powered and subject to type two (beta) error.

CONCLUSIONS

The strongest available evidence in the present literature suggest capsular plication at the time of revision hip arthroscopy has meaningful impacts on patient outcomes after surgery. There is insufficient evidence in the present literature to indicate routine closure of inter-portal capsulotomies in a primary hip arthroscopy setting, however this may be a consideration if extensile capsulotomies are created. Athletes who present with an element of micro-instability may have better return to sport rates with capsular closure or plication, however further studies are warranted. Capsular management does not appear to impact rates of heterotopic ossification. Further prospective studies are indicated to elucidate the impact of capsular management on patient reported outcomes after hip arthroscopy.

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COMBINED FEMORAL-SCIATIC NERVE BLOCK IS SUPERIOR TO CONTINUOUS FEMORAL NERVE BLOCK DURING ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION IN THE PEDIATRIC POPULATION

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ABSTRACT

Background: Despite advancements in minimally invasive arthroscopic surgical techniques, post-operative pain management following ACL reconstruction remains a concern. This study compares the effectiveness of two common intraoperative pain management strategies - a femoral nerve catheter (FC) versus a combined femoral nerve catheter and single injection sciatic nerve block (FSB) - in pediatric patients undergoing ACL reconstruction.

Methods: The medical records of patients age 8 to 18 who underwent ACL reconstruction at our institution were reviewed retrospectively. All subjects underwent general anesthesia with either FC or FSB. Multivariable linear regression, or modified Poisson regression were used to compare outcome variables across groups. Propensity scores were used to minimize bias due to the non-randomized allocation of the regional anesthesia protocol.

Results: The study population included 18 subjects in the FC group and 32 subjects in the FSB group. There was no difference in incidence of nausea or opioid prescription refill requests between groups. Total intravenous (IV) morphine equivalent dose, maximum numerical rating scale (NRS) pain score, and percentage of subjects requiring one or more opioid doses in the PACU were significantly greater in the FC group relative to the FSB group. PACU length of stay (LOS) was also significantly greater in the FC group than the FSB group.

Conclusion: This study suggests that FSB may be a more effective pain management technique for reducing the total IV morphine equivalent dose, maximum NRS pain scores, number of PACU post-operative opioid doses, and PACU LOS following ACL reconstruction in the pediatric population.

Level of Evidence: III

Keywords: regional anesthesia, anterior cruciate ligament reconstruction, post-operative pain management

INTRODUCTION

Anterior cruciate ligament (ACL) ruptures are a common injury among pediatric patients. Approximately 17.97 ACL reconstruction procedures per 100,000 person-years are performed in patients younger than 20 years of age in the United States each year.[1] Despite advancements in minimally invasive arthroscopic surgical approaches, there is controversy regarding the management of post-operative pain following ACL reconstruction.[2] Determining the most efficacious pain management protocol may reduce unplanned hospital admissions due to uncontrolled pain, facilitate early rehabilitation, and increase patient satisfaction.[3-5]

Regional anesthesia is becoming more common as an adjunct to general anesthesia during pediatric outpatient orthopedic procedures.[6-13] However, the majority of literature considering regional anesthesia for ACL reconstruction addresses only adult populations. Of the 75 randomized trials identified in a systematic review evaluating the effects of regional anesthesia blocks on surgical postoperative pain in pediatric patients, only one study considered regional anesthesia for ACL re-

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Table I. Demographics and Clinical Characteristics

	Femoral Catheter (N=18)		Combined (N=32)		P Value
Male Gender, N (%)	6	33.3%	18	56.3%	0.1195
Concomitant Meniscus Injury, N (%)	12	66.7%	22	68.8%	0.8795
Concomitant Chondral Injury, N (%)	0	0.0%	1	3.1%	>0.9999
Concomitant Ligamentous Injury, N (%)	0	0.0%	1	3.1%	>0.9999
MOI, N (%)					
Soccer	4	22.2%	9	28.1%	0.8954
Football	4	22.2%	8	25.0%	
Basketball	3	16.7%	7	21.9%	
Snow sports	1	5.6%	1	3.1%	
Other	6	33.3%	7	21.9%	
Previous Knee Injury, N (%)	3	16.7%	2	6.3%	0.3363
Age [yrs], Mean (stdev)	15.7	1.7	15.8	1.3	0.8428
BMI [kg/m2], Mean (stdev)	25.3	5.6	23.4	3.5	0.2018
Time from Injury to Surgery, Median (IQR)	37.5	28-84	35	24-57	0.2907

construction.[14] Pediatric pain management should be considered separately from that of adults due to differences between the two populations in terms of anatomy and drug metabolism.[15-16] In addition, the need to improve pain management protocols for the pediatric population is underscored by the finding that pediatric patients report greater pain and anxiety than adults at 24 hours after ACL surgery.[17]

This retrospective cohort study compares the effectiveness of two commonly used regional pain management protocols for ACL reconstruction: femoral nerve catheter (FC) protocol versus a combined femoral nerve catheter and single injection sciatic nerve block (FSB) protocol. The post-operative outcomes assessed as indicators of pain management were: 1) opioid-related side effects, 2) oral opioid prescription refill requests, 3) total equivalent IV morphine dose, 4) maximum post-anesthesia care unit (PACU) numerical rating scale for pain (NRS), 5) incidence of one or more opioid doses in the PACU, and 6) PACU length of stay (LOS). We hypothesized that these six post-operative outcomes would be more favorable for subjects in the FSB group than in the FC group.

MATERIALS AND METHODS

The present retrospective cohort study compares the effectiveness of FC versus FSB protocols in managing post-operative pain following ACL reconstruction. After approval from the local Institutional Review Board, ICD-9 procedure codes were used to identify patients between the ages of 8 to 18 years old who underwent an ACL reconstruction between December 13, 2013 and September 1, 2014 at the present institution. A single sports medicine pediatric surgeon performed all surgeries. All subjects underwent general anesthesia in addition to one of the two regional anesthesia pain protocols.

A single investigator not involved in the clinical care of the patients retrospectively reviewed the medical records of all subjects meeting the inclusion criteria. Demographic and pre-operative clinical variables include age, time from injury to surgery, gender, presence of concomitant ligamentous, meniscal, or chondral injuries on the pre-operative magnetic resonance imaging (MRI), history of previous knee injury, body mass index (BMI), and mechanism of injury. Intra-operative variables include operative time, tourniquet time, anesthesia time, graft type, and need for additional surgical procedures. Systemic pain medications, as well as opioids and non-steroidal anti-inflammatory drugs (NSAIDs) administered prior to discharge (pre-, intra- and post-operatively), were recorded. Opioid doses were normalized to the patients' weight and converted to an IV morphine equivalent dose [mg/kg] according to previously published conversion factors.[18] Due to the lack of equivalent analgesic IV morphine doses, ketorolac and ketamine were considered categorical variables (administered versus not administered). Ondansetron and dexamethasone administration during surgery was recorded.

Postoperative outcome variables included opioid-related side effects, oral opioid prescription refill requests, total equivalent IV morphine dose, maximum PACU NRS pain scale, incidence of one or more opioid doses in the

Table II. Operative Characteristics

	Femoral Catheter (N=18)		Combined (N=32)		P Value
Operative Time [min], Median (IQR)	156	134-182	148	137-159	0.3465
Tourniquet Time [min], median (IQR)	106	100-115	106	98-111	0.6432
Anesthesia Time [min], median (IQR)	227	186-241	209	200-234	0.5876
Additional Procedures, N (%)	9	50.00%	21	65.63%	0.279
Intra-Operative Morphine Equivalents [mg/kg], mean (stdev)	0.26	0.15	0.21	0.08	0.1513
Ketamine, N (%)	1	5.6%	0	0.0%	0.36
Ketorolac, N (%)	18	100.0%	28	87.5%	0.2828
Ondansetron, N (%)	15	83.3%	29	90.6%	0.6538

PACU, and PACU LOS. Patients self-reported pain level using a standard 0-10 NRS at regular intervals. PACU nurses administered narcotics on a standardized basis using the NRS scale. Subsequent analysis accounted for the maximum NRS score recorded in the PACU. The acute pain service contacted patients on post-operative day 1 to obtain verbal pain scores. Opioid-related side effects considered are the documentation of nausea or vomiting and/or the postoperative administration of drugs aimed at treating these side effects.

Regional Block Technique

Following general anesthesia, the anesthesiologist performed the regional block prior to the initiation of surgery. The femoral nerve catheter was placed with ultrasound guidance. After identification of the femoral artery, an 18-gauge Touhy needle was inserted in-plane, between the iliopsoas muscle and its fascia slightly lateral to the femoral nerve. The catheter was inserted using ultrasound guidance. Position was confirmed by ultrasound and then the catheter was secured. The femoral nerve block was established with an initial bolus of variable concentrations of Bupivacaine or Ropivacaine. In the PACU the anesthesiologist initiated an infusion of ropivacaine 0.2% at 5-10 mL/hour that continued for a duration of 3 days. The single-injection sciatic nerve block was performed using ultrasound guidance to identify the popliteal artery, the common peroneal and tibial nerves. A total of 10-20 mL of local anesthetic was incrementally injected to achieve circumferential fill around the targeted nerves. The type and concentration of local anesthetic used for the sciatic nerve block varied in the combined (FSB) group.

Statistical Methods

Chi-square, Fisher's exact or Student's t-tests, as appropriate, compared differences in demographics and clinical characteristics across the two groups. Due to the non-randomized nature of this retrospective study, we used propensity scores to adjust for differences in baseline characteristics across the two pain protocols. Variables selected for inclusion into the propensity score model were restricted to pre-operative variables that may have influenced decisions regarding pain protocol allocation. The propensity score model included age, time from injury to surgery, gender, presence of concomitant ligamentous, meniscal or chondral injuries on the pre-operative MRI, history of previous knee injuries, and BMI. Multi-variable linear regression analyses compared total IV morphine equivalent dose, maximum NRS PACU pain score, post-operative day 1 pain report, and PACU length of stay (log minutes) between the two groups. The linear regression model testing total IV morphine equivalent dose included propensity scores and ketorolac administration. The linear regression models testing pain scores and PACU length of stay included the following covariates: intra-operative and pre-operative morphine IV equivalent dose, intra-operative ketorolac administration, and propensity scores. Modified Poisson regression models compared the risk of PACU opioid administration (1 or more opioid doses given in the PACU), the risk of opioid related side effects, and the risk of an oral opioid prescription refill request between the two groups. Propensity scores, intra-operative morphine equivalent dose and intra-operative ketorolac administration were included as covariates in the models that tested the risk of PACU opioid administration and the risk of an opioid prescription refill. Propensity scores, intra-operative morphine equivalent dose and subsequent dosing of ondansetron were included as covariates in the models that tested the risk of opioid related side effects. All tests were 2-sided with an alpha level of 0.05.

RESULTS

The study cohort included 18 subjects in the FC group and 32 subjects FSB group. There were no significant differences in the distribution of demographic, pre-oper-

Table III. Crude Incidence of Complications

	Femoral Catheter (N=18)		Combined (N=33)		P Value
Nausea/ Vomiting, N (%)	5	27.8%	5	15.2%	0.4627
Pruritus, N (%)	1	5.6%	0	0.0%	0.3600
Unplanned Admissions, N (%)	1	5.6%	0	0.0%	0.3600

ative, or operative characteristics across the two study groups (Tables I and II). One subject (6%) in the FC group was admitted due to excessive pain compared to 0 subjects (0%) in the combined group (Table III). After controlling for propensity scores, intra-operative morphine equivalent dose and intra-operative ondansetron administration, there was no difference in the incidence of nausea or vomiting in the FC group compared to the FSB group [Risk Ratio: 1.7, 95% CI: 0.5 to 5.8, p = 0.4194].

Post-Operative Opioids

There was a significant [p= 0.0238] difference in the total IV morphine equivalent dose (pre-, intra- and post-operative dose) between the two groups. After controlling for propensity scores and ketorolac administration, the IV morphine equivalent dose in the FC group was an average of 0.10 mg/kg [95% CI: 0.01 to 0.14] higher than the IV morphine equivalent dose in the FSB group. A significantly higher percentage of subjects in the FC group required one or more opioid doses in the PACU compared to the FSB group [p=0.0070]. After controlling for intra-operative and pre-operative IV morphine equivalent dose, intra-operative ketorolac administration, and propensity scores, the risk of PACU opioid administration in the FC group was 1.7 [95% CI: 1.2 to 2.5] times the risk of PACU opioid administration in the FSB group. After controlling for propensity scores and intra-operative morphine equivalent dose, there was no significant difference in the proportion of subjects that requested an oral opioid prescription refill in the post-operative period [Risk Ratio: 2.0, 95% CI: 0.4 to 8.5, p = 0.3734] between the two groups.

Pain Scores

PACU pain scores were available for 88% (44/50) of the subjects included in the cohort. After controlling for intra-operative and pre-operative morphine equivalent dose, intra-operative ketorolac administration, and propensity scores, there was a significant difference in the maximum verbal pain score recorded in the PACU between the two groups [p=0.0074]. Verbal pain scores in the FC group were an average of 2.9 units [95% CI: 0.8 to 4.9] higher than the verbal pain scores in the FSB group. Pain scores on post-operative day 1 were available for 84% (42/50) of the subjects. There was no difference in pain scores on post-operative day 1 in the FC compared to the FSB group [adjusted mean difference: 1.26, 95% CI: -1.2 to 3.7, p = 0.3067].

PACU Length of Stay

The median PACU LOS was 159 minutes [95% CI: 128 to 199 minutes] in the FC compared to 130 minutes [95% CI: 115 to 139 minutes] in the FSB group. After controlling for propensity scores, intra-operative morphine equivalent dose, intra-operative ketorolac administration, and intra-operative ondansetron administration, the likelihood of a longer PACU LOS for a given subject in the FC was 2.2 [95% CI: 1.1 to 4.6, p = 0.0290] times the likelihood of longer PACU LOS for a given subject in the FSB group.

DISCUSSION

Regional pain management protocols for pediatric ACL reconstruction lack standardization. The need for better pain management in pediatric populations is evident considering the differential response to post-operative pain between adult and pediatric patients, and also negative consequences of excessive pain such as increased hospitalization and delayed rehabilitation.[3,9,19] In this cohort of pediatric patients undergoing ACL reconstruction, the addition of a single injection sciatic nerve block to continuous femoral nerve block improved analgesia, spared opioid consumption, and shortened PACU LOS as compared with a continuous femoral nerve block alone.

The present findings are consistent with regional anesthesia studies on adult populations. Jansen et al. concluded the combined femoral and sciatic nerve block provided better analgesia than a femoral nerve block alone following adult ACL reconstruction, concurrent with the present findings within a pediatric population.[20] The present results also parallel those of Cook et al. in that the combined femoral and sciatic nerve block displays greater effectiveness than the femoral block in orthopedic knee surgeries.[21] In addition, Williams et al. contend that the combined femoral and sciatic block is associated with an increased likelihood of PACU bypass and reliable same-day discharge following complex outpatient knee surgery compared to femoral nerve block alone.[22] Of note, the present study considers a femoral nerve catheter, opposed to a single-shot approach considered in the above studies. However, the benefits of multimodal peripheral nerve blocks remain consistent between the present study and extant literature.

The results of the present study show that PACU LOS was significantly greater in the FC group that in the FSB group. A reduction in PACU LOS implies superior pain management, as patients were comfortable enough to function independently of PACU resources. The PACU medical providers used NRS pain scores as a metric for PACU discharge. Reducing PACU LOS has positive implications for overall PACU efficiency, patient satisfaction, resource planning, staffing for outpatient facilities, and hospital costs.[23] The present findings of reduced PACU LOS are consistent with previous literature suggesting that multimodal pain management is correlated with a decreased PACU LOS.[24]

The femoral nerve block is frequently used for patients undergoing ACL reconstruction as it innervates the anterior thigh, the anterior aspect of the knee, and a small part of the medial aspect of the lower leg.[25] A femoral nerve catheter is used at the present institution because it allows for a longer period of analgesia than does a single injection. The sciatic nerve block is commonly utilized in procedures involving the hip, knee, or distal lower extremity.[25] The results of the present study suggest that the combined femoral and sciatic nerve block significantly improve short-term pain control compared to the femoral nerve block alone.

Limitations

The present study utilized a retrospective, non-randomized study design. There is risk of bias as the two pain management methods, FC and FSB, were compared without blinding or randomization. Propensity scores aimed to mitigate this potential for bias. The choice of inhalational agent versus intravenous induction and use of intraoperative dexamethasone for antiemetic prophylaxis were at the discretion of the attending anesthesiologist. Due to the lack of a standardized post-operative analgesic protocol, opioid and non-opioid analgesics administration relied upon the discretion of the anesthesiology and PACU care teams after considering NRS pain scores.

CONCLUSION

This study highlights the effectiveness of femoral nerve catheter with single injection sciatic nerve block to that of a femoral nerve catheter alone for managing early pain following ACL reconstruction in adolescents. A longer follow-up period beyond the patient discharge is necessary to assess the long-term effectiveness of the combined femoral catheter protocol and its influence on the initiation of post-operative rehabilitation. Additionally, future studies should consider cost-benefit analyses of the FSB protocol in relation to the associated reduction in PACU LOS.

Ethical Statement

The present study is approved by the Colorado Multiple Institution Review Board.

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IN VIVO TOXICITY OF LOCAL ANESTHETICS AND CORTICOSTEROIDS ON SUPRASPINATUS TENOCYTE CELL VIABILITY AND METABOLISM

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ABSTRACT

Background: This study was conducted to evaluate the effects of commonly used injection medication combinations on supraspinatus tenocyte cell viability and tissue metabolism.

Methods: Twenty adult dogs underwent ultrasound guided injection of the canine equivalent of the subacromial space, based on random assignment to one of four treatment groups (n=5/group): normal saline, 1.0% lidocaine/methylprednisolone, 1.0% lidocaine/triamcinolone or 0.0625% bupivacaine/triamcinolone. Full-thickness sections of supraspinatus tendon were harvested under aseptic conditions and evaluated on days 1 and 7 post-harvest for cell viability and tissue metabolism. Data were analyzed for significant differences among groups.

Results: Tendons exposed to 1% lidocaine/methylprednisolone had significantly lower cell viability at day 1 as compared to all other groups and control. All local anesthetic/corticosteroid combination groups had decreased cell viability at day 7 when compared to the control group.

Conclusions: This study demonstrated significant in vivo supraspinatus tenotoxicity following a single injection of combination local anesthetic/corticosteroid when compared to saline controls.

Level of Evidence: Level II

Keywords: local anesthetic; injections; corticosteroid; tendon; tenotoxicity

INTRODUCTION

Peri-articular injections are commonly performed for diagnostic and therapeutic purposes when managing acute and chronic soft tissue conditions about the shoulder and other joints.[1] Many different combinations and dosages have been used, based on the condition being treated and individual surgeon preference.[2] Injection of local anesthetic, corticosteroid, or combination agents may improve diagnostic accuracy and provide short-term pain relief for a variety of acute inflammatory and chronic degenerative soft tissue conditions.[3-5] Despite widespread clinical use for rotator cuff pathology, the long-term consequences and potential toxicity of subacromial injection on supraspinatus tenocytes and other peri-articular structures has not been fully elucidated. Numerous in vitro studies have demonstrated the damaging effects of local anesthetics, corticosteroids, or combination agents on intra-articular chondrocytes.[3,5-15] Several in vitro studies have confirmed similar toxicity to tenocytes, demonstrating decreased cell proliferation and viability following even single exposure to these agents.[16-21] Previous in vitro supraspinatus tendon explant studies have demonstrated significant toxicity of various concentrations of lidocaine, bupivacaine, and several cortisone derivatives on tenocyte viability and metabolism.[17,18,22]

Despite growing concern, there has been a paucity of in vivo studies investigating these effects on supraspinatus tendons. There exists a disparity between the apparent clinical safety of routine combination subacromial injections and the detrimental results reported from in vitro models. It has been postulated that the extracellular matrix of the intact tendon may provide protection for tenocytes, thus mitigating the damaging effects observed using in vitro monolayer cell culture models.[16,18,23] Therefore, the purpose of the present study was to use a translational in vivo model to investigate the effects of a single subacromial injection of local anesthetic/corticosteroid on supraspinatus tenocyte viability and cell metabolism. Our hypothesis was that there would be

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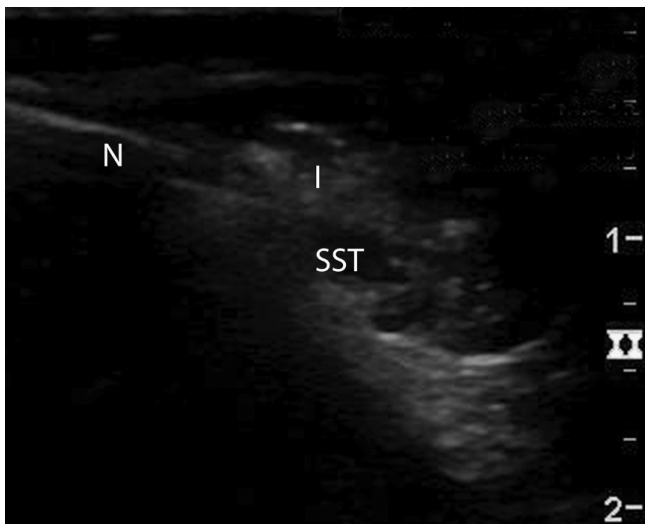

Figure 1 – Image from a canine in this study showing ultrasound guided injection. A 1.5-inch 22 gauge needle (N) is used to inject the respective injectate (I) immediately superficial to the supraspinatus tendon (SST) 1 cm from its insertion on the greater tuberosity.

toxic effects of local anesthetic/corticosteroid injectates on supraspinatus tenocytes following single peri-tendon injection in this in vivo model.

METHODS

With Institutional Animal Care and Use Committee (IACUC) approval, adult purpose-bred dogs (n=20; mean weight = 28.6 kg) were sedated (medetomidine 0.04 mg/kg) and prepared for aseptic injection of the left supraspinatus tendon. Each dog (shoulder) was randomly assigned to one of four groups (N=5 per group):

- Control = 5 ml of 0.9% saline
- L/M = 4 ml of 1% lidocaine (pH 6.5) + 1 ml of 40 mg/ml methylprednisolone (pH 6.5)
- L/T = 4 ml of 1% lidocaine + 1 ml of 40 mg/ml triamcinolone (pH 7.0)
- B/T = 4 ml of 0.0625% bupivacaine (pH 6.5) + 1 ml of 40 mg/ml triamcinolone

The dosage of 40 mg corticosteroid was selected as it is the recommended dose for the human wrist, which would be similar in size/volume to the canine shoulder. Additionally, the recommended clinical veterinary dose for the canine shoulder is 30 mg to 40 mg. For each treatment, a 1.5-inch 22 gauge needle was inserted to be immediately superficial to the supraspinatus tendon 1 cm from its insertion on the greater tubercle and just distal to the acromion, verified by ultrasonography (GE Logiq i portable ultrasound machine with 10-14 MHz linear transducer; GE Healthcare, Milwaukee, WI, USA) (Fig. 1), and then used to deliver the entire volume of the respective injectate into the area. The dogs were recovered from sedation and allowed full activity in their runs. The dogs were euthanatized 24 hours after injection as part of another IACUC-approved study. The injected tissues were aseptically harvested and full-thickness sections from the supraspinatus tendon were placed in sterile closed containers filled with tissue culture media, transported to the laboratory, and assessed immediately (day 1) or processed for tissue culture.

Tissue Culture

Two 4 mm diameter explants per canine were aseptically prepared from the harvested tendon tissue using a dermal biopsy punch (Fray Products, Buffalo, NY). One explant was used for day 1 assessment of tissue viability, and the other explant was placed in a well of 24-well tissue culture plates (Becton Dickinson Labware, Franklin Lakes, NJ) containing 1 ml Dulbecco's modified Eagle's medium with high glucose (Gibco, Invitrogen, Carlsbad, CA) supplemented with 1% ITS, penicillin, streptomycin, amphotericin B, L-ascorbic acid, L-glutamine, and nonessential amino acids. Explants were cultured in dedicated incubators at 37°C with 5% CO2 at 95% humidity, and the media was changed on day 1 and 3 of culture.

Toxicity Assessments

Tendon explants were assessed immediately after harvest (day 1) and on day 7 of culture. Cell viability was determined using a live-dead cell assay (Invitrogen, Carlsbad, CA). Tissues were incubated with Calcein AM (live cell stain) and Sytox Blue (dead cell stain) using manufacturer's instructions and then assessed by fluorescent microscopy to determine the number of live and dead cells in each section. Images of each section were captured using commercially available software (Microsuite, Olympus, Tokyo, Japan), and a subjective assessment of viability was performed by 6 investigators blinded to treatment. Each tendon tissue explant was given a score from 0 (0% viability) to 5 (100% viability). The scores from all observers were averaged to give a mean tenocyte subjective viability score (VS) for each explant.

Tissue metabolism was assessed on day 1 and 7 of explants cultured for 7 days using the resazurin (Sigma-Aldrich, St. Louis, MO) fluorescent metabolic assay. Resazurin is converted to a fluorescent compound (resorufin) by metabolically active cells. The degree of fluorescence detected in the media provides a quantitative measure of the number of viable cells in tissue.[24] For day 1 testing, 100 uL of resazurin reagent was added to 900 uL of media of each tissue section and incubated overnight at 37°C. Fluorescence was measured (Ex: 530, Em: 590) on a 200 uL sample of the media the following day using a Synergy HT plate reader (BioTek, Winooksi, VT). After testing on day 1, the media was removed from

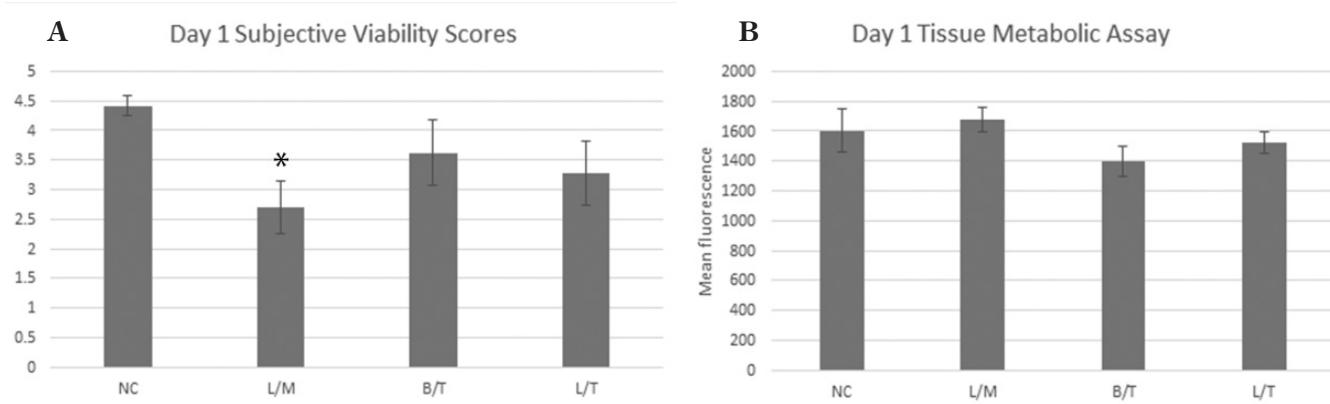

Figure 2 – Day 1 (24 hours after intra-articular injection) Subjective viability score (SVS) (a) and tissue metabolic activity (b) for tendon explants in each treatment group. Tendon tissue exposed to L/M (*) had significantly (p=0.006) lower SVS compared to the saline injected control. No statistically significant differences in tissue metabolism levels were noted between groups.

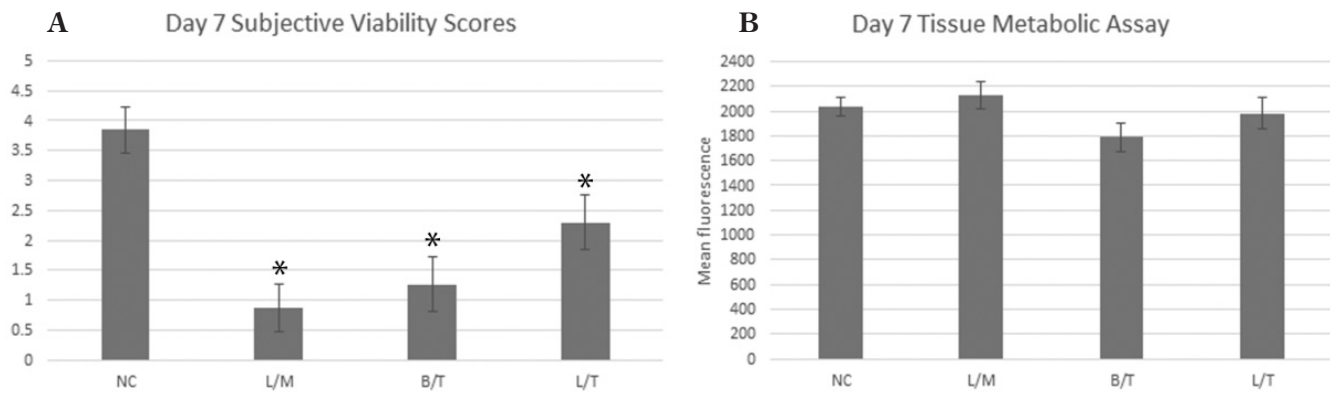

Figure 3 – Day 7 Subjective viability score (SVS) (a) and tissue metabolic activity (b) for tendon explants in each treatment group. Tendon tissue exposed to L/M (p=0.001), L/T (p=0.041), and to B/T (p=0.004) had significantly (*) lower SVS compared to the saline injected control. No statistically significant differences in tissue metabolism levels were noted between groups.

the tissue, the tissue explant was washed twice with clean supplemented media, and the tissue explant then placed in a fresh 1 ml of media for culture as described above. On day 6 the media was removed and a fresh 900 uL of media and 100 uL of resazurin stain was added to the tissue explants and tested as described above.

Statistical Analysis

Tendon VS and metabolic assay fluorescence data were assessed for statistically significant differences among groups at each assessment time point using a one-way ANOVA with Holm-Sidak post-hoc analyses. Significance was set at $p < 0.05$.

RESULTS

At day 1 (24 hours after injection) the viability score for tendon tissue exposed to L/M was significantly (p=0.006) lower than the saline injected control (Fig. 2a). However, the resazurin assay did not identify a statistically significant (p=0.28-0.69) difference in tissue metabolic activity among groups at the day 1 time point (Fig. 2b). After 7 days of culture, tendon tissue exposed to L/M (p=0.001), L/T (p=0.041), and B/T (p=0.004) all had significantly lower viability scores compared to the saline injected control (Fig. 3a). No statistically significant differences in tissue metabolism among groups were identified by the resazurin assay on day 7 (Fig. 3b).

DISCUSSION

The results of this study using an in vivo model demonstrate that a single injection of local anesthetic/corticosteroid into the subacromial space had deleterious effects on supraspinatus tenocyte viability when compared to a saline control. Compared to saline, all treatment groups showed decreased cell viability at days 1 and 7, with the 1% lidocaine/methylprednisolone group reaching statistically significant lower levels at post-injection day 1. This confirmed our hypothesis that there would be significant

toxic effects of these injectates on supraspinatus tenocytes after a single peri-tendon injection.

In a systematic review, Dean et al. found significant negative effects of corticosteroids in both in vitro and in vivo tendon studies.[25] In vitro findings included reduced cell viability, cell proliferation, and collagen synthesis; and in vivo studies showed increased collagen disorganization and necrosis in the limited series.[25] Many laboratory studies demonstrate tenotoxicity at the cellular level with use of these agents, and clinical studies suggest increased risk of delayed tendon healing or tendon rupture.[2,18-21,24-28] Specific to local anesthetics, Scherb et al. showed reduced tenocyte proliferation after bupivacaine exposure and Piper et al. demonstrated incrementally damaging effects of lidocaine on bovine tenocytes.[16,17] Similarly, our study showed decreased cell viability at day 1 for lidocaine, and at day 7 for both lidocaine and bupivacaine. Regarding independent corticosteroid use, Wong et al. and Scutt et al. both showed that dexamethasone reduced tenocyte collagen synthesis and cell proliferation and viability.[18,20] In an in vivo study, Dean et al. compared histological and immunohistochemical effects of glucocorticoid injection versus surgical rotator cuff repair for rotator cuff tendinopathy.[29] They noted increases in cell proliferation, vascularity and hypoxia inducible factor 1α after the surgical repairs but not after the injections, and concluded that further tendon damage may result after glucocorticoid injection. Similar to these studies, our studies showed decreased cell viability with both dexamethasone and triamcinolone at day 7. Our study did not show significant effects of the triamcinolone group at day 1, however. Another difference from previous studies was that our study did not show significant differences in cellular metabolism in any of the study groups. A potential reason for this could be that the specimens were tendon explants, thus limiting the release of matrix metalloproteinases that could influence metabolism. We attempted to mitigate this factor by preserving the extracellular matrix and cell heterogeneity of the tendon itself.

Previous in vitro studies have shown tenotoxicity to a single exposure with the individual injectates 1% lidocaine, methylprednisolone, bupivacaine, and triamcinolone.[17-22] Most injections administered clinically are given in combination, however. Data from previous in vitro results, along with common clinical combinations, provided the rationale for the combination injectate groups used in this in vivo translational study. Based on data from previous screening studies, number of dogs available, and a pre-study power analysis, three local anesthetic-corticosteroid combinations were chosen: 1%L/M as the "worst case scenario", 0.0625%B/T as the "best case scenario", and 1%L/T as the "mismatched" group to help determine whether local anesthetic or corticosteroid might be most influential in terms of in vivo effects. Dosage and volume of subacromial injectate was chosen to directly correspond to those used in human patients, as well as current standard of care in veterinary medicine.

In general, physicians often utilize combination injections in clinical practice. The local anesthetic provides initial pain relief and allows the practitioner to perform a Neer's Impingement Test to differentiate the injected subacromial space as a major pain generator or not, while the corticosteroid is included to decrease inflammation so that the patient may rehabilitate effectively. Piper et al. investigated the effects of independent usage of local anesthetic and cortisone versus combined use. They found that longer acting ropivacaine alone was not found to have significantly negative toxic effects, but short acting lidocaine was noted to have dose dependent toxic effects. More importantly, they demonstrated that when both anesthetics were combined with dexamethasone, there was noted to have significantly increased toxicity to tenocytes.[13] Previous in vitro data demonstrates similar independent toxicity with lidocaine and less toxicity with longer acting dilute anesthetic (i.e., 0.0625% bupivacaine).[22] Similar to results from Piper et al., however, this study exhibited that the combination of agents that may be safe in isolation (i.e., bupivacaine), remain a significant concern when used in combination. The synergistic and deleterious mechanism of action for tenotoxicity is unknown and should be the subject of future research, but our results are nonetheless potentially valuable to the clinician. Unfortunately, limitations in number of animals did not allow for independent testing of local anesthetic or corticosteroid injection alone in this study. Future study is warranted, particularly to answer whether agents such as triamcinolone and dilute bupivacaine are safe when used in isolation, as they have been shown to be in some in vitro studies.[18-22]

Based on the current study and the available data in the literature, the authors have now discontinued the use of lidocaine in our practices for both intra-articular and peri-tendinous injections. We now use low dose (0.0625%) bupivacaine sparingly for diagnostic purposes only. Our data and others also support potential toxicity with the use of methylprednisolone or dexamethasone, which we also avoid for subacromial injection. Data regarding triamcinolone is mixed, with some studies demonstrating toxic effects only when used as a combination agent and others demonstrating no long-term negative effects of independent injection.[18-20,23] In all of the intra-articular and subacromial in vitro and in vivo studies conducted at our institution, we have demonstrated no deleterious effects of independent usage of triamcinolone versus negative

control. Based on the available data, the authors now clinically use isolated triamcinolone with a normal saline carrier for intra-articular and subacromial injections.

Financial and ethical limitations dictated the number of specimens for this study and prohibited the use of more canines and potentially more treatment groups. Treatment groups of local anesthetic-corticosteroid pairs were chosen based on previous in vitro studies evaluating each substance alone, prior peer reviewed literature, pre-study power analysis, and the common clinical practice pattern of combination injections. Future in vivo study should investigate these and other substances (i.e., ropivacaine, dexamethasone) individually to control for variables that may have influenced the results. In this study, saline injection was used as negative control, as the contralateral shoulder was unavailable and being utilized for a different study. While it can be argued that saline injection is not equivalent to an untouched normal shoulder, our results in the saline group consistently demonstrated high viability and metabolic function for all samples at all time points. This profile compares favorably with results from historical controls using normal canine tenocytes. When financial and/or ethical considerations limit use of research animals, placebo or sham controls are preferred over unaltered or normal controls and are considered adequate for hypotheses testing. In fact, placebo or sham controls (e.g., saline injection as in the present study) are required by most regulatory bodies, whereas unaltered, normal controls are not. Regarding the potential issue involving the use of the canines for multiple simultaneous studies, it is noted that this was IACUC approved and addresses the NIH mandate of "Reduce, Refine, and/or Replace." Canines did not experience lameness or dysfunction in the 24 hours of study duration and the other study involving the contralateral shoulder joint did not involve any systemic treatments. As such, we do not think this in any way effected the study results.

