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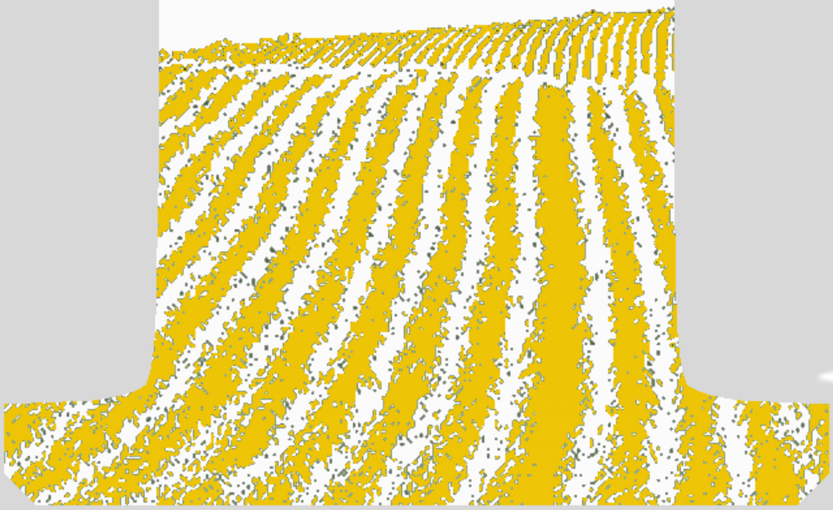
ISSUE 1



THE IOWA ORTHOPEDIC JOURNAL

2019

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

THE IOWA ORTHOPEDIC JOURNAL

2019 • Volume 39 • Issue 1

INSTRUCTIONS FOR AUTHORS, 2019 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, friends, and 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. Statements including sources of funding and 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).

3. **REFERENCES**: References must list references ***in order of 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. Journal names should be abbreviated and capitalized according to the National Library of Medicine. https://www.ncbi.nlm.nih.gov/nlmcatalog?term=currentlyindexed

4. **ILLUSTRATIONS/IMAGES/LEGENDS:** Each figure and table should be submitted on its own, separate page. Tables are preferred to be submitted as separate word or excel files. Figures are preferred to be submitted as high resolution (300 ppi) jpeg, pdf or tif files. 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. 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.

5. **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, Discussion, Acknowledgements (if any), References, and Figure Legend.

6. **SUBMISSION OF MANUSCRIPT:** Authors may submit the manuscript in a word file with continuous numbering and as many additional files (figures, illustrations, legends, etc.) as needed. Please visit https://ioj.scholasticahq.com to submit your manuscript.

7. 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.

FOR EPUBLICATION THIS FALL

2019 • Volume 39 • Issue 2

Due to increased volume we are excited to introduce an epublication version to be released in the late fall each year.

Here is what you can expect to find in our second issue later this year!

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

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Craig G. Mohler
Joseph E. Mumford

1991
Devon D. Goetz
Thomas K. Wuest

1992
Robert L. Bass
Brian D. Mulliken

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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