Other limitations include the use of normal non-pathologic canine supraspinatus tendons. While the canine shoulder is very similar to its human counterpart in terms of pathophysiology and clinical treatment—including injections—differences do exist and should be taken into account when applying the results to a human patient population. Moreover, the use of healthy tendons may not replicate the exact biologic responses a pathologic subacromial space might have to an injection, but we believe the use of normal tendons shows even a stronger impact of the potential damaging effects of the medications tested. Nonetheless, these results should be replicated in a model of tendon pathology before definitive treatment recommendations can be made. Another limitation could be the use of only two early time points. While significant effects on cell viability were noted at these time points, there were not significant differences noted in cell metabolism. It is possible that further time points could exhibit differences between groups. It is also possible that the methodology employed for the metabolism assay influenced these results. Overnight incubation of the explants in the indicator dye resulted in high-metabolism samples reaching the maximum level of fluorescence, such that relative differences among these samples could not be distinguished. Therefore, shorter incubation times may be used for ongoing studies. However, cell viability and cell metabolism can, and often are, uncoupled, especially with respect to anabolism versus catabolism. As such, cell viability was considered the most important factor for clinical applicability in the present study and therefore was the primary outcome measure.

The negative effects on viability at even these early time points, however, raises concern that long-term clinically significant toxicity is possible and should be investigated prior to recommending routine use of the combinations shown to be toxic in this study.

This study demonstrated significant in vivo supraspinatus tenotoxicity following a single injection of combination local anesthetic/corticosteroid when compared to saline controls. This data raises significant concern regarding the clinical use of combination peri-tendinous injections near supraspinatus tendons.

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EFFICACY AND VALIDATION OF A SIMULATION-BASED COMPARTMENT SYNDROME INSTRUCTIONAL COURSE

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ABSTRACT

Background: This study reports the validity and effectiveness of a simulation-based compartment syndrome instructional course.

Methods: Six post-graduation year one (PGY1) orthopaedic residents and six PGY5 residents participated in the study. All PGY1 residents participated in a four-hour compartment syndrome training simulation. An anatomic compartment model was used to test needle placement accuracy in four leg muscle compartments. Pre-training, immediate post-training, and one-month post-training performance data were collected from all PGY1 residents, as well as data from a one-time assessment of all PGY5 residents. These assessments included a paper test for lower leg anatomy (anatomy module), a procedural test of needle placement accuracy using an anatomic compartment syndrome simulation module (needle placement module), and an assessment of ability to measure compartment pressure via low cost simulation (pressure measurement module). Face validity of the needle placement module and pressure measurement module were assessed using a structured questionnaire given to all 12 study participants and three orthopaedic faculty.

Results: The PGY1 residents demonstrated significant improvement at immediate post-training in all three assessments compared to their pre-training performances (anatomy p=0.019, needle placement p=0.026, pressure measurement p=0.033 and Objective Structured Assessment of Technical Skill (OSATS) score for pressure measurement p <0.0001). This performance was maintained at the one-month post-training assessment. Immediate post-training and one-month post-training PGY1 resident performances were comparable with PGY5 resident performance in all tests.

Fifteen participants rated the face validity of the needle placement and pressure measurement modules. For the needle placement module, 73.3% of participants highly rated (4 out of 5 or greater) for realism, 86.7% highly rated for being an effective tool for teaching, and 80% highly rated for needing the model to be available throughout their training. The pressure measurement module did not receive high face validity ratings.

Conclusions: With minimal, inexpensive training, the performance of junior residents in a compartment syndrome simulation was improved to a level comparable with senior residents. In addition, this performance was maintained at one-month post-training. The compartment syndrome anatomic module had highly-rated face validity.

Clinical Relevance: Training junior residents to accurately diagnose compartment syndrome using a realistic simulation may allow for greater diagnostic accuracy in the clinical setting.

INTRODUCTION

The clinical diagnosis of compartment syndrome can be confirmed via compartment pressure measurements[1]. At teaching institutions, patients with possible compartment syndrome are often assessed by junior residents. The ability to correctly diagnose and accurately measure muscle compartment pressures is an important skill for post-graduate year one (PGY1) residents. Training via simulation can increase knowledge and skills relevant to this important diagnosis prior to encountering actual patients in an emergent setting[2–7].

The American Board of Orthopaedic Surgery (ABOS) has developed a series of training modules used to teach skills at the PGY1 level, including a module for learning procedural skills for diagnosing compartment syndrome[8]. This study assesses the validity and efficacy

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of the educational material and simulations in this module by training PGY1 residents and comparing their pre and post-intervention scores to those of PGY5 residents. The study assesses face validity of the simulation models used in this exercise[9,10]. We hypothesized that these exercises would effectively improve PGY1 resident skills and that the simulation models used in this exercise would have highly-rated face validity.

METHODS

Six PGY1 and six PGY5 residents volunteered to participate in this study following institutional review board review. All tests at every time point were the same including a medical knowledge test for lower leg anatomy (*anatomy module*), accuracy of needle placement for compartment pressures using a Sawbones™ anatomic compartment syndrome simulation (*needle placement module*), and a test to assess the ability to measure compartment pressure in a low cost simulation (*pressure measurement module*).

Prior to beginning the course, the PGY1 residents were given verbal instructions and goals of the training day. Following these instructions, all PGY1 residents took a pretest without any task-specific preparation. Then, the PGY1 residents participated in a four-hour compartment syndrome training module, consisting of a lecture, instructor demonstration and time to practice procedural skills on the simulations (Appendix 1). Following this, all PGY1 residents took an immediate post training test, followed by a retention test one-month post-training. The PGY5 residents participated in a single series of three assessments without any specific preparation.

The number of correct answers on the anatomy test, the number of correct needle placements into muscle compartments, the error of pressure measurements, and Objective Structured Assessment of Technical Skill (OSATS) scores were recorded. Face validity of the needle placement module and pressure measurement module were assessed using a structured questionnaire given to all 12 study participants. In addition, three orthopaedic faculty were invited to utilize the simulators and complete the face validity questionnaire.

The assessments are described below:

Anatomy module:

A lower leg anatomy test using pictures of cross sectional anatomy of the lower leg was administered. The full score for this test was 15 points (one point per question).

Needle placement module:

The ability to locate lower leg muscle compartments with a needle was assessed using an anatomic compartment syndrome simulation simulation with an electronic needle transducer. This model consists of a simulated anatomic lower leg with synthetic tibia and fibula and a silicone skin which can be palpated to find landmarks. Four foam compartments of the lower leg are anatomically located within the simulated soft tissues and conduct a current when the needle is placed into the compartment, lighting a corresponding section of the feedback unit (Figure 1). Before testing, a random order of 10 measurements of the four compartments of the lower leg was selected and used across all tests (three lateral, two superficial posterior, two anterior, three deep posterior). Participants were blinded from the results of needle placement and were instructed to alert the examiner once they thought they were in the correct compartment.

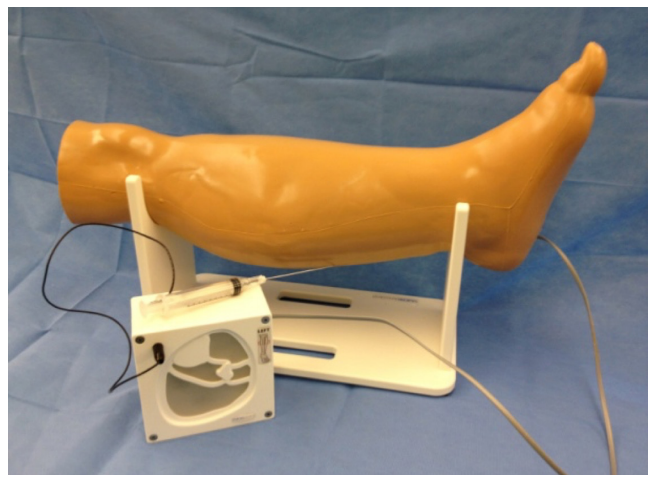

Figure 1: Anatomic compartment syndrome simulation with an electronic needle transducer

Pressure measurement module:

Compartment pressure measurement was simulated using a Stryker™ needle pressure measurement device. The measurement tools were calibrated by orthopaedic faculty before the test. A 500mL saline bag was wrapped with standard blood pressure cuff then the cuff was inflated to a randomly selected pressure. The participant was blinded to this pressure. The participant assembled the instrument and then inserted the needle into saline bag to measure the pressure. The cuff pressure and measured pressure were recorded, and the difference between the two measurements was calculated. This was repeated in three trials. Orthopaedic faculty scored participants using the OSATS score at the end of the procedure (Appendix 2).

Face validity test:

A questionnaire was provided to all 12 study participants and three orthopaedic faculty (Appendix 3, 4). The

Table I. Average scores ± standard deviation (SD) of PGY1 and PGY5 performances in each test.

	PGY1 pre-training (average ± SD)	PGY1 immediate post-training (average ± SD)	PGY1 one-month post-training (average ± SD)	PGY5 (average ± SD)
Lower leg anatomy (out of 15)	10.17 ± 2.4	13.7 ± 1.4	14.2 ±0.9	14.5 ±0.5
Needle placement (out of 10)	5 ± 3	8.8 ± 0.8	8.3 ± 1.8	8 ± 0.9
Pressure measurement (∑ measurement error)	7.3 ± 4.9	3.3 ± 2.3	2.8 ± 1.2	4.8 ± 2.2
OSATS score for pressure measurement (out of 35)	18.3 ± 1	29.2 ± 1.5	30 ± 3.2	29.5 ± 1.9

Table II. Percent improvement and paired t-test results between PGY1 pre-training test, immediate post-training test, and one-month post-training test.

	PGY1 pre-training versus immediate post-training scores	PGY1 immediate post-training versus one-month post-training scores	PGY1 pre-training versus one-month post training scores
Lower leg anatomy	Posttest ↑34.4% p=0.019*	Late posttest ↑3.7% p=0.49	Late posttest ↑39.35 p=0.025*
Needle placement	Posttest ↑76.7% p=0.026*	Late posttest decreased 5.7% p=0.33	Late posttest ↑66.7% p=0.036*
Pressure measurement (∑ measurement error)	Posttest was 54.5% less measurement error p=0.033*	Late posttest was 15% less measurement error p=0.42	Late posttest was 61.4% less measurement error p=0.048*
OSATS score for pressure measurement	Posttest ↑59% p<0.0001*	Late posttest ↑2.9% p=0.56	Late posttest ↑63.6% p=0.0003*

Table III. Unpaired t-test between PGY5 and PGY1 performance (OSAT score).

	PGY5 versus PGY1 pre-training scores	PGY5 versus PGY1 immediate post-training scores	PGY5 versus PGY1 one-month post-training scores
Lower leg anatomy	PGY5 42.6% better p=0.0015*	PGY5 6% better p=0.196	PGY5 2.3% better p=0.48
Needle placement	PGY5. 60% better p=0.043*	PGY5 10.4% worse p=0.111	PGY5 4.2% worse p=0.69
Pressure measurement (∑ measurement error)	PGY5 had 51.7% less measurement error p=0.28	PGY5 had 31% more measurement error p=0.28	PGY5 had 70% more measurement error p=0.08*
OSATS score for pressure measurement	PGY5 60.9% better p<0.0001*	PGY5 1.1% better p=0.74	PGY5 1.7% better p=0.75

questionnaire rated realism of the simulation, realism of the tactile/force feedback, effectiveness in teaching trainees, likeliness of retaining the skill(s) after training, as well as the necessity, availability, and use of each model throughout residency training. Ratings were from one to five, with one referring to an absolute disagreement with the statement and five referring to an absolute agreement with the statement. For analysis, four or five was considered agreement with the statement, three was considered neutral to the statement, while one or two were considered disagreement with the statement.

The anatomic compartment syndrome simulation was donated for the purposes of this study ($829.00 USD). The needle pressure measurement device and blood pressure cuff were obtained from the Hospital stores. Saline bags (500mL) were purchased with departmental funds.

Paired t-tests were used for comparison of pre-training test, post-training test and one-month post-training test in PGY1. T-tests were similarly used to compare between PGY1 and PGY5 performance. Alpha was set at 0.05.

RESULTS

The six PGY5 residents were a mean age of 32 at the time of testing with more than 4.5 years of training, while PGY1 residents were a mean age of 27.5 with less than three months of orthopaedic residency training. None of the PGY1 residents had experience using the needle

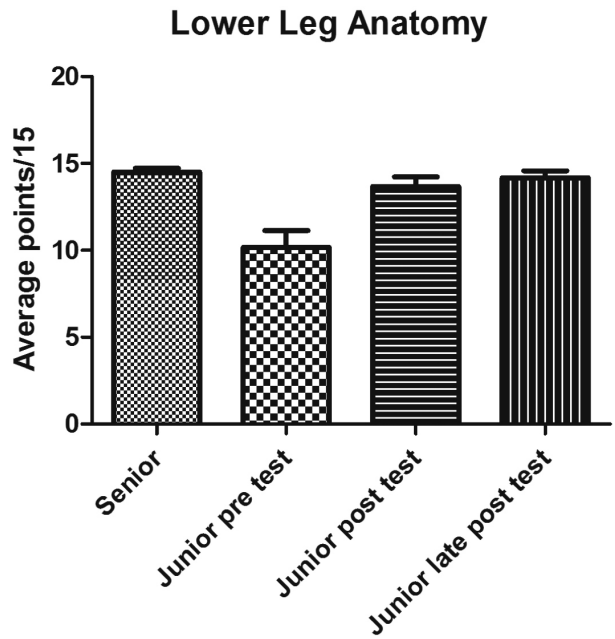

Figure 2: Lower leg anatomy test results

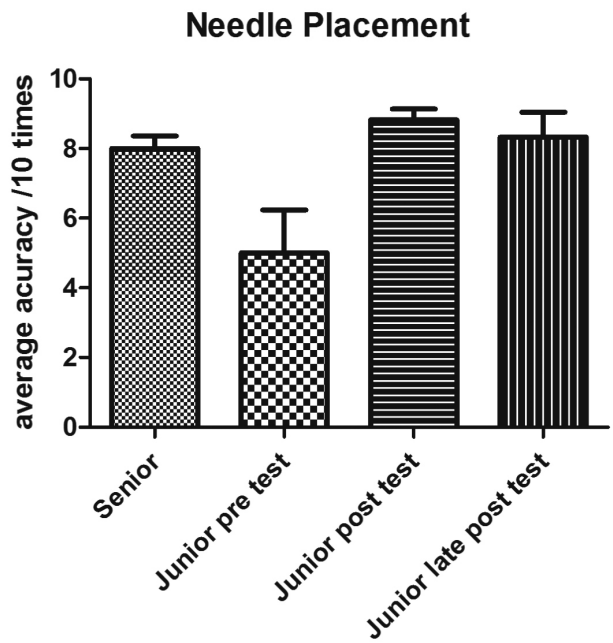

Figure 3: Needle placement module test results.

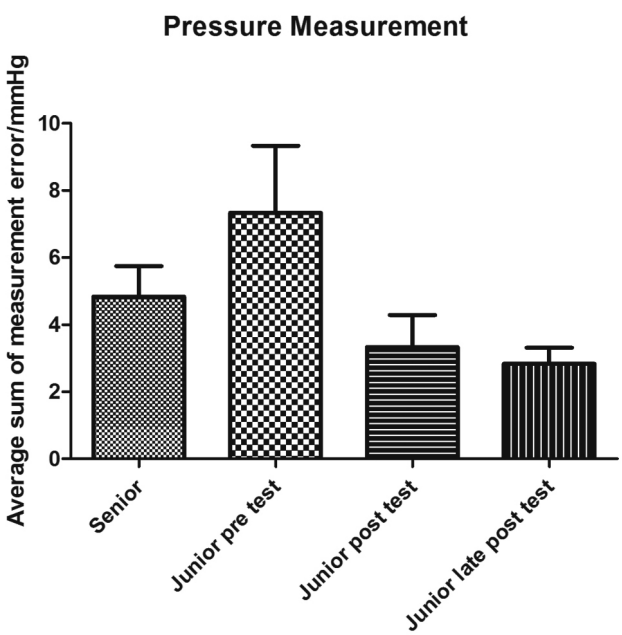

Figure 4: Pressure measurement error test results

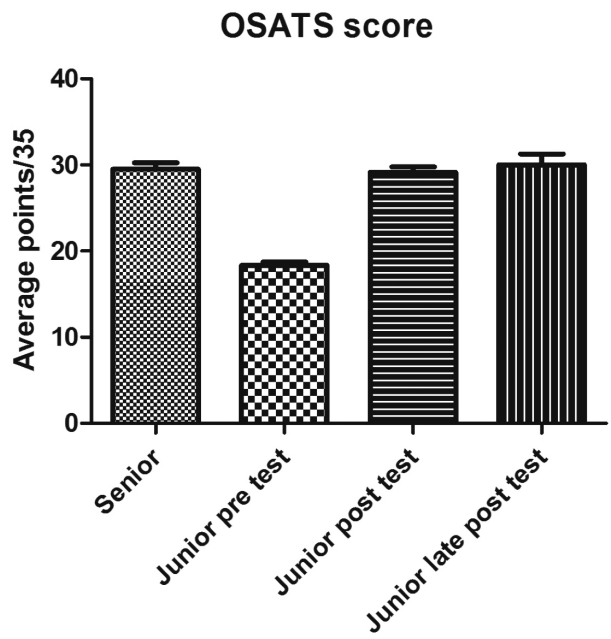

Figure 5: Results of OSATS score for pressure measurement module

pressure measurement device. The scores from each test are shown in Table 1. The comparison of results between the PGY1 pre-training test, immediate post-training test and one-month post-training test are shown in Table 2. The comparison of results between PGY1 and PGY5 performance (OSAT score) at different time points are shown in Table 3 and Figures 2-5.

Pre-training *anatomy* scores for PGY1 residents were 10.17 ± 2.4 out of 15 which significantly improved to 13.7 ± 1.4 at the immediate post training test (p=0.019). Improvement in the immediate post-training scores was not significantly different from PGY5 resident baseline scores (p=0.196) and was retained at one month (p=0.025).

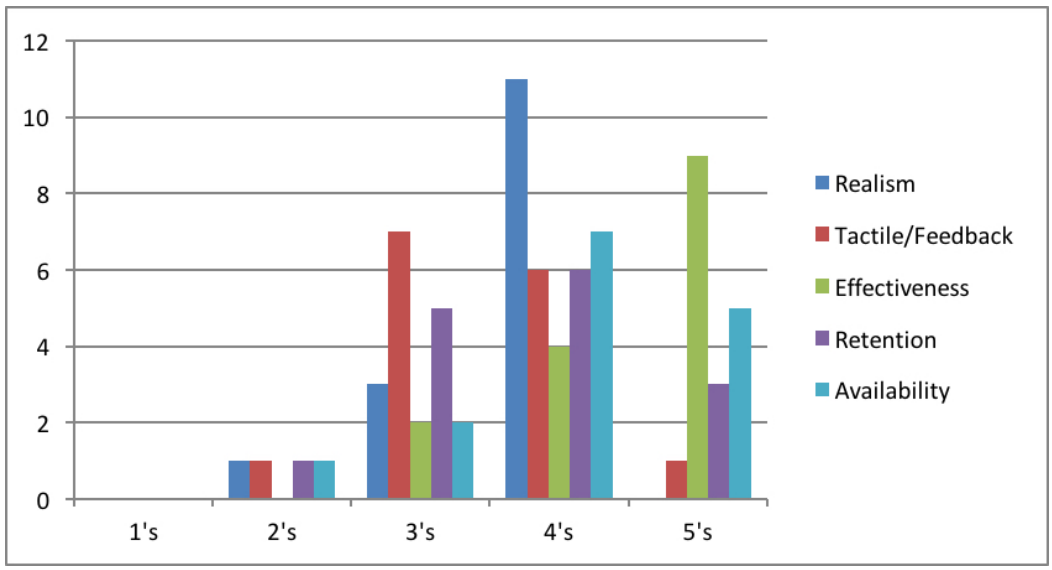

Figure 6: Face validity results for the needle placement module

Pre-training *needle placement* scores for PGY1 residents were 5 ± 3 out of 10 which significantly improved to 8.8 ± 0.8 at the immediate post training test (p=0.026). Improvement in the immediate post-training scores was not significantly different from PGY5 resident baseline scores (p=0.111) and was retained at one month (p=0.036).

Pre-training *pressure measurement* error for PGY1 residents was greater at initial testing (7.3 ± 4.9) which improved to 3.3 ± 2.3 at the immediate post training test (p=0.033). Improvement in the immediate post-training scores was not significantly different from PGY5 resident baseline scores (p=0.28) and was retained at one month (p=0.048).

Face validity results for needle placement module:

Of 15 participants who completed the questionnaire for face validity, 11 (73.3%) agreed that the model looked realistic compared to an actual leg with compartment syndrome, seven (46.5%) agreed that the model provided good tactile/force feedback to the surgeon, 13 (86.7%) agreed that the model is an effective tool for teaching anatomical needle placement, nine (60%) agreed that they will retain this skill and need no further practice with this simulator, and 12 (82%) agreed that this simulator should be available for learner practice throughout training. (Figure 6).

Face validity results for pressure measurement module:

Of 15 participants who completed the questionnaire, three (20%) agreed that the model felt realistic compared to pressure measurement of actual lower leg compartment syndrome, three (20%) agreed that the model provided good tactile/force feedback to the surgeon. Nine (60%) agreed that the model is an effective tool for teaching compartment syndrome of the leg pressure measurement, seven (46.6%) agreed that they will retain this skill and need no further practice with this simulator and six (40%) agreed that this simulator should be available for learner practice throughout training. (Figure 7).

DISCUSSION

Surgical simulation in resident training has gained increasing attention as high-fidelity simulators have become more widely available[3,11,12]. Residents trained via simulated procedures have demonstrated improved skills during actual surgical procedures[13,14]. Since 2013 the Residency Review Committee (RRC) for Orthopaedic Surgery— a review committee of the Accreditation Council for Graduate Medical Education (ACGME)— and the American Board of Orthopaedic Surgery (ABOS) have mandated laboratory-based skills training and have provided a suggested curriculum to this end[8]. While many previous investigations of simulated procedures in orthopaedic surgery have focused on arthroscopic skills training[2,3,11,12,14], to date, few studies that have assessed efficacy or validated the simulations included in the ABOS curriculum. This study evaluates a module which focuses on the knowledge and technical skills necessary for the assessment of compartment syndrome.

Compartment syndrome is an emergent condition for which early diagnosis and management not only improves outcome but also may be associated with

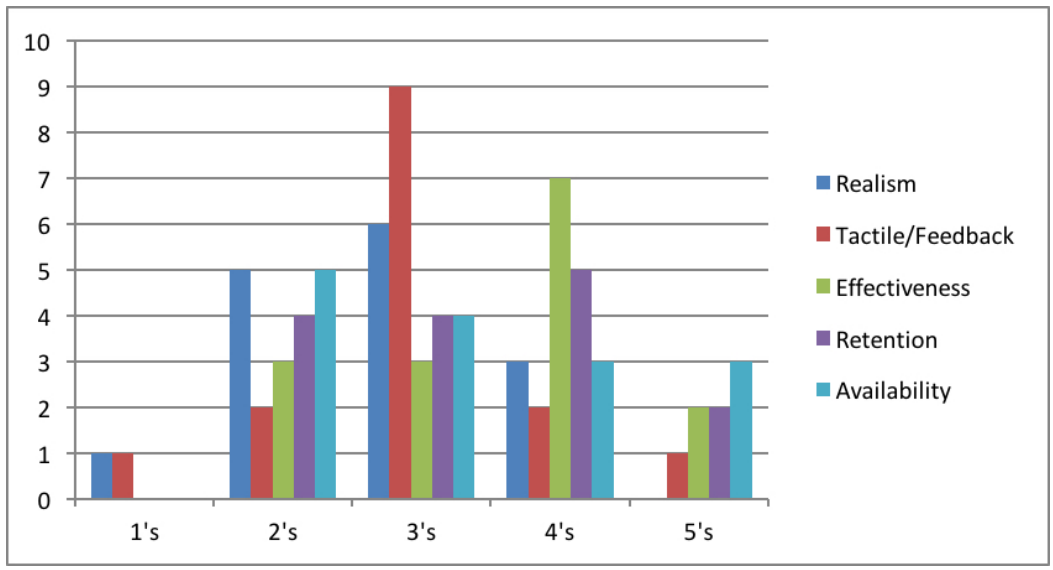

Figure 7: Face validity results for pressure measurement module

decreased indemnity risk[15]. In teaching hospitals, junior residents with little prior experience are often the first to evaluate patients who may have compartment syndrome. Making the correct diagnosis and performing an accurate compartment pressure measurements are therefore critical skills to learn early in training. The aim of this study was to examine the effectiveness of a compartment syndrome skills instructional course (an ABOS module) and to validate the simulations used.

PGY1 residents improved and maintained at one month their performance on all three assessments (*anatomy, needle placement, pressure measurement*) to a level comparable with PGY5 residents. This suggests that the instructional course set out to achieve its aims—novice resident trainees were able to acquire skills to adequately prepare them to match the performance of PGY5 residents on clinically relevant simulations.

Participants highly rated the *needle placement module* for realism (73.3%), being an effective tool for teaching (86.7%) and needing the model to be available throughout their training (80%). Previous studies have suggested that one of the most important elements of a simulation is the realism of the model[11]. The tactile feedback of the anatomic compartment syndrome simulation received the lowest score. With the use of high-fidelity simulators in training environments, the literature suggests that tactile feedback may be important for "force-skill" tasks such as drilling, where a certain amount of applied force will achieve a predictable result[16]. It is unclear in this study whether limited tactile feedback in the simulation would translate to difficulty with the same procedure in a clinical setting.

The pressure measurement module was rated poorly for face validity by many participants. Despite these subjective ratings, the model provides an opportunity to deploy the needle pressure measurement device in a simulation setting, giving participants the opportunity to physically assemble and use the device in a safe, non-clinical setting.

There are significant limitations to this study. The number of participants was small. The simulation models themselves have weaknesses. After many uses, the anatomic compartment syndrome simulation developed permanent perforations that may have helped to guide subsequent participants in needle placement. Technical inconsistencies with assembling the blood pressure cuff and saline bag left to slight differences in measured pressures. Most importantly, this study does not demonstrate whether skill improvement on a simulator would in fact translate to the clinical setting.

Via a brief instructional course attainable at relatively little expense, the knowledge and performance of junior residents in a compartment syndrome simulation were significantly improved to a level comparable with senior residents. These improvements were maintained at one-month post-training. Further investigation may show whether simulation training of this type will lead to improved skill when treating patients.

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Appendix 1: Abbreviated course schedule.

CLASSROOM:

1. Pre-tests (anatomy, needle placement, pressure measurement)
2. Presentation review and discussion of anatomy
3. Verbal group quiz of anatomy
4. Presentation and discussion of core knowledge of compartment syndrome
5. Needle pressure measurement device introduction and technique

LAB:

6. Practice with needle pressure measurement device on pressurized saline bags
7. Practice location of needle with anatomic compartment syndrome simulation
8. Cadaver approaches to fasciotomies
9. Cadaver anatomy of lower limb/perform fasciotomies
10. Post-tests (anatomy, needle placement, pressure measurement)

Appendix 2: OSATS score sheet for pressure measurement module.

Preparation for Procedure	1 Did not organize equipment well. Has to stop procedure frequently to prepare equipment.	2	3 Equipment generally organized. Occasionally has to stop and prepare items.	4	5 All equipment neatly prepared and ready for use.
Time and Motion	1 Many unnecessary moves.	2	3 Efficient time/ motion, but some unnecessary moves.	4	5 Clear economy of movement and maximum efficiency.
Instrument Handling	1 Repeatedly makes tentative or awkward moves with instruments.	2	3 Competent use of instruments, but occasionally appeared stiff or awkward.	4	5 Fluid moves with instruments and no awkwardness.
Flow of Procedure	1 Frequently stopped procedure and seemed unsure of next moves.	2	3 Demonstrated some forward planning with reasonable progression of procedure.	4	5 Obviously planned course of procedure with effortless flow from one move to the next.
Knowledge of Procedure	1 Deficient knowledge.	2	3 Knew all important steps.	4	5 Demonstrated familiarity with all aspects of the procedure.
Overall Performance	1 Very Poor	2	3 Competent	4	5 Clearly Superior
Overall, should the candidate:	Pass / Fail				

Appendix 3: Face validity questionnaire for pressure measurement module.

Compartment syndrome pressure measurement simulation survey

Pick best answer for each question:

1. Is this a realistic simulation compare to actual compartment syndrome measurement.

Disagree strongly 1 2 3 4 5 Agree strongly

2. Does this simulator provide good tactile/force feedback (haptics) to the surgeon.

Disagree strongly 1 2 3 4 5 Agree strongly

3. This simulator is an effective tool for teaching correct compartment pressure measurement

Disagree strongly 1 2 3 4 5 Agree strongly

4. I will retain these skills and need no further practice with this simulator.

Disagree strongly 1 2 3 4 5 Agree strongly

5. This simulator should be available for learner practice throughout training.

Disagree strongly 1 2 3 4 5 Agree strongly

Anonymous Comments:

Appendix 4: Face validity questionnaire for needle placement module.

Compartment syndrome leg simulation survey

1. Please indicate your level of training

□ Orthopaedist □ Advanced trainee (Fellow, PGY3-5) □ Basic Trainee (PGY1-2)

2. □ Male □ Female

3. _____**Age**

4. Have you used this compartment leg simulator before? □ Yes □ No

Pick best answer for each question:

5. Is this a realistic simulation compare to actual compartment syndrome measurement.

Disagree strongly 1 2 3 4 5 Agree strongly

6. Does this simulator provide good tactile/force feedback (haptics) to the surgeon.

Disagree strongly 1 2 3 4 5 Agree strongly

7. This simulator is an effective tool for teaching correct anatomical needle placement

Disagree strongly 1 2 3 4 5 Agree strongly

8. I will retain these skills and need no further practice with this simulator.

Disagree strongly 1 2 3 4 5 Agree strongly

9. This simulator should be available for learner practice throughout training.

Disagree strongly 1 2 3 4 5 Agree strongly

Anonymous Comments:

THE SIGNIFICANCE OF A "CLOSE" MARGIN IN EXTREMITY SARCOMA: A SYSTEMATIC REVIEW

Ike Hasley, BS[1], Yubo Gao, PhD[2], Amy E. Blevins, MALS[3], Benjamin J. Miller, MD, MS[2]

ABSTRACT

Background: An important measure of successful sarcoma treatment is the surgical tumor margin, yet defining and reporting the tumor margin has remained a source of controversy. Our study sought to determine whether there is a need to be more specific in classifying a margin by distinguishing a 'close' margin, or if simply calling a margin positive or negative is sufficient.

Methods: We performed a comprehensive literature search in which all studies were reviewed independently by two separate reviewers. Studies eligible for inclusion and data analysis consisted of those that reported on at least ten patients with a primary sarcoma of the extremities who received limb-salvage or amputation surgery with a report of the final surgical margin as well as the histologic grade. Only studies that provided local recurrence outcomes with a minimum follow-up of two years were included.

Results: Our literature search and article exclusion process resulted in 22 articles that contained 498 patients for data analyses. We found that the Enneking classification system distinguishes between intralesional, marginal, and wide/radical margins, and that a close margin behaves closer to a positive margin than a negative margin. When all tumors were analyzed, a marginal margin gave a recurrence rate of 50.48% compared to an intralesional margin recurrence rate of 75.76% and a wide/radical margin of 7.22%. A marginal margin set to a positive margin gave the highest sensitivity compared to comparing marginal margins to wide and intralesional margins alone. This was also observed when tumors were stratified into high-grade osteosarcomas treated with chemotherapy. In addition, we found that chemotherapy dramatically reduced local recurrence rates in osteosarcoma.

Conclusions: Our literature search and data analysis showed that the Enneking classification system was able to give more information on local recurrence compared to a simple dichotomous system, and therefore may be considered a more successful predictor of treatment outcomes. As a result, this investigation may lead a suggestion of a practice-changing proposal of how surgical margins in sarcoma should be reported universally amongst multiple disciplines and institutions.

Level of Evidence: II

INTRODUCTION

Sarcomas are relatively rare tumors of mesenchymal origin that comprise approximately 2% of all adult malignancies and 15% of pediatric cancers[1]. The majority of sarcomas originate from soft tissue while the remaining are from bone. They can occur at nearly any anatomic site, with the extremities and trunk being the most common[2]. Soft tissue sarcomas have an overall mortality rate of 30 to 50%[3]. Sarcomas encompass a wide variety of histologic subtypes and grades, which causes an inherent complexity in the way these tumors behave and are treated. Local recurrence is associated with a poor prognosis[4,5], and is influenced by a variety of factors, including, but not limited to, tumor histologic subtype, grade, stage, anatomic location, size, adjuvant treatments or margin status[1,3,6].

Due to the complex nature of sarcomas, they require a multidisciplinary treatment team consisting of pathologists, radiologists, radiation oncologists, medical oncologists, and specialized surgeons[7,8]. Historically, sarcomas of the extremity were treated with amputation[4], in which the entire limb or compartment was removed in order to decrease the risk of metastases and local recurrence. However, with the development and advancement of CT, MRI, radiation therapy, and chemotherapy, limb and functional preservation became feasible[4,8]. The current standard approach for treating sarcoma of the extremities is surgical resection, either by amputation or prefer-

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ably limb-sparing surgery, with or without chemotherapy and/or radiation[1,7,9,10]. The major goals of limb-sparing surgery for sarcoma include removing the entire tumor while preserving limb function when possible[10]. From a surgical perspective, the surgical margin of the tumor, also called the tumor margin or simply "the margin", is an essential focus of this process[3].

Following sarcoma excision surgery, the tumor margin is classified in various ways, typically as some iteration of positive or negative. The simplest systems use a dichotomous terminology in which the presence or non- presence of tumor cells at or near an inked margin of tissue sample indicates positive or negative margins. Other systems are more complex, such as the Enneking system, a common classification system used in extremity sarcoma[8,10], which classifies margins as the following[2,10,11]:

1. Intralesional – resection plane goes through the tumor, resulting in parts of the tumor being left behind
2. Marginal – resection plane goes through a surrounding area called the pseudo capsule, or "reactive zone"
3. Wide – resection plane goes through normal tissue and therefore the tumor and surrounding pseudo capsule are removed entirely
4. Radical – entire anatomic compartment is removed

In the Enneking system, intralesional and marginal excisions are often considered positive surgical margins, while wide and radical excisions are considered negative[10,11,12]. Multiple studies have established that obtaining negative margins leads to improved local recurrence rates, while positive margins increase local recurrence rates[1,4,5,7,10]. Therefore, the pathologic assessment of margin status is considered the standard for determining the quality of local treatment[3]. Yet despite the recognized importance of surgical margins, reporting margins remains controversial[3,5,7,10].

Currently, at least six different margin classification systems exist, and there is not a universally accepted method of margin reporting[8]. In addition to the various reporting systems used for margins, discrepancies exist even within classification systems. For instance, some authors consider a one to two centimeter margin of normal tissue around the tumor as "generally accepted" as standard practice, but also state that a margin less than one centimeter is acceptable when trying to preserve a critical neurovascular structure[7]. Others classify margins as positive or negative based on whether or not tumors are within one millimeter of an inked surface[3]. Furthermore, other authors recognize that some systems may consider a marginal margin to correspond to a negative margin instead of a positive margin as previously defined by Enneking[3,13]. Not only does this confound analysis of oncologic results, but also limits comparison between investigative reports.

There is a large amount of literature addressing sarcoma excision and local recurrence, although the margin classifications used varies widely. Yet lack of congruity between and within margin classification systems remains an area of concern. It remains unclear whether one margin system, such as the Enneking system, is superior to another, such as a dichotomous system. Therefore, the question arises on whether there is a need to be more specific in classifying a margin by distinguishing a 'close' margin, or if simply calling a margin positive versus negative is sufficient. This led us to the pursuit of investigating (1) whether designation of marginal margin is necessary, (2) if it behaves closer to a positive or negative margin, and (3) whether marginal margins behave differently with different histologic subtypes or adjuvant treatments.

METHODS

The aim of our study was to perform a systematic review of literature to investigate the association between sarcoma excision margins and local recurrence. We developed a comprehensive literature search strategy of the following databases: Ovid MEDLINE (1946 to present), CINAHL, Cochrane Library, Web of Science, Embase, and ClinicalTrials.gov. The initial search was performed in July 2015, with follow-up searches performed in March 2016 and April 2017 to identify newly published articles. The search strategy and search were performed under guidance of a clinical education librarian (AB). Terms used in the search were those related to sarcoma, limb salvage, amputation, surgical margins, and recurrence. A detailed report of the specific literature search is available upon request. All studies generated from the initial search were reviewed independently by two separate reviewers (BJM and IH).

Studies eligible for inclusion and data analysis consisted of those that contained at least ten patients with the following criteria:

- Primary non-metastatic sarcoma of the extremities who received limb salvage or amputation surgery
- Report of final surgical margin via Enneking system
- Histologic type and grade
- Specification on whether or not chemotherapy and/or radiation therapy was given
- Recurrence outcomes
- Minimum follow-up of two years

Lastly, we determined that to successfully perform analyses on these papers, they must provide the above selected criteria for each individual patient in their re-

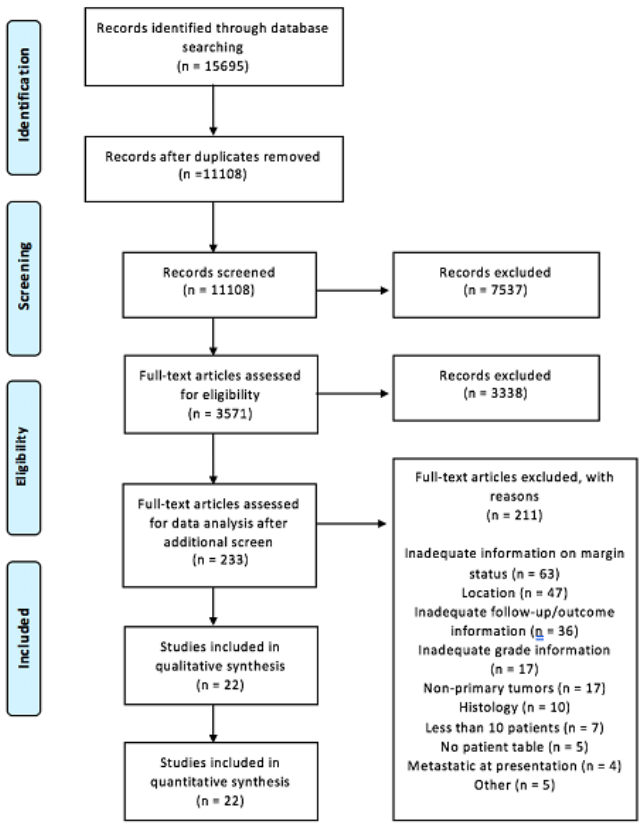

Figure 1: Flowsheet of articles included in analysis

spective series so that we could enter information into a cumulative data table. This often came in the form of studies providing a patient table of the subjects in their series. Therefore, if each patient in a series did not have information on the above inclusion criteria, that patient would be excluded from our data analyses. In this way, we could specifically trace each patient in our collective series. If these criteria were not met, the study was excluded.

Data analysis was performed using SAS software, version 9.4 (SAS Institute, Inc. of Cary, North Carolina). Between group comparisons of categorical variables were analyzed using chi-square or Fisher exact test, as appropriate.

The total number of subjects included in the study were viewed with respect to the surgical margin they were assigned at initial operation and were therefore divided into the following groups: intralesional, marginal, and wide/radical. In order to determine whether the Enneking marginal margin behaved differently than a dichotomous system, additional margin classification systems were created based off the original margin data. This consisted of a dichotomous system in which a marginal margin was converted to a positive margin (along with intralesional), as well as a dichotomous system in which a marginal margin was converted to a negative margin (along with wide/radical). This provided the following three margin systems to compare:

1. Enneking – intralesional, marginal, and wide/radical
2. Dichotomous (marginal = positive) – positive (intralesional and marginal), and negative (wide/radical)
3. Dichotomous (marginal = negative) – positive (intralesional), and negative (marginal and wide/radical)

The chi-square test was used to assess the association between margins and local recurrence.

Lastly, in an attempt to identify confounding variables, effect modifiers, and other variables/relationships of interest, subjects were further classified based on histology and adjuvant treatment. Further classification consisted of the following groups:

- High-grade osteosarcoma treated with chemotherapy
- High-grade osteosarcoma treated without chemotherapy
- Other bone tumors
- High-grade soft tissue sarcoma treated with perioperative radiation therapy
- High-grade soft tissue sarcoma treated without radiation therapy
- Low-grade soft tissue sarcoma

These groups were assigned margins and analyzed in the same manner as described above.

RESULTS

The initial literature search generated 15,695 articles. After removing duplicates, there were 11,108 articles available for title and abstract review. Elimination of 7,537 articles based on title and abstract produced 3,571 remaining for full text analysis. Of these, 233 articles appeared to be eligible for data analysis. After further consideration with a stricter inclusion criteria applied, 211 articles were eliminated, and 22 articles remained in the final pool[17-38]. These 22 articles contained 498 patients in which data analyses were performed. This process of study selection is summarized in the flowchart (Figure 1). Of note, the most common reason for elimination of the last 211 articles was inadequate information on margin status (n = 62).

The overall local recurrence rate in our series was 20.88% (Table 1). Patients with bone tumors had a local recurrence rate of 17.7%, while those with soft tissue sarcomas had a local recurrence rate of 28.1%. Chi-square analysis showed that the Enneking classification system distinguished between intralesional, marginal, and wide/radical margins (Table 2A). When all tumors were analyzed, a marginal margin gave a recurrence rate of

Table I. Margins and local recurrence rates in Enneking classification system

	# Total	# LR	% LR Rate	p
All tumors				
Intralesional	33	25	75.76%	<0.001
Marginal	105	53	50.48%	
Wide/Radical	360	26	7.22%	
Total	498	104	20.88%	
HG OS w/ chemo				
Intralesional	0	0	0.00%	1
Marginal	2	0	0.00%	
Wide/Radical	53	2	3.77%	
Total	55	2	3.64%	
HG OS w/o chemo				
Intralesional	10	9	90.00%	<0.001
Marginal	12	9	75.00%	
Wide/Radical	53	2	3.77%	
Total	75	20	26.67%	
Other bone				
Intralesional	18	15	83.33%	<0.001
Marginal	37	15	40.54%	
Wide/Radical	160	9	5.63%	
Total	215	39	18.14%	
HG STS w/ rad				
Intralesional	2	0	0.00%	1
Marginal	10	3	30.00%	
Wide/Radical	18	6	33.33%	
Total	30	9	30.00%	
HG STS w/o rad				
Intralesional	2	1	50.00%	<0.001
Marginal	33	24	72.73%	
Wide/Radical	65	6	9.23%	
Total	100	31	31.00%	
LG STS				
Intralesional	1	0	0.00%	1
Marginal	11	2	18.18%	
Wide/Radical	11	1	9.09%	
Total	23	3	13.04%	

50.48%, a statistically significant difference compared to an intralesional margin recurrence rate of 75.76% and a wide/radical margin of 7.22% (p-value <0.001) (Table 1).

We discovered that a close margin behaves closer to a positive margin than a negative margin when looking at all tumors historically as a group. This is apparent in that the marginal recurrence rate itself (50.48%) is closer to the intralesional recurrence rate (75.76%) compared to the wide/radical recurrence rate (7.22%) (Table 1). This is also evident when comparing local recurrence rates of the Enneking system to the dichotomous (marginal = positive) system, as converting a marginal margin to a positive margin is associated with a local recurrence rate of 56.52% (Table 2A). However, accuracy is substantially lower when comparing marginal margins to intralesional margins, possibly reflecting the difficulty in distinguishing between the two and suggesting a continued need to distinguish a "close" margin (Table 2B).

While comparing all margin classification systems with all tumors analyzed, specificity was consistently higher than sensitivity, with an average specificity of 89.0%, compared to an average sensitivity of 49.5% (Table 2B). This may suggest that margins are best when used to identify patients at high risk of recurrence with a low incidence of false positives, as opposed to identifying patients at low risk of recurrence given a larger number of false negatives.

We found that chemotherapy dramatically reduced local recurrence rates in osteosarcoma (local recurrence rate of 3.64% compared to 26.67%), although the difference in recurrence rates within the osteosarcoma group treated with chemotherapy were not significantly significant. There were also substantially fewer intralesional and marginal margins in the chemotherapy group (2 out of 55 total (3.6% positive margin rate)) compared to the group without chemotherapy (22 out of 75 total (29.3% positive margin rate)) (Table 1).

Lastly, although radiation does slightly diminish local recurrence rates in high grade soft tissue sarcomas, there is still a substantial local recurrence rate even with radiation therapy (30% in those receiving radiation therapy, 31% in those who did not). Unlike in osteosarcoma patients where chemotherapy was associated with considerably reduced rates of local recurrence and positive margins, this effect was not seen with radiation in high grade soft tissue sarcomas. Of the 30 patients with high grade soft tissue sarcoma treated with radiation, 12 had positive margins (40% positive margin rate), while 35 out of 100 patients with high grade soft tissue sarcoma without radiation treatment had positive margins (35% positive margin rate).

DISCUSSION

Our literature search and data analysis suggest that the Enneking margin classification system provides more information on the association between margins and local recurrence rates compared to a simple dichotomous system, and therefore may be considered a more successful predictor of treatment outcomes. When looking at the entire cohort, patients with marginal margins

Table IIA. Comparing margin classification systems in all tumors

Margin classification	Margins	# Total	# LR	% LR Rate	p
Enneking	Intralesional	33	25	75.76%	<0.001
	Marginal	105	53	50.48%	
	Wide/Radical	360	26	7.22%	
Dichotomous (marginal = positive)	Positive	138	78	56.52%	<0.001
	Negative	360	26	7.22%	
Dichotomous (marginal = negative)	Positive	33	25	75.76%	<0.001
	Negative	465	79	16.99%	

Table IIB. Sensitivity, specificity, PPV, NPV, and accuracy in all tumors

	Sensitivity	Specificity	PPV	NPV	Accuracy
Enneking marginal vs wide	0.671	0.865	0.505	0.928	0.832
Enneking marginal vs intralesional	0.321	0.867	0.758	0.495	0.558
Dichotomous (marginal=positive)	0.750	0.848	0.565	0.928	0.827
Dichotomous (marginal=negative)	0.240	0.980	0.758	0.830	0.825

had a recurrence rate of 50.48% compared to a wide/radical margin of 7.22%. The differences in these rates are consistent with those seen other studies[10]. He et al performed a systematic review and meta-analysis of osteosarcoma of the pelvis and extremities, and report a local recurrence rate of 30.5% in patients with marginal margins and 6.0% in those with wide margins. They relate that with the development of chemotherapy, amputation is being decreasingly used for osteosarcoma treatment, causing a reduction in the number of radical margins. Meanwhile, intralesional resection carries a poor prognosis and is hence little used in osteosarcoma treatment. With a smaller number of radical and intralesional margins being used, the difference between a positive and negative margin relies heavily on the difference between a wide and marginal margin and is therefore an increasingly important detail to distinguish. He et al concluded that the risk of local recurrence in osteosarcoma of the pelvis or extremity are significantly increased with marginal margin compared to wide margins[10].

When all subjects were analyzed, local recurrence rate in this series was 20.88%. Soft tissue sarcomas were associated with a local recurrence rate of 28.1%, while bone tumors were associated with a local recurrence rate of 17.7%. These rates may be considered high, as the local recurrence rates for soft issue sarcomas given in most modern series are approximately 15-20%[14,15], while osteosarcoma local recurrence rates are estimated at roughly 10-15%[6,16].

One limitation of this study is the small sample size, which was especially apparent when stratifying into groups such as high-grade osteosarcoma treated with chemotherapy, high grade soft tissue sarcoma treated with radiation therapy, and low grade soft tissue sarcomas. The small number of patients in these groups made it difficult to make statistically significant conclusions due to high p-values and low statistical power. Casting a 'larger net' and including more patients in the study could have prevented this limitation, but doing so may have led to other complications such as introducing more confounding variables. For example, a greater number of histologic subtypes, such as Ewing sarcoma patients, were initially included, but later excluded due to the unique biological characteristics of this type of tumor and the inherent complications that this causes when comparing to other bone or soft tissue tumors. Considering another example, being more inclusive in regard to anatomic locations, such as by including tumors of the pelvis, retroperitoneum, rib, or spine would have undeniably increased the statistical power of this study. Yet pelvic tumors alone may result in a considerably higher local recurrence rate than those in the extremity[10]. We did not stratify by tumor size, patient age, type of chemotherapy, radiation dose, or depth of tumor, many of which are known variables that contribute to local recurrence rates[1,3,6]. Due to these and other factors that contribute to the inherent complexities of sarcoma management, a great deal of thought and discussion went into defining the inclusion and exclusion criteria, as there are undoubtedly advantages and pitfalls to both increasing or decreasing the criteria's inclusiveness. The tradeoff between external validity, generalizability, and

internal validity was greatly considered with respect to the way these tumors should be included in and grouped within the study. Should we sacrifice number of patients and power of study to get rid of various possible confounding variables? Our ultimate decision was to do so, and this was the reasoning behind an additional layer of 'screening' that occurred which is not always performed in systematic reviews. Finally, histologic classification of margins is inherently subjective and left to the interpretation and experience of the pathologist.

Kandel et al performed a similar investigation and touched upon some of these issues regarding the evaluation of sarcoma margins. In a systematic review of thirty-three papers focusing on the handling of margins in soft tissue sarcoma of the extremities, they conclude by suggesting that a 'close' margin be considered less than one centimeter, and that radiation therapy should be considered in the circumstance of a close or positive margin. They also recognize the limitations of heterogeneity and issues of confounding that inevitably arise when undertaking investigations such as these. They state, "studies are confounded by differences in treatments received: some patients received preoperative, and others postoperative, RT or chemotherapy, or both" (page e252). In their particular review, many studies were excluded because they did not stratify results by type of sarcoma, such as truncal and extremity sarcomas being grouped together. They relate this by saying, "when the clinical groupings are not uniform, it is difficult to interpret results because it is impossible to tell whether a treatment is effective or whether some combination of the location, type, size, or grade of the sarcoma is influencing the results" (page e252). Although our study accounts for many of these variables, it is simply too difficult at this point in time to account for them all, and this may be a focus of future studies.

We did not see an overall improvement with local recurrence rates in those treated with radiation therapy compared to those treated without. However, this may simply be a reflection of a type of selection bias, as a 'riskier' tumor may receive radiation treatment, whereas a 'safer' tumor may not. This may be supported by our finding that radiation did not improve the rates of wide margins. Another possible explanation is that surgeons could be relying on radiation therapy too much. If negative margins are not able to be obtained via surgery alone in anticipation of relying on radiation therapy to achieve clear margins, then this may explain the findings seen in this series, causing a sense of 'false confidence' in the operating room. Of note, the local recurrence of high-grade soft tissue sarcoma treated with marginal margins and radiation (30%), while substantial, is improved from marginal margins without radiation (73%). Again, the lack of details known about how margins are handled at different institutions and geographic areas, as well as the discrepancies seen across studies, do not allow for the explanation of this at this particular moment in time.

In conclusion, there is strong evidence to support that wide margins provide better local recurrence outcomes than intralesional or marginal margins[1,4,5,7,10]. However, these studies are often not homogenous in terms of types of patients, treatments, or margin reporting systems, and it is difficult to determine exactly what the effect of margins are on outcomes. In this series, a marginal margin was shown to provide more information as a predictor of local recurrence compared to a positive or negative margin alone, suggesting that the Enneking marginal classification system provides more information than a dichotomous margin system. Marginal margins without adjuvant treatment behave more closely to positive margins than negative margins, and should therefore be treated as such. The need for a universal margin classification system remains, and will undoubtedly be the focus of future studies.

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WHAT ARE THE RESULTS OF SURGICAL TREATMENT OF POSTOPERATIVE WOUND COMPLICATIONS IN SOFT TISSUE SARCOMA? A RETROSPECTIVE, MULTI-CENTER CASE SERIES

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ABSTRACT

Background: Non-oncologic wound complications are common following resection of soft tissue sarcomas and factors predisposing to the development of complications have been extensively studied. To our knowledge, the methods and results of surgical treatment of these complications have not been reported. The purposes of this study were to 1) identify time to recognition, treatment employed, and eventual outcome of complications 2) investigate risk factors that may predispose patients to failure in management of complications following resection of soft tissue sarcomas.

Methods: This was a multi-institutional, retrospective case series of patients treated with a primary closure of a limb sparing resection of a soft tissue sarcoma of the pelvis or extremity who developed a non-oncologic wound complication requiring operative intervention. The primary outcomes were a healed wound at the end of treatment and the total number of procedures required to address the complication.

Results: There were 61 patients from 11 institutions included in the analysis. The median time from surgery to the initial recognition of a complication was 22 days (range 0-173 days), with 51 patients (84%) presenting in the first six weeks postoperatively. The definitive procedures included primary closure (44), healing by secondary intention (9), muscle flap (6), and skin graft (2). No patient was treated with an amputation. Six patients (10%) had a wound requiring continued dressing changes. 12 patients (20%) required at least one (range 1-4) additional unplanned procedure. In a bivariate analysis, we found patients with an infection were at increased risk of requiring multiple unplanned procedures (p=0.024).

Conclusion: Limb sparing resection of a soft tissue sarcoma is known to be at high risk of postoperative wound complications. We found that complications uncommonly present greater than six weeks after initial treatment and surgical management predictably results in retention of the affected limb and a healed wound in those requiring operative treatment.

Key Words: Soft tissue sarcoma, postoperative complications/etiology, postoperative complications/therapy, wound healing

Level of Evidence: 4 – Case Series

INTRODUCTION

There is little debate that the optimal treatment of soft tissue sarcoma includes complete surgical resection of the primary tumor. These procedures are associated with a high rate of non-oncologic wound complications such as infection, wound dehiscence, necrosis, hematoma, and seroma, and have been estimated at an incidence of 16-53%.[1-4] The increased risk of wound complications is due to many factors specific to the patient (age, medical comorbidities, obesity, smoking), tumor (size, location), and treatment (adjuvant radiation).[2,5-7] Although the risk factors for postoperative wound complications have been extensively studied and are well known, the methods and results of surgical treatment of these complications, to our knowledge, have not been reported.

A clear understanding of the results of treatment following the development of a postoperative wound complication is important to practitioners and patients alike. For surgeons, guidance regarding the types, expected outcomes, and success rates of interventions can help with decision-making, procedural choices, and patient counseling. For patients, postoperative wound complications come at a time that is physically and emotionally difficult, as they have all recently experienced a cancer

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diagnosis and are currently recovering from a significant surgical procedure. Accurately defining the goals of treatment of wound complications may help alleviate anxiety and disappointment by providing appropriate expectations of the remaining clinical course and ultimate result.

In order to further define the results of surgical management of wound complications in soft tissue sarcoma, we sought to 1) identify the time to complication, treatment employed, and eventual outcome of wound complications and 2) investigate risk factors that may predispose patients to failure in complication management.

MATERIALS AND METHODS

This was a multi-institutional, retrospective case series of patient data from December 1, 2009 to November 30, 2014. Thirteen fellowship-trained orthopaedic oncologists at 11 institutions submitted de-identified patient data. The institutions contributed a median of three patients (range 1- 18 patients). Patients were followed until death, clear documentation of a healed wound, or for at least six months after the primary procedure.

We included all patients treated with a primary closure of a limb sparing resection of a soft tissue sarcoma of the pelvis or extremity who developed a non-oncologic wound complication requiring operative intervention. Of note, we were interested only in patients who experienced a wound complication necessitating surgical intervention; we did not collect any patients who did not experience a wound complication, or those who had a wound complication but were treated non-operatively. We excluded patients who were treated with a soft tissue reconstruction (free flap, fasciocutaneous rotational flap, or skin graft) at the time of tumor resection, infections present at time of resection, use of prosthesis or allograft, and atypical lipomatous tumors. Rotational muscle flaps to fill a defect were permitted provided that the wound was closed primarily.

Patients were identified, and patient data was entered, by the participating institutions into a de-identified Research Electronic Data Capture (REDCap) database managed by the primary research team. The primary research team commonly would clarify discrepancies or incomplete entries with the site investigators to ensure appropriate inclusion criteria and recording of outcomes, but did not have the ability to confirm the exact details of patient or treatment data through examination of medical records.

We recorded patient (age, sex, body mass index, Age-Adjusted Charlson Comorbidity Index Score), tumor (histology, size, grade, location, depth, primary or recurrent), and treatment (chemotherapy, preoperative radiation) factors. The type of complication was defined as an infection (a wound with gross purulence, positive cultures, or labeled as an infection by the treating surgeon), wound dehiscence/necrosis (a wound that was open, draining, necrotic, or non-healing and thought to be attributed to underlying aseptic tissue compromise), or a hematoma/seroma (a wound with a large fluid collection and/or drainage not attributable to underlying infection or tissue compromise). Any wound labeled as an infection by the treating surgeon, regardless of the presence of necrosis or hematoma/seroma, was categorized as such; any wound without concern for infection but with a wound dehiscence or necrosis was labeled as "dehiscence/necrosis." Only wounds without underlying infection or tissue compromise were categorized as "seroma/hematoma." The primary outcomes were 1) a healed wound at the end of treatment and 2) the total number of additional unplanned procedures required to address the complication. Secondary outcomes included the time from the initial tumor resection to the recognition of the wound complication and the time from recognition of the complication to the surgical intervention to address it.

Contributing centers recorded the type of procedure utilized to address the complication, specifically a repeat primary closure, debridement with healing by secondary intention, skin graft, muscle flap, or amputation. Presence of a healed wound was entrusted to the subjective judgment of the treating surgeon, but was defined as an epithelialized surgical incision or tumor bed not requiring dressing changes. In addition, each center recorded the number of procedures needed to finally address the complication. We queried specifically if the treatment included a planned multiple-stage debridement, which was analyzed as if it were only one procedure. This was to clearly distinguish between an "unplanned" return to the operating room to address the complication. The follow-up regimens were not standardized and were at the discretion of the treating surgeon. We also recorded the use of anticoagulation, antibiotics, and surgical drains in the perioperative and postoperative time periods. However, due to extreme variability in the method and duration of these interventions, and the small apparent effect they had on the success of complication management, we decided not to include them in the final analysis.

We performed a descriptive analysis to report the time to surgical treatment, modalities of surgical treatment, and final wound status. One-tailed bivariate methods (chi-square and Fisher's exact testing) were used to investigate clinical associations that resulted in failure of wound healing or requirement of multiple unplanned procedures. Calculations were performed with SAS ® software, version 9.4 (SAS Institute, Inc. of Cary, North Carolina).

There were 61 patients from 11 institutions included in the analysis. The median age of the cohort was 67 years old (range 14-96 years old) with a median length of follow-up of 13.3 months (range 0.4-65.8 months) from the time of the final procedure, and 14.7 months (1.3-66.5 months) from the time of tumor removal. 31 patients were male and 30 were female. The mean BMI was 30.9 (standard deviation 8.9) with a mean Age Adjusted Charlson Comorbidity of 5.2 (standard deviation 2.8). Age adjusting was done by adding one point for each decade over 50 years old.[8] The median tumor size was nine centimeters (range 1.3-32 centimeters). 50 tumors were deep and 11 were superficial. Patients presented with 54 primary and seven recurrent tumors.

Tumors were located in the thigh (41), leg (4), pelvis (4), hip (4), knee (4), foot (1), chest/axilla (1), shoulder (1) and arm (1). Histologic diagnoses included undifferentiated pleomorphic sarcoma (25), liposarcoma (11), leiomyosarcoma (6), myxofibrosarcoma (6), malignant peripheral nerve sheath tumor (3), synovial sarcoma (3), chondrosarcoma (2), angiosarcoma (1), epithelioid sarcoma (1), fibrosarcoma (1), fibromyxoid sarcoma (1), and rhabdomyosarcoma (1). 39 were high-grade, 15 were intermediate-grade, and seven were low-grade. 32 patients were treated with preoperative radiation and 11 were treated with perioperative chemotherapy.

RESULTS

The median time from surgery to the initial recognition of a complication was 22 days (range 0- 173 days), with 51 patients (84%) presenting in the first six weeks. The median time from the recognition of a complication to surgery was five days (range 0-219 days). The complications treated included infection (32), wound dehiscence/necrosis (23), and seroma/hematoma (6).

The definitive procedures included primary closure (44), debridement with healing by secondary intention (9), muscle flap (6), and skin graft (2). No patient was treated with an amputation to manage the wound complication. Six patients (10%) had a non-healed wound requiring continued dressing changes after the treatment of dehiscence/necrosis (3) or infection (3). In these patients, the median time of follow-up from the time of the final procedure was 5.8 months (range 0.9-39.5 months). Four of these patients died prior to wound healing, two patients are currently alive 6.4 and 39.5 months after the last procedure. 12 patients (20%) required at least one (median 2 [range 1-4]) additional unplanned procedure to address an infection (10) or hematoma/seroma (2). Eight patients had a planned two-stage procedure (six for infection and two for dehiscence/necrosis), all but one of whose wounds healed without further complication.

In a bivariate analysis, we found patients with an infection were at increased risk of requiring multiple unplanned procedures (p=0.024). No other factors, including patient age, delays of treatment, type of complication, use of preoperative radiation, tumor location, or tumor size appeared to have any meaningful influence on wound healing or unplanned procedures following the development of a wound complication (Table I).

DISCUSSION

Limb sparing resection of a soft tissue sarcoma is known to be a procedure with a high risk of postoperative wound complications. Although there are several studies illustrating the incidence and risk factors for postoperative wound complications, we are unaware of any investigation that identifies the surgical treatment and eventual outcome of these complications. Our results showed that the majority of complications arise within six weeks of resection and were successfully treated with a single-stage debridement and primary closure. In patients with an infection, there was an increased likelihood of requiring more than one procedure to address the complication.

This study had a number of limitations that warrant further discussion. First, our inclusion criteria limited the investigation to patients that required operative intervention to address a complication. Therefore, we do not have any knowledge of the outcome or successful treatment of complications that were able to be treated non-operatively. There were also no standard criteria to objectively determine which complications required an operation, and this decision was left to each individual surgeon. This resulted in some variability in patient selection and introduced a source of bias that is not easily mitigated. Second, heterogeneity in perioperative and postoperative decision-making by the individual practitioner, including the type of procedure, use of antibiotics, thromboembolic prophylaxis, negative pressure wound therapy, and drains may have led to variation in the incidence of wound complications or the successful treatment of those complications that we were not able to detect. Finally, the research team did not have access to the complete medical records of each patient, and the accuracy of data collection was dependent on the investigators at each site individually. In a retrospective, multi-institutional project dependent on the tendencies of individual practitioners, there is assumed to be some heterogeneity of treatment decisions and follow-up protocols, but it does not detract from the summary of our overall findings.

Postoperative wound complications are adverse events common to all surgical procedures. Soft tissue sarcoma resection is known to have a substantially higher risk of wound problems than many routine elective procedures, likely resulting from unique challenges such as large surgical wounds, post-resection tissue voids, thin skin flaps,

Table I. Risk factors for multiple unplanned procedures an non-healed wounds

Risk factor	One or multiple planned procedures	Multiple unplanned procedures	p value	Healed	Not healed	p value
Patient age						
≥65	28	5	0.335	28	5	0.205
<65	21	7		27	1	
BMI						
≥30	23	4	0.522	25	2	0.685
<30	26	8		30	4	
Location						
Proximal thigh	11	4	0.467	12	3	0.152
Other	38	8		43	3	
Size						
≥10 cm	24	5	0.649	25	4	0.411
<10 cm	25	7		30	2	
Depth						
Deep	39	11	0.438	46	4	0.294
Superficial	10	1		9	2	
Radiation						
Preop	27	6	0.751	29	4	0.678
Not preop	22	6		26	2	
Delay in treatment						
>2 weeks	11	2	1.000	12	1	1.000
≤2 weeks	38	10		43	5	
Cause						
Infection	22	10	0.004	29	3	0.836
Dehiscence	23	0		20	3	
Seroma	4	2		6	0	

and use of adjuvant radiation.[9-10] An estimated 16-53% [1-4] of soft tissue sarcoma resections develop complications that require some form of additional management, but no report of which we are aware has discussed the results of subsequent surgical intervention. In our series, the postoperative complications consisted of infection (52%, 32/61), dehiscence/necrosis (38%, 23/61), and hematoma/seroma (10%, 6/61). We found that 84% of the complications arose within six weeks of surgery. All patients in this cohort retained the affected extremity, and the majority of patients (90%) had a healed wound at the time of death or last follow-up, although 20% required at least one additional unplanned procedure to effectively address the complication. Taken together, this information provides assistance to the treating physician when counseling patients by identifying the common etiologies, timing, and eventual outcome of wound complications.

The risk factors for developing a complication after soft tissue sarcoma resection have been previously described, and include older patient age,[3] large tumor size,[11] tumors deep to the muscle fascia,[1] location in the lower extremity,[12] and preoperative radiation.[13] Once a wound complication has developed and the treating physician has deemed it necessary to return to the operating room, we did not find definitive evidence that these same factors influenced the ability to obtain a healed wound in a single procedure. Furthermore, it did not appear that delays in management after the recognition of the complication increased the likelihood of multiple surgical procedures or a non-healed wound, which is consistent with prior research.[14] This finding suggests

that an initial attempt at nonsurgical management does not negatively alter the subsequent surgical course or eventual outcome.

We did find an association between infections and multiple unplanned surgical procedures, (10/32 patients with an infection required multiple unplanned procedures compared to 2/29 aseptic complications, p = 0.024). While aseptic complications were often successfully managed in a single intervention, infections pose an additional challenge by requiring eradication of a pathologic organism in addition to obtaining healing in compromised tissue. Infections in sarcoma patients specifically are difficult clinical scenarios, as there is often a substantial amount of necrosis from radiation or ischemia that requires extensive debridement. There were six patients with an infection who were treated with a planned two-stage (5) or three-stage (1) procedure. Although we do not know the details of the presentation, or objective measures used for decision-making, they were cases in which the treating surgeon felt there was extensive necrosis or the infection was significant enough that it was unlikely to be successfully managed in a single operation. Of the six patients with an infection treated with a planned multiple-stage debridement and closure, 5/6 (83%) went on to heal without further incident. Given the high rate of unplanned reoperations in patients with an infection treated with an attempted single-stage debridement (10/26 [38%]), a planned two-stage debridement may be an effective means to expedite healing and minimize that chances for failure in this scenario.

CONCLUSION

In conclusion, postoperative wound complications in soft tissue sarcoma resections, while common, are always an unfortunate event to patients and practitioners. Our findings detail the types of complications, timing of presentation, surgical modalities employed, and eventual outcome after surgical management. We believe this knowledge will enhance the ability of the treating surgeon to counsel patients both prior to surgery and after a complication develops. Our data demonstrate that a wound complication uncommonly presents greater than six weeks after treatment, and that assertive surgical management predictably results in limb retention and a healed wound in the substantial majority of patients needing operative treatment. Surgeons should be wary of postoperative infections, and may consider a planned multiple-stage approach to surgical management given the high rate of failure with an attempted single-stage debridement. Future research should focus on minimizing the incidence of wound complications. Strategies such as predicting wounds at risk,[15] use of negative-pressure wound therapy,[16] or selective closure with free tissue transfer are all additional avenues that may diminish the incidence of wound complications after resection.

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RADIOLOGIC EVALUATION OF THE DISTAL RADIUS INDICES IN EARLY AND LATE CHILDHOOD

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ABSTRACT

The osseous anatomy of the distal radius is well documented in adults. Three commonly discussed variables are the volar tilt (also known as palmar tilt or palmar inclination), radial inclination, and radial height. These values are not well defined in the growing skeleton. We studied the radiographic measurements of normal distal radius osseous anatomy in children and identified how these values change with age. 372 patients (215 males and 157 females) between the ages of 8 and 16 were included in the study. Normal values of volar tilt, radial inclination, and radial epiphyseal height were defined for each age group. Regression analysis showed that volar tilt increased significantly by increase in age (P <0.001). Radial inclination and radial epiphyseal height both showed significant increase with increase in age (P<0.001). This is the first study to define these radiographic values in children and their change with age.

Keywords: volar tilt, distal radius, radial inclination, epiphysis

INTRODUCTION

The osseous anatomy of the distal radius is well documented in adults. This knowledge has helped us guide clinical treatment of pathologies involving the wrist and distal radius. Three commonly discussed variables are the volar tilt (also known as palmar tilt or palmar inclination), radial inclination, and radial height. These values are not well defined in the growing skeleton. Previous radiographic studies using pediatric patients have identified the distal radius growth plate-shaft angle as the angle between a line drawn down the long axis of the radius and a line drawn across the distal radius physis, with a normal of 90 degrees on the AP and lateral radiographs[1-4]. To our knowledge, there has been no study identifying the age based values of volar tilt, radial inclination, and radial height in the pediatric population. We studied the radiographic measurements of normal distal radius osseous anatomy in children and identified how these values change with age.

METHODS

We performed a retrospective review of wrist radiographs performed at our center from 2009 to 2013. We identified all patients ages 8-16 who had wrist radiographs taken during that time period. We chose our cut off age of 16 because by that age both males and females will presumably have reached skeletal maturity. We systematically reviewed every radiograph and excluded all patients who had any evidence of trauma (acute or chronic) to the distal radius. The PA and lateral radiographs were used to obtain our measurements. Only true lateral radiographs were included in the study which was defined as having the ulnar head completely superimposed behind the radius[2-4]. Johnson showed that on a conventional lateral wrist radiograph, a 5 degree rotational change produces a 1.6 degree change in volar tilt, where an increase in supination causes an increase in volar tilt[5]. The volar tilt was measured on the lateral view. It was defined as the angle between a line drawn perpendicular to the long axis of the radius and a tangent line drawn along the slope of the dorsal-to-palmar surface of the radius. We chose to use the Cobb angle technique to get the volar tilt. A normal adult volar tilt angle has been identified as 10-25 degrees[6-8]. An example of volar tilt measurement is shown in figure 1. Radial

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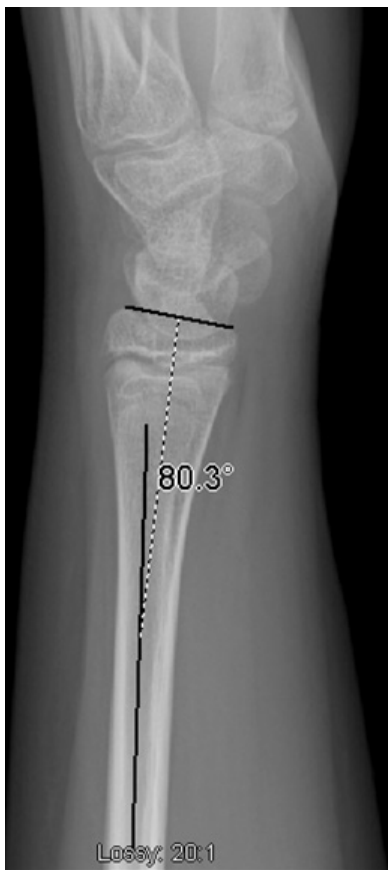

Figure 1: Measurement of volar tilt

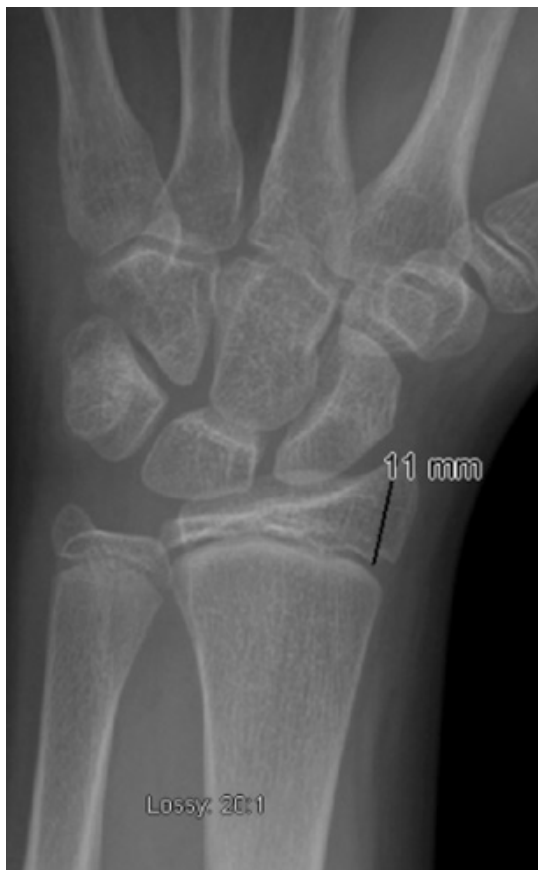

Figure 2: Measurement of radial inclination

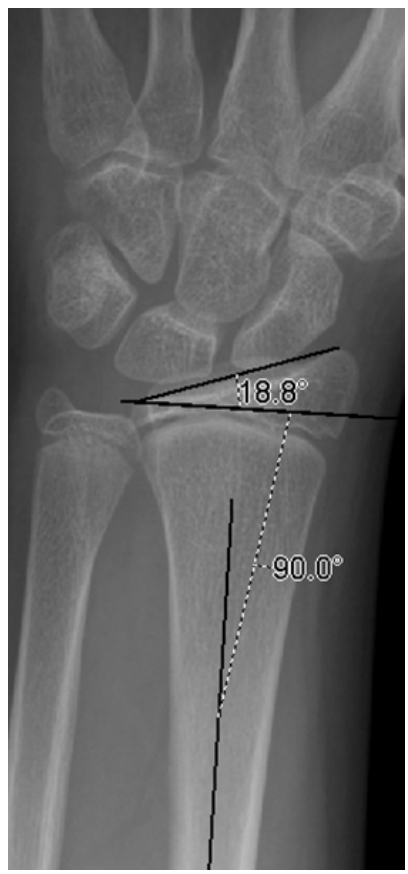

Figure 3: Measurement of radial epiphyseal height

inclination is measured on PA view as the angle between a line drawn perpendicular to the long axis of the radius along the articular surface of the distal radius and a line drawn down from the tip of the radial styloid. A normal adult radial inclination is 15-25 degrees[6,7]. An example of this measurement is seen in figure 2. Traditionally in adults radial height is measured as the distance between two parallel lines. One line perpendicular to the long axis of the radius is drawn along the ulnar aspect of the articular surface and the other line is drawn at the tip of the radial styloid. A normal radial height in adults is 9.9-17.3 mm[9]. However, in children the distal radius physis complicates the measurement of radial height. We chose to measure the height of the distal radial epiphysis as the measurement of radial height. An example of distal radial epiphysis measurement in children is shown in figure 3. All of the data collection was performed by one senior orthopedic surgery resident. Skeletal age was also measured using Greulich and Pyle's Radiographic Atlas of Skeletal Development of the Hand and Wrist. Average values of all these measurements were calculated for 4 age groups (8-9, 10-11, 12-13, and 14-16 years of age). The total number of wrist radiographs examined for each age group includes 74 for the 8-9 year old age group, 122 for the 10-11 year old group, 77 for the 12-13 year old group, and 99 for the 14-16 year old age group. A regression analysis was performed to determine the statistical significance of change in radiographic measurements (volar tilt, radial inclination, and radial epiphyseal height) with regards to chronologic age and skeletal age.