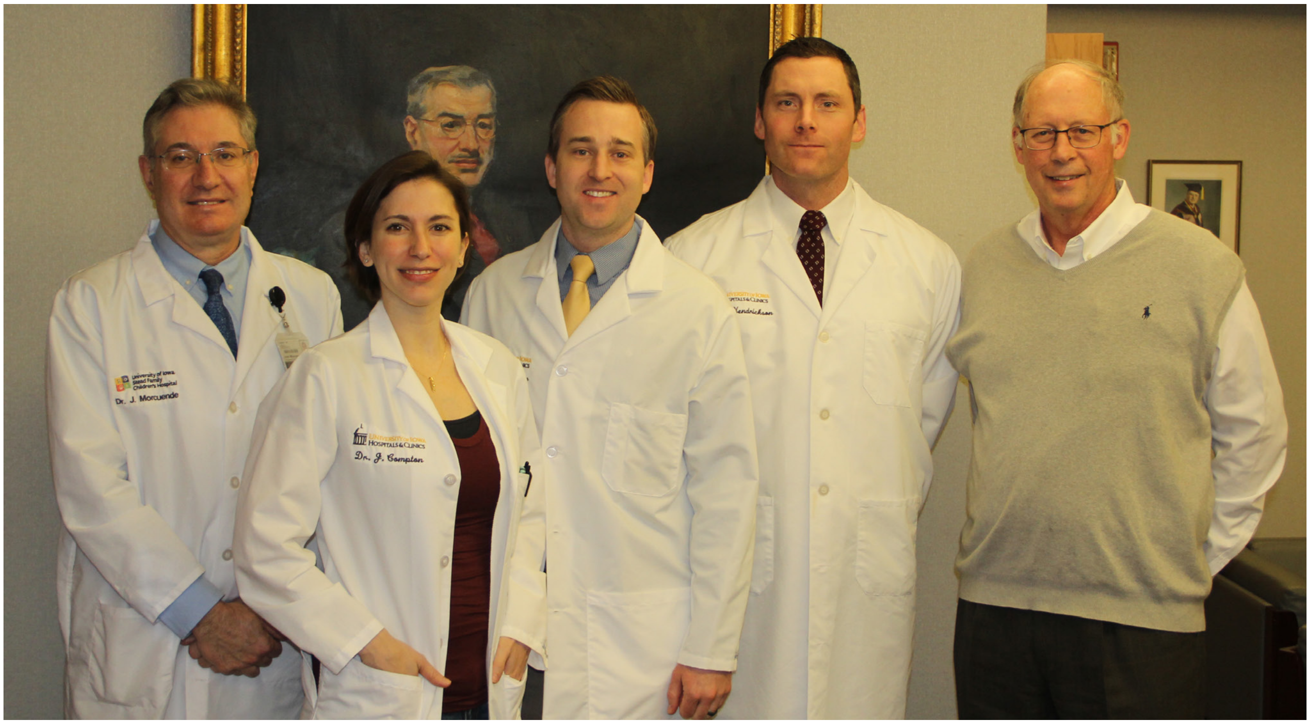
2016
Joshua Holt
Kyle Duchman

2017
Jacob Elkins
J. Joseph Gholson

2018
S. Blake Dowdle
Sean Sitton

2019
Jocelyn Compton
Nathan Hendrickson

2019 IOJ EDITORS' NOTE



From left to right: Dr. Jose Morcuende (Staff Advisor), Dr. Jocelyn Compton (2019 Resident Editor), Dr. Brandon Wilkinson (2019 Resident Business Manager), Dr. Nathan Hendrickson (2019 Resident Editor), Dr. Lawrence Marsh (Staff Advisor)

Continued growth and quality of the articles published have been the staples of the 39th edition of the *The Iowa Orthopedic Journal* (IOJ). This year, a record 90 submissions were considered for publication. 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. The widespread contributions to and readership of the IOJ is a testament to Iowa's continued quality and growing impact on the national and international stage.

We would like to recognize and thank our graduating senior residents, Drs. Christopher Anthony, Tyler CarlLee, S. Blake Dowdle, Kyle Hancock, Sean Sitton and Josef Tofte. They have consistently provided excellent leadership as well as perspective and humor during their tenure at the University of Iowa. From the operating room to the resident room, they have made a lasting impression on their co-residents that both precede and proceed them. Each will continue their training in fellowship next year. We wish them all the best during the next steps and throughout the rest of their careers.

The publication of the IOJ would not be possible without the assistance of several individuals. Specifically, Kelly Kauffman 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. Brandon Wilkinson has also worked tirelessly to obtain corporate sponsorship to finance the printed version of this year's issue. We would also like to thank the sponsors for their generous support of the IOJ. Dr. Jose Morcuende has also provided his expertise as faculty advisor, ensuring the annual success of the IOJ. Finally, we would like to recognize Dr. John Yanik as the unparalleled outstanding Resident Reviewer of the Year, providing timely and thorough insight for a number of articles published this year.

It has been an honor to serve as the editors for the IOJ for 2019. 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.

Jocelyn T. Compton, MSc, MD
Nathan Hendrickson, MD, MS
Co-Editors
Iowa Orthopedic Journal
University of Iowa Hospitals and Clinics
Department of Orthopedics and Rehabilitation

2019 DEDICATION OF THE IOWA ORTHOPEDIC JOURNAL

DR. FRED DIETZ

Excellence in Education and Leadership in Orthopedic Surgery

Fred Dietz, MD

The Orthopedic world as well as a multitude of grateful patients, colleagues, past residents and students will forever mourn the passing of Fred Dietz, MD. A trusted colleague, mentor, teacher, friend and damn good guy who had his perpetual and contagious smile confronted by stage 4 pancreatic cancer succumbing to its challenges on August 12, 2018. He was 67.