RESULTS

372 patients (215 males and 157 females) between the ages of 8 and 16 were included in the study. Normal values of volar tilt, radial inclination, and radial epiphyseal height were defined for each age group. The age based values of volar tilt, radial inclination, and radial epiphyseal height are summarized in tables 1-3. Regression analysis showed that volar tilt increased significantly by increase in age ($P < 0.001$). Volar tilt values correlated both with skeletal age ($R = 0.5$) and chronological age ($R = 0.4$) which is shown in table 4. Radial inclination and radial epiphyseal height both showed significant increase with increase in age ($P < 0.001$). Radial inclination values

Table I: Average values of volar tilt for each age group; VT: Volar tilt

Age	Female VT	Male VT	Combined Male and Female VT
8-9	10.15	9.23	9.96
10-11	10.63	10.18	10.43
12-13	12.89	12.22	12.56
14-16	14.21	12.35	13.57

Table II: Average values of radial inclination for each age group; RI: Radial inclination

Age	Female RI	Male RI	Combined male and female RI
8-9	19.85	18.3	19.66
10-11	21.75	20.36	21.14
12-13	24.73	23.61	24.17
14-16	24.99	24.4	24.79

Table III: Average values of radial epiphyseal for each age group; REH: Radial epiphyseal height

Age	Female REH	Male REH	Combined male and female REH
8-9	8.62	8.86	8.73
10-11	10.93	10.33	10.66
12-13	13	13.32	13.16
14-16	13.36	15.25	14.01

correlated both with skeletal age(R=0.6) and chronological age (R=0.6) which is shown in table 5. Radial epiphyseal height also showed strong correlation with skeletal (R=0.8) and chronological age (R=0.8) which is shown in table 6.

DISCUSSION

The cumulative risk of fracture from age 0-16 is 27% in girls and 42% in boys[10]. The distal end of the forearm is one of the most commonly fractured sites of a child's body[10]. Fortunately it is well accepted that most distal radius fractures in children that are properly reduced and treated will heal without any clinical consequences. Even though this is a very common injury there has been no radiographic study of the distal radius anatomy correlated with the child's age. Three values commonly used to determine need for surgery as well as quality of correction in adults are volar tilt, radial inclination, and

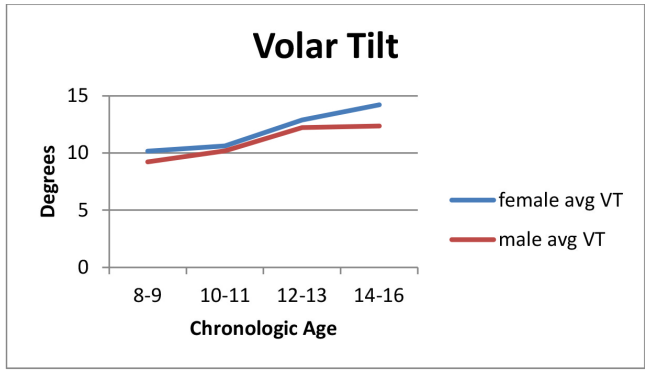

Table 4: Change in volar tilt in males and females based on chronological age (R: 0.4)

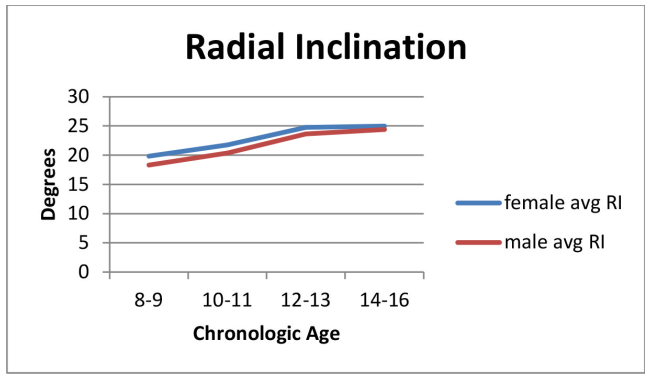

Table 5: Change in radial inclination in males and females based on chronological age (R: 0.6)

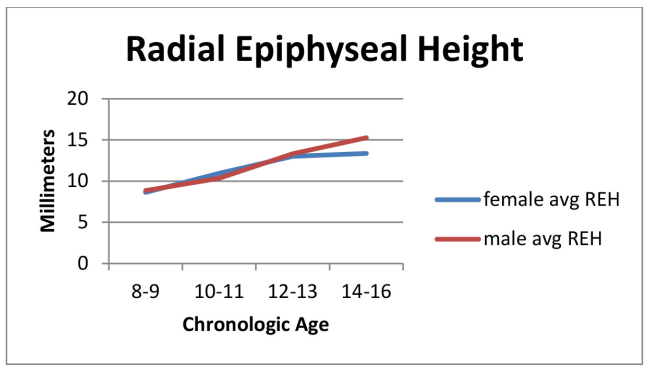

Table 6: Change in REH in males and females based on chronological age (R: 0.8), RH: Radial Epiphyseal Height

radial height. Average values of these three measurements are known for adults, but not for the pediatric population.

Our study identified the normal values of volar tilt, radial inclination, and radial height in children in different age groups. All these values showed to increase significantly with increase in age and showed correlation

with both chronological and skeletal age in children. The highest correlation was seen between radial epiphyseal height and age. We have identified that the radiographic anatomy of the distal radius in children is different than that of the mature skeleton and changes with age.

Our study has its limitations. The error in the measurements and potential unknown metabolic bone disease or fully remodeled previous fractures in some children may have affected our results. Also, one must realize that the periarticular osseous anatomy in children is very different from that of adults due to the significant cartilaginous epiphyseal component. Our study only focused on ossified anatomy visible on plain radiographs. MR imaging would greatly improve visualization of this cartilaginous component, but becomes impractical when trying to get a large volume of patients included in the study, as it is cost prohibitive to perform MR screening of all wrist injuries. We also realize that the general ethnicity statistics provided may not be indicative of those patients who show up to the Emergency Room with complaints of wrist pain, and that this information would change the anthropometric data. Lastly, we note that it is a widely accepted fact that girls reach skeletal maturity earlier than boys, typically at age 14 for girls and at age 16 for boys. However there are age ranges for each of the different stages of skeletal development. For instance, Gruelich and Pyle in their extensive atlas on hand bone age note an age range for "Early and Mid-Puberty" for females to be 7-13 years of age and for males to be 9-14 years of age. This does illustrate that in general females develop skeletal anatomy at a younger age than males, but it also illustrates that these are broad ranges of ages. In our study both boys and girls had an increase in the indices studied at the same 11-13 age range. This could be because we chose narrower age ranges, or it could also indicate that a larger patient population should be studied in this age range to see if this equivalent increase in indices holds true.

The shape of the epiphysis and/or pattern of the physeal line, as well as the ratio of the radial height, i.e., height of the epiphysis in relation to the total length of the radius, was not evaluated in the study, although these would be interesting values to pursue further with follow up studies.

Another limitation of the study is the lack of data about the ethnicity of the subjects. The study was performed at a large teaching hospital in Kentucky. Although the ethnicity of each patient was not noted for this study, results of the 2010 census reveal that in the state of Kentucky, particularly, for Fayette County (where the study was performed), the population consists of 75.7% Caucasian, 14.5% African American, 6.9% Hispanic/Latino, 3.2% Asian and 0.3% American Indian and Alaska Native[11]. Based on the population, we expect our study results to mostly represent normal values in Caucasians.

In summary, we have identified normal age based values for distal radius anatomy in children and have shown how they change with growth.

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OPENING WEDGE OSTEOTOMY FOR THE CORRECTION OF ADOLESCENT TIBIA VARA

Branum Griswold, MD[1], Shawn Gilbert, MD[1], Joseph Khoury, MD[2]

ABSTRACT

Background: Tibia vara, or Blount's disease, is a pathologic angular deformity of upper tibial physis causing a bow leg deformity. Adolescent Blount's disease may be unilateral or bilateral and is diagnosed during or just before the adolescent growth spurt. In addition to predisposing genetic factors, biomechanical overload of the proximal tibial physis causes asymmetric growth leading to a varus deformity.

Surgical intervention is usually required for adolescent Blount's disease. Hemiepiphysiodesis has had some success in arresting or correcting the deformity. Tibial osteotomy can achieve correction acutely with internal or external fixation or gradually with external fixation.

This article reports the outcomes of correcting adolescent tibia vara with a proximal opening wedge osteotomy (POWO) and internal fixation in nine patients with a primary diagnosis of Adolescent Blount's Disease.

Methods: We conducted a retrospective review of patients treated with POWO between April 2007 and July 2015. Fifty charts were selected using ICD9 codes for tibia vara and CPT codes for osteotomy. Nine patients (11 tibia) meeting eligibility criteria were identified. In addition to pre-operative data; operative factors, such as blood loss; and post-operative outcomes such as radiographic accuracy of correction, time to healing, time to full weight-bearing, number of office visits and complication rates were collected.

Results: Pre-operative radiographic measurements showed the varus deformity was primarily tibial. Post-operative correction demonstrated a mean correction of 17.64° (range, 7°-26°). Patients returned to full weight bearing status around 67 days after surgery and required very few follow-up visits during the course of treatment. Three of nine patients experienced complications including seroma requiring drainage, metallosis mistaken for infection leading to hardware removal, and a wound abscess treated with antibiotics (one patient each). No patients lost correction, experienced nerve palsy, compartment syndrome nor complained of leg length discrepancy.

Conclusions: Proximal opening wedge osteotomy (POWO) is a reproducible, safe and effective technique for correction of adolescent tibia vara, with potential advantages of fewer return visits and sooner return to weight bearing than external fixation. In select patients, it is a useful alternative to external fixation or closing wedge osteotomy.

Level of Evidence: IV

Keywords: adolescent, blount's disease, tibia vara, internal fixation, proximal opening wedge osteotomy

INTRODUCTION

Tibia vara, or Blount's disease, is a pathologic angular deformity of the lower extremity focused at the upper tibial physis causing a bow leg deformity. The pathophysiology of Blount's disease is thought to be due to improper distribution of biomechanical forces and predisposing genetic factors. Biomechanical overload of the proximal tibial physis causes asymmetric growth leading to a pathologic varus deformity[1,2]. Blount's disease generally presents in two distinct age groups: infantile and adolescent. Adolescent Blount's disease may be unilateral or bilateral and is diagnosed during or just before the adolescent growth spurt. Blount's disease more commonly affects African-Americans and those with a body mass index (BMI) >40. The increase

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Compliance with Ethical Standards:

This study was supported internally by the University of Alabama. The authors, Joseph G. Khoury, MD; Branum G. Griswold, MD and Shawn R. Gilbert, MD declare that they have no conflict of interest. The retrospective chart review study was conducted under expedited review (No. X160311011) by the Institutional Review Board for Human Use at the University of Alabama at Birmingham.

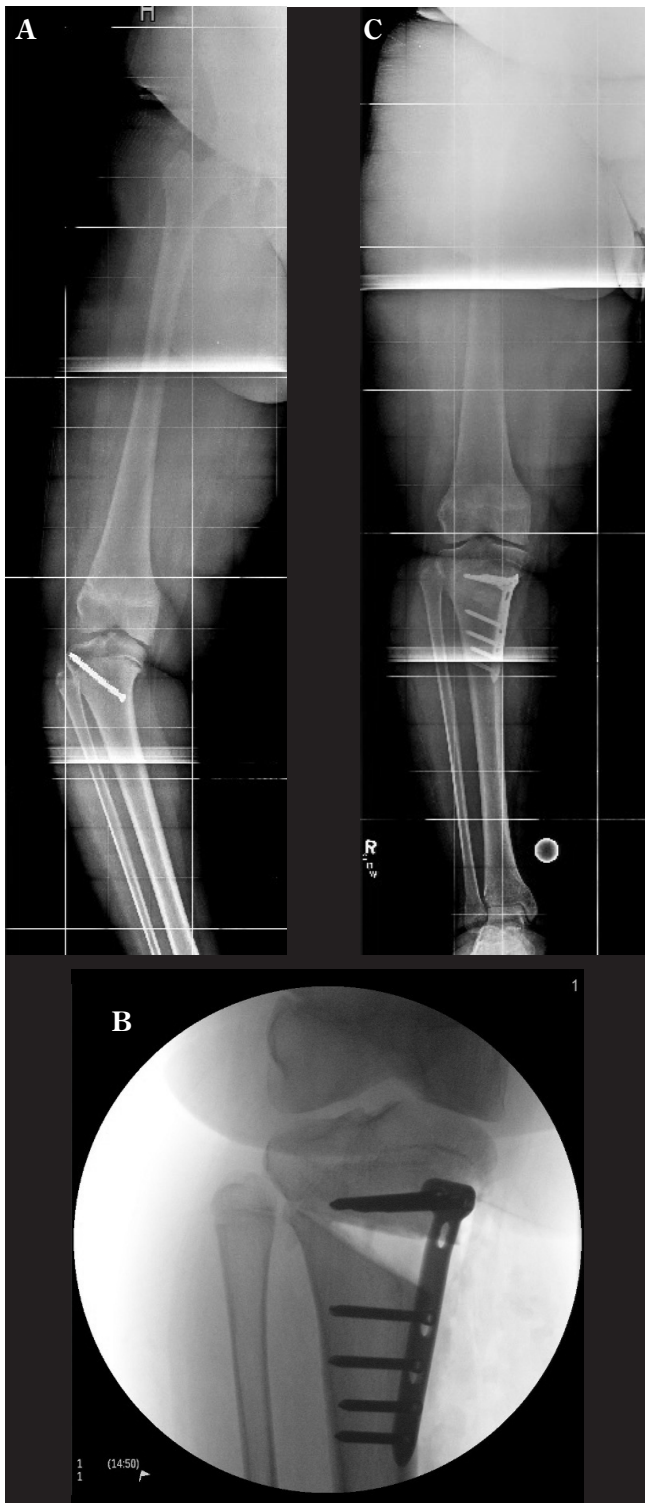

Figure 1: A. Pre-operative long leg radiograph reveals persistent tibia vara after failed screw epiphysiodesis. B. Intraoperative fluoroscopic image reveals completed osteotomy fixed with locking plate before placement of structural and morselized allograft. C. 10 week post-operative long leg radiograph reveals healed osteotomy.

in body weight seen in individuals with Blount's disease creates an excess force on the posteromedial portion of the proximal tibial physis. This compressive force leads to relative growth inhibition, as described by the Heuter-Volkmann principle, creating a varus deformity[1,3-5]. The deformity may be exacerbated by varus moments which result from the gait pattern of patients with increased BMI and thigh girth attempting to avoid contact between the thighs as described by Davids et al.[1]. Often times there may be associated deformities of the distal femur (varus or valgus) and the distal tibia[6,7].

Surgical intervention is usually required for adolescent Blount's disease. For the growing child with mild to moderate deformity, hemiepiphysiodesis has had some success in arresting or correcting the deformity. Tibial osteotomy is generally required in those with severe deformity or those nearing skeletal maturity. Tibial osteotomy can achieve correction acutely with internal or external fixation; or gradually with external fixation. Previous studies have reported success in the treatment of tibia vara with osteotomy with either gradual or acute correction and various forms of external fixation[8-18]. In this article, we will report the outcomes of correcting adolescent tibia vara with a proximal opening wedge osteotomy (POWO) of the tibia and internal fixation in a patient population with the primary diagnosis of Adolescent Blount's Disease.

METHODS

After Institutional Review Board approval, 55 patient records were identified using ICD9 codes for Tibia Vara and CPT codes for osteotomy for the peroid April 2007 to July 2015. Retrospective chart review was performed. Inclusion criteria included primary diagnosis of adolescent Blounts, correction by POWO and follow-up to radiographic union. Exclusion criteria were insufficient follow up, inadequate radiographs to assess pre-operative deformity or postoperative correction, patients with a primary diagnosis infantile Blount's, or diagnosed with tibia vara secondary to another pathophysiologic process.

Charts were reviewed for: the age at which the patient underwent surgical correction for tibia vara; estimated blood loss during the procedure; duration of surgery; time to full weight bearing status; weight at the time of procedure; weight at time of full weight bearing status; number of office visits from the time of surgery to full weight bearing status and time to last follow-up. The length of time until full weight bearing status was determined by the documentation by the primary surgeon stating that patient was able to fully bear weight without any limitations. Complications were described in one of the following categories: wound problems such as dehiscence or cellulitis, and deep infection; nerve injuries; nonunion; malunion; compartment syndrome; symptom-

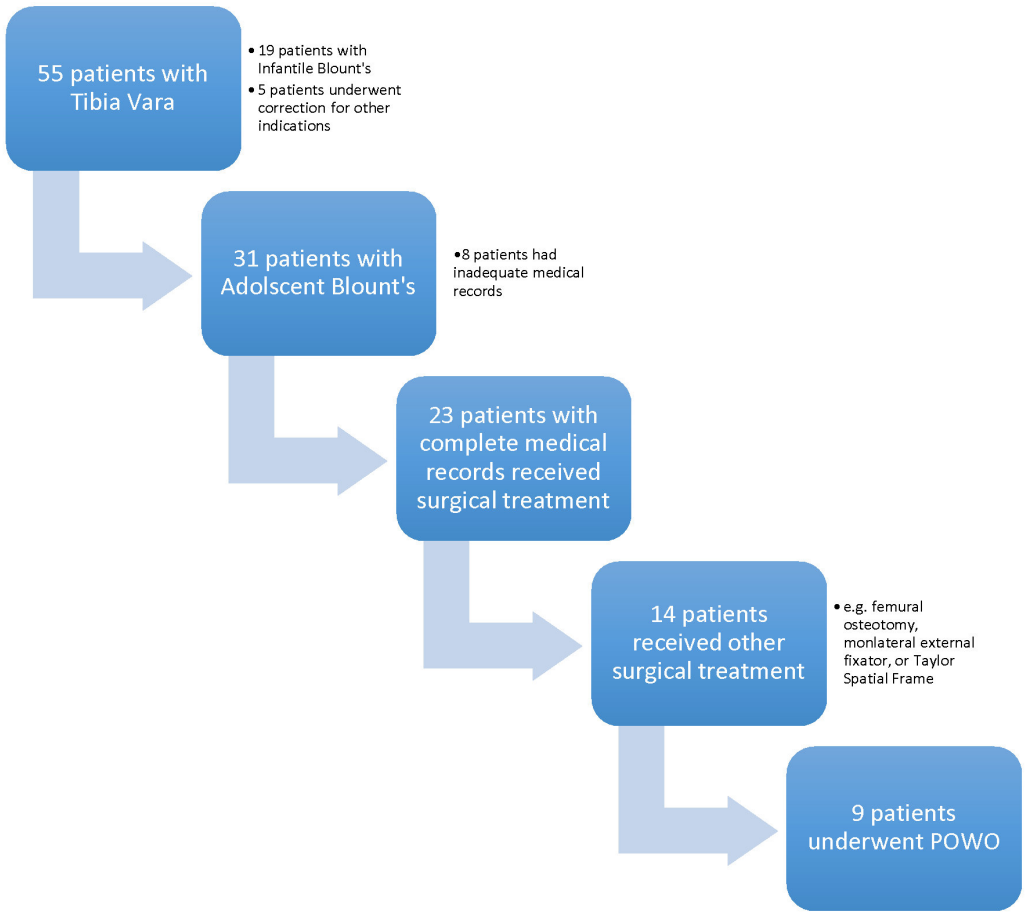

Figure 2: POWO; Proximal Opening Wedge Osteotomy

atic limb length discrepancy that required long term use of a shoe insert; and need for reoperation secondary to infection, or need of realignment.

All radiographic measurements were performed by an independent observer. Seven full length lower extremity weight bearing films were selected at random to be reviewed by the pediatric orthopedist. Angulation measurements of preoperative and postoperative MAD, MPTA and LDFA were in good agreement with an intraclass correlation coefficient varying between 0.97 (95% CI, 0.87-0.99) and 1.0 (95% CI, 1.0-1.0). Patients had preoperative and follow-up full-length standing anteroposterior films. Special care was taken to ensure the patients' pelvis and femoral heads were adequately visualized with their knees in full extension and patella directed anteriorly for proper radiographic analysis. Analysis of frontal plane radiographs consisted of measurement of the lateral distal femoral angle (LDFA), the medial proximal tibial angle (MPTA), mechanical axis (MA) and mechanical axis deviation (MAD). These measurements were made preoperatively and postoperatively at the latest follow-up. The degree of correction was calculated by subtracting the MA at the latest follow-up from the preoperative MA.

Deformities were corrected acutely with a proximal opening wedge osteotomy with internal fixation using either a plate incorporating a block (Puddu, Arthrex, Naples, FL) or a locking plate designed for the proximal tibia (Tomofix, Synthes, West Chester, PA). The osteotomy was generally oriented obliquely toward the proximal tibia-fibula joint leaving the lateral cortex intact for stability. A fibular osteotomy is not performed. The osteotomy was gradually opened while monitoring the position of the weight bearing axis by using a bovie cord positioned over the femoral head and ankle. The goal is to recreate a mechanical axis that passes through the middle of the knee erring on the side of medialization. A piece of tricortical iliac crest allograft is fashioned to fit snugly into the gap and this is supplemented with cancellous allograft chips. The plate is then applied medially to stabilize the osteotomy further. The osteotomy was generally combined with a prophylactic anterior compartment fasciotomy performed through the same

Table I. Pre-Operative Radiographic Measurements

POWO (n=11)		
Variable	**Mean**	**Range**
MA, degree	24.64	15.0 - 36.0
MAD, cm	8.87	4.3 - 13.2
LDFA, degree	95.82	90.0 - 101.0
MPTA, degree	79.00	70.0 - 84.0
Age, years	15.01	11.9 - 19.1
Weight, kg	137.1	72.0 - 184.3

POWO, proximal opening wedge osteotomy with internal fixation; MA, mechanical axis; MAD, mechanical axis deviation; LDFA, lateral distal femoral angle; MPTA, medial proximal tibial angle.

Table II. Post-Operative Radiographic Measurements

POWO (n=11)		
Variable	**Mean**	**Range**
MA, degree	7.00	-2.0 - 15.0
MAD, cm	2.48	0.5 - 4.9
MPTA, degree	89.54	84.0 - 94.0
LDFA, degree	93.64	85.0 - 98.0
Correction, degree	17.64	7.0 - 26.0
Correction, cm	6.39	2.6 - 9.4

POWO, proximal opening wedge osteotomy with internal fixation; MA, mechanical axis; MAD, mechanical axis deviation; LDFA, lateral distal femoral angle; MPTA, medial proximal tibial angle.

Table III. Follow up Variables

POWO (n=11)		
Variable	**Mean**	**Range**
Time to last follow up, years	1.45	0.19 - 5.38
Follow up visits	2.55	2 - 3
Time to full weight bearing status, days	66.91	33 - 91
Blood loss, mL	168.64	10.0 - 1000
Surgery Time, hr:min	1:52	0:38 - 2:40
POWO (n=9)		
Variable	**Mean**	**Range**
Weight at full weight bearing status, kg	132.4	69.7 - 162.4
Weight change during treatment, kg	-0.84	-5.0 - 4.0

POWO, proximal opening wedge osteotomy with internal fixation.

incision and placement of a drain (figure 1A-C). No postoperative immobilization was used and patients were made touch down weight bearing immediately with progression to full weight bearing between week 6 and week 10 postoperatively. Patients were typically left with intentional residual varus in order to improve ambulation and compensate for their large thigh girth.

PATIENT RESULTS

Fifty five patients were initially identified. Nineteen had originally been diagnosed with infantile Blount's, 14 received other treatment for adolescent Blount's (e.g.: femur osteotomy or acute correction with monolateral external fixation or external fixation with Taylor Spatial Frame), and five received tibial osteotomy for other indications (e.g.: familial hypophosphatemic rickets), eight had inadequate medical records. The remaining nine had POWO (11 tibiae) (Figure 2). The mean age at operation was 15 years and mean preoperative weight was 137.1 kg (Table 1).

RADIOGRAPHIC RESULTS

Pre-operative radiographic measurements (Table 1), showed the varus deformity was primarily in the tibia. Post operative correction as seen in Table 2 demonstrated a mean MA 7° varus and MAD of 2.48 cm medial, and mean correction of 17.64° (range, 7°-26°). Mean MPTA of 89.54° (range, 84.0° - 94.0°) and LDFA of 93.64° (range, 85.0° - 98.0°). In each case, MPTA and LDFA did not show significant unintended residual deformity in our sample.

CLINICAL RESULTS

Our group returned to full weight bearing status around 67 days after surgery. There were very few follow-up (average 2.55/patient) visits during the course of treatment and patients also experienced an average weight loss of 0.84 kg as a group (Table 3). Mean blood loss 168.64 mL, and mean duration of surgery was one hour and fifty-two minutes. Three of nine patients experienced complications including seroma requiring drainage, metallosis mistaken for infection leading to hardware removal, and a wound abscess treated with antibiotics (one patient each). No patients lost correction, experienced nerve palsy, compartment syndrome nor complained of leg length discrepancy.

DISCUSSION

The obesity epidemic assures a continued need to correct adolescent tibia vara. The goals of reestablishing normal joint alignment, correcting the gait pattern, and possibly delaying the onset of osteoarthritis can be pursued using a variety of correction techniques, but further

comparative studies are needed. We have described the outcomes of POWO and found that similar radiographic outcomes could be obtained with POWO compared to other techniques with few clinic visits and early return to full weight bearing. Further, POWO patients did not experience weight gain during the treatment period, a significant positive in this already overweight population.

Gilbody et al. published a systematic review using two major medical literature databases comparing acute and gradual correction after a single level tibal osteotomy for primary treatment with children with idiopathic tibia vara and concluded there was weak evidence that the Taylor Spatial frame provides a more accurate correction of the MA. In this review, there were five studies that reported gradual correction with external fixation with a mean MA ranging from 1° to 7.5° of valgus[19]. The final range of MA for the POWO group in our study was within this range.

Surgeons may be reluctant to perform POWO in adolescent tibia vara due to concerns about compartment syndrome, neurovascular injury and wound complications related to obesity and ability to achieve and maintain satisfactory correction[8,18-22]. Most patients in this series were obese. We did have three wound complications, with two requiring re-operation, but none compromising the final result. Acute correction has been implicated as being more likely to result in compartment syndrome and neurovascular compromise,[19,23], but in our series all patients with POWO had prophylactic fasciotomy and there were no compartment syndromes or neurovascular complications in either group. Regarding correction, the senior author prefers to leave patients with slight varus in order to help with gait, our POWO patients maintained correction to healing with no loss of fixation.

Advantages of POWO, as compared to alternative methods such as gradual correction with Taylor Spatial, included fewer return visits and earlier time to weight bearing, avoidance of pins, as well as avoidance of a mandatory second procedure for Ex-Fix removal. Avoiding weight gain during treatment could prove to be very impactful, as a prior study has shown that patients gain an average of 3.7 kg over the course of Ex-Fix treatment[24].

Despite some of the potential advantages of POWO, it does have limitations. More severe deformities may make the size of wedge required impractical. Also, this technique does not allow for correction of additional deformities such as leg length difference and rotational deformities.

Limitations of the current study include the retrospective nature with lack of standardized protocols for weight bearing or specific selection criteria for particular procedures. In addition, the inclusion criteria utilized to select a consistent patient population resulted in small numbers.

This technique is a valuable treatment option for surgical correction of Adolescent Blount's Disease and it is a useful alternative to an external fixator or closing wedge osteotomy in selected patients. This technique was performed on 11 knees with tibia vara, and it was completely successful in all cases. In conclusion, POWO is a reproducible, safe and effective technique for correction of adolescent tibia vara, with potential advantages of fewer return visits and sooner return to weight bearing.

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FACTORS THAT PREDICT OVERALL HEALTH AND QUALITY OF LIFE IN NON-AMBULATORY INDIVIDUALS WITH CEREBRAL PALSY

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ABSTRACT

Background: It is unknown what role specific tasks associated with personal care, positioning, communication and social interaction, and comfort and emotions play in predicting the overall health and quality of life of individuals with non-ambulatory cerebral palsy (CP). In this study, we prospectively evaluated which of these factors were significant predictors of overall health and quality of life.

Methods: Parents and guardians of non-ambulatory children, adolescents and young adults with CP were prospectively recruited from the Cerebral Palsy Clinic of a large pediatric academic hospital. Caregivers completed the CP Child Questionnaire®. Univariate analyses were used to identify relationships between overall health, overall quality of life (QOL), and responses in the following categories: personal care and activities of daily living, positioning and transfer mobility, comfort and emotions, and communication and social interaction. Significant predictors of overall health and QOL were then determined via logistic regression.

Results: 64 patients ages 0-20 years and Gross Motor Function Classification System levels IV and V were included in our study (mean age 9.16 ±4.96 years). Overall QOL (OR 194.2, 95% CI, 9.5-3964.9) and comfort while sitting (OR 15.9, 95% CI, 1.2-205.3) were significant predictors of overall health. Feelings of unhappiness or sadness (OR 59.9, 95% CI, 1.6-2209.8), difficulty understanding the parent or guardian (OR 29.8, 95% CI, 1.6-543.7), and not attending school (OR 57.2, 95% CI, 2.6-1274.4) were significant predictors of lower overall quality of life.

Conclusions: Overall QOL appears to predict overall health. Factors associated with comfort and emotions and communication and social interaction appear to predict overall QOL to a greater extent than personal care and transfer mobility.

Level of Evidence: Prognostic II

Key words: neuromuscular scoliosis, cerebral palsy, quality of life

INTRODUCTION

Cerebral palsy (CP) is the most common motor disability in childhood and has an estimated prevalence of 1.5-4 per 1,000 live births.[1] It includes a variety of deficits in posture and movement which limit performance of daily life activities, independence, and hinders quality of life.[2] Decreased quality of life (QOL) has been reported in individuals with CP[3], but there is variability in these findings and predicting factors are not well understood.[4-6]

QOL is a multidimensional construct that reflects subjective perceptions of goals, expectations, and concerns in the context of one's culture and value system.[12,13] Health-related quality of life (HRQOL) focuses on components which include self-care, mobility, and communication[11], as well as functional status, mental health, and parental impact.[3] QOL broadly refers to the notion of holistic well-being, whereas HRQOL focuses on physical and mental functioning and its impact on daily life and social functioning.[14,15] Evidence suggests that psychosocial well-being is not associated with functional ability or physical well-being,[3,4,16] but rather behavioral difficulties resulting in an inability to adapt to everyday demands and integrate socially.[6,17] However, despite the prevalence of CP, little is known about the ways in which CP impacts health status and QOL.[4-6,16] Measures of QOL have been correlated with motor functioning as it relates ambulation,[10,18,19] but it is unknown whether QOL also correlates with the specific tasks associated with personal care, positioning, and mobility. Similarly, there have been attempts to correlate QOL with psychological and social functioning[20,21] but not emotions and interactions associated with those tasks.

In this study, we investigated the degree to which personal care, mobility, positioning, comfort, emotion, communication and social interaction predicted overall health and QOL in a cohort of children, adolescents and young adults with CP.

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Table I: Demographic data for parents and caregivers of child

Sex	
Male	11% (n = 7)
Female	81% (n = 52)
Unknown	8% (n = 5)
Average Age (Years)	38.5 ± 8.5 (n = 58)
Age Range (Years)	20-60 (n = 58)
Highest Level of Schooling Completed	
Some Elementary School	5% (n = 3)
Completed Elementary School	2% (n = 1)
Some High School	5% (n = 3)
Completed High School	22% (n = 14)
Some Community College/Technical School	16% (n = 10)
Completed Community College/Technical School	17% (n = 11)
Some University	6% (n = 4)
Completed University (Undergraduate)	9% (n = 6)
Completed University (Graduate)	8% (n = 5)
Unknown	11% (n = 7)
Location of Residence	
City (> 5000 people)	64% (n = 41)
Town (500-4999 people)	17% (n = 11)
Village (100-499 people)	2% (n = 2)
Farm (< 100 people)	0% (n = 0)
Unknown	16% (n = 10)
Total Gross Annual Income	
$0-$9,999	8% (n = 5)
$10,000-$19,000	16% (n = 10)
$20,000-$29,999	9% (n = 6)
$30,000-$39,999	11% (n = 7)
$40,000-$49,999	6% (n = 4)
$50,000-$59,999	5% (n = 3)
$60,000-$69,999	3% (n = 2)
$70,000-$79,000	5% (n = 3)
Over $80,000	14% (n = 9)
Not reported	23% (n = 15)
Does Child Live With You?	
Yes	94% (n = 60)
No	0% (n = 0)
Unknown	6% (n = 4)
Average Time Spent with Child (Hours/Week)	55.3 ± 33.2 (n = 55)
Range Time Spent with Child (Hours/Week)	8-168 (n = 55)
Do You Have Help Caring For Child?	
Yes	78% (n = 50)
No	14% (n = 9)
Unknown	8% (n = 5)

METHODS

Study Design and Setting

All study procedures were approved by The Children's Hospital of Philadelphia Institutional Review Board. Parent(s)/guardian(s) of children with CP were prospectively recruited and surveyed via the CPChild® Questionnaire (Appendix A) in our CP clinic at The Children's Hospital of Philadelphia (CHOP).

Participants/Study Subjects

Inclusion criteria for this study were patient age of 0-23 years; diagnosis of cerebral palsy; inability to ambulate; parental/guardian permission (informed consent) and child assent of a minor if the patient was able to assent. We excluded patients with a diagnosis of neuromuscular disease unrelated to CP.

Description of Experiment

The CPChild® is a 37-item questionnaire that was developed and validated for use in children with CP to assess general physical functioning and QOL. The individual completing the instrument is asked to respond based on events and observations that occurred in last 2 weeks. The CPChild was administered to our cross sectional sample.[22,23] Ordinal scores of responses to questions from four sections of the CPChild (Personal Care/Activities of Daily Living, Positioning/Transferring/Mobility, Comfort/Emotions, Communication/Social Interaction) were related to scores of overall health and overall QOL. Scores were also dichotomized and compared in the following manner:

1. *Personal Care/Activities of Daily Living, Positioning/Transferring/Mobility, and Communication/Social Interaction:* A score of 0 was given if the difficulty of performing a related task was rated "not possible/almost impossible", "very difficult", "slightly difficult", or "easy". A score of 1 was given if the task was rated "very easy" or "no problem at all"
2. *Comfort/Emotions:* A score of 0 was given if the frequency of pain or discomfort of performing a related task occurred "every day", "very often", "fairly often", or "a few times." A score of 1 was

Table II: Final Logistic Regression for significant variables that predicted Overall Health

Variables in Model	Odds Ratio	95% Confidence Interval	p Value
Overall Quality of Life	194.2	(9.5, 3964.9)	0.001
Comfort and Emotions: How often the child experienced pain and discomfort while seated	15.9	(1.2, 205.3)	0.034

Table III: Final Logistic Regression for significant variables that predicted Overall Quality of Life

Variables in Model	Odds Ratio	95% Confidence Interval	p Value
Comfort and Emotions: How Often Child was Unhappy or Sad	59.9	(1.6, 2209.8)	0.026
Communication and Social Interaction: Child's Ability to Understand You	29.8	(1.6, 543.7)	0.022
Communication and Social Interaction: Playing With Others	0.022	(0.001, 0.9)	0.047
Communication and Social Interaction: Attending School	57.2	(2.6, 1274.4)	0.011

given if the frequency occurred "once or twice" or "none of the time."

3. *Overall Health and Overall QOL:* A score of 0 was given if the rating was "very poor", "poor", "fair", or "good." A score of 1 was awarded if the rating was "very good" or "excellent."

Statistical Analysis

The relationships between responses to questions in the four sections mentioned above and overall health and overall QOL were investigated using Spearman's rank correlation. Variables found to have significant relationships with overall health or overall QOL were then dichotomized as described above and incorporated into a multivariate logistic regression model to determine which factors were independent predictors of overall health and overall QOL. A cutoff of 0.10 and backwards stepwise method was used for the model. Level of significance, beta coefficient, odds ratios, and 95% confidence intervals were calculated for each variable. Data analysis were constructed in such a way that regression coefficients greater than one indicated a positive relationship between the predictor and the outcome variable (good outcome) and coefficients less than one indicated a negative relationship between the predictor and the outcome variable. All statistics were calculated with SPSS version 22.0 (IBM-SPSS Inc. New York, USA)

RESULTS

We identified and screened Eighty-nine patients for this study. Of these patients eighty eight were deemed eligible and mailed surveys. Sixty-four surveys were returned for a response rate of 73%. The Mean age was 9.16 ±4.96 years with a range of 3 months to 20. Twenty-four patients were female (37.5%) and 40 were male (62.5%). Parent and caregiver demographic information is shown in Table 1.

Following univariate analysis to determine which variables were to be included in the model, binary logistic regression with backward stepwise elimination was performed. Univariate predictors of good overall health were mobility parameters such as wheelchair sitting, moving outdoors and visiting public places, and seating comfort. Additionally communcation and social factors such as caregiver understanding, stranger understanding, playing alone and with others, and attending school were found to be statistically significant on univariate analysis. Following multivariate anlaysis, patients with a higher overall quality of life were found to have a higher overall health rating. Additionally, increased comfort with sitting was associated with 15 times higher quality of life (Table 2). This model was associated with a pseudo R2 of 0.693.

Another logistic regression was performed to determine predictors of quality of life. Univariate analysis revealed that personal care factors such as eating and bathing, mobility factors such as wheelchair sitting, visiting public places and getting into and out of a vehicle were important in quality of life. Social and communication factors such as caregiver and stranger understanding, and overall emotional happiness were also important quality of life predictors. Following multivariate analysis, we found that emotions and interactivity were the most

important independent predictors of quality of life (Table 3). Interestingly, playing with others was an unexpectedly reverse correlation in this model. This suggests that children playing with others are actually less happy OR (0.022; p value 0.047). This model was associated with a pseudo R2 of 0.686

DISCUSSION

Our study identified predictors of overall health and quality of life in a sample of non-ambulatory children, adolescents, and young adults with CP. Factors associated with comfort and emotions, and communication and social interaction predicted overall QOL to a greater extent than personal care and transfer mobility. How often the child was unhappy or sad (OR 59.9, 95% CI, 1.6-2209.8), the degree to which the child understood the parent or caregiver (OR 29.8, 95% CI, 1.6-543.7), and whether the child attended school (OR 57.2, 95% CI, 2.6-1274.4) were significant predictors of overall quality of life. Overall quality of life (OR 194.2, 95% CI, 1.6-2209.8) and how often the child experienced pain and discomfort while seated (OR 15.9, 95% CI, 1.2-205.3) were also found to be predictors of overall health. The latter suggests orthopedic procedures to relieve pain while seated such as spinal fusion may be beneficial.

A recent study by Colver et al[24] examined how QOL of adolescents with cerebral palsy varies with impairment and which factors in childhood predict adolescent QOL. The study prospectively evaluated 355 patients with cerebral palsy at 8-12 years and then at 13-17 years utilizing the KIDSCREEN® questionnaire. They found the severity of impairment was significantly associated with reduced adolescent QOL in the domains of mood and emotions, autonomy, social support, and peers ($p < 0.01$). They also found childhood QOL was a consistent predictor of adolescent QOL. Though this study was performed in Europe and in adolescents, it emphasized importance of comfort and emotions, and communication and social interaction in predicting QOL.

Our results support previous findings that psychosocial well-being is related to coping and social integration,[6,17] but not physical function.[3,4,16] Additional studies have also shown that assessments of quality of life are a consequence of relative internal standards and desires,[3,17,25,26] such that one's physical limitations do not necessarily correlate with quality of life. Overall quality of life, however, may impact perception of overall health. Our results also support this conclusion. Overall quality of life was found to be a strong predictor of overall health (OR 194.2, 95% CI, 9.5-2209.8).

Effect modification may explain why playing with others was found to negatively predict overall QOL (OR 0.022, 95% CI, 0.001-.9). This suggests playing with others is not actually a negative predictor of overall QOL, rather its negative predictability strengthened the relationship of other variables significant in the model. It is possible that this might be also related to the disabilities effect on the child's overall happiness as suggested by the Colver study,[24] although it is difficult to know for sure and this finding may be more of a statistical artifact.

Contextual factors are important determinants of QOL,[27-30] and family coping mechanisms, child's motivation and attitudes, and the availability of resources have been shown to correlate with perception of QOL.[17,29] The majority of our patients reported that both their overall health and overall quality of life were at least good. This may be a consequence of the fact that our study population consisted largely of patients with CP whose caretakers had the means to bring their children to doctors' appointments, follow up with specialists, and generally provide, at minimum, a basic level of care. Our regression model sought to determine those factors that predicted an optimal overall health and QOL, which translated to a response rating of at least "very good." We therefore assumed that ratings of overall QOL and health were not optimal if they were "good" or poorer, which introduces a degree of measurement bias into the analysis.

There are two additional limitations to our study. First, our findings are not generalizable to all non-ambulatory individuals with CP. The majority of our patients lived in an urban area and had a female caretaker. Most caregivers also reported having assistance caring for their child. Second, caregiver responses may not be accurate representations of overall health and QOL. We examined the predictors of health and QOL with proxy assessments from caregivers, and it has been shown that Parent-reported and self-reported QOL are often inconsistent.[2,7-9 10] The strengths of our study include the fact that it was prospective and that it was conducted at a large tertiary care center with ample access to patients with CP.

In conclusion, HRQOL is an important factor that should be considered in the overall health of a patient with CP. Factors relating to comfort and emotions as well as communication and social interaction appear to be more important than personal care and mobility in predicting overall quality of life.

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CROSSED K-WIRES VERSUS INTRAMEDULLARY HEADLESS SCREW FIXATION OF UNSTABLE METACARPAL NECK FRACTURES: A BIOMECHANICAL STUDY

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ABSTRACT

Background: Intramedullary headless screw (IMHS) has shown promise as an alternative to other fixation devices for metacarpal neck fractures. The purpose of this study was to assess the biomechanical performance of IMHS versus the commonly-used crossed K-wire technique. We hypothesized that IMHS fixation provides superior stability to K-wires.

Methods: A metacarpal neck fracture model in 23 human cadaveric metacarpals was created. The specimens were divided into two groups based upon fixation method: Group 1, 3 mm intramedullary headless screw; and Group 2, 0.045 inch crossed K-wires. A cantilever bending model was used to assess load-to-failure (LTF), maximum displacement, energy absorption, and stiffness.

Results: The mean LTF was 70.6 ± 30.1 N for IMHS and 97.5 ± 34.7 N for crossed K-wires. Mean stiffness was 11.3 ± 3.4 N/mm and 17.7 ± 7.8 N/mm for IMHS and crossed K-wires, respectively. The mean maximum displacement was 20.2 ± 4.6 mm for IMHS and 24.1 ± 3.7 mm for crossed K-wires. Moreover, mean energy absorption was 778.3 ± 528.9 Nmm and 1095.9 ± 454.4 Nmm, respectively, for IMHS and crossed K-wires. Crossed K-wires demonstrated significantly higher stiffness and maximum displacement than IMHS ($p < 0.05$).

Conclusions: IMHS fixation of unstable metacarpal neck fractures offers less stability compared to crossed K-wires when loaded in bending.

Clinical Relevance: Crossed K-wires offer superior stability for the treatment of metacarpal neck fractures. These results reveal that IMHS fixation is less favorable biomechanically and should be cautiously selected with regards to fracture stability.

Keywords: Biomechanical; fracture; intramedullary; metacarpal neck

INTRODUCTION

Metacarpal fractures are common injuries treated by the orthopaedist and hand surgeon. They are third in frequency in fractures of the hand and forearm, behind radius/ulna fractures and phalangeal fractures, comprising 18% of these injuries as a whole.[1] The majority of metacarpal fractures can often be treated non-operatively, with some combination of splinting, casting, buddy taping, and/or early motion protocols. Non-operative treatment is not without its limits, however, as it is difficult to maintain rotational stability and length with this technique. This is particularly critical since it has been shown that for every 2 mm of shortening, a resulting extensor lag of 7° will occur that may lead to a "pseudoclawing" appearance.[2] Operative indications for metacarpal neck fractures have differed in the literature, but most employ acceptable reduction parameters of no rotational deformity and angulation of 15° at the index finger, 20° at the middle, 30° at the ring, and 40 – 50° at the small, with published ranges of 20 – 70° for the small finger.[3]

In order to treat those fractures amenable to surgical intervention, numerous open and closed operative techniques for managing unstable metacarpal fractures have been proposed. These include, but are not limited to, closed reduction with percutaneous pinning in varying configurations, percutaneous insertion of locked or non-locked intramedullary nails, intramedullary wires, and open reduction with screws alone or plate/screw constructs.[4-6] Each method has presented with its own unique complication profile, such as wire tract

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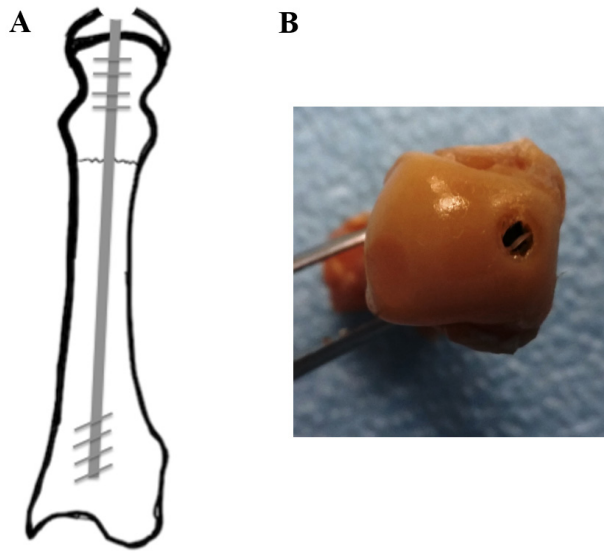

Figure 1. Schematic of intramedullary headless compression screw across metacarpal neck fracture.

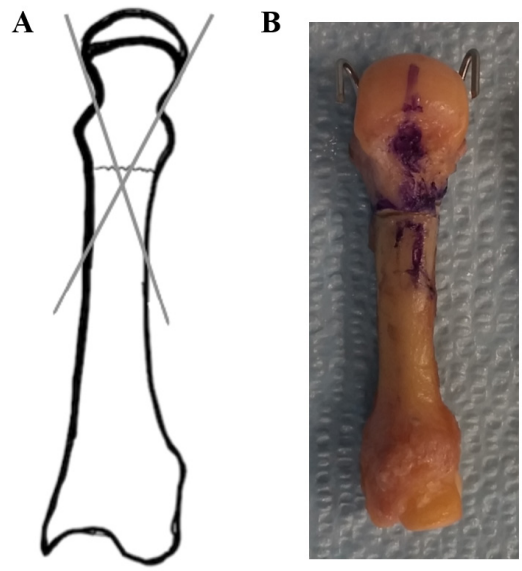

Figure 2. Schematic of placement of crossed K-wires, engaging the far cortex.

infection, hardware prominence, and extensor tendon irritation, while all are associated with varying degrees of malunion, nonunion, and infection.[7] Headless screws have been used for fixation of other hand fractures, carpal injuries, and radial head fractures with success seen in these arenas.[8-10] Intramedullary headless screws have been applied to metacarpal shaft fractures as well as comminuted sub-capital fractures with success.[4] Advantages of percutaneous, intramedullary headless screw fixation include minimal soft tissue dissection, rigid fixation in the distal fragment and isthmus of the metacarpal, and limited required immobilization time to prevent the stiffness that occurs all too commonly in these injuries. Mechanical analyses of the headless screw technique, however, are sparse and conflicting within the literature.[11, 12]

The objective of the present study was to compare the biomechanical characteristics of intramedullary headless screw (IMHS) fixation with crossed K-wires (CKW) in metacarpal neck fractures. We hypothesized that IMHS is biomechanically superior to the percutaneous CKW construct.

METHODS

Twenty-three age-matched cadaveric metacarpal specimens were used in this study. Specifically, metacarpals two (index), three (middle), four (ring), and five (small) were utilized. In order to introduce a replicable fracture, a transverse osteotomy was performed using a precision, thin-blade oscillating saw at the metacarpal neck of each specimen. A smooth osteotomy cut was created in order to mitigate the challenges of reproducing the same interdigitating pattern among numerous osteotomies. Each of metacarpal specimens was then randomly assigned to undergo fixation by one of two distinct constructs. Eleven of the specimens were assigned to receive IMHS fixation while the remaining 12 underwent CKW pinning. The IMHS implants used were Medartis 3 mm CCS Speedtip screws (Basel, Switzerland). After over-drilling the metacarpal head with a cannulated drill bit, the screws were inserted in a retrograde manner with the guide wire placed in the dorsal, central half of the metacarpal in line with the intramedullary canal to a depth of approximately 1 mm below the level of the articular surface (Figure 1). CKW implants were 0.045 inches in diameter, non-threaded wires and were placed retrograde with a starting point at the collateral recess with care taken to engage the far cortex with the wire (Figure 2).

Each specimen was tested with a bending moment provided by a servo-hydraulic testing machine (MTS 858 Mini Bionix, MTS Systems, Corp.; Eden Prairie, MN), as seen in Figure 3, and loaded to failure at the distal fragment. Failure was defined as a distinct change in the load-displacement curve, and the load was incrementally increased until the fixation construct failed by implant deformity, loss of reduction, or metacarpal fracture. Mechanical parameters that were calculated and recorded included stiffness (slope of the linear portion of the stress/strain curve, N/mm), load-to-failure (N), maximum displacement (displacement at failure, mm), and energy absorption (area under the curve, Nmm).

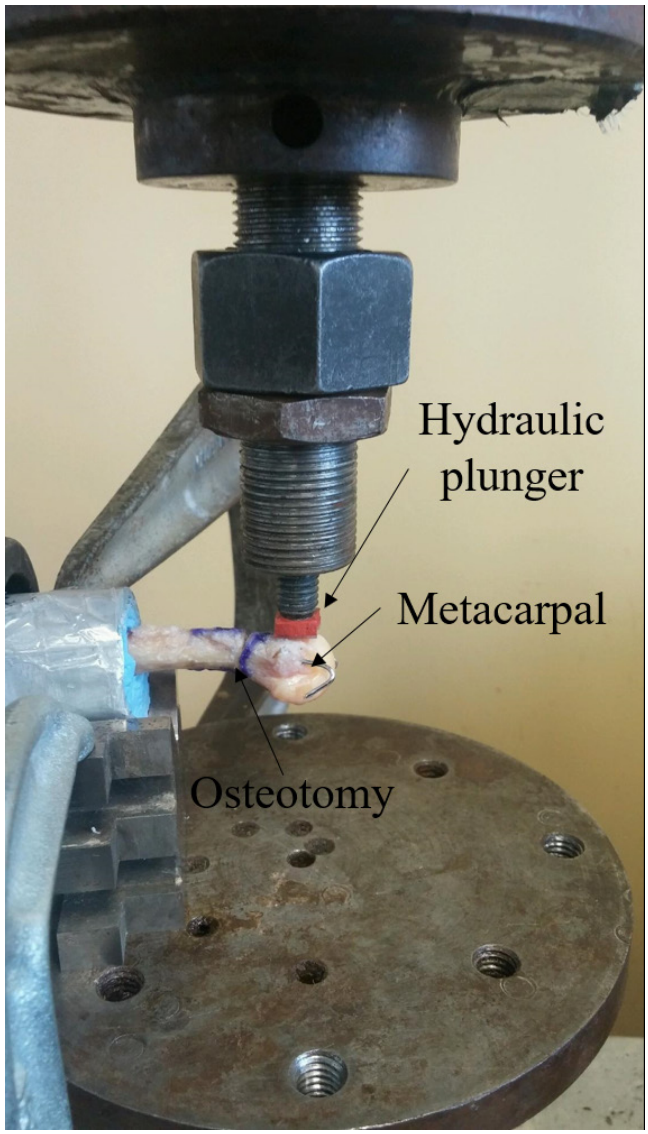

Figure 3. MTS machine with metacarpal mounted.

Data are presented as mean and standard deviation (SD). For statistical analyses, groups were initially assessed for normality of distribution using the Kolmogorov-Smirnov test and then compared using an unpaired student's t-test. For those variables failing the normality test, a nonparametric Mann-Whitney U Test was implemented. R-project statistical software (R Foundation, Boston, MA) were used for all statistical analyses. A p-value of less than 0.05 was considered to be significant.

RESULTS

The biomechanical characteristics of both IMHS and CKW constructs are shown in Table 1. Of the fixation constructs, CKW demonstrated a higher stiffness (17.7 N/mm) than IMHS (11.3 N/mm). This difference was statistically significant (p = 0.02).

Table I. Biomechanical characteristics of both fixation constructs

Parameter	IMHS		CKW		P-Value
	Mean (SD)	Range	Mean (SD)	Range	
Stiffness (N/mm)	11.3 (3.4)	5.8 - 16.2	17.7 (7.8)	5.9 - 30.1	0.02
Load-to-Failure (N)	70.6 (30.1)	32.8 - 123.8	97.5 (34.7)	41.8 - 157.5	0.06
Maximum Displacement (mm)	20.2 (4.6)	11.5 - 26.4	24.1 (3.7)	19 - 30	0.04
Energy Absorption (Nmm)	778.3 (528.9)	272.9 – 1,790.5	1,095.9 (454.4)	397.8 – 1,933.3	0.14

IMHS, intramedullary headless screw; CKW, crossed K-wires; N, newtons; mm, millimeters; SD, standard deviation

Further analysis was performed of the load-to-failure. As with stiffness characteristics, CKW had a higher load-to-failure (97.5 N) compared to IMHS (70.6 N). However, this finding only trended toward, but did not achieve, statistical significance (p = 0.06).

The displacement at the time of failure was also evaluated. As with the other aforementioned parameters, CKW had a greater maximum displacement (24.1 mm) than IMHS (20.2 mm). This difference was statistically significant (p = 0.04).

Additionally, CKW had approximately 40% higher energy absorption (1,095.9 Nmm) when compared to IMHS (778.3 Nmm). Like the load-to-failure analysis, however, this difference was not statistically significant (p = 0.14).

DISCUSSION

Of metacarpal fractures, the most common injury pattern is a metacarpal neck fracture, particularly among younger, active patients. Indications for surgery are largely dictated by the degree of dorsal angulation, with the more radial digits tolerating less deformity due to their more rapid decrease in grip strength with increasing angulation compared to the ulnar digits, as well as presence of a rotational deformity. With surgical complication rates as high as 36%, there appears to be no definitive consensus on the ideal fixation method for metacarpal neck fractures.[13]

Our results demonstrate the biomechanical superiority of CKW as compared to IMHS for the treatment of metacarpal neck fractures. This was evidenced by the significantly higher stiffness and maximum displacement required to induce construct failure with CKW fixation. Of note, consistent with this trend was the

observation that CKW constructs also had higher load-to-failure values and energy absorption, although these two characteristics were not statistically significant. Overall, these findings indicate that CKW confers a more stable construct than IMHS. This contrasts with the limited extant literature, which includes only two studies investigating the mechanics of IMHS. Jones et al performed a comparative mechanical analysis of IMHS, CKW, and locking plate fixation for the treatment of metacarpal neck fractures in 30 specimens.[12] Similar to the present study, they found no difference in the load-to-failure between the constructs. However, unlike the current investigation, they reported a higher stiffness with IMHS compared to CKW and similar maximum displacement between both. Their use of composite Sawbones instead of cadaveric specimens could account for such differences. Ultimately, Jones et al concluded that both methods provide comparable mechanical fixation properties. Additionally, Avery et al conducted a biomechanical evaluation of cadaveric metacarpal neck fractures treated with either IMHS or intramedullary K-wire fixation.[11] They found IMHS to be superior in 3-point bending, axial loading, and load-to-failure. However, their analysis included a limited mechanical evaluation of only stiffness and load-to-failure, whereas the present study performed a more robust assessment with four parameters. Also, as noted, Avery et al compared IMHS to longitudinally-oriented intramedullary K-wires, which is an inherently different K-wire configuration than CKW. Other fixation methods for metacarpal neck fractures, such as the metacarpal sled, locking plate, and various other K-wire configurations have demonstrated comparable biomechanical profiles.[14-16]

While the findings of the present study indicate that the more traditional fixation method of CKW yields superior mechanical stability, recent clinical studies investigating IMHS have sparked interest in this newer technique. In a small series examining the short-term (average of 36 weeks) results of metacarpal neck and shaft fractures treated with IMHS, Doarn et al showed a mean return to work at six weeks and radiographic healing at 49 days.[17] They supported the use of IMHS for these injuries due to the advantages of early motion without immobilization and relative technical ease. In another, larger series, 39 patients were evaluated after undergoing IMHS with 3-month follow-up.[18] All patients had full motion with extensor lags resolving by three weeks, with full return of grip strength and radiographic union by six weeks. Concerns regarding the use of IMHS fixation include the necessary violation of the articular surface of the metacarpal with the drill and the implant. This was evaluated using 3-dimensional CT analysis and determined that the recommended dorsal starting point for the IMHS involved only 4% of the articular surface in the sagittal plane of motion and did not engage through most of this arc.[19]

This study, however, is not with its limitations. Specifically, the present study employed a relatively small sample size. Nonetheless, the sample size is similar to those utilized in other metacarpal fracture fixation studies, and it was large enough to detect multiple statistically significant differences between the two study groups.[11, 12] Additionally, as the specimens were cadaveric, they were likely largely from older patients as compared to the typically younger patient who sustains a metacarpal neck fracture. Also, as the specimens were from various patient donors, there may be inherent differences in structural characteristics between the metacarpals, such as the bone mineral density, which could impact the mechanical testing results.

The biomechanical properties of the CKW technique were found to be superior to those of IMHS. This, coupled with their lower cost compared to the implants utilized in other fixation methods (such as IMHS and plate constructs), make CKW a preferred technique. However, the amount of strength required for stable fixation in the clinical setting has not been determined. Thus, biomechanically inferior constructs such as IMHS may be suitable for fixation and should be customized to the particular fracture. Given this, as well as the relative ease of insertion of the IMHS implants, the avoidance of postoperative immobilization, and the clinical outcomes as reported in the previously-cited studies, IMHS should still be placed in the surgeon's toolbox for the treatment of metacarpal neck fractures.

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SINGLE FOREARM VESSEL INJURY IN A PERFUSED HAND: REPAIR OR LIGATE? A SYSTEMATIC REVIEW.

Sarah M. Schippers MD, Christina Hajewski MS MD, Natalie A. Glass PhD, Lindsey Caldwell MD

ABSTRACT

Background: The purpose of this study was to systematically review available literature reporting vessel patency and how this correlates with cold symptoms following the treatment of a single forearm artery injury when the hand remains perfused. The outcomes of those treated by ligation were compared to those treated with vessel repair.

Methods: Electronic databases including PubMed, Embase (Elsevier) and Cochrane Central Register of Controlled Trials (Willey) were searched for studies that reported the outcomes of patients who underwent either ligation or repair of single vessel injuries to hands that remained perfused at time of presentation. Level of evidence was determined by two independent reviewers. Studies were then sorted based on Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and application of inclusion and exclusion criteria. A total of 19 studies were included for statistical analysis. The patency of repaired vessels was calculated (with comparison between those with radial versus ulnar repair) as was the prevalence of cold symptoms in both ligation (or repairs that went on to occlusion) and repair groups.

Results: The average patency of radial and ulnar artery repairs was 68.39% and 65.56% respectively. There was no significant difference between the success rates of these repair groups (pooled estimates for odd ratios was 1.02, p=0.867). The average incidence of cold symptoms in those who underwent ligation (or repair that when on to occlusion) and those that had patent repairs were 19.82% and 17.27% respectively. There was no significant difference between the incidence of cold symptoms between these groups (pooled estimate for proportion of patients with cold symptoms was 0.223, p=0.573).

Conclusions: This review showed there to be no significant difference in patency of isolated radial or ulnar artery repairs. There was also no significant difference in the prevalence of cold sensitivity in patients who underwent vessel ligation compared to those who underwent repair (and subsequently remained patent). These results support the conclusion of there being no clear benefit to attempting repair of a single vessel, although further studies are needed given the often incomplete reporting of clinical outcomes in this patient population. Additionally, though a cost-benefit analysis was not included in this review, exploring this aspect of the decision making process could be valuable.

Level of Evidence: IV

INTRODUCTION

Arterial injury in the upper extremity is a diagnosis encountered by not only hand surgeons but by orthopedic surgeons who operate on the upper extremity or manage basic orthopedic trauma. It is most often faced in the setting of acute trauma but can also result from intra-operative, iatrogenic injury to a forearm vessel. When presented with this scenario, the first question asked is often whether the hand remains well-perfused by the uninjured second forearm vessel. A hand that lacks adequate blood flow obviously necessitates intervention to restore perfusion. However, the more critical clinic decision-making comes when the hand remains well-perfused and/or is asymptomatic (absence of paresthesias or cold sensitivity).

Historically, while there has been no clear consensus on how to manage these single vessel injuries, expected repair patency rates of less than 50% are frequently cited[1]. Another study notes that the failure to reestablish blood flow through a forearm vessel is thought to be associated with hand claudication and cold sensitivity[2]. There are also reports that cold sensitivity is a complication that can occur independent of the long-term patency which might lead one to favor ligation over repair[3]. However, when there is a paper that cites a six-fold increased risk

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of wound healing complications in patients who undergo arterial ligation, this rationale is also questioned[4]. Most studies of this injury were conducted over twenty years ago and a more recent review of outcomes in single-vessel trauma is lacking[1-7].

Given the infrequency with which single vessel injuries may present to one surgeon or one hospital, it is apparent that a systematic review of the literature would allow for the best analysis of patient outcomes. Our goal was to identify all literature reporting outcomes of ligation or repair of single vessel injuries in a perfused hand, specifically patency rates and incidence of cold sensitivity symptoms. Our hypothesis was that there would be no difference in patency between radial and ulnar artery repairs but that there would be an increased incidence of cold symptoms in those that were treated with ligation or those whose attempt at repair failed, thereby justifying attempts at repair.

METHODS

Inclusion Criteria

Studies eligible for inclusion included the following: (1) patients presenting with an asymptomatic, perfused hand after sustaining an injury to either the radial or ulnar artery; (2) minimum 1 month follow up for outcomes; (3) published in English language; (4) study defined by two independent evaluators as level III or IV evidence.

Exclusion Criteria

Studies with the following criteria were excluded: (1) animal studies and case reports; (2) no record of repaired vessel patency or no stratification of outcomes based on treatment type.

Literature Search

Search strategies were developed with the assistance of a health sciences librarian with expertise in searching for systematic reviews. Comprehensive search strategies, including both subject and keyword methods, were developed in April 2017 for the following databases PubMed, Embase (Elsevier), and Cochrane Central Register of Controlled Trials (Wiley). Additionally, manual bibliographic review was used to retrieve additional studies that may have been missed during the primary study. In order to maximize sensitivity, English language was the only database filter applied. The full PubMed search strategy, as detailed in Appendix A, was adapted for use with the other electronic databases. Complete search strategies are available upon request. Total yield and duplicate count can be found in the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) flow diagram- Figure 1. Duplicates were managed primarily by the health sciences librarian using reference management software (EndNote X7) but also by manual title/ abstract review to exclude all duplicates.

Study Evaluation

The systematic review was conducted according to the PRISMA statement, the flow diagram of this process has been included in Figure 1[8]. Our initial search yielded 2,785 studies. After duplicates were removed, 2013 studies remained. Initial titles and abstracts were screened for relevance and 86 studies remained. These studies were evaluated by two independent assessors to determine level of evidence and exclude Level 5 studies. The remaining studies were then evaluated based on inclusion and exclusion criteria. Five studies were excluded because they either did not specify which artery was repaired or did not include patency and/or cold sensitivity results to be included in our outcomes analysis. This left a total of 19 studies for full text analysis; the details of these studies can be found in Table 1 and Table 2.

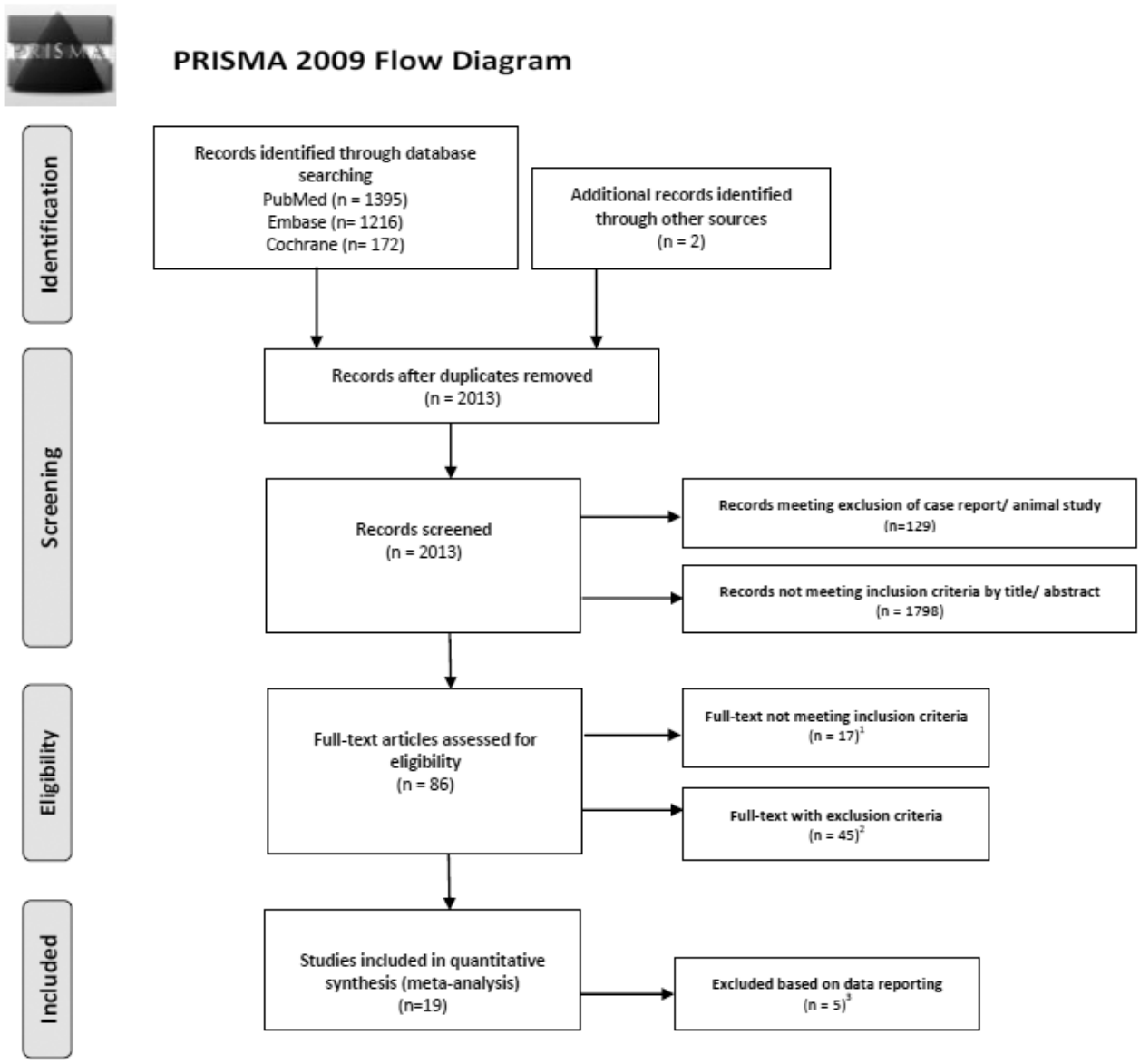
Once results were compiled, patency rates of radial artery repairs were averaged and then compared to ulnar artery patency rates. Next, the prevalence of cold symptoms in those with a patent, repaired vessel were averaged across all studies that reported this data point and compared to the average prevalence of cold symptoms in those that underwent initial ligation (or who had a repaired vessel that later occluded).

To evaluate whether surgical repair location influenced subsequent patency, odds ratios for patency were determined for radial versus ulnar repairs. To determine whether surgical intervention was associated with later development of cold symptoms, the proportions of patients with patency out of all patients were determined for repaired and ligated vessels for each study and transformed using the Freeman-Tukey double-arcsine method to stabilize variances.

Evaluation of Funnel Plots and Egger's tests could not rule out publication bias. Heterogeneity across studies was present as determined using the Q and I^2 statistics. Therefore, inverse-variance weighted random-effects models were used to evaluate the pooled estimates using R software. Forest plots were also generated to display the odds ratios (analysis 1) and the proportion with cold symptoms (analysis 2) and exact 95% confidence interval for each study as well as the overall, random-effects pooled estimate for each group and its confidence interval. These figures are also available upon request.

RESULTS

A total of 19 articles were included in final analysis (Table 1 and 2). Studies were all retrospective and either Level III or IV evidence. Thirteen of the studies were used for comparing difference in patency between



1. reported on patients who were symptomatic at time of presentation
2. did not report outcomes (patency or cold symptomes) or did not report cold symptoms based on treatment type
3. did not specify which vessel was repaired

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For more information, visit www.prisma-statement.org.

Figure 1. PRISMA Flow Diagram

Table I. Studies reporting patency of either radial or ulnar artery repair

Author_year	Title	Radial		Ulnar	
		Total	N_pat	Total	N_pat
Lee_2008[4]	Acute penetrating arterial injuries of the forearm. Ligation or repair?	20	18	24	19
Sitzman_1984[6]	Management of arm arterial injuries	20	12	24	13
Johnson_1993[2]	Radial or ulnar artery laceration. Repair or ligate?	12	6	14	6
Aftabuddin_1995[3]	Management of isolated radial or ulnar arteries at the forearm	26	14	20	10
Lannau_2015[10]	Long-term Patency of Primary Arterial Repair and the Modified Cold Intolerance Symptom Severity Questionnaire	4	4	6	3
Park_2014[11]	Timing of forearm arterial repair in the well-perfused limb	13	13	13	13
Gelberman_1982[1]	The results of radial and ulnar arterial repair in the forearm. Experience in three medical centers	14	9	20	7
Nunley_1987[12]	Arterial stump pressure: a determinant of arterial patency?	12	5	15	10
Bacakoglu_2001[9]	Multifactorial effects on the patency rates of forearm arterial repairs	8	5	18	15
Raza_2014[13]	Flexor Zone 5 cut injuries: emergency management and outcome	6	4	10	10
Stricker_1989[14]	Single-vessel forearm arterial repairs. Patency rates using nuclear angiography	10	7	10	6
Klocker_2010[15]	Repair of arterial injury after blunt trauma in the upper extremity - immediate and long-term outcome	6	5	4	4
Dorweiler_2003[16]	Limb trauma with arterial injury: long-term performance of venous interposition grafts	5	4	2	2

radial and ulnar arteries, five of which were also used in addition to the remaining six studies (for a total of 11) to compare the incidence of cold symptoms in patent versus ligated or thrombosed vessels. Studies that were used to compare patency of radial versus ulnar repairs had a total of 418 patients and studies used to compare prevalence of cold symptoms had a total of 337 patients.

In our review of overall vessel patency, we included 155 attempted radial repairs and 180 ulnar repairs. These repairs were identified from studies that also had a collective 83 initial ligations of injured vessels meaning that repair was attempted in just over 80% of cases. Radial artery patency rates were 68.39% whereas ulnar artery patency was 65.56%. This was not found to be a significant difference (pooled estimates for odd ratios was 1.02, p=0.867).

When analyzing the prevalence of cold symptoms we identified 119 vessels with patent repairs, of which 19 (17.27%) reported cold symptoms. These studies also included 227 patients that had either undergone initial ligation of the injured vessel or had attempted repairs that went on to be non-patent at follow-up. From this group, 45 patients (19.82%) had complaints of cold sensitivity. These differences were again not statistically significant (pooled estimate for proportion of patients with cold symptoms was 0.223, p=0.573).

DISCUSSION

This systematic review of outcomes associated with single forearm artery injuries that were asymptomatic at time of presentation revealed there to be no significant difference in long-term patency of radial versus ulnar artery repairs. These rates were found to be 68% and 66% respectively. Additionally, we did not identify a significant difference in the reporting of cold sensitivity symptoms between patients with either a patent or occluded vessel with there being 17% and 20% prevalence respectively.

As previously mentioned, it has long been held that patency rates in repairs of single-vessel injuries with intact retrograde flow from the uninjured vessel are thought to be around 50%, which is less than the expected patency of two vessel repairs[1]. Multiple mechanisms are thought to be responsible for this decreased patency when there is perfusion through the second vessel including back

Table II. Studies reporting cold insensitivity outcomes following vessel injury

Author_year	Title	Repair		Ligation	
		Cold_symp	Total	Cold_symp	Total
Lee_2008[4]	Acute penetrating arterial injuries of the forearm. Ligation or repair?			1	12
Sitzman_1984*[6]	Management of arm arterial injuries	0	25	0	34
Johnson_1993*[2]	Radial or ulnar artery laceration. Repair or ligate?	2	12	2	20
Aftabuddin_1995*[3]	Management of isolated radial or ulnar arteries at the forearm	3	24	11	72
Boretto_2017*[17]	Delayed Repair of Ulnar Artery at the Distal Forearm	0	7	1	1
Park_2014[11]	Timing of forearm arterial repair in the well-perfused limb	4	26		
Bornmyr_1994*[18]	Laser Doppler imaging of finger skin blood flow in patients after microvascular repair of the ulnar artery at the wrist	10	11	4	4
O'Toole_2013*[19]	Fracture of the distal radius with radial artery injury: injury description and outcome of vascular repair	0	5	0	2
O'Shaughnessy_1991[5]	Consequences of radial and ulnar artery ligation following trauma			12	30
Gelberman_1979[7]	Forearm arterial injuries			14	20
Ballard_1992[20]	Management of small artery vascular trauma			0	32

pressure at the stump causing increased risk of occlusion[9]. Though our review did show single-vessel repairs patency to be considerable higher than 50%, we did not include any two vessel repairs in our analysis, so we are unable to comment on the relationship between patency and number of vessels injured/ repaired.

Our finding that cold symptoms, though anecdotally related to vessel injury/patency, were not influenced by long-term patency (or by initial ligation at time of injury) supports recent evidence that cold sensitivity is more impacted by concomitant nerve injury than by vessel patency[10]. This identifies another weakness in our study, since we were unable to account for, or identify, patients that had a nerve injury at the time of presentation. Similarly, there are several other complications such as work-induced claudication, hand weakness, and paresthesias, which have been postulated to arise from arterial injury. However, the literature again seems to suggest that these are less influenced by the return of blood flow through the injured vessel but more so by involvement of surrounding nerves and tendons.

As with all systematic reviews, our study is limited by the variability in study designs and the specific reporting of outcomes. For many of the studies that listed patency, there was no long-term follow up for reporting of negative outcomes such as cold sensitivity. Moreover, even the studies that did include outcomes did not specifically state that patients were asked about the presence of negative symptoms. Instead, it seemed that most outcomes were documented only after patient complaints, not due to standardized surveying. Future research could be focused on a prospective trial that randomizes patients to either ligation or repair and compares these outcomes with validated questionnaires. Additionally, while there was no cost analysis performed in association with this review, it can be inferred that the expenses associated with a microvascular procedure to repair a damaged vessel may far outweigh any theoretical benefits given the findings of this review. As such, a formal cost-benefit analysis would be a good addition to future projects.