Fred was a product of the Cleveland area and forever struggled as a diehard Indians and Browns fan. He was a graduate of Harvard College, and received his medical degree from Columbia University. Dr. Reg Cooper took on the challenge of having Fred as one of his Orthopedic Surgery Residents here at Iowa, and wisely convinced Fred to remain as a cherished faculty member. Fred spent his entire professional career of 33 years as a member of the faculty in Orthopedic Surgery at the University of Iowa. Thank Heavens...

Pediatric Orthopedics was Fred's passion. Yes, he loved being surrounded by kids, but he was also confronted with an environment where the potential treatment options were ill defined and never in the style of a cookbook. He mostly dealt with pediatric orthopedic problems that others shied away from...congenital deformities, cerebral palsy, neuromuscular disease, trauma residual, pediatric infections. He dealt with children with lifelong impairments and disabilities, as well as their extended families. A full hour plus lecture on gait was a cake walk and standard teaching for Fred. Much of his clinical practice was in a specialty where there were no straight forward correct answers, but yet had longstanding consequences. There was no dogma in his world. This caused him to constantly question himself and ask questions of others. He viewed every clinical scenario as a dilemma that required careful thought and reconsideration. Did he do that surgical case well enough? Many of his OR cases were followed by long contemplative directionless strolls, early on often combined with a smoke. He always wanted to do the right thing and the morally correct thing. That was his driving force. Through all of this he became a pillar in the Pediatric Orthopedic Surgery arena and a heavily sought after consultant and confidant.

Dr. Fred Dietz clubfoot casting in Southeast Asia.

Fred was a master at reconstructing a congenital hip deformity (2.5 RVU). He was a master at applying a clubfoot cast (.25 RVU). He was a master at evaluating a child's toeing in appearance and alleviating parental anxiety (.025 RVU). He was a master at teaching the learner's around him what was important (.0025 RVU). Many of these activities are lightly valued in an RVU productivity based system, a fact that was never an issue for Fred. He was "the best resident I ever worked alongside with"[1] (.00025 RVU).

Fred also had a keen social conscience. He loved people and their interactions. He recognized BS and called out those engaged in that practice. He loved words and how thoughts are properly expressed. He wanted to understand people. He was very interested in how decisions were made. He sought social justice. Ethics, morality, and mortality were easy discussion fodder for him. He, on one day, would self-describe himself as a liberal atheist with no direction, followed the next day as a reactionary diehard traditionalist. His lack of ego allowed him to drive about in an aging blue Honda Fit (into which he barely fit). Why? Because it got him where he needed to go, had

2013 Department of Orthopedics 100th Year Anniversary Celebration. Auction of old departmental relics, Dr. Fred Dietz holding an item up for bid, Dr. James Nepola holding a microphone (as always), and Dr. Ernest Found was the auctioneer.

room for his lunch, books, loose papers, 5 tennis racquets, 2 trombones, a guitar with broken strings, a baseball glove and bat, and an odiferous gym bag. He loved the water... bridge jumps into the Iowa River at night, being thrown by ocean waves, the crispness of freshwater lakes, aimlessly floating on an inner tube.

Fred travelled the world, partly recreationally, but mostly in conjunction with the treatment of clubfoot. This took him to many underdeveloped environments where language was a barrier, but the need for medical care was great. Fred was an icon in these environments. His patience, understanding, and treatment of patients and colleagues with dignity regardless of their station in life is unsurpassed. It was Fred being Fred. He spread the values so important to mankind in an unassuming and most often unappreciated way. No fanfare, no headlines.

Fred's family was his ultimate consumption. He often spoke about his mother in Akron, Ohio and his brother and sister. He admired his father and younger brother, whose passings preceded Fred. His two sons, Alex and Andrew are Fred's "raisson d'être." Fred adored his wife

Photo courtesy of Dr. Dietz's family.

Photo courtesy of Dr. Dietz's family.

of 18 years, Meg, and his two stepdaughters, Sarah and Liza. Fred and "my Sweetie, Meg" had four teenagers under one roof for several years. Oh, the stories he told... book material.

Our world of Orthopedics can be a double edged sword... often providing lifechanging contributions, yet in an environment conducive to excess and exploitation. It is easy to slowly slide into an era of selling procedures and tests and in ways corrupting peoples' values. Fred Dietz was at the other end of the spectrum. Doing the right thing with dignity to all always came first for Fred. Those who knew Fred recognized this in him and appreciated his attributes. They realize that it often went underappreciated. Our profession needs more Fred Dietz's. Those who knew Fred are lucky. The Orthopedic world will miss Fred and will long for more like him; unfortunately, we fear that this precious mold may have been broken forever.

We should all take a moment and recognize Fred's smile, his laugh, his values, his knowledge, and his life and be thankful that he shared it with us. There's a simple way to honor him. Nothing would make Fred happier than to "pour a Manhattan and drink it with someone you love."[2]

~ Ernest M. Found, Jr., MD

[1]Dr. Tom Fox, Orthopedic Resident, 1984 Graduate

[2]Dr. Dietz's obituary, https://gayandciha.com/tribute/details/3443/Frederick-Dietz/obituary.html

2019-2020
DEPARTMENT OF ORTHOPEDICS AND REHABILITATION
SCHEDULE OF LECTURESHIPS AND CONFERENCES

Carroll B. Larson Shrine Memorial Lecture
May 31, 2019

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

Ira Zaltz, MD
Professor of Orthopedic Surgery
Oakland University William Beaumont Medical School
Division Head of Pediatric Orthopaedic Surgery
Beaumont Hospital
Royal Oak, MI

Spring 2020 to be arranged.
Contact Nancy Love: (319) 356-1872

2019 Senior Residents' Day
June 14-15, 2019

Urmila Sahai Seminar Room
University of Iowa
Medical Education Research Facility

David Ring, MD, PhD
Associate Dean for Comprehensive Care
Professor of Surgery and Psychiatry
Dell Medical School, The University of Texas Austin

Judy Baumhauer, MD, MPH
Professor and Associate Chair of Orthopaedics
University of Rochester School of
Medicine and Dentistry

35th Annual
University of Iowa Sports Medicine Symposium
December 12-13, 2019

Marriott Hotel & Conference Center
300 East 9th Street, Coralville

Dustin Grooms, PhD, ATC, CSCS
Ohio Musculoskeletal and Neurological Institute,
Ohio University
Athens, OH

Cynthia R. LaBella, MD
Northwestern Medicine; Lurie Children's Hospital
Chicago, IL

Brett Owens, MD
Brown University, Alpert School of Medicine
Providence, RI

Bryce Gaunt, PT, SCS
Director of Physical Therapy
HPRC @ St. Francis Rehabilitation Center
Columbus, GA

2020 Senior Residents' Day
June 5-6, 2020

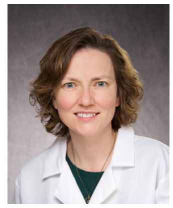
Discussants to be arranged.
Contact Jessica Dorsman: (319) 353-6747

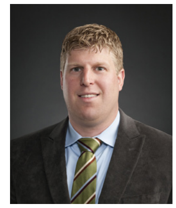
DEPARTMENT OF ORTHOPEDICS AND REHABILITATION STAFF 2018-19