With these limitations in mind, our systematic review of existing literature demonstrates there to be no significant difference in patency rates of ulnar versus radial artery repairs when the hand is perfused prior to intervention. Additionally, there is no difference in the prevalence of cold sensitivity symptoms in patients who undergo initial ligation compared to those who undergo successful repair when they are asymptomatic hand at time of presentation. Therefore, when deciding whether to attempt repair of a single forearm vessel injury, the decision should not be based on which vessel was injured or on the goal of preventing cold insensitivity.

ACKNOWLEDGEMENTS

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Appendix A

#1

(patency [Text Word] OR patent[Text Word] OR temperature intolerance[Text Word] OR cold intolerance[Text Word])

AND

(surgery[Text Word] OR surgical[Text Word] OR nonoperative[Text Word] OR operative[Text Word] OR repair[Text Word] OR ligations[Text Word] OR repairs[Text Word] OR ligation[Text Word] OR reconstruction [Text Word])

AND

(radial [Text Word] OR ulnar [Text Word] forearm [Text Word] AND (arteries[Text Word] OR artery [Text Word])

= 1191

#2

("Treatment Outcome"[Mesh] OR "Vascular Patency"[Mesh] OR "Ischemia"[Mesh] OR "Hand/blood supply"[Mesh] OR "Thermosensing"[Mesh] OR "Temperature"[Mesh]) AND (radial[Text Word] OR ulnar[Text Word] OR forearm[Text Word] OR "Arm Injuries"[Mesh])

AND

("Arteries/surgery"[Mesh] OR "Vascular System Injuries/surgery"[Mesh] OR "Radial Artery"[Mesh] OR "Ulnar Artery"[Mesh]) AND ("Ligation"[Mesh] OR "Microsurgery"[Mesh:noexp] OR "Orthopedic Procedures"[Mesh] OR "Reconstructive Surgical Procedures"[Mesh:noexp] OR "Anastomosis, Surgical"[Mesh:noexp] OR "Vascular Surgical Procedures"[Mesh:noexp])

= 447

#1 OR #2 AND English[lang]) = 1333

TRENDS AND COSTS OF ANTERIOR CERVICAL DISCECTOMY AND FUSION: A COMPARISON OF INPATIENT AND OUTPATIENT PROCEDURES

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ABSTRACT

Study Design: Epidemiologic Study.

Objectives: To identify the trends in utilization of outpatient discharge for single level anterior cervical discectomy and fusion (ACDF), between 2007 and 2014, and to compare the costs and incidence of complications against a cohort of inpatients.

Methods: We retrospectively reviewed 18,386 patients from the PearlDiver database from between 2007 and 2014. Discharge status was determined from billing codes. The total cost of all procedures and diagnostic tests, was determined for the global period from the time of diagnosis up until 90-days post-operatively, and the incidence of complications was recorded for 30-days.

Results: The proportion of outpatient discharges was stable around 20% from 2007 to 2014 (range17-23%). The mean 90-day cost was lower for outpatients ($39,528 v. $47,330) but reimbursement fell nearly 1/3 from 2007-2014 for both groups, and the difference between the two narrowed over time ($13,745 difference in 2008, to $3,834 in 2014). Outpatients had a lower incidence of overall 30-day complications (9.5% v. 18.6%, p<0.0001), but were also significantly less comorbid (mean Charlson comorbidity index 2.32 v. 3.85, p<0.001). Older patient age, obesity, cardiac, renal, and pulmonary comorbidity were each more common in the inpatients (p<0.05 for each).

Conclusions: Outpatient discharge after ACDF is a viable treatment option with a reasonable safety profile and decreased costs relative to inpatient admission. Appropriate patient selection is key, and the standard of care nationally for the comorbid patient remains inpatient admission. The economic trends and epidemiologic data presented here should be useful for health policy decisions.

INTRODUCTION

Anterior cervical discectomy and fusion (ACDF) is amongst the most common procedures performed in the cervical spine.[1] The procedure is generally successful, and the incidence of major morbidity is low.[2] Historically, patients were admitted for a 2-4 day inpatient hospital stay post-operatively, the principal advantage of which is close monitoring of the patient's neurologic and respiratory status.[3] However, inpatient admissions add to the cost of the procedure,[4] and it is not clear that observation in the hospital actually reduces the incidence of major complications.[2,4] Indeed, some authors have argued that inpatient admission actually increases the risk of nosocomial complications, without increasing the overall safety.[4-9] Furthermore, emergent complications are most likely to occur after multi-level procedures, or after procedures involving the upper cervical spine.[3] Thus, some authors have argued that single level procedures, or procedures in the sub-axial spine are safe enough to be performed on an outpatient basis.[7]

The bulk of this literature was published after 2010, with few papers appearing before 2007.[4] Thus, the evidence basis for outpatient treatment after ACDF is relatively new, and it is not clear what impact it has had on national practice patterns. Furthermore, several

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Conflict of Interest Statement:
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.

Ethical Review Committee Statement:
This study received an exemption by the institutional review board.

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Table I: ACDF Case Volumes By Discharge Status

Year	Inpatient	Outpatient	Total ACDF Patients	Cases Per 10,000 Population	% of Total That were Outpatients
2007	1034	282	1316	2.02	21
2008	1197	356	1553	2.39	23
2009	1394	382	1776	3.22	22
2010	1715	391	2106	3.70	19
2011	1858	403	2261	3.53	18
2012	2095	432	2527	3.59	17
2013	2552	605	3157	4.05	19
2014	2995	833	3828	3.97	22
Totals	14721	3665	18386	n/a	20

Table II: Comparison of Comorbidities Between Inpatients and Outpatients

Comorbidities	Outpatient (%) n=3665	Inpatient (%) n=14721	P Value
Age <40 yrs	9	4	<0.0001
Age 40-65 yrs	67	52	
Age > 65 yrs	24	43	
Female	51	53	0.0733
Male	49	47	
Obesity	17	21	<0.0001
Morbid Obesity	6	9	<0.0001
Smoke	38	40	0.0141
Diabetes	24	34	<0.0001
Apnea	11	14	<0.0001
Hyperlipidemia	56	68	<0.0001
Hypertension	59	73	<0.0001
PVD	3	5	<0.0001
Heart Failure	5	9	<0.0001
Artery Disease	16	24	<0.0001
Kidney Disease	5	10	<0.0001
Dialysis	<0.3	<0.3	0.8327
COPD	6	12	<0.0001
Liver Disease	5	6	0.0068
Charlson Comorbidity Index (Mean, sd)	2.32 (4.03)	3.85 (2.0)	<0.001

of the prior studies demonstrating cost reduction with outpatient ACDF used hospital billing records as the basis for their data. Hospitals are often reimbursed far less than they bill, and thus these records may not accurately represent true cost savings for the procedure.[10]

Thus, the purpose of the current study was to define the epidemiology and reimbursement patterns for outpatient ACDF since 2007. We utilized the PearlDiver database, which includes insurance reimbursement information, rather than hospital billing data. A detailed cost analysis was performed and a univariate analysis was conducted in order to determine which patient factors were associated with outpatient treatment.

METHODS

Patient Selection

We retrospectively reviewed patient records from 2007-2014 from the PearlDiver patient record database (PearlDiver Technologies, Inc. Warsaw, IN, USA), which has the insurance billing code records of millions of orthopedic patients. Current Procedural Terminology (CPT) codes for single level ACDF (22554 or 22551) were used to identify the cohort, and we then used a combination of International Classification of Disease, 9th edition (ICD-9) codes and CPT codes to exclude patients who had undergone concomitant multilevel procedures involving the cervical or thoracic spine, patients undergoing a discectomy without fusion, or patients undergoing a revision surgery. A full listing of the included codes is provided in the Appendix (Appendix Table 1).

Comorbidities and Complications

Patient comorbidities and post-operative complications that occurred within 30-days of the procedure were identified using ICD-9 codes, and a complete listing of the included codes is provided in the Appendix (Appendix Table 2 and Table 3). 30-days was chosen as the cutoff because it is a common metric used by the Center for Medicare and Medicaid Services as a quality measure. Some patients had more than one complication, and thus the composite category of "any complication," has

Table III: Average Total 90 Day Reimbursements

Year	Inpatients	Outpatients	Difference
2007	$51,080	$43,664.81	$7,414.72
2008	$55,732	$41,986.75	$13,745.12
2009	$57,058	$44,027.86	$13,030.44
2010	$53,826	$45,698.02	$8,128.07
2011	$52,690	$43,937.62	$8,752.03
2012	$47,584	$42,876.49	$4,707.51
2013	$43,246	$35,320.58	$7,925.45
2014	$33,980	$30,146.03	$3,833.58
Totals	47330.17	$39,527.96	$7,802.21

*P-Values could not be calculated for this analysis due to limitations of the PearlDiver Database

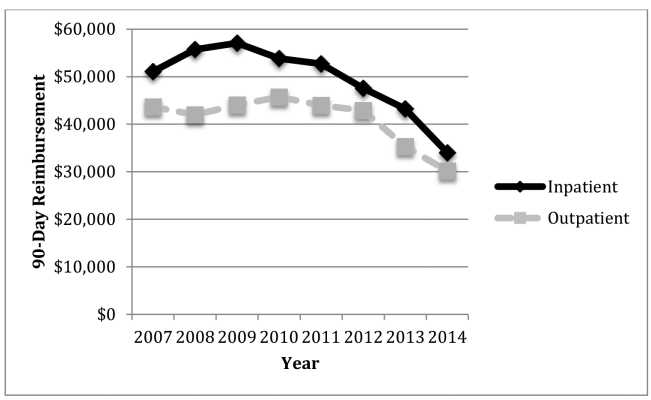

Figure 1: Trends in reimbursement from 2007 to 2014.

a lower total number than the sum of each of the individual categories. In addition, we determined the average Charlson comorbidity index of the cohort.

Costs

PearlDiver provides a total cost for the entire cohort and also an average cost per patient, starting from the time of their initial diagnosis in clinic, and continuing up to 90-days after their procedure. 90 days was chosen because it corresponds to the 90-day global fee period for reimbursement. The cost includes the reimbursement paid out by the insurance provider for all diagnostic tests, clinic visits, and procedures during the time period. The database will not provide standard deviation information for this analysis, and thus p-values cannot be provided.

Statistical Analysis

For the trends, comorbidities, and complications categories, patients were divided into cohorts of inpatients and outpatients, with discharge status determined by billing codes submitted to the payor. We then conducted a univariate analysis to compare the two cohorts, using a chi-squared test for categorical variables and a student's t-test for continuous variables. Statistical analysis was performed using SAS 9.3 (SAS Institute, Cary, NC).

Table IV: Average Reimbursement for Diagnostic Studies During the 90-Day Period

Year	Inpatients	Outpatients	Difference
2007	$27,739.50	$26,936.66	$802.84
2008	$28,849.77	$24,064.20	$4,785.58
2009	$28,314.46	$25,755.14	$2,559.32
2010	$27,781.31	$27,057.66	$723.65
2011	$25,917.10	$25,334.04	$583.06
2012	$25,285.11	$25,285.18	**-$0.07**
2013	$24,597.94	$23,643.59	$954.35
2014	$23,044.57	$22,840.61	$203.95
Totals	$25,843.61	$24853.78	$989.83

RESULTS

Trends

Between 2007 and 2014, the total number of ACDF performed on patients in the PearlDiver dataset increased from 1,316 annually up to 3,828 annually, which is a 191% increase (Table 1). However, enrollment in the PearlDiver dataset also increased during this time, and the per-capita utilization was a more modest 97% (Table 1). Of the total cohort, 20% were done on an outpatient basis, and the proportion of cases done on an outpatient basis was similar over time (Table 1).

Demographics and Comorbidities

On average, the inpatients were older (43% over age 65 years v. 24% of the inpatients, $p<0.001$), and were more comorbid overall, with a higher incidence of obesity (21% v. 17%, $p<0.001$), morbid obesity (9% v. 6%, $p<0.001$) diabetes (34% v. 24%, $p<0.001$), hyperlipidemia (68% v. 56%, $p<0.001$), hypertension (73% v. 59%, $p<0.001$), coronary artery disease (24% v. 16%, $p<0.001$), and chronic obstructive pulmonary disease (12% v. 6%, $p<0.001$). In addition, the average Charlson Comorbidity Index was significantly higher for the inpatients (mean 3.85 v. 2.32, $p<0.001$) (Table 2).

Reimbursement

The total reimbursement for the procedure, including all diagnostic tests and procedures performed from the time of the patient's diagnosis up until 90-days after their operation, on average was higher for inpatients, as compared to outpatients (Mean $39,528 for outpatients

Table V: Complications By Discharge Status

Complication	Outpatient (%) n=3665	Inpatient (%) n=14721	P-Value
Pulmonary Embolism	0.4	0.6	0.0783
DVT	0.4	0.9	0.0018
MI	<0.3	0.5	0.0115
Renal Failure	0.7	1.5	0.0001
UTI	1.8	4.1	<0.0001
Stroke	1.5	2.9	<0.0001
Wound Complication	1.2	2.2	<0.0001
Neurologic Deficit	<0.3	0.3	0.2862
Other Complication	1.3	1.7	0.0681
Any Complication	9.5	18.6	<0.0001

Some patients had more than one complication, and thus the total incidence of any complication is not the sum of the other categories.

v. $47,330 for inpatients) (Table 3). The average fell for both groups between 2007-2014. Specifically, for outpatients the average fell from $43,664 in 2007 to $30,146 in 2014, which is a 31% decrease. For inpatients, the average fell from $51,080 to $33,980, which is a 33% decrease (Figure 1). Furthermore, over time the difference between inpatient and outpatient reimbursement fell from a high of $13,745 in 2008, to $3,833 in 2014 (Table 3). PearlDiver provides a separate breakdown of reimbursement due to the ordering of diagnostic tests. The reimbursement for diagnostic tests was similar between both inpatient and outpatient groups, with an average of $25,844 for inpatients and $24,854 for outpatients (Table 4). However, this difference also decreased over time, from a high of $4,785.58 in 2008 down to $203.95 in 2014.

Complications

The incidence of complications within 30-days of surgery was significantly higher in the inpatient cohort, as compared to the outpatient cohort (18.6% v. 9.5%, p<0.001, Table 5). The most substantial increases were seen in the incidence of urinary tract infections (UTI) (4.1 v. 1.8%, p <0.001), renal failure (1.5 v. 0.7%, p<0.001), stroke (2.9 v. 1.5%, p=0.014), and wound complications (2.2 v. 1.2%, p<0.001) (Table 5).

DISCUSSION

The data presented here show relatively constant proportion of outpatient discharges for ACDF over time, with decreasing reimbursement for both inpatient and outpatient procedures. Complications were higher in the inpatients, but that cohort was also more comorbid at baseline. Several of these findings merit further discussion.

Trends

Somewhat to our surprise, and in spite of a majority of literature focusing on the issue recently,[2] outpatient discharges have not become more common since 2007, accounting for roughly 20% of the discharges in each year of our study. The first reports of outpatient ACDF appeared as early as 1996,[4] and it is possible that many surgeons had already adopted outpatient treatment into their practice prior to 2007. Furthermore, medical comorbidity was strongly associated with inpatient admission, indicating that surgeons are fairly selective in choosing which patients to treat as outpatients. The pool of patients for whom outpatient discharge is appropriate may be somewhat limited, thus limiting increased utilization.

Complications

Similar to the previously reported results from several studies, the unadjusted comparison of complications showed a higher incidence amongst the inpatient cohort.[4-9] In particular, the greatest magnitude of difference between the two cohorts was seen in the incidence of UTI (4.1 v. 1.8%, p<0.001), with each of the remaining categories being within 1-2% different. UTI is commonly a nosocomial complication associated with catheter insertion, and it seems reasonable that inpatients might have a longer exposure to indwelling catheters than do outpatients who are discharged more rapidly. Nonetheless, it is important to note that the limitations of the PearlDiver database precluded matching patients based on comorbidities, and thus the outpatient cohort was significantly less comorbid overall. Furthermore, a prior study in which patients were matched using propensity scores found no difference in complication incidence between inpatients and outpatients.[2] Thus, our results should be interpreted with caution, and do not imply that outpatient discharge is safer than inpatient admission. Rather, they likely reflect the fact that complications are more common in comorbid patients.

Factors Associated with Outpatient Discharge

It is clear that surgeons selectively choose their healthiest patients for outpatient discharge. In our univariate analysis, every recorded comorbidity was significantly more common in the inpatients. Ideally, this type of analysis would be done with a multivariate statistical comparison in order to determine which factors had the strongest independent association with outpatient discharge. However, the PearlDiver database limits access to individual patient data for privacy reasons, and thus only this composite comparison is available to us. A multivariate analysis of these factors would be

an interesting avenue for future study. Nonetheless, we feel these results help to define the standard practice nationally, and should provide some guidance to surgeons considering patients for outpatient discharge. We believe the standard of care for the multiply comorbid patient should remain inpatient admission.

Reimbursement

Inpatient surgery was more expensive, but this difference narrowed over time. The difference in reimbursement for diagnostic studies also decreased during this period, indicating that physicians may have become more conservative in their ordering of tests on post-operative patients. However, this decrease in diagnostic testing accounted for only 45.6% of the total decrease, indicating that a majority of the reduction came from the decreased cost of the hospitalization itself.

In 1996, Silvers et al multiplied the expected cost savings by an estimated annual number of inpatient procedures and argued that conversion of all ACDF patients to outpatient discharge would save the U.S. health system more than $100 million annually.[4] Data from the National Inpatient Sample estimates that roughly 125,000 ACDF were annually between 2007 and 2013.[11] Thus, using similar calculations, a conversion to all outpatient surgery would have saved U.S. health system over $1.6 billion in 2008 (the year of maximum difference between inpatients and outpatients in our study), but only $451.5 million in 2014. If the difference in costs between inpatient and outpatient procedures continues to narrow, the relative economic benefit may also continue to decrease.

The majority of prior economic studies in spine have concluded that national expenditure and costs per case are rising dramatically.[12-15] Somewhat in contrast to these studies, we found that average reimbursement per case has fallen from 2007 to 2014, both for inpatient (mean 33% decrease) and outpatient procedures (mean 31% decrease). There are two explanations for this discrepancy. First, the data from our study is relatively recent, spanning the time period from 2007 to 2014. During this recent time period, significant emphasis has been placed on cost containment, and many hospitals have engaged in cost reduction strategies specifically in spine. It is possible that these strategies have been at least partially successful, thus contributing to a reduction in costs. Secondly, prior studies on costs in spine have mostly utilized hospital charges,[10,12-15] which represent the bill sent to the insurance payor, but not the actual cost or the actual reimbursement received. Some hospitals are reimbursed a percentage of the bill they send out. One strategy to fight falling reimbursements might be to simply increase the hospital charge, and hospital bills may in fact be artificially elevated in response to the decreased reimbursement trend that we observed here.[10] Thus, studies that drew conclusions from hospital charge data might have been biased by an artificial billing practice, rather than from actual changes in the economics of the procedure.

Limitations

Our study does have several limitations. Notably, we calculated costs using reimbursement data, and included both pre-operative testing as well as fees from the 90-day global period post-op. Prior studies on reimbursement for ACDF have reported costs ranging from $10,879 to $24,923, with significant geographic variation,[10] and significant variation depending on whether hospital charges or insurance reimbursement was used to define costs.[16-18] However, the majority of these studies reported only the costs associated with the surgical admission, and thus the numbers in our study are understandably higher. Focusing solely on the initial surgical procedure might have excluded costs associated with the readmission of outpatients, or with additional procedures or tests done after discharge. Thus we felt that a comparison of reimbursements from the period both before and after the surgery would provide a more accurate assessment of cost differences between inpatients and outpatients. Nonetheless, a direct comparison of the costs from our paper to these other studies is not possible because of differences in methodology. Furthermore, our conclusions are based on insurance billing records, which may be subject to some level of coding error, and this limitation is present in any database study. Lastly, the PearlDiver dataset limits what information is available to researchers in order to protect patient privacy. Thus, some data points, such as the standard deviation of the cost information, and individual patient medical comorbidities, are not available to us. This limits the type and scope of the statistical analysis that can be performed. For example, we cannot definitively say that the difference in reimbursement between inpatients and outpatients is statistically significant. However, the trends in reimbursement are clear, and we believe that these paint an accurate picture for the reader.

CONCLUSIONS

Outpatient discharge after ACDF is a viable treatment option with a reasonable safety profile and decreased costs relative to inpatient admission. Appropriate patient selection is key, and the standard of care nationally for the comorbid patient remains inpatient admission. The economic trends and epidemiologic data presented here should be useful for making health policy decisions, and for future researchers in this area.

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Appendix Table I: Inclusion and Exclusion Criteria

Codes to Include	Codes to Exclude
ICD9 Diagnosis of 710-739 (includes musculoskeletal conditions and arthropathy of the spine), 341 (demyelinating diseases), 342 (hemiplegia or hemiparesis), 344 (other paralysis). and 22554: Arthrodesis, anterior interbody technique, including minimal discectomy to prepare interspace (other than for decompression); cervical below C2. or 22551: *Arthrodesis, anterior interbody, including disc space preparation, discectomy, osteophytectomy and decompression of spinal cord and/or nerve roots; cervical below C2*	ICD9 Codes Below 710, or above 739, except those listed to the left. 22533 or 22532 – Thoracic or lumbar interbody arthrodesis from an anterior approach. 22856 – Cervical total disc arthroplasty. 22633 – Posterior lumbar fusion 22318 or 22319 – Open treatment of odontoid fracture. 22220, 22224, 22226 – osteotomies. 22548 – Anterior C1-2 arthrodesis. 22590 – Occiput –C2 arthrodesis. 22595 – Posterior C1-2 fusion 22600 – Posterior cervical arthrodesis. 22612 – Posterior lumbar fusion 22630 – Posteiror Lumbar interbody fusion 62287 – Needle based discectomy, any level. 63001-63047– Laminectomy codes 63081 – Cervical corpectomy. 63082 – Cervical corpectomy, each additional level. 63075 and 63076 – Cervical discectomy codes. Exclude these if they appear alone, without an associated code for fusion 63050 – Cervical Laminoplasty 63051 – Laminoplasty with reconstruction of bony elements 63081 – Partial cervical corpectomy 63101-63103 – Vertebrectomy in thoracic or lumbar spine. 63300-63308 – Excision of spinal neoplasm codes. 22855 – Removal of anterior instrumentation 22830 – Exploration of a fusion 22849 – Reinsertion of a spinal fixation device 22840-22844 – Posterior segmental instrumentation 22610-22614 – Posterior thoracic fusions.

Appendix Table II: Complications by ICD-9 Code

Dysphagia, vocal cord paralysis	
478.30-34	Paralysis of vocal cords or larynx
784.4	Voice and resonance disorder
787.2	Dysphagia
Nerve system complications	
997.0	Nervous system complication
997.00	Nervous system complication, unspecified
997.01	Central nervous system complication
997.09	Other nervous system complication
Wound complication	
998.1	Hemorrhage or hematoma or seroma complicating a procedure
998.11	Hemorrhage complicating a procedure
998.12	Hematoma
998.13	Seroma
998.3	Disruption
998.31	Disruption of internal surgical wound
998.32	Disruption of external operation wound
998.5	Postoperative infection
998.51	Infected postoperative seroma
998.59	Other postoperative infection
998.83	Non-healing surgical wound
999.3	Other infection
DVT	
453.40	Acute venous thrombosis or venous thromboembolism of the lower extremities.
453.41	Acute DVT of proximal lower extremity
453.42	Acute DVT of the distal lower extremity.
453.82	Acute DVT of upper extremity
Pulmonary Embolism	
415.11	Iatrogenic Pulmonary Embolism
415.13	Saddle Embolus of the pulmonary artery
415.1	Pulmonary Embolism and Infarction
415.19	Other pulmonary embolism
Acute Myocardial Infarction	
410.00	Acute MI of anterolateral wall
410.01	Acute MI of anterolateral wall
410.10	Acute MI of other anterior wall
410.11	Acute MI of other anterior wall
410.20	Acute MI of inferolateral wall
410.21	Acute MI of inferolateral wall
410.30	Acute MI of inferoposterior wall
410.31	Acute MI of inferoposterior wall
410.40	Acute MI of inferior wall
410.41	Acute MI of inferior wall
410.50	Acute MI of lateral wall
410.51	Acute MI of lateral wall
410.60	Posterior Wall Infarction
410.61	Posterior Wall Infarction
410.70	Subdendocardial Infarction
410.71	Subendocardial Infarction
410.80	Acute MI of other wall site
410.81	Acute MI of other wall site
410.90	Acute MI of unspecified site
410.91	Acute MI of unspecified site

Appendix Table II: Complications by ICD-9 Code

Respiratory Failure	
518.0	Pulmonary Collapse
518.51	Acute respiratory failure following surgery
518.52	Other respiratory failure
518.81	Acute pulmonary insufficiency
518.82	Other pulmonary insufficiency
Urinary Tract Infection	
996.64	Infection due to indwelling urinary catheter
599.0	Urinary tract infection
Acute Renal Failure	
584.5	Acute kidney failure due to ATN
584.6	Acute kidney failure due to renal cortical necrosis
584.7	Acute kidney failure due to renal medullary necrosis
585.8	Acute kidney failure of other lesion
584.9	Acute kidney failure, unspecified
Stroke	
430-436	Intracranial hemorrhage or CVA
Other Medical Complications Medical	
997.1	Cardiac complication
997.2	Peripheral vascular complication
997.3	Respiratory complication
998.0	Postoperative shock
998.8	Other specified complication of procedure, not elsewhere classified
998.89	Other specified complication
998.9	Unspecified complication of procedure, not elsewhere classified
999.9	Other and unspecified complication of medical care, not elsewhere classified

Appendix Table III: Comorbidities by ICD9 Code

Obesity	ICD-9-D-27800,ICD-9-D-V853,ICD-9-D-V8530:ICD-9-D-V8539
Morbid Obesity	ICD-9-D-27801,ICD-9-D-V854,ICD-9-D-V8541:ICD-9-D-V8545
Smoking History	ICD-9-D-3051,ICD-9-D-V1582
Diabetes Mellitus	ICD-9-D-24900,ICD-9-D-24901,ICD-9-D-24920,ICD-9-D-24921,ICD-9-D-24930,ICD-9-D-24931,ICD-9-D-24940,ICD-9-D-24941,ICD-9-D-24950,ICD-9-D-24951,ICD-9-D-24960,ICD-9-D-24961,ICD-9-D-24970,ICD-9-D-24971,ICD-9-D-24980,ICD-9-D-24981,ICD-9-D-24990,ICD-9-D-24991,ICD-9-D-25000:ICD-9-D-25003,ICD-9-D-25010:ICD-9-D-25013,ICD-9-D-25020:ICD-9-D-25023,ICD-9-D-25030:ICD-9-D-25033,ICD-9-D-25040:ICD-9-D-25043,ICD-9-D-25050:ICD-9-D-25053,ICD-9-D-25060:ICD-9-D-25063,ICD-9-D-25070:ICD-9-D-25073,ICD-9-D-25080:ICD-9-D-25083,ICD-9-D-25090:ICD-9-D-25093
Obstructive Sleep Apnea	ICD-9-D-32723
Hyperlipidemia	ICD-9-D-2720:ICD-9-D-2724
Hypertension	ICD-9-D-4010,ICD-9-D-4011,ICD-9-D-4019
Peripheral Vascular Disease	ICD-9-D-44020:ICD-9-D-44024,ICD-9-D-44029:ICD-9-D-44032,ICD-9-D-4404,ICD-9-D-4408
Congestive Heart Failure	ICD-9-D-4280,ICD-9-D-4281,ICD-9-D-42820,ICD-9-D-42822,ICD-9-D-42830,ICD-9-D-42832,ICD-9-D-42840,ICD-9-D-42842,ICD-9-D-4289
Coronary Artery Disease	ICD-9-D-41400:ICD-9-D-41405,ICD-9-D-4142:ICD-9-D-4144,ICD-9-D-4148,ICD-9-D-4149
Chronic Kidney Disease	ICD-9-D-5851:ICD-9-D-5856,ICD-9-D-5859
Dialysis	ICD-9-P-3995
Chronic Obstructive Pulmonary Disease	ICD-9-D-4910,ICD-9-D-4911,ICD-9-D-49120:ICD-9-D-49122,ICD-9-D-4918:ICD-9-D-4920,ICD-9-D-4928
Liver Disease	ICD-9-D-5712,ICD-9-D-5713,ICD-9-D-57140,ICD-9-D-57142,ICD-9-D-57149,ICD-9-D-5715,ICD-9-D-5718,ICD-9-D-5719

LONG-TERM FUNCTIONAL OUTCOMES OF DISTAL FEMORAL REPLACEMENTS COMPARED TO GEOGRAPHIC RESECTIONS FOR PAROSTEAL OSTEOSARCOMAS OF THE DISTAL FEMUR

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Mark T. Scarborough MD, Andre R. Spiguel MD*

ABSTRACT

Background: Parosteal osteosarcoma is a rare tumor with increased survival compared to conventional high-grade osteosarcoma. Due to this increased survival comes the need for reconstructive options that provide good long-term functional results. Current treatment methods include geographic resection with allograft reconstruction versus resection and reconstruction with a distal femoral replacement.

Purpose: Our purpose was to compare the long-term functional outcomes of distal femoral replacements to allograft reconstructions, using the musculoskeletal tumor society (MSTS) scoring system.

Methods: After querying our database, 12 patients were identified and completed a MSTS questionnaire.

Results: There was no difference in functional outcomes between the cohorts at an average of 14 years follow up for the endoprosthetic group and 25 years of follow up for the geographic resection group.

Conclusion: At long-term follow-up, patients who undergo a distal femoral replacement for a parosteal osteosarcoma have no difference in functional outcomes compared to those who undergo an allograft reconstruction.

Level of Evidence: IV

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INTRODUCTION

Parosteal osteosarcomas are rare tumors, accounting for up to 6% of all osteosarcomas.[1-3] They are located most commonly on the posterior aspect of the distal femoral metaphysis with a female predominance and a peak incidence in the 3rd and 4th decades of life.[1-5] Patients with these typically low grade tumors experience a markedly increased survival compared to conventional high grade osteosarcoma.[1,3,4,6]

Multiple treatment options have been described for parosteal osteosarcoma, the most common of which involve wide resection with either allograft or endoprosthetic reconstruction.[3,7,8] While there are many studies evaluating oncologic outcomes following these surgical treatments, there is currently limited data on long-term functional results. Given the young age and long-term survival in these patients following resection, a durable reconstruction with a good functional outcome is paramount. Our purpose in this study, therefore, was to compare directly these two surgical techniques based on patient-reported functional data utilizing the Musculoskeletal Tumor Society (MSTS) scoring system in order to determine the best reconstructive option following resection of a distal femoral parosteal osteosarcoma.

METHODS

Following our institutional review board approval we identified patients by querying our prospectively collected musculoskeletal oncology database for cases of parosteal osteosarcoma from 1965 - 2010. We identified 53 patients with parosteal osteosarcoma. Patients whose tumor was not located in the distal femur and who did not undergo either a geographic resection with allograft reconstruction or endoprosthetic replacement were excluded; this included five patients who underwent an osteoarticular allograft reconstruction, four patients who underwent a knee fusion, two patients who received an amputation, one patient who underwent a resection only, and one patient who underwent a rotationplasty. In total, nineteen patients met the inclusion criteria, however three patients were deceased. We then attempted written and telephone contact in order to complete a questionnaire containing the modified musculoskeletal tumor society (MSTS) scores as reported by Enneking et al.[9]

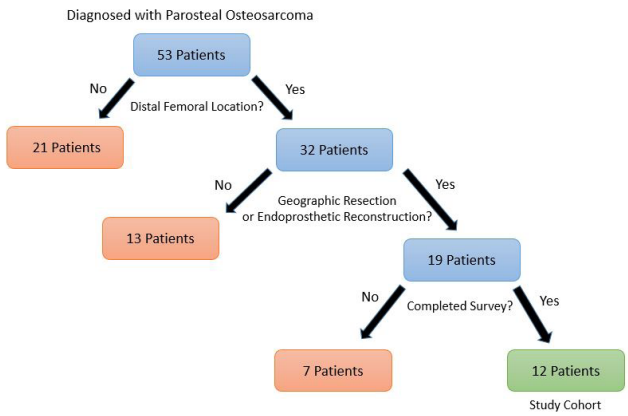

Figure 1: A flow diagram demonstrating arrival at the patient cohort

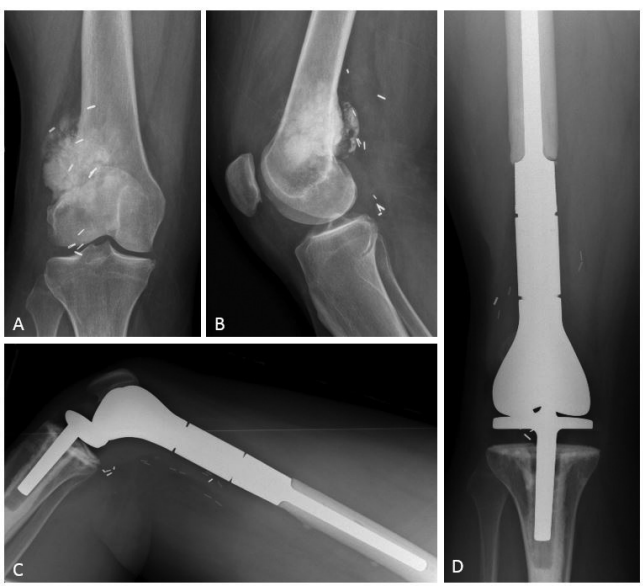

Figure 2: Anteroposterior (A) and lateral (B) radiographs of a dedifferentiated parosteal osteosarcoma that had recurred after attempted resection at an outside institution. Lateral (C) and anteroposterior (D) radiographs 3 years following resection and endoprosthetic reconstruction of the distal femur.

Twelve of sixteen patients responded to the questionnaire and were included in the study (Figure 1).

Medical records were reviewed to obtain demographic data as well as treatment details. The surgical procedure was recorded from the operative note and the tumor size and margin status were obtained from the pathology report. Margins were defined as previously described by Enneking et al.[10] Complications were recorded and defined as the need for any additional surgical procedure.

Statistics

Descriptive statistics and comparisons of mean MSTS questionnaire scores were calculated. For comparisons of means between two groups, two-sample independent t-tests or Mann-Whitney tests were performed with significance level of 0.05. All analyses were performed using SPSS (version 24, IBM).

RESULTS

Demographic data is recorded in Table I. There were 2 males (17%) and 10 females (83%). Five patients (42%) underwent endoprosthetic replacement (Figure 2) and 7 (58%) underwent geographic resection with allograft reconstruction (Figure 3). The average age at the time of surgery was 27 years (± 12 years). The average age of patients who underwent endoprosthetic replacement was 31 years (± 12.3 years), compared to 24 years (± 12.5 years) in the geographic resection cohort (p= 0.36). At the time of the questionnaire, the average age of the patients was 46 years (± 12 years) in the endoprosthetic cohort and 51 years (± 13 years) in the geographic resection group (p = 0.46). The average follow-up at the time of the survey was 14 years (± 11.9 years) for the endoprosthetic group versus 25 years (± 9.6 years) for the geographic resection group (p =0.92).

The average size of the tumor in greatest dimension was 8.9 cm (± 4.5 cm) for the endoprosthetic replacement cohort and 6.5 cm (± 4.3 cm) for the geographic resection cohort (p = 0.39). Two of the five tumors (40%) that were reconstructed with an endoprosthetic were resected with a marginal margin, compared to 4 of the 7 tumors (57%) that underwent geographic resection (p=0.58).

Table I: Demographic Data

	Endoprosthetic Reconstruction	Geographic Resection with Allograft Reconstruction	p value
Mean age at surgery (yrs.)	31 (± 12.3)	24 (± 12.5)	0.36
Mean Follow up (yrs.)	14 (± 11.9)	25 (± 9.6)	0.92
Average size of tumor (cm.)	8.9 (± 4.5)	6.5 (± 4.3)	0.39
Wide margin obtained	3 of 5 (60%)	3 of 7 (43%)	0.68
Required additional surgery	1 of 5 (20%)	3 of 7 (43%)	0.58

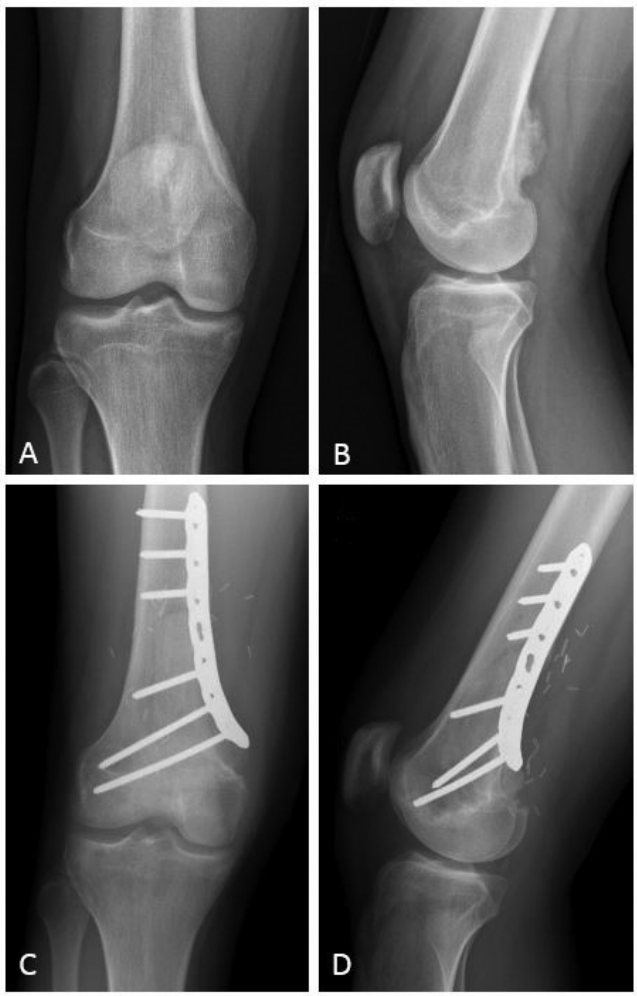

Figure 3: Anteroposterior (A) and lateral (B) radiographs of a parosteal osteosarcoma involving the anteromedial aspect of the distal femur. Anteroposterior (C) and lateral (D) radiographs 6 months following geographic resection with allograft reconstruction.