Dr. John Albright

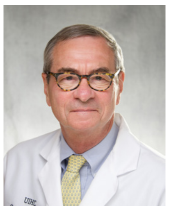

Dr. Donald Anderson

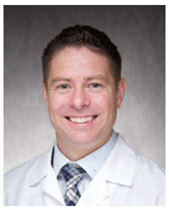

Dr. Eric Aschenbrenner

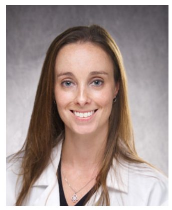

Dr. Heather Bingham


Dr. Matthew Bollier


Dr. Timothy Brown


Dr. Joseph Buckwalter

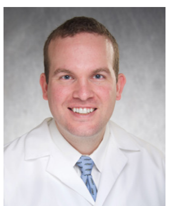

Dr. Joseph Buckwalter V


Dr. Lindsey Caldwell


Dr. Philip Chen

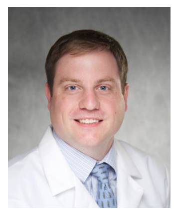

Dr. Charles Clark

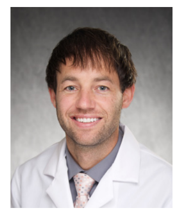

Dr. Mitchell Coleman


Dr. Kyle Duchman


Dr. John Femino

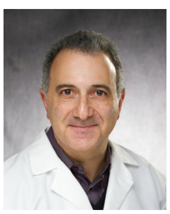

Dr. Timothy Fowler


Dr. Matthew Hogue


Dr. Joshua Holt

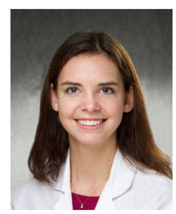

Dr. Jessica Goetz

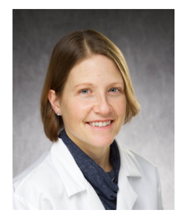

Dr. Mederic Hall


Dr. Cassim Igram


Dr. Matthew Karam


Dr. Valerie Keffala


Dr. Heather Kowalski


Dr. Ericka Lawler


Dr. J. Lawrence Marsh


Dr. James Martin

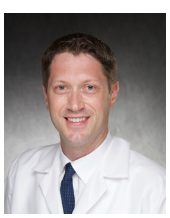

Dr. Benjamin Miller

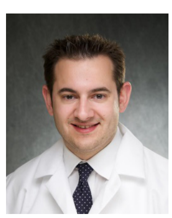

Dr. Jose Morcuende


Dr. James Nepola

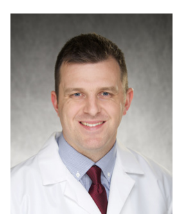

Dr. Nicolas O. Noiseux


Dr. Jesse Otero

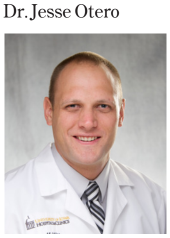

Dr. Brendan Patterson


Dr. Andrew Pugely


Dr. Stuart Weinstein


Dr. Robert Westermann


Dr. Mindy Trotter


Dr. Michael Willey


Dr. Brian Wolf

1. Stuart Weinstein, MD
2. John Femino, MD
3. Robby Westermann, MD
4. J. Lawrence Marsh, MD
5. David DeMik, MD
6. Molly Day, MD
7. Joseph A. Buckwalter V, MD, PhD
8. Joseph A. Buckwalter IV, MD
9. Valerie Keffala, MD
10. Chris Carender, MD
11. Matthew Hogue, MD
12. Kyle Kesler, MD
13. James Nepola, MD
14. Malynda Wynn, MD
15. Nathan Hendrickson, MD, MS
16. Michael Willey, MD
17. John Yanik, MD
18. Brendan Patterson, MD
19. Heather Kowalski, MD
20. Cassim Igram, MD
21. Kyle Duchman, MD
22. Nicolas Noiseux, MD
23. Ericka Lawler, MD
24. John Albright, MD
25. Brian Wolf, MD
26. Brandon Wilkinson, MD
27. Josh Holt, MD
28. Cameron Barton, MD
29. Blake Dowdle, MD
30. Don Anderson, PhD
31. Jose Morcuende, MD
32. Tyler CarlLee, MD
33. Josef Tofte, MD
34. Chris Anthony, MD
35. Sean Sitton, MD
36. Tim Fowler, MD
37. Scott Muffly, MD
38. James Kohler, MD
39. Alan Shamrock, MD
40. Emily Connor, MD
41. Elizabeth Scott, MD
42. Chris Cychosz, MD
43. Joshua Eisenberg, MD
44. Christina Hajewski, MD
45. Jocelyn Compton, MSc, MD
46. Sarah Schippers, MD
47. Chris West, MD

2019 GRADUATING ORTHOPEDIC RESIDENTS

Christopher Anthony, MD

Dr. Chris A. Anthony grew up in rural Iowa where he enjoyed sports and exploring from a young age with his two brothers, Tom and Erich. Chris attended college at Iowa State University where he earned a BA in Political Science. He played football at Iowa State and served as team captain his junior and senior seasons. Chris subsequently played professional football in the Arena Football League (AFL) serving as team captain of the NY Dragons and also as Vice President of the Arena Football League Players Union. Prior to medical school, he attended the New York University Interactive Telecommunications Program where he studied human computer interaction. He returned to Iowa and earned his MD with an emphasis in research from The University of Iowa Carver College of Medicine.

Chris' primary research interest considers how we can utilize computer software and hardware to communicate and interact with patients. He enjoys bringing people together in cross-disciplinary teams to propose questions and consider unique solutions to orthopaedic problems. He has been fortunate to work with many of the faculty at UIHC and has also conducted software based projects at multiple other academic centers around the country. Chris plans on pursuing an academic orthopedic practice focused on joint preservation and hip and knee replacement. He will be attending the Washington University joint preservation, resurfacing and arthroplasty fellowship.

Chris would like to first thank his wife Jess for her friendship, encouragement and patience. It has been Chris' great privilege to take part in Jess' beautiful and inspirational artistic work that she has accomplished over the past decade in Iowa. He hopes for many more adventures with Jess in the coming years. Chris would also like to thank his children Beck (8), Perrine (4), and Eleanor (1) for providing inspiration and hope every day. Chris also recognizes his parents Claire and the late Wayne Anthony for always sacrificially supporting him and his brothers so they could pursue their dreams. Chris would like to acknowledge and thank Dr. John Albright for providing him a start in orthopaedics and research. He would like to thank Dr. Joseph Buckwalter IV for his many impromptu conversations and Dr. Larry Marsh for encouraging and supporting his many interests during residency. Chris would also like to give a special thanks to Dr. John Callaghan and Dr. Stu Weinstein for serving as mentors and "champions" in his career; without their guidance and support he would not be on his current path. Finally, Chris would like to thank his close friends and classmates Kyle, Blake, Sean, Tyler and Joe for their loyalty, character and excellence.

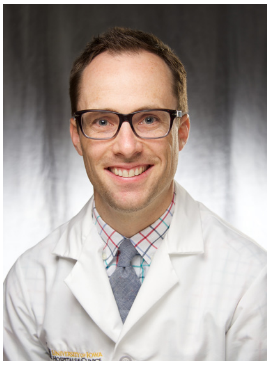
Tyler CarlLee, MD

Tyler was born and raised in Little Rock, Arkansas to Lewis and Brenda CarlLee. After surviving his childhood, his parents determined he would remain an only child. He attended the historic Little Rock Central High School followed by the University of Arkansas where he received degrees in Biology and Finance. Inspired by several mentors in high school and college he chose to pursue a career in medicine at the University of Arkansas for Medical Sciences. It was during his first year of medical school when he met his eventual wife Sheena.

As a second-year medical student, Tyler spent his time on weekends volunteering at a local orthopedic sports medicine clinic. This experience sparked his interest in the field and led him to take call and scrub in on cases with the orthopedic residents. It was on an away rotation in Houston, Texas where he was introduced to the Iowa program through former resident Scott McKay. Tyler and Sheena were excited to couples match at UIHC in orthopedics and internal medicine, respectively. While in Iowa, they have made many new lifelong friends and have welcomed their son Merritt to the family in August of 2018.

Tyler would like to thank his research mentors including Dr. Bollier, Dr. Hettrich, Dr. Wolf, Dr. Karam, Dr. Marsh, Dr. Anderson, and Dr. Willey. His experiences have taught him the importance of continuing to pursue personal and professional goals in the face of adversity. The ability to dive into multiple projects in several different subspecialties speaks to the strength of the department to provide a culture of advancing orthopedic education.

Following residency Tyler will be a Sports Medicine fellow at OrthoCarolina in Charlotte, North Carolina. He is extremely grateful for the support of faculty and his residency classmates. Finally, he would also like to express his gratitude to his parents and extended family, and his wife for their continued encouragement, guidance and love.