Patient-reported MSTS scores are recorded in Table II. The average total MSTS score was 23 (16-30) in the endoprosthetic group. This was the same as the score of 23 (18-26) in the geographic resection population. We did not find a significant difference in the pain scores (p=0.26), functional scores (p=0.24), emotional acceptance (p=0.91), ambulatory assist scores (p=0.36), walking tolerance (p=0.42), or total scores (p = 1.0) between the cohorts.

One patient (20%) required an additional surgical procedure in the endoprosthetic cohort, which consisted of a revision arthroplasty. This is compared to three (43%) reoperations in the geographic resection cohort. Two of the three procedures consisted of hardware removal for symptomatic hardware. The third procedure involved an above-knee amputation for a radiation-associated sarcoma. There was no significant difference in the rate of additional surgical procedures between the cohorts (p = 0.58) Individual patient data is recorded in Table III.

Table II: Patient-reported MSTS values

MSTS Parameter	Endoprosthetic Reconstruction	Geographic Resection with Allograft Reconstruction
Pain	4.6 (3-5)	4 (3-5)
Function	3.4 (3-5)	2.7 (1-4)
Emotional Acceptance	3.4 (3-5)	3.3 (1-5)
Ambulatory Assist	4.2 (1-5)	4.9 (4-5)
Walking Tolerance	4.4 (3-5)	4.6 (4-5)
Description of Walking	3.0 (1-5)	3.6 (3-5)
Total Score	23 (16-30)	23 (18-26)

DISCUSSION

Parosteal osteosarcoma is typically a low-grade tumor with low metastatic potential. Several studies have recommended wide resection in order to reduce the risk of recurrence.[5,11] If wide resection is performed, overall survival is quite high, with several studies demonstrating 90% survival at 10 years of follow up.[1,3,12] With this increased survival in a young patient population comes the need for a durable reconstructive option that offers the patient a high-functioning quality of life. Currently, however, there is limited data on functional outcomes following various reconstructive options. The purpose of this study, therefore, was to compare functional outcomes for the two most common reconstructive options following wide resection of a distal femur parosteal osteosarcoma in order to provide patients and physicians' information to help make well-informed decisions prior to surgery.

Previous reports have limited functional comparisons. For example, in a report by Lewis et al, the average range of motion at the knee following wide resection with hemicortical allograft reconstruction was 0-122 degrees. In their study 80% of patients were free of pain and had returned to preoperative functional activities at a mean of 4.3 years postoperatively.[8] The authors did not include MSTS scores in their review. Similarly, Kavanagh et al. reported outcomes following resection of a parosteal osteosarcoma with endoprosthetic reconstruction. Out of 14 cases, they reported eight outcomes as excellent, four good, one fair, and one poor, based on MSTS scoring.[7] Both studies were however limited to a single reconstructive technique, making comparisons difficult. Alternatively, Funovics et al. compared 12 patients that underwent endoprosthetic replacement to 11

Table III: Parosteal cohort included in the analysis

Sex	Involved Side	Surgery	MASS - GREATEST DIMENSION (cm)	Age at Surgery (yrs)	Age at the time of Survey (yrs)	Additional Procedure	TOTAL MSTS SCORE
Female	Left	Endoprosthetic Reconstruction	4.0	45	50		24
Male	Left	Endoprosthetic Reconstruction	8.0	43	47		24
Female	Right	Endoprosthetic Reconstruction	14.9	21	30	revision arthroplasty	21
Female	Right	Endoprosthetic Reconstruction	12.0	30	62		16
Male	Left	Endoprosthetic Reconstruction	5.5	18	39		30
Female	Left	Geographic Resection with Allograft Reconstruction	6.2	32	48	hardware removal	21
Female	Right	Geographic Resection with Allograft Reconstruction	7.0	11	31		18
Female	Left	Geographic Resection with Allograft Reconstruction	14.0	16	51		26
Female	Right	Geographic Resection with Allograft Reconstruction	3.5	18	51	AKA for possible radiation associated sarcoma	24
Female	Left	Geographic Resection with Allograft Reconstruction	6.0	42	73		25
Female	Right	Geographic Resection with Allograft Reconstruction	0.0	14	44	hardware removal	26
Female	Left	Geographic Resection with Allograft Reconstruction	9.0	38	62		21

that received biologic reconstruction, which included hemicortical or intercalary allografts. They noted no difference in local recurrence, metastatic spread, or functional outcomes (based on MSTS scoring) between the two cohorts. They reported a mean MSTS score of 89% for the endoprosthetic replacement group versus 91% in the biological reconstruction group. They did note significantly more revisions in the endoprosthetic group (58%) compared to the biologic reconstruction cohort (18%) at an average of 10 years, but concluded that either procedure was an effective option for reconstruction.[3] A limitation in this study, however, was the retrospective nature of obtaining the MSTS scores.

Similar to previous studies we report good outcomes following both treatment methods. Our average MSTS score (77%) for both cohorts was lower than that reported by Funovics. Part of this may be explained by the longer average follow up recorded in our study. In addition, unlike the report by Funovics, we noted an increase in surgical procedures following allograft reconstruction as compared to endoprosthetic replacement. Our revision rate for endoprosthetic replacement was 20% at an average of 14 years. This is especially important considering the young average age of these patients. Larger studies are needed to verify the true reoperation rate.

There are several unavoidable limitations inherent in this study. The data was collected from a single site and therefore the results may not be generalizable to a larger population. The greatest limitation, however, is the small sample size. Due to the rarity of this tumor, a multi-center study would be needed to overcome this limitation.

The strengths of this paper include the prospective nature in which we calculated the MSTS scores. This

method eliminated the recall bias that is inherent in retrospective reviews. In addition, our follow up is one of the longest reported for parosteal osteosarcomas.

In conclusion, at long-term follow-up, patients who undergo a distal femoral replacement for a parosteal osteosarcoma have no difference in functional outcomes compared to those who undergo an allograft reconstruction. We feel both geographic resection with allograft reconstruction and endoprosthetic replacement remain viable options for treatment of distal femoral parosteal osteosarcomas.

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SYSTEMIC LUPUS ERYTHEMATOSUS IS A RISK FACTOR FOR COMPLICATIONS IN TOTAL JOINT ARTHROPLASTY

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ABSTRACT

Introduction: Systemic Lupus Erythematosus (SLE) has been associated with increased complications following hip and knee arthroplasty. The Purpose of this study was to determine the extent to which SLE is a risk factor in outcomes following total joint arthroplasty (TJA)

Methods: The nationwide inpatient sample was used to identify a cohort of 505,841 patients who had a total hip arthroplasty (THA) or total knee arthroplasty (TKA) between 2009-2011. Of these patients, 2,284 patients (0.45%) had been previously diagnosed with SLE. The impact of SLE on short-term TJA outcomes was determined using multivariate logistic regression. Differences in discharge destination and length of stay were also evaluated.

Results: SLE patients were more likely to have an all-cause medical complication, (OR 1.9, p<0.0001) and more likely to have an all-cause surgical complication (OR 1.3, p<0.0001). SLE patients were four times more likely to become septic in the post-operative period (OR 3.8, p<0.0487). SLE patients were more likely to have a genitourinary complication (OR 1.7, p<0.0001) and bleeding complications requiring transfusion (OR 2.1, p<0.0001). Patients with SLE also had an increased length of stay (0.38 days, p<0.0001) and increased probability of discharging to a facility (OR 2.1, p<0.0001).

Discussion: Patients with SLE had an increased rate of both medical and surgical all-cause complications. Patients were specifically found to be at higher risk for sepsis, genitourinary complications, and blood transfusions. Future risk adjustment models should include SLE as a contributor to medical and surgical complications in the post-operative period.

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INTRODUCTION

Systemic Lupus Erythematosus (SLE) is a complex autoimmune disease with wide variation in clinical manifestations and an incidence of 3.2-10.6 per 100,000 in the United States.[1–3] SLE manifestations include skin, joint, serological, hematological, immunological and renal disorders[4] with most common associated causes of death being organ failure, infection, and cardiovascular disease.[5] Ninety-five percent of patients develop arthritis[6] and 4.6-40% develop osteonecrosis during their lifetimes.[7–9] Prior to 1950, SLE had a five-year survival of 50%[10], but with modern medical treatment the 5-year survival rate now surpasses 95%.[11]

Traditionally, patients with SLE had arthroplasty for osteonecrosis, but as patients with SLE have increased lifespan and different medication regimens, many patients with SLE are having arthroplasty for osteoarthritis.[12] Arthroplasty rates in patients with SLE doubled from 1991 to 2005, and in 2005 osteoarthritis was the indication for arthroplasty in 61% of patients compared with osteonecrosis being the indication in 24% of patients.[13] Historically, SLE has been implicated as a risk factor for poor surgical outcomes including increased rates of postoperative mortality.[14–16] The literature is mixed, however, with multiple studies suggesting increased complications, adverse postoperative events and mortality in SLE patients,[17–20] while other studies have not found increased rates of complications.[21–23] These previous studies have been limited to small patient populations and frequently did not distinguish between other types of inflammatory arthropathies.

Therefore, the purpose of this study was to evaluate short-term complications of total hip and total knee arthroplasty in patients with a known diagnosis of SLE compared to a matched cohort of similar patients without SLE using a large inpatient database. We specifically investigated individual complications as well as composite medical complications and composite surgical complications utilizing the National Inpatient Sample (NIS) database. We further evaluated for potential dif-

Table I. Un-matched patient factors and demographic information

Variables	Controls	SLE	p-value
Number of surgeries	503,557	2,284	
Age, years, mean (sd)	65.73(10.94)	58.85(12.94)	<0.0001
Sex, %(N)			<0.0001
Male	39.53(198,715)	9.64(220)	
Female	60.47(303,947)	90.36(2,063)	
Race, %(N)			<0.0001
White	84.68(367,999)	68.70(1,385)	
Black	7.27(31,589)	21.83(440)	
Hispanic	4.47(19,419)	5.26(106)	
Other	3.58(15,579)	4.22(85)	
Corticosteroid, %(N)	0.72(3,612)	12.00(274)	<0.0001
Osteonecrosis of the hip, %(N)	2.93(14,769)	15.81(361)	<0.0001
Spasm of muscle, %(N)	0.18(888)	0.44(10)	0.0031
Gait abnormality, %(N)	0.58(2,928)	0.66(15)	0.6369
Contracture of joint, pelvic region and thigh, %(N)	0.14(726)	0.09(2)	0.7782
Hospital region, %(N)			<0.0001
South	35.60(179,277)	44.22(1,010)	
Northeast	18.16(91,427)	15.89(363)	
Midwest	26.36(132,746)	22.42(512)	
West	19.88(100,107)	17.47(399)	
Vitamin D deficiency, %(N)	0.88(4,410)	1.66(38)	<0.0001
Surgery Type, %(N)			<0.0001
THA	31.70(159,624)	36.56(835)	
TKA	68.30(343,933)	63.44(1,449)	
Charlson comorbidity index, mean(sd)	0.63(0.95)	1.61(0.91)	<0.0001

ferences in length of stay and facility discharge rates for patients with SLE.

MATERIALS AND METHODS

The Nationwide Inpatient Sample was utilized to identify a cohort of patients undergoing total joint arthroplasty (TJA) between January 1st, 2009 and December 31st, 2012, utilizing ICD-9 codes 81.51 and 81.54 for total hip arthroplasty and total knee arthroplasty respectively. SLE patients were identified using ICD-9 code 710.0. The NIS is part of a family of tools designed for the Healthcare Cost and Utilization Project (HCUP) and contains weighted data from more than 35-million hospitalizations nationally and is the largest public all-payer inpatient health care database in the United States. NIS data includes patient outcomes of procedures performed including demographics, length of stay, complications, facility discharges among other measures. Patients were excluded from the study if they had an emergency procedure, fracture, revision procedure, surgery for infection, or surgery for fracture. Additionally, patients with other inflammatory conditions including rheumatoid arthritis, psoriatic arthritis, inflammatory bowel disease, juvenile idiopathic arthritis, and septic arthritis were excluded from the study. The current project was granted exemption by the institutional review board at our institution.

ICD-9 coding was utilized in the NIS to identify individual perioperative complications as well as combine complications grouped into medial or surgical complications. Surgical complications were comprised of: acute postoperative hemorrhagic anemia (285.1), Hematoma/seroma (998.11- 998.13, 729.92, 719.15, 719.16), wound infection (998.5x, 682.6, 682.9, 998.83, 890.0- 890.2, 894.0- 894.2), wound dehiscence (998.3x), mechanical

Table II. Logistic regression analysis of SLE-related perioperative complications (Un-matched cohort)

Variables	Odds ratio (95% Confidence interval)	P-value
Any complication	1.505(1.386,1.635)	<0.0001
Surgical complications	1.349(1.233,1.476)	<0.0001
Medical complications	1.664(1.521,1.820)	<0.0001
Individual Complications		
Acute postoperative hemorrhagic anemia	1.346(1.229,1.474)	<0.0001
Hematoma/seroma	1.420(0.932,2.163)	0.1025
Wound infection	0.849(0.352,2.045)	0.7152
Mechanical complication of implant	1.175(0.747,1.848)	0.4852
Periprosthetic infection	1.000(0.140,7.149)	1
Dislocation of prosthetic joint	1.480(0.368,5.949)	0.5806
Fever	1.555(1.244,1.946)	<0.0001
Altered mental status	1.898(0.983,3.662)	0.0561
Thrombocytopenia	1.796(1.419,2.274)	<0.0001
Central nervous system	0.551(0.077,3.923)	0.5517
Cardiac	1.316(0.837,2.069)	0.2345
Peripheral vascular	0.394(0.055,2.799)	0.3517
Gastrointestinal	0.374(0.121,1.161)	0.089
Genitourinary	1.565(1.322,1.853)	<0.0001
Sepsis	2.937(1.214,7.103)	0.0168
Pulmonary embolism	0.670(0.279,1.612)	0.3716
Deep venous thrombosis	1.659(0.939,2.932)	0.0814
Transfusion	1.658(1.498,1.836)	<0.0001

complication of implant (996.40, 996.41, 996.43- 996.49, 996.76- 996.79), periprosthetic infection (996.66, 996.67, 996.69), dislocation of prosthetic joint (996.42), peripheral nerve injury (956.0- 956.9), fall (E885, E886, E888). Medical complications included: Fever (780.60, 780.62), altered mental status (780.97), thrombocytopenia (287.4, 287.5), central nervous system (349.9x), cardiac (997.1), acute myocardial infarction (410), peripheral vascular (997.2), pulmonary insufficiency following surgery (518.51, 518.52, 518.53) pulmonary (997.3, 997.31, 997.32), pulmonary embolism (415.11, 415.13, 415.19), deep venous thrombosis (451.11, 451.19, 451.2, 451.81, 453.40-453.42), gastrointestinal (997.4), genitourinary (584.x , 599.0, 997.5), sepsis (995.91-2), postoperative shock (998.0), transfusion (procedure codes 99.03- 99.05, 99.07). Furthermore, discharge to home versus facility and length of stay calculated by date of admission and date of discharge. SLE patients undergoing TJA were compared with matched controls.

Statistical Analysis

Medical complications, surgical complications, and individual complications were first compared to the overall cohort of patients not having SLE through linear regression analysis. To control for demographic differences in the SLE patient population, a 3:1 propensity score matched cohort was then created to prevent confounding based on demographic differences. Logistic regression was then utilized to determine the odds ratio of having a medical complication, surgical complication, any complication, or an individual complication such as sepsis or blood transfusion. Length of stay differences for SLE patients compared to non-SLE patients was determined using the paired t-test.

RESULTS

After application of our exclusion criteria, 2,284 patients with SLE and 503,557 patients without (controls) totaling 505,841 patients were identified as undergoing TJA during our study period. The prevalence of SLE in the cohort was 0.45%. There were 160,459 THAs (835 SLE) and 345,382 TKAs (1,449 SLE) performed. Average age, sex, and ethnic majority for SLE patients were 58.9 years, 90% female, and 69% Caucasian. Patients with SLE had higher percentages of both steroid use and diagnosis of osteonecrosis of the hip compared to non-SLE patients. A complete list of demographics is provided in Table 1. Patients with SLE were also noted to have higher

Table III. Length of stay and discharge destination

Variable: LOS (Length of stay in days)				
	Number (n)	**Mean (days)**	**Std Dev**	**P-value**
Non-SLE	503,556	3.22	1.54	
SLE	2,284	3.5	1.62	p<0.001
Discharge Destination	**Odds ratio (95% Confidence interval)**	**P-value**		
Not home vs. Home	1.219(1.104,1.346)	<0.0001		

Table IV. Matched cohort patient factors and demographic information

	3:1 Matched Cohort		
Variables	**Controls**	**SLE**	**P-value**
Number of surgeries	6,852	2,284	
Age, years, mean(sd)	65.41(11.09)	58.85(12.94)	<0.0001
Sex, %(N)			<0.0001
Male	39.78(2696)	9.64(220)	
Female	60.22(4082)	90.36(2,063)	
Race, %(N)			<0.0001
White	82.96(667)	68.70(1,385)	
Black	8.71(70)	21.83(440)	
Hispanic	4.48(36)	5.26(106)	
Other	3.86(31)	4.22(85)	
Corticosteroid, %(N)	0.73(50)	12.00(274)	<0.0001
Osteonecrosis of the hip, %(N)	2.61(179)	15.81(361)	<0.0001
Spasm of muscle, %(N)	0.20(14)	0.44(10)	0.059
Gait abnormality, %(N)	0.35(24)	0.66(15)	0.0517
Contracture of joint, pelvic region and thigh, %(N)	0.15(10)	0.09(2)	0.7417
Hospital region, %(N)			<0.0001
South	20.94(1435)	44.22(1,010)	
Northeast	3.58(245)	15.89(363)	
Midwest	62.27(4267)	22.42(512)	
West	13.21(905)	17.47(399)	
Vitamin D deficiency, %(N)	1.50(103)	1.66(38)	0.5899
Surgery Type, %(N)			<0.0001
THA	30.75(2107)	36.56(835)	
TKA	69.25(4745)	63.44(1,449)	
Charlson comorbidity index, mean(sd)	0.62(0.95)	1.61(0.91)	<0.0001

proportion of patients undergoing total hip arthroplasty (THA) as compared to non-SLE patients (36.6% vs 31.7%, p<0.0001). Prior to matching, SLE patients were 1.5 times more likely to have any complication (OR 1.5, p<0001), 1.7 times more likely to have a medical complication (OR 1.7, p<0.001) and 1.3 times more likely to have a surgical complication (OR 1.3, p<0.0001). Specifically, SLE was associated with a nearly three-fold increase in sepsis (CI 1.214-7.103, p<0.017), and significant increased odds of thrombocytopenia, transfusion, genitourinary complications, fever and pulmonary insufficiency (Table II). SLE patients also had a 0.3 day increased length of stay as well as increased rate of discharge to a care facility with an OR of 1.2 (Table III).

After 3:1 matching of Non-SLE to SLE patients, demographic data including age, gender, and race distributions remained relatively the same when comparing to un-matched data (Table IV). Corticosteroid use and osteonecrosis was similarly unchanged (Table IV). In the matched cohort, SLE patients were 1.5 time more likely to have any complication (OR 1.5, p<0.0001), 1.3 times more likely to have a surgical complication, (OR 1.3, p<0.0001) and 1.9 times more likely to have a medical complication (OR 1.9, p<0.0001). When looking at specific complications, SLE patients were 1.3 times more likely to have acute postoperative anemia (OR 1.3, p<0.0001), 1.6 times more likely to have fever (OR 1.6, p=0.0008), 3 times more likely to have altered mental status (OR 3.0, p=0.0196), 1.4 times more likely to have thrombocytopenia (OR 1.4, p=0.023), 1.7 times more likely to have genitourinary complications (OR 1.7, p<0.0001), 4 times more likely to have sepsis (OR 3.8, p=0.0487) and 2 times more likely to receive a transfusion (OR 2.1, p<0.0001) (Table V). Additionally, SLE patients were twice as likely to discharge to a facility than non-SLE patients (OR 2.1, p<0.0001) (Table VI).

TABLE V. Logistic regression analysis of SLE-related perioperative complications (Matched cohort)

	3:1 Matched Cohort	
Variables	**Odds ratio (95% Confidence interval)**	**P-value**
Any complication	1.476(1.340,1.627)	<0.0001
Surgical complications	1.273(1.146,1.414)	<0.0001
Medical complications	1.871(1.679,2.084)	<0.0001
Individual Complications		
Acute postoperative hemorrhagic anemia	1.249(1.123,1.390)	<0.0001
Hematoma/seroma	1.471(0.882,2.455)	0.1395
Wound infection	0.937(0.343,2.562)	0.8996
Mechanical complication of implant	1.634(0.933,2.862)	0.086
Periprosthetic infection	1.000(0.104,9.618)	1
Dislocation of prosthetic joint	3.002(0.423,21.322)	0.2718
Fever	1.600(1.215,2.106)	0.0008
Altered mental status	3.008(1.193,7.587)	0.0196
Thrombocytopenia	1.362(1.027,1.806)	0.032
Central nervous system	1.500(0.136,16.552)	0.7406
Cardiac	1.429(0.826,2.472)	0.2022
Peripheral vascular	0.333(0.042,2.630)	0.297
Gastrointestinal	0.309(0.094,1.017)	0.0533
Genitourinary	1.653(1.343,2.034)	<0.0001
Sepsis	3.756(1.008,13.999)	0.0487
Pulmonary embolism	0.651(0.247,1.715)	0.3856
Deep venous thrombosis	1.503(0.750,3.010)	0.2505
Transfusion	2.054(1.811,2.329)	<0.0001

DISCUSSION

The current study shows SLE patients undergoing TJA are at markedly increased risk for medical complications and surgical complications post-operatively. Musculoskeletal manifestations of SLE include high rates of arthritis and osteonecrosis. Given the increase in arthroplasty in SLE patients in recent years and improved disease survival in this patient population, it is imperative to understand the perioperative outcomes and complications associated and inherent to SLE surgical candidates.

Our results show an increase in overall postoperative complications (OR 1.5, p<0.001) in SLE patients. This in in agreement with previous literature which also showed increased rates of complications in SLE patients.[14,20,24,25] Elevated hematologic complications in SLE included increased rates of acute postoperative hemorrhagic anemia (OR 1.35, p<0.0001), thrombocytopenia (OR 1.8, p<0.0001) and blood transfusion (OR 1.7, p<0.0001). Aggressive blood preservation programs should be employed in this population. Our results are further corroborated by literature suggesting SLE has been implicated in platelet dysfunction and antibodies to coagulation factors.[4,26–28] With SLE patients vulnerable to both the inherent bleeding from major joint and SLE induced platelet dysfunction including antibodies against coagulation factors—it is no wonder SLE patients show increased odds of perioperative anemia, thrombocytopenia and transfusion requirements in our study. Therefore, surgeons should take care to limit bleeding in SLE patients.

SLE patients had a 4 times higher rate of sepsis compared to patients without SLE. Previous rheumatology studies on SLE patients have found that infectious etiology accounts for 37% of hospitalizations and one-third of deaths in SLE patients.[29–34] The most common reasons for hospitalization being pneumonia, urinary tract infections, and skin infections—while bacteremia and sepsis complicated by organ failure are leading causes of mortality.[35–39] Tektonidou et al. reported the risk of hospitalization for serious infections in SLE patients were 12-24

times higher than in the general population.[29] These high rates of postoperative infections are in stark contrast to expected rates of postoperative infection in primary hip and knee arthroplasty of 0.5-3%[40–43] and <1%[44] respectively.

Corticosteroid use, however, continues to be a major confounder in the literature. Unfortunately, the risk of complications due to corticosteroids alone is nearly impossible to determine, and the question remains, "are complications secondary to steroids alone or to the underlying condition?" The literature is mixed regarding corticosteroid use in SLE patients and postoperative complications. Migliaresi et al, and Fein et al. concluded ON and adverse events were not related to steroid use.[21,45] Furthermore, Migliaresi et al. suggest complications are dose dependent and some doses may be protective.[45] On the contrary, multiple studies point to corticosteroid use as a major risk factor of ON and complications in SLE patients.[46–50] The current study showed the proportion of SLE patients on corticosteroids was significantly greater than non-SLE patients (12% vs 0.72%, $p<0.0001$).

There are several limitations of this study inherent to the retrospective study design and database utilization. There is significant heterogeneity of the hospitals and surgeon factors included in the NIS database. Furthermore, the NIS database only accounts for data collected from the surgical procedure date until discharge—thus relevant to the immediate and short-term postoperative periods only. Therefore, it is likely that the findings in this study underestimate the postoperative complications on a global level. Lastly, it is not feasible to control for all patient variables leaving the study vulnerable to confounding, however, the large sample size, patient matching, and multivariate analyses all contribute to a reduction in the confounding effects.

Overall, SLE patients undergoing TJA have increased rates of early postoperative surgical and medical complications. SLE patients are particularly vulnerable to postoperative anemia, thrombocytopenia, transfusion, genitourinary complications, and sepsis. SLE were also found to have longer lengths of stay and higher rates of discharge to a facility. As SLE patients continue to become a growing part of the total joint arthroplasty population, it is important to optimize medical and surgical risk factors in SLE patients to decrease the risk of complications in this susceptible patient population.

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TOTAL HIP ARTHROPLASTY FOR CROWE TYPE IV DEVELOPMENTAL DYSPLASIA OF THE HIP USING A TITANIUM MESH CUP AND SUBTROCHANTERIC FEMORAL OSTEOTOMY

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ABSTRACT

Background: Treatment of Crowe IV developmental dysplasia of the hip (DDH) with total hip arthroplasty (THA) reconstructs the true acetabulum, which improves hip biomechanics and function. However, restoration of the native acetabulum may lead to limb lengthening and traction neuropraxia. The purpose of this study is to describe the short term results of a retrospectively reviewed series of patients with Crowe IV DDH treated with THA using a titanium mesh cup, cemented liner, and subtrochanteric femoral shortening osteotomy.

Methods: Eighteen patients (21 hips) with an average age of 47 years (age range: 28–61 years) with Crowe IV DDH underwent reconstructive THA and subtrochanteric femoral shortening osteotomy between September 2005 and February 2014. Follow up was assessed at 1, 3, 6, 9, and 12 months post operatively and then annually after the first year. The average follow up was 3.5 years (range 0.5–9 years). At each follow up visit, radiographs were used to assess for osteolysis and subsidence. Preoperative and postoperative patient reported outcomes including Harris Hip Score and Modified Merle d'Aubigne Hip Score were compared.

Results: At the minimum 6 month follow up, all radiographic assessments showed no signs of osteolysis or subsidence of the implants. Both the Harris Hip Score and Modified Merle d'Aubigne Hip Score improved from preoperative assessments ($p<0.05$). Three patients developed symptoms of sciatic nerve neuropraxia that subsequently resolved.

Conclusion: THA of Crowe IV DDH by reconstructing the acetabulum with bone graft, a titanium mesh cup, cemented liner, and subtrochanteric femoral shortening osteotomy demonstrated no osteolysis or subsidence and improved function with a low incidence of sciatic nerve palsy at short term follow up.

Keywords: Acetabular reconstruction; Subtrochanteric osteotomy; Crowe IV; Developmental dysplasia of the hip; Total hip arthroplasty

Level of evidence: IV

INTRODUCTION

Crowe type IV developmental dysplasia of the hip (DDH) is one of the most complex types of hip deformities to reconstruct.[1] Total hip arthroplasty (THA) has been shown to successfully reconstruct advanced DDH with functional impairment.[2-4] However, THA for Crowe IV DDH is a technically challenging procedure because of the extensive distortions to the native anatomy. DDH patients may have a shallow acetabulum, a straight narrow femoral canal, and associated circumferential soft-tissue deformities.[4]

Various methods and techniques have been proposed to restore the normal anatomic relations of the distorted hip joint in Crowe IV DDH. The main goal of these techniques is to improve hip biomechanics and increase subsequent survival rate of the hip implants.[4,5] It is imperative that the true acetabulum be restored to the anatomic position during reconstruction. Previous literature described several strategies to reconstruct the abnormal acetabulum using bone graft and small cups during THA.[2,6] However, extensive bone grafting may be complicated by resorption and subsidence, while small cups with thin polyethylene liners may aseptically loosen and displace.[7] The purpose of this study is to describe the short term results of a retrospectively reviewed series of patients with Crowe IV DDH treated with THA using a titanium mesh cup, cemented liner, and subtrochanteric femoral shortening osteotomy.

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Conflict of Interest:
The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

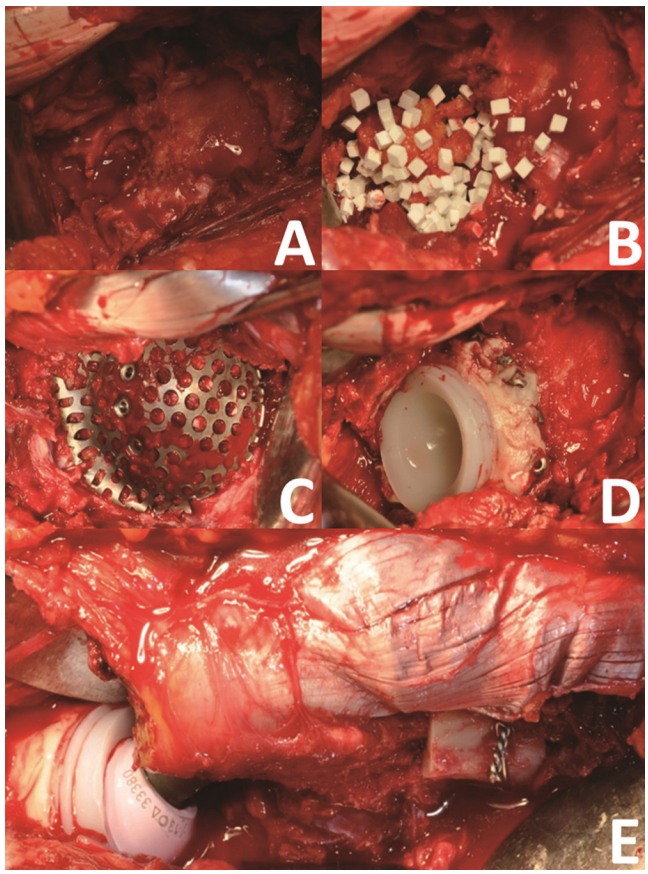

Figure 1: Photo graphs illustrating the acetabular reconstruction using the titanium mesh cup and subtrochanteric femoral shortening osteotomy in a patient undergoing THA. (A) Identification of the true acetabulum. (B) Bone grafting the true acetabulum with mixed autologous bone and artificial bone substitutes. (C) Implantation of the titanium mesh cup. (D) Cement fixation of the polyethylene liner into the titanium mesh cup. (E) Final femoral and acetabulum implants after reconstruction and femoral shortening osteotomy and fixation.

MATERIALS AND METHODS

After obtaining approval from the Institutional Review Board, we conducted a retrospective review of a consecutive series of adult patients with Crowe type IV DDH that underwent reconstruction with THA using a titanium mesh cup, cemented liner, and femoral shortening osteotomy in an academic university hospital setting. Patients were identified from the senior surgeon's database between September 2005 and February 2014. Inclusion criteria included preoperative radiographic evidence of Crowe IV DDH, treatment with THA using a titanium mesh cup, cemented liner, and femoral shortening osteomy with minimum follow up of 6 months, and had records of patient reported outcomes (Harris Hip Score and Modified Merle d'Aubigne Hip Score) both preoperative and postoperatively. Patients were excluded if they were less than 18 years of age.

Surgical Technique

The patient was positioned in the lateral decubitus position and the Southern approach was used to expose the hip. After transecting and removing the femoral head, the false acetabulum and dysplastic true acetabulum were identified after removing obscuring osteophytes. The true acetabulum was then debrided and reamed to expose healthy bleeding bone. Autologous bone and artificial bone substitutes were then impacted into the acetabulum.[8] The titanium mesh cup was then impacted into the acetabulum and fixation was obtained with two to four cancellous screws. The polyethylene liner was then cemented into the mesh cup with the desired anteversion and abduction to optimize stability (Figure 1).[9,10]

The femur was then prepared. The proximal femur was prepared for the femoral component by broaching. Next, the transverse shortening osteotomy level was identified 1 cm distal to the lesser trochanter. A longitudinal mark was made on the femur through the planned osteotomy site as a reference to re-establish femoral rotation following the osteotomy. The transverse osteotomy was then performed and a trial stem was seated into the proximal femur with a trial head. The trial femoral components and proximal femur were then provisionally reduced into the acetabulum. The distal femur was then held with manual traction and the second osteotomy to shorten the distal femur was made at a level based on muscle tension and position of the proximal and distal femur relative to one another so that the trial stem could be reduced without excessive traction. The proximal femur's trial stem was then reduced into the distal femur segment (Figure 1E). Hip range of motion and stability was then assessed and trial implants were adjusted as needed. Morselized autologous bone was placed grafted about the osteotomy site. The excised cylindrical segment of the femur for the shortening osteotomy was longitudinally split into 2 or 3 segments and used to reinforce the osteotomy site as onlay grafts fixed with a titanium wire. Postoperatively, patients were limited to partial weight bearing activity restrictions and posterior hip precautions for 12 weeks postoperatively.

Postoperative Follow Up

All patients underwent follow-up examinations at 1, 3, 6, and 12 months postoperatively and annually thereafter. At each visit, the Harris Hip Score (HHS) and the modified Merle d'Aubigne hip score were assessed.[11,12] Radiographic evaluation was performed at each visit with standard anterior-posterior radiographs of the pelvis and full-length radiographs of the lower extremities. Osteolysis of the acetabulum and femur were evaluated as previously described.[13,14] The criteria described by Engh et al. were used to assess for femoral implant loosening.[15]

TableI: Pre- and postoperative hip assessments

Assessment	Preoperative Value	Postoperative Value
Harris Hip Score	47.9±9.1 (range 20–65)	88.4±3.5 (range 82–93)*
Modified Merle d'Aubigne Hip Score	10.5±3.1 (range 8–12)	16.4±1.5 (range 15–17)*
Limb-length discrepancy (cm)	4.2±1.2 (range 2.5–7)	0.6±0.5 (range 0–1.5)*
Trendelenburg sign	18 positive	2 positive

*P < 0.05 compared to the preoperative value

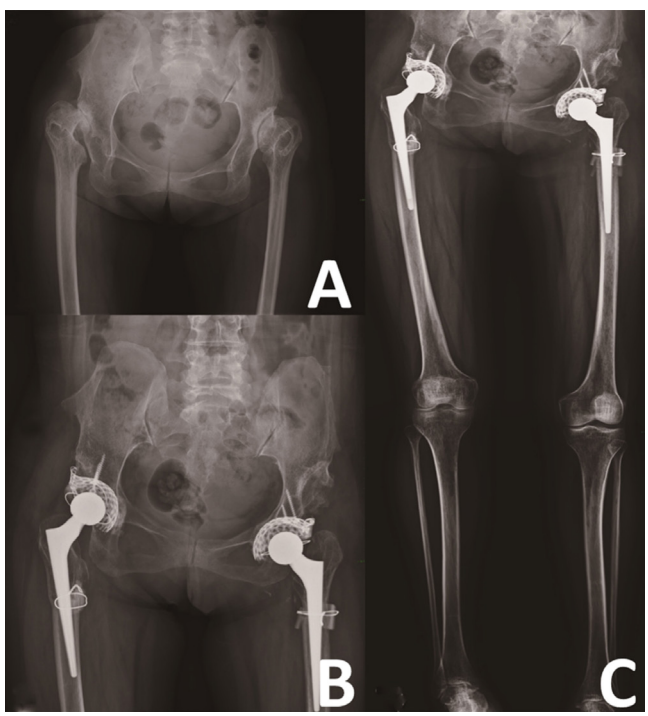

Figure 2: Pre- and postoperative radiographs of a woman with Crowe type IV DDH. (A) Preoperative pelvis radiograph of a 41-year-old woman with bilateral Crowe type IV DDH. (B) Postoperative pelvis radiograph demonstrating bilateral acetabular reconstruction using a titanium mesh cup, cemented liner, and femoral shortening osteotomy on each side. (C) Postoperative full length standing radiograph of the lower limbs illustrating satisfactory leg alignment and limb length discrepancy less than 0.5 cm.

Statistical analysis

Data were analyzed using Paired Student's t-test and are presented as the mean ± SEM. Significance was set at $p < 0.05$.