Blake Dowdle, MD

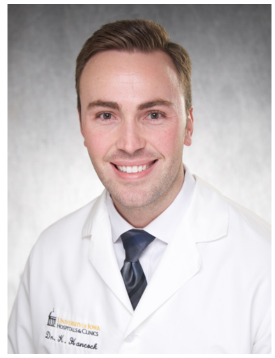
Blake was born and raised in Salt Lake City, Utah by his parents Mike and Gayla Dowdle. At an early age Blake recalls learning the importance of an education and hard work exemplified by his father and mother, both of whom remain Blake's greatest heroes. Following high school, Blake chose to postpone his university studies, instead choosing to serve a 2 year religious mission for the LDS church in Barcelona, Venezuela. Blake credits his mission for changing his perspective on service to others and influencing his decision to pursue a career in medicine.

Following his return from Venezuela, Blake rekindled his relationship with Emily, whom he had met in seventh grade. They were married in August 2005 in Salt Lake City, Utah. He chose to study at the University of Utah and graduated with a degree in Exercise Physiology. During his undergraduate studies he was fortunate to be mentored by Dr. Roy Bloebaum at the Veterans Hospital Bone and Joint Lab, who introduced Blake to the academic world of orthopedics. There he performed studies on particulate debris from metal on metal arthroplasty. Following his graduation he was accepted to the University of Utah School of Medicine.

It was during medical school that Blake continued his passion for orthopedic surgery and the restoration of function to those afflicted with musculoskeletal disease. While performing an away rotation at Iowa, Blake gained a deep appreciation for the department, faculty and residents and he was fortunate enough to match at the Iowa for residency. During residency several faculty have provided meaningful mentorship in research namely Drs. Callaghan, Wolf and Lawler. Blake's research interests have spanned several subspecialties during residency and have included projects in hand, total joint arthroplasty and sports medicine. Additionally, Blake would like to thank the faculty as a whole as he has been mentored by some of the of the giants in the field of orthopedics who have influenced his career and future direction as a sports medicine surgeon.

Blake will be returning home to Salt Lake City, Utah to join the University of Utah as a sports medicine fellow. He is ecstatic to be able to take care of his alma mater's sports athletes as well as the Utah Jazz. Following fellowship, Blake wishes to stay active in academic pursuits with teaching and research. He wishes to pass along the invaluable lessons he has learned from his mentors here at Iowa to the next generation of orthopedic surgeons.

Blake is extremely grateful for and he would like to acknowledge his co-residents. Joe, Tyler, Sean, Kyle and Chris have been the best group of residents with whom to share this journey. Most importantly, Blake wants to thank his wife Emily. Along this journey she has been the glue that keeps their family together. Lastly, Blake and Emily have been blessed to welcome 4 wonderful children into their lives. Audrie (11), Olivia (8), Isaac (6), and Eden (1) have always provided their unconditional love following those long and hard days in the hospital.



Kyle Hancock, MD

Kyle started life as a country boy born in the small town of Evanston, Wyoming, as the youngest of six children to a loving mother and father. During childhood and adolescence he participated in many sports including basketball, football, soccer, track, wakeboarding, snowboarding, and the myriad outdoor activities that mountainous Wyoming offers. He graduated as valedictorian of his high school class before leaving for Los Angeles to put his National Merit Scholarship to work studying biology at the University of Southern California. After college he then attended medical school in Seattle at the University of Washington where he graduated with honors. During medical school he volunteered in multiple student organizations, including founding and presiding over the Policy and Business of Medicine Society. In this role he worked closely with the CEO of UW Medicine, to become familiar with the current landscape of healthcare business and its reform. Having banked all of his elective time, he then spent the last three months of medical school backpacking around the world before beginning orthopedic surgery residency at the University of Iowa.

Outside of his medical career, Kyle has a passion for entrepreneurialism and business that he has maintained throughout his formal schooling. He paid for college by founding and operating a landscape design and construction company that seasonally employed 47 people. While in medical school he then founded a private investment fund that specializes in the rehabilitation of distressed real estate and which currently operates in four states. He also manages three other holding companies with various real estate, entertainment, and other ventures.

Kyle's research interests during residency have included work in multiple areas including the validation of novel patient reported outcomes instruments in various sports medicine populations, investigating treatment trends in the management of osteochondral defects, and a randomized controlled trial using multimodal analgesic injections in patients with ankle fractures with the goal of improving postoperative pain control.

After residency Kyle will be attending a one year sports medicine fellowship at the Hospital for Special Surgery in New York City. After fellowship he plans to develop an active clinical practice and integrate his passion for business by leading his practice or institution in an administrative role and pursuing continued growth in real estate. He is excited for this next step before beginning his career and is grateful to his mentors at Iowa, his exceptional residency classmates, his parents, and his beautiful girlfriend Ashley for their continued love and support.

Sean Sitton, MD

Sean was born and raised in Chandler, AZ as the second oldest of 5 children to Edward and Kelly Sitton. Growing up in the warm Arizona weather, he enjoyed playing sports year round including football, baseball and basketball.

Sean graduated from Corona del Sol High School in 2003, where he played football and ran track & field. When it came time to decide where he would attend college, there was no question in his mind where he would go. It had always been his dream to attend Brigham Young University in Provo, UT. Both of Sean's parents and all 4 of his siblings have attended and/or graduated from BYU.

After completing his first semester at BYU, Sean was blessed to spend 2 years as a full-time missionary for the Church of Jesus Christ of Latter-day Saints in the Northern Philippines. This was a life-changing experience, and it played a large role in inspiring him to pursue a career in medicine. Sean returned to BYU after his mission, where he soon met his wonderful wife, Leslee. They were married later that year. Their first two children, Summer and Knox were born during their final years in Provo. Sean and Leslee both graduated from BYU with degrees in Exercise Science (2009), and Elementary Education (2008) respectively. After graduating from BYU, Sean worked for a year as an Exercise Therapist and strength & conditioning coach in Provo, UT while applying for medical school.

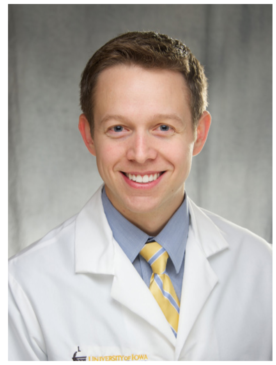
Sean and Leslee left Provo in the Summer of 2010 and moved their small family to Houston, TX for him to attend Baylor College of Medicine. During the first year of medical school he quickly realized that he was destined to become an orthopedic surgeon. He became involved early on in orthopedic research with that same attending and eventual mentor, Dr. Lee M. Reichel, MD.

Sean was thrilled to match at his top choice program, The University of Iowa for Orthopedic Surgery Residency in 2014. Although the move from Houston to Iowa City was a cold one, the Sitton Family has really enjoyed their time in Iowa City and are grateful for the lifelong friends they have made throughout their 5 years here. Sean is also grateful for the opportunity to be a part of the greatest class of 6 orthopedic residents to ever come through Iowa, as well as the privilege of working with such great faculty at Iowa. He takes great pride in being an Iowa orthopedic resident, and is grateful for having trained at the best orthopedic residency program in the country.

After residency, Sean will pursue further training in Sports Medicine and Arthroscopy at the ASMI/Andrews Sports Medicine & Orthopedic Center in Birmingham, AL. His ultimate plan is to hopefully return to his home state of Arizona, become a team physician and take care of athletes.

Sean is eternally grateful for his amazing and beautiful wife, Leslee, who deserves all of the credit for any of his accomplishments thus far. She has put up with all of the long nights, call shifts, cold winters, etc. She has dealt with getting kids ready and to school and church on time, teaching pre-school, teaching multiple fitness classes at the gym, and has been the president of the Iowa Medical Partners. She is truly what holds their family together, which now includes 4 beautiful children; Summer (11), Knox (9), Lacey (6), and Saige (1). Sean would also like to acknowledge his wonderful parents, Eddie and Kelly for all of their love and support throughout the years, and for instilling in him important core values of faith and hard work. He would also like to thank his 4 siblings; Ashley, Chelsea, Zach and Beau for their love and support. He thanks his co-residents and especially his 5 classmates; Chris, Blake, Tyler, Kyle and Joe. There has been a lot of blood, sweat and tears over the last 5 years, and there's no better group of guys that he would've rather gone through it with.

Josef Tofte, MD



Josef grew up in Duluth, Minnesota, a small city on the very western tip of Lake Superior. He was introduced to biology and engineering at an early age thanks to his parents: his mother a biologist by training and his father, an industrial safety engineer. He spent his childhood roaming the Northern