RESULTS

Eighteen patients (total of 21 hips – 15 patients that underwent a unilateral procedure and 3 patients that underwent bilateral procedures) with Crowe type IV DDH were identified from the senior surgeon's database with procedures between September 2005 and February 2014. The cohort included 3 men and 15 women with a mean age of 47 years (range 28–61 years). One patient had previously undergone Salter osteotomy and 5 others had undergone shelf arthroplasty. All prior hip procedures were performed a minimum of 7 years prior to THA. Preoperatively, all patients complained of progressive pain and impaired hip range of motion, especially abduction and internal rotation. The mean preoperative limb length discrepancy was 4.2 cm (range 2.5–7.0 cm). The mean follow-up duration was 3.5 years (range 0.5–9 years).

Good to excellent results were achieved in all cases postoperatively. There was a significant improvement in postoperative HHS and Modified Merle d'Aubigne Hip Score from preoperative scores. Furthermore, fewer patients displayed the Trendelenburg sign at latest follow up (Table 1). However, all patients described improvements in gait following reconstructive surgery. Postoperative radiographs illustrated a significant decrease in limb length discrepancy compared to preoperative values with no signs of component migration or subsidence (Figure 2). At the latest follow-up, radiographs showed that 3 stems had stable bone in-growth and 18 stems showed stable fibrous in-growth as characterized by the criteria by Engh et al.[15] Solid union at the osteotomy site was achieved in all the cases.

Three patients developed postoperative sciatic nerve palsy, with the symptoms ranging from muscle spasms and skin numbness to motor and sensory loss. After continued observation the 2 patients with mild symptoms recovered function during their initial postoperative hospital admission. The patient with the most severe symptoms had partial recovery of motor function 6 months after surgery without further invasive treatment.

DISCUSSION

THA for Crowe IV DDH is widely acknowledged to have a higher incidence of complications and failure rates than routine THA for primary osteoarthritis.[2] Accurate preoperative assessment and advanced surgical experience are essential for achieving successful results in this patient population. The purpose of this study is to describe the short term results of a retrospectively

reviewed series of patients with Crowe IV DDH treated with THA using a titanium mesh cup, cemented liner, and subtrochanteric femoral shortening osteotomy.

Restoration of the true acetabulum during DDH reconstruction has been previously shown to improve hip biomechanics.[16-18] Many different strategies have been employed to reconstruct the acetabulum.19 In this study, a titanium mesh cup was placed at the true acetabulum to restore the socket and act as a scaffold for bone graft. The benefit of a titanium mesh cup is that it has a similar modulus to bone with a reliable history of osteo-integration across the implant-bone interface.[16-20] In our short term study, there were no obvious signs of aseptic loosening or subsidence of the implant.

After reconstruction of the true acetabulum the leg length was adjusted using a femoral shortening osteotomy to prevent sciatic nerve injury. There are various methods to perform this osteotomy.[2,3,16-20] Subtrochanteric step-cut osteotomy or oblique osteotomy would provide rotational stability after osteosynthesis while the method is technical demanding and the amendment of femoral anteversion could be challenging without a modular femoral component.[3,17] Alternatively, a transverse osteotomy, as used in our series, was easy to perform and could be made to facilitate adjustments of femoral anteversion. Additionally, Muratli et al. showed no significant difference in biomechanical properties comparing osteotomy methods.[21] In our series we had no cases of delayed union or nonunion of the osteotomy site, consistent with low incidence reported in prior studies.[6,22,23] The favorable union rates could be attribute to using a press fit stem and femoral struts that may have improved the strength of our construct.

Sciatic nerve dysfunction is a common complication associated with increased leg length by more than 4 centimeters.[2-5,22-25] In reconstructions with drastic limb lengthening, femoral shortening osteotomy is often used to avoid neuroraxia. However, although femoral shortening osteotomy was performed in all our patients to prevent sciatic nerve dysfunction, three patients were noted to have symptomatic sciatic nerve dysfunction after operation. One patient had unilateral leg lengthening of 5.4 cm developed peroneal nerve sensory deficits and a foot drop post operatively. The patient was treated with an ankle-foot orthosis to prevent development of an equines deformity and was closely observed post-operatively. Symptoms partially resolved at 3 months and by 6 months, the patient experienced near complete resolution of the neuropraxia without operative intervention. Two other patients developed mild ankle dorsiflexion weakness that resolved within 2 weeks after reconstruction. Preoperative planning to determine limb length discrepancy and taking this measurement into account for the femoral shortening osteotomy is paramount to avoid nerve dysfunction.

There were several limitations in our study. First, we recognize the limitations of a retrospective case series. There are many reconstructive techniques for DDH and this series is unable to compare our results to other approaches. Second, we recognize a small cohort in this series with short follow up. Long term complications such as aseptic loosening may not be observed without long follow up. Lastly, reconstruction of severe DDH is technically challenging and may pose a steep learning curve for less experienced surgeons. Despite these limitations, this report shows that reconstruction of Crowe IV DDH with THA using a titanium mesh cup and femoral shortening osteotomy has acceptable results in the short term and may be an acceptable treatment option for patients with this severe deformity.

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PRIMARY TOTAL HIP ARTHROPLASTY FOR LEGG-CALVÉ-PERTHES SYNDROME: 20 YEAR FOLLOW-UP STUDY

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ABSTRACT

Background: Patients with Legg-Calvé-Perthes Syndrome (LCPS) are at an increased risk for developing osteoarthritis of the hip and undergoing total hip arthroplasty (THA) at an early age. Importantly, this younger age may put them at a higher risk for failure and revision surgery. The purpose of the study was to assess the clinical and radiographic outcomes as well as implant failure rate and risk for revision surgery at an average 20 years follow up.

Methods: Data from LCPS patients treated with THA were collected including age, gender, operative date, revision date, as well as reason for and type of revision. Living patients filled the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) questionnaires at the time of last follow-up. Radiographs were evaluated for lucencies, debonding, loosening, osteolysis, wear, heterotopic ossification and sclerosis.

Results: Nineteen patients (20 hips) treated with THA were followed-up for a mean of 18.3 years (range, 10.1 – 36.2 years). Radiographic evidence of lucency of the acetabular component was seen in 70% of the patients and femoral cortical hypertrophy in 85% at last follow-up. The rate of revision for any reason was 35%, mostly due to aseptic acetabular loosening.

Conclusions: Our findings support the use of THA for the treatment of OA in patients with LCPS, bearing in mind the potentially lower survival rate at 20 years as compared those treated with THA for primary OA. Further studies are needed to identify the possible causes of the high rate of cortical hypertrophy seen in this patient population.

Level of Evidence: IV Therapeutic

Keywords: long-term follow-up, total hip arthroplasty, perthes

INTRODUCTION

The clinical course of Legg-Calvé-Perthes Syndrome (LCPS) is highly variable and data in the literature has varied widely with regards to the prevalence of osteoarthritis (OA) (7%-100%) and the need for total hip arthroplasty (THA) (0%-43%)[1-6]. A gender and age-matched case-control study found that those with LCPS did have an overall increased risk of radiographically evident OA and a need for THA, particularly with Stulberg classes III/IV/V femoral heads, at a mean of 47 years follow-up[7]. This data supports previous literature suggesting that the most important prognostic factors are the deformity of the femoral head and hip joint incongruity, and that more than half of all LCPS patients develop osteoarthritis[5].

LCPS patients that develop clinically relevant OA often need to undergo THA at a younger age than those with primary OA, with an average age of 37.8 years at THA surgery[8]. Importantly, this younger age may put them at a higher risk for failure and revision surgery. Traina et al. evaluated the long-term outcome of LCPS patients at an average follow-up of 10 years and reported only one revision out of 32 hips (3.1%)[8]. However, data from the Danish Hip Arthroplasty Registry of THA in childhood found that the overall 10-year failure rate in LCPS patients was 13%, mostly due to aseptic loosening of the acetabular component[9]. A recent systematic review of six studies which included follow up from 2 - 21 years reported a 7% revision rate at a mean of 7.5 years[10]. The combined Danish and Swedish registries showed no difference in the rate of revision, aseptic loosening, dislocation, and infection when comparing patients with LCPS who underwent THA to those with primary OA[11].

The purpose of the present study was to assess the clinical and radiographic changes, implant failure rate, and risk for revision surgery in patients with LCPS at an average 20 years follow-up and compare with a historical control group of patients with primary OA treated with THA[12,13].

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Conflict of interest: none

Table I. Patient characteristics and follow-up period

Hip no.	Gender	Age at OP (years)	Side	Follow-up period (years)	Cemented
1	M	48.3	R	36.2	Y
2	M	54.8	L	19.8	Y
3	F	56.6	L	35.6	Y
4	F	60.0	R	29.3	Y
5	M	63.9	R	11.2	Y
6	M	62.6	L	11.4	Y
7	M	73.3	R	14.7	Y
8	F	46.2	L	11.5	Y
9	M	58.2	L	15.4	Y
10	M	66.6	L	13.7	Y
11	M	39.7	R	10.1	Y
12	M	64.2	R	34.3	N
13	M	59.5	L	13.4	Y
14	M	59.5	R	13.4	Y
15	M	41.5	R	22.2	Y
16	F	40.9	R	14.6	Y
17	M	46.0	R	14.7	Y
18	M	36.5	R	20.4	N
19	F	70.1	R	10.3	Y
20	M	52.1	L	13.5	Y

OP = surgery; M = male; F = female; R = right; L = left; Y = yes; N = no

MATERIALS AND METHODS

Patient Population

After receiving institutional review board (IRB) approval from the University of Iowa and Iowa Health – Des Moines, 24 patients with LCPS treated with THA between 1972 and 1993 were identified in the database. Five cases were excluded: three had insufficient follow-up data and two had missing radiographic jackets. Nineteen patients (20 hips) were therefore evaluated. Demographic and surgery data were recorded including age, gender, primary THA operative date, revision surgery (if applicable), and last radiographic follow-up. All procedures were performed using the standard lateral approach by two hip surgeons at our institution.

Evaluation of clinical outcomes

Living patients were interviewed with the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) questionnaire at the time of last follow-up[14]. All initial surgeries were performed with either Charnley or Iowa cemented or cementless femoral components.

Radiographic evaluations

Preoperative, postoperative, and most recent radiographs were evaluated for lucencies, debonding, loosening, osteolysis, heterotopic ossification and sclerosis and wear with the measurements and criteria used in previous reports[12,13].

Follow-up time periods

When revision surgery had not been done, the length of time until the patient's last follow-up or death was considered to be the length of survival of the prosthesis. When a patient did require revision surgery the length of time from the initial surgery to the revision surgery was recorded, as was the length of time from the revision surgery till the patient's last follow-up or death.

Statistical analysis

The Kaplan-Meier method was used to determine revision-free survival of the components. The end point for failure was revision for any reason.

RESULTS

Of the 19 patients (20 THA), 14 were males and 5

Table II. WOMAC scores

Patient number	Pain	Stiffness	Physical function
1	0	1	33
2	0	0	12
3	0	2	9
4	0	0	0
5	0	0	7
6	1	0	4
7	0	0	8
8	0	0	1

females, with an average age at initial primary surgery of 55.1 years (range, 36.5 – 73.3). Cemented stems were used in 18 hips and cementless stems in the remaining two. The mean follow-up period was 18.3 years (range, 10.1 – 36.2 years) (Table 1).

Clinical evaluation

Of the 19 patients, 10 were living at the time of this study. One patient could not be reached and one had suffered a massive cerebrovascular accident, rendering her unable to respond to the WOMAC questionnaire. Therefore, eight patients had a WOMAC score for this study. Living patients were evaluated at an average follow-up of 27.5 years (range, 18 – 36 years).

The average WOMAC score was 133.9 (range, 87.9 –152.5). The average WOMAC pain score was 0.125 (range, 0 – 1) out of a maximum possible total of 20. The average WOMAC stiffness score was 1.375 (range, 0 – 4) out of a maximum possible total of 8. The average WOMAC physical function score was 9.25 (range, 0 – 33) out of a maximum possible total of 68. These results are listed in Table 2.

None of the patients had pain at rest or while climbing stairs, while only one patient reported mild pain while walking and one patient reported the use of a walker. Three patients reported unlimited walking ability, while there was one patient in each of the next three categories (10 – 20 blocks, 5 – 10 blocks, 1 – 5 blocks), and two patients that could not walk one full block. Three patients reported using an arm rest to push themselves out of the seated position, while the remaining five patients got out of the chair normally. Three patients reported the use of a rail for support/pull while down/up stairs, while two used a rail for balance, and three did not need the use of a rail.

Radiographic evaluation

There was evidence of heterotopic ossification seen in eight hips in seven patients. Of these, four were grade 1, one was grade 2 and three were grade 3. There was no visible acetabular migration seen in any of the patients. Cortical hypertrophy was seen in 17 hips (85%) in both post-operative and last follow-up radiographs. At last follow-up, radiographic evidence of lucencies, osteolysis, and loosening of the acetabular component was seen in 14 hips (70%), two hips (10%), and one hip (5%), respectively. As for the femoral component, at last follow-up, radiographic evidence of lucencies, osteolysis, and loosening was seen in one hip (5%), three hips (15%), and two hips (10%), respectively. There was evidence of debonding in three hips (15%), all in Gruen Zone 1. These results are summarized in Table 3.

Revision surgery

There were a total of six revisions performed on five patients. These five patients included three men and two women. Thus, the rate of revision for any reason in LCPS hips was 30 %. Five revisions were performed for aseptic acetabular loosening and one for aseptic femoral loosening. Revisions performed for aseptic acetabular loosening involved exchanging the cup, with an incidental exchange of the femoral component in two patients from a Charnley to an Iowa stem.

The average age at the time of the first revision surgery for these patients was 57.9 years (range, 49.5 – 65.0). The average time to revision (first or second) was 9.5 years (range, 5 – 13) and the average age at final follow-up was 73.6 years (range, 55.6 – 84.5). These results are summarized in Table 2.

Table III. Characteristics and follow-up of patients who underwent revision surgery

Patient no.	Age at first revision (years)	Time to revision (years)	Age at last follow-up (years)
1	59.3	11.3	84.5
2	62.8	8.3 / 8.0*	74.6
3	65	5.1	89.3
4	52.9	11.9	55.6
5	49.5	13.0	57.0

* This patient underwent two revision surgeries

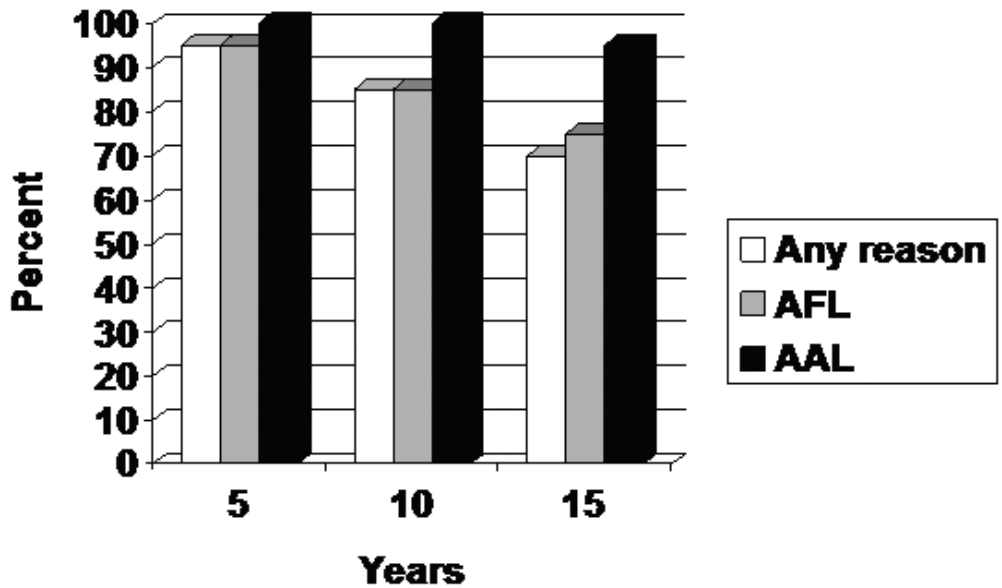

Figure 1: Revision-free survival. AFL = aseptic femoral loosening. AAL = aseptic acetabular loosening.

Revision-free survival

The overall revision-free survival rate was 95%, 85%, and 70% at 5 years, 10 years, and 15 years follow-up, respectively, when the end point was revision for any reason. When the end point was revision for aseptic femoral loosening, the revision-free survival rate was 95%, 85%, and 75% at 5 years, 10 years, and 15 years follow-up, respectively. When the end point was revision for aseptic acetabular loosening the revision-free survival rate was 100%, 100%, and 95% at 5 years, 10 years, and 15 years, respectively. These results are summarized in Figure 1.

DISCUSSION

The purpose of the present study was to assess the long term results of THA in patients with LCPS and the risk for revision surgery. Our results revealed that the cumulative survival of the implants was 70% at 20 years follow-up when revision for any reason was the endpoint. This is lower than the 96.9% survival rate at 15 years reported in a long-term follow-up of LCPS patients who underwent THA[8]. Luo et al. reported a 98.6% survival rate at 10 years, while Lee et al. reported no revisions at a mean of 8.5 years[15,16]. The implant survival rate in the current study's group of patients was also lower than the 35-year survival rate of 78%, which we have previously reported, in patients who underwent THA for OA[12]. The 10-year revision-free survival rate of 85% in our study was similar to that reported in the Danish Hip Arthroplasty Registry (87%), while slightly higher than that reported in the Norwegian Arthroplasty Register (80.5%), when considering all cases of THA[9,17]. However, in the Norwegian Register, LCPS and slipped capital femoral epiphysis were evaluated as one entity since they had been reported together on a standard form[17].

The average age at initial surgery in the present study was 55.1 years, which was higher than that of previously quoted data on LCPS patients undergoing THA[8,9,10,15,16]. The average time to revision was 9.5 years in the present study, which is slightly higher than a mean of 7.5 years reported in a recent systematic review of the literature[10].

In the present study all but one patient had cemented stems used in their initial surgery. This is counter to previous data from this patient population whereby the majority of the stems were cementless and/or modular[8,9,15,18,19]. This difference is most likely due to the time period during which the patient population in the current study underwent their THA, which was two or more decades earlier than that of previous studies[8,15,16,18,19]. However, there is a high rate of reported intraoperative fracture in patients undergoing cementless THA for LCPS, ranging from 8% to 13%[19,20] with only one study reporting two fractures in 88 hips[15].

With regards to clinical outcomes, the patients in the current study faired well in comparison to a historical group of patients who underwent THA for OA at our institution[12]. The average WOMAC score for pain, stiffness, and physical function were all better in the current study. The follow-up period in the historical group was 30 years, while the average follow-up for living patients evaluated in the current study was 27.5 years. These findings seem paradoxical since previous studies suggest that poorer WOMAC scores were related to revision

surgery for acetabular loosening, yet four of the five patients that underwent revision surgery were among the living patients that were evaluated for clinical outcomes in the current study[12]. Traina et al. found that there was a higher rate of neurological complications in their patient population as compared to previous studies of patients undergoing primary THA[8,21]. Such complications were not encountered in the present study, which may suggest that their presence was incidental, particularly that it was only observed in two out of 32 patients. Hanna et al. found a 3% overall rate of sciatic nerve palsy in their systematic review[10].

Radiographic findings in the present study show that there is a high rate of radiolucencies seen around the actabular component at the last follow-up radiograph. Data on long-term follow-up radiographs in this patient population is scarce, and a recent study reported no lucencies in the acetabular component, while there was only one femoral component with radiographic evidence of a radiolucent line <2mm wide[8]. Another radiographic finding in the current study was a high rate of cortical hypertrophy seen in both the post-operative and most recent follow-up films of 85% of the hips reviewed. This has not been previously reported in any of the studies of THA in patients with LCPS. This finding may be due to altered bone metabolism in these patients; however, more research is needed to determine the reason for this phenomenon which could possibly shed light on the etiology of LCPS, which remains largely unknown.

Revision surgery for aseptic acetebular loosening was more common than aseptic femoral loosening (5 versus 1 revision, respectively) in the current study. This confirms data from a previous study which showed that the most common reason for revision was aseptic acetabular loosening (37%) followed by aseptic femoral loosening (16%)[9]. These findings were also true for patients who underwent THA for OA, whereby the rate of revision for aseptic acetabular loosening was twice that of aseptic femoral loosening[12].

The authors recognize the limitations inherent in all retrospective studies. This study is also limited by the small sample size, and the smaller number of patients who were evaluated clinically. However, the number of patients in this study was sufficient considering the rarity of the condition being studied and the small percentage that eventually undergo THA. It is also one of the few studies with long term radiographic and clinical outcomes of patients with LCPS who undergo THA. Our findings support the use of THA for the treatment of OA in patients with LCPS.

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MIGHT DOCTORS REALLY "KNOW BEST"?: UTILIZING SURGEON INTUITION TO STRENGTHEN PREOPERATIVE SURGICAL RISK ASSESSMENT

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ABSTRACT

Background: Many clinical factors are known to increase an individual patient's risk of perioperative complications and hospital readmission. Several novel risk calculators have been created to predict the risk of postoperative complications for specific procedures that rely entirely on objective measurements. Our goal was to determine if surgeon intuition (an estimate of the percent likelihood of minor and major medical and surgical complications and 30-day readmission) could provide an additional source of data in the preoperative setting that may enhance the prediction of complications after surgery.

Methods: We targeted the operative practices of three subspecialized orthopedic surgeons over a 6-month period (February 1 to July 31, 2015). We administered surveys to attending surgeons and assisting residents or nurse practitioners prior to each operation. Surgeons were asked to predict each patient's likelihood, on a scale from <1-100, for experiencing a complication. Following the procedure, we analyzed each patient's electronic medical record to determine any adverse events and readmissions. We then looked at levels of association between predictor variables and complications. Analysis of maximum likelihood estimates for complication outcome was performed comparing objective variables and surgeon prediction.

Results: A total of 417 surveys in 270 patients were available for analysis. Defining the predicted likelihood of minor medical complications as <10% (low), 10-40% (intermediate), and >40% (high), provided discrimination of postoperative complications for a single observer in the first three month. These cutoff ranges showed inter-observer consistency and a trend towards intra-observer consistency. The only three variables predictive of minor medical complications were ASA class (OR=3.63, 95%CI=1.76-7.52, p=0.0005; comparing >2 vs ≤2), age (β=0.034±0.012, p=0.0032) and surgeon prediction when comparing high to low risk (β=0.034±0.008 (0.018-0.049), p<0.0001).

Conclusions: Quantitative surgeon preoperative risk assessment was able to accurately discriminate between low- and high-risk groups of minor medical complications. We did not find a similar association between major complications and readmissions.

Level of Evidence: IV

INTRODUCTION

Many clinical factors (such as age, sex, smoking, body mass index [BMI], and medical comorbidities) are known to increase an individual patient's risk of perioperative complications and hospital readmission. Recently, several novel risk calculators have been created to predict the risk of postoperative complications for specific procedures. These models have been shown to be moderately effective at stratifying patient risk into graded risk categories based upon various patient characteristics[1]. In general, these calculators rely primarily on objective measures and do not quantitatively account for the treating surgeon's risk assessment. With medicine transitioning to a performance based pay system, accurate risk stratification will be of utmost importance to providers, hospitals, and health systems in the coming years.

The American College of Surgeons Surgical Risk calculator (ACS NSQIP) has become a commonly used tool, which specifically looks at a number of objective measurements and calculates a patient's operative risk for adverse outcomes (serious outcome, pneumonia, urinary tract infection [UTI], prolonged hospitalization, etc.). It was initially developed in 2009 specifically for patient undergoing colorectal surgery, but has since been expanded to include more than 1500 unique surgeries[1]. Subsequently, the ACS NSQIP calculator has been applied across the surgical spectrum and been studied extensively in its application to various fields, including but not limited to general surgery, gynecology oncology, plastics and even to orthopedics[2-5]. While this model does seem to be effective at predicting outcomes in a certain

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subset of patients, it seems to lack strength in others, specifically in orthopedics[3,4]. Although the current model of ACS NSQIP does allow treating surgeon to modify the risk 1-2 standard deviations, up or down, there is no option for a subjective quantitative evaluation.

Outside of prediction accuracy, the ideal risk assessment tool is one that is easy to derive and maintains strength across a spectrum of patients and observers[6]. To date, there have been no studies evaluating the use of a surgeon's quantitative subjective evaluation as means for bolstering risk assessment models. The ACS NSQIP relies mostly on objective measurements and only allows for a standard deviation adjustment by the treating surgeon. Furthermore, it has not been shown to be entirely effective in the orthopedic patient[5,7]. Our goal was to determine if surgeon intuition (an estimate of the percent likelihood of minor and major medical and surgical complications and 30-day readmission) could provide an additional source of data in the preoperative setting that may enhance the prediction of complications after surgery. Specifically, we questioned 1) if there are surgeon predictive values that distinguish between low, intermediate, and high likelihood of complications, 2) if the values maintain discrimination when applied to other observers, and 3) the relative importance of including a measure of the surgeon's assessment in a multivariate regression model alongside objective patient characteristics. Better identification of patients at risk for surgical complication would allow for better perioperative counseling, better risk mitigation, and ultimately better patient care.

MATERIALS AND METHODS

We targeted the operative practices of three subspecialized orthopedic surgeons (one oncology and two total joint arthroplasty) over a 6-month period (February 1 to July 31, 2015). We administered surveys (Appendix A) to attending surgeons and assisting residents or nurse practitioners prior to each operation. Surgeons were asked to predict each patient's percent likelihood, on a scale from <1-100, for experiencing minor medical complications, major medical complications, minor surgical complications, major surgical complications, and readmission in the first 30 days after surgery. A detailed description (modified Clavien-Dindo classification system)[8] of each complication category was provided with each survey to ensure consistency across observer (Appendix B). In brief, minor medical complications (MnMC) are those that require pharmacologic intervention and prolong hospital course but ultimately don't affect outcome, while major medical complications (MjMC) are significant or life threatening. Minor surgical complications (MnSC) are those that prolong hospital stay and may require changes in wound management, but do not effect functional outcome, while major surgical complications (MjSC) are those requiring reoperation and would adversely impact the patient's functional outcome.

Following a procedure, we analyzed each patient's discharge summary, postoperative clinic notes, and documented telephone conversations within our electronic medical records to determine any adverse events and readmissions experienced in the 30 days following surgery. All adverse events were documented and assigned to a complication category. Additionally, we collected sex, age, BMI, smoking status, diabetes, ASA and a calculated Charlson score for each patient in order to compare these objective measurements to the surgeon predictions.

To assess if surgeons could distinguish between low, intermediate, and high likelihood of complications, we selected one surgeon's first 3 months of data (BJM) to determine appropriate values to set for risk stratification for the remainder of the observations. Low, medium and high risk cutoffs were established utilizing complication frequency histograms and creating cutoffs based upon the distribution of preoperative prediction and complication rates.

Next, to assess for inter and intra-observer consistency of these predictions, we applied the cutoff values to the second three months of data collection for the same observer, and to the data provided by the other attending surgeons and residents.

Lastly, to evaluate the relative importance of surgeon prediction, we looked at univariate associations between the objective variables and outcomes. We next incorporated the surgeon prediction variable into a multivariate logistic regression model along with the collected objective variables. Analysis of maximum likelihood estimates were calculated, including the variables found to be predictive of outcomes, as means to determine relative strength of each variable.

RESULTS

A total of 417 surveys of 270 patients were available for analysis. Of the 270 patients, 69 experienced minor medical complications (24.8%), 7 major medical complications (2.5%), 12 minor surgical complications (4.3%), 3 major surgical complications (1.1%), and 8 required readmissions in the first 30 days after surgery (2.9%). We found that defining the predicted likelihood of minor medical complications as <10% (low risk), 10-40% (intermediate risk), and >40% (high risk), provided discrimination of postoperative complications for a single observer (BJM) in the first three months of data recording (low vs intermediate OR=7.31 (1.05-51.10), p= 0.044; low vs high OR= 58.50 (6.88-497.29), p= 0.0002; intermediate vs high

Table I. Performance of low- and high-risk values for readmission and complications

Outcome	% Complications		P value
30-Day Readmission	**Prediction <5**	**Prediction ≥5**	
8/270=3.6%	6/212 (2.8%)	2/58 (3.4%)	0.3511
Major medical	**Prediction <5**	**Prediction ≥5**	
7/270=2.52%	3/216 (1.4%)	4/54 (7.4%)	0.0365
Major surgical	**Prediction <5**	**Prediction ≥5**	
3/270=1.08%	2/216 (0.9%)	1/54 (1.8%)	0.3631
Minor surgical	**Prediction <10**	**Prediction ≥10**	
12/270=4.0%	9/203 (4.4%)	3/67 (4.4%)	1.0000

Table II. Number of minor medical complications in each category of risk stratification

	Low (0-10)	Intermediate (11-40)	High (>40)	P value
BJM Baseline	2/41 (4.9%)	3/12 (25.0%)	6/7 (85.7%)	<0.0001
BJM Second timepoint	5/27 (18.5%)	4/14 (28.6%)	8/16 (50.0%)	0.111
Other attendings	12/79 (15.2%)	8/22 (36.4%)	3/5 (60.0%)	0.0084
Residents	25/151 (16.6%)	20/37 (54.1%)	3/6 (50.0%)	<0.0001

OR= 8.00 (1.001-63.96), p=0.049). We attempted to define a cutoff for the other outcome variables by simplifying to only two categories (low vs high), but did not find a similar level of discrimination, even when pooling all 270 patients into one group (Table 1).

When applying these cutoffs for minor medical complications to the second three months of data collection for the same observer, and to the data provided by the other attending surgeons/residents, we found that there was a trend for inter-observer consistency (Table 2). Intra-observer consistency was maintained when comparing low vs high risk cut offs (OR=4.40 (95%CI=1.11-17.48), p=0.035), but did not demonstrate a similar strength of association between the risk of complications for low vs Intermediate (OR=1.76 (95%CI=0.39-7.99), p=0.464) or intermediate vs high groups (OR=2.50 (95%CI=0.55-11.41), p=0.237).

Table III. Univariate associations between predictors and outcome

	Minor Medical Complication (MnMC)
Charlson score	β=0.158±0.100, p=0.1148
Diabetes	β=0.161±0.691, OR=1.18 (0.30-4.55), p=0.8152
Smoking status	β=0.110±0.273, p=0.6879
ASA	OR=3.63, 95%CI=1.76-7.52, p=0.0005
BMI	β= -0.019±0.035, p=0.5829
Gender	β= -0.023±0.433, OR= 0.98 (95%CI=0.42-2.89), p=0.9596
Surgeon Prediction	β=0.034±0.008 (0.018-0.049), p<0.0001
Age	β=0.034±0.012, p=0.0032

Univariate associations between predictor variables (age, sex, body mass index, ASA class, diabetes, smoking status, Charlson comorbidity score, and surgeon prediction) and outcomes showed that the only three variables predictive of minor medical complications were ASA class (OR=3.63, 95%CI=1.76-7.52, p=0.0005; comparing >2 vs ≤2), age (β=0.034±0.012, p=0.0032) and surgeon prediction when comparing high to low risk (β=0.034±0.008 (0.018-0.049), p<0.0001) (Table 3). When performing analysis of maximum likelihood for the age, ASA, and surgeon prediction, only surgeon prediction was found to be significant, with age and ASA no longer being significant predictors (Table 4).

DISCUSSION

Accurate stratification of surgical candidates allows for targeted, prioritized preoperative counseling. Current risk models predominately focus on objective variables. We questioned if a quantitative global assessment by treating surgeon may be useful in risk stratification, as

Table IV. Analysis of maximum likelihood estimates for MnMC outcome

Parameter	DF	Estimate	Standard error	Wald Chi-square	Pr> Chi Sq
Intercept	1	-3.6799	1.0317	12.7224	0.0004
Age	1	0.00748	0.0142	0.2783	0.5976
ASA	1	0.6275	0.4631	1.8366	0.1754
Surgeon prediction	1	0.0258	0.00882	8.5887	0.0034

means for improving the current models. While sample size precluded analysis of several collected variables, we found that a quantitative surgeon preoperative risk assessment was able to accurately discriminate between low- and high-risk groups of minor medical complications and may be more accurate than objective patient characteristics.

Utilizing a single observer's first 3 months of data to determine appropriate values for low, medium and high risk categories, we found <10% (low risk), 10-40% (intermediate risk), and >40% (high risk) provided accurate discrimination of postoperative complications. Similar analysis of other outcome variables did not reveal a similar level of discrimination. When comparing these established cutoffs to the same observers second three months of data, to assess for intra-observer consistency, we found consistency was maintained when comparing low vs high risk cutoffs. Applying these same cutoffs to different surgeon's predictions, we found a similar trend towards inter-observer consistency (Table 2). Lastly, the surgeon prediction variable proved to be as predictive, and even more predictive in some cases, than the collected objective variables. Collectively, this tells us that a quantitative surgeon assessment can accurately identify at risk patients, potentially better than objective variables alone, and that the established cutoff values may be consistent across observers.

One study similar to ours looked at patient characteristics associated with adverse outcomes (defined as reoperation during same admission, extended length of stay, and 30-day readmission) in 5314 TJA patients[9]. They found preexisting genitourinary, circulatory and respiratory conditions, ASA >2, advanced age and prolonged operating time to be associated were the only predictors of adverse outcomes. This further reflects the need to identify patients at risk of complications in the perioperative setting, but also emphasizes that there is not a great model currently for the orthopedic patient, and none that allow for a quantitative evaluation by the treating surgeon.

Another group looked to create an effective risk assessment model specific to the spinal surgery patient[10]. Retrospective assessment of surgical patients revealed several objective, radiographic, and surgical factors associated with outcomes and were included into the new model. Like other models however, it does not incorporate a quantitative surgeon assessment. With many new, field specific models being created, it seems reasonable for one to incorporate a subjective evaluation by the treating surgeon.

The potential value of this new subjective element to preoperative risk assessment is better identification of patients at increased risk of post-operative complications, thus allowing for stronger pre-operative counseling and awareness of the need for mitigation of all modifiable risk factors. The American College of Surgeons NSQIP has shown its limitations in the orthopedic setting[5,7]. Its utilization in orthopedic trauma patients and total joint arthroplasty patients has not been shown to be effective in complication assessment. By showing that surgeons can effectively stratify their patients' risk, it seems practical that the addition of surgeon intuition might strengthen the current risk models. Although 91/270 patients in our study were total arthroplasty patient, the majority were tumor patients (189/270). To date, no one has looked specifically at orthopedic tumor patients and the accuracy of the NSQIP calculator in this patient subset.

There are several limitations to this investigation and require further discussion. One source of error in this study, and the reason we could not assess the remaining 4 variables, was the small sample size. With reported rates of major medical complications and major surgical complications as low as 1.2% and 1.6% respectively[8], it is likely there were too few patients to capture such occurrences. Another potential source of error in this study is the under representation of documented complications. While analyzing patient charts for complication occurrence, we only had access to the notes/encounters at our center. While the majority of patients did seek postoperative care within out hospital system, and patients are routinely seen at 6 weeks postoperatively at which time an adverse event would likely be recounted and noted; it is possible that there were visits to outside emergency departments, or unscheduled readmissions locally that were never reported and documented into our medical records. This would effectively decrease our documented rate of complications.

With both pay-for-performance and individualized medicine becoming more common, the incorporation of a subjective global assessment by the treating surgeon seems like an appropriate step forward in risk assessment. Further investigation is warranted to better study this new variable and its application in risk assessment. Exploring the major medical/major surgical complications with a larger data set may reveal a similar finding to that of this study, with minor medical complications. Many surgical fields have failed to show ACS NSQIP to be effective when stratifying their patients based upon risk. Future studies incorporating treating surgeon predictions, expanded across different surgical fields, may find similar outcomes to that of this study. Ultimately, the development of a global risk assessment that is easy to calculate, has strong inter-observer consistency, and can be applied across surgical specialties will provide for more effective perioperative management. Such calculators may wish to include treating surgeon intuition as another source of evaluation in their models.

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Appendix A: Sample survey administered to surgeons preoperatively

Orthopedic Complication Prediction Quality Control Pilot Project

Patient initials:
MRN:
Date of surgery:
Attending:
Form completed by: Resident Faculty (circle one)

Record the likelihood of experiencing the following category of complications in the perioperative period up to 30 days after surgery on a numeric scale from 1-100. If you think the likelihood of a certain type of complication is <1%, record "<1." Explanations and examples on back of sheet.

PRE-OP

Minor medical complication:_____
Major medical complication:_____
Minor surgical complication:_____
Major surgical complication:_____
30-day all-cause readmission:_____

Appendix B: modified Clavien-Dindo complication classification system

1. Minor medical:
These are medical events that may or may not require pharmacologic treatment or other intervention and are not life-threatening. Minor issues that prolong a hospital admission fall under this category.
Examples: DVT, UTI, acute renal failure that resolves over time, delirium/transient confusion, fevers of unknown origin that delay discharge but resolve, urinary retention requiring catheter placement, blood transfusion for anemia, cardiac arrhythmia, electrolyte abnormality requiring replacement

2. Major medical:
These are medical events that are significant and/or life threatening.
Examples: PE, stroke, MI, renal failure requiring dialysis, sepsis, fat embolus, any unplanned admissions to the ICU for acute decompensation

3. Minor surgical:
These are events that require a change in postoperative management, but generally will not affect the patient's overall outcome.
Examples: Wound dehiscence treated with observation, cellulitis requiring oral antibiotics, blistering/ulcers that require changes in wound management, hematoma/seroma treated with observation or aspiration, incomplete peripheral nerve palsy

4. Major surgical:
These are events that require readmission and/or return to the operating room and/or would adversely impact the expected functional outcome of the patient.
Examples: Deep infection requiring I&D, dislocation, periprosthetic fracture, implant loosening/loss of fixation, compartment syndrome, readmission for IV antibiotics, drainage of hematoma/seroma in OR, complete peripheral nerve palsy

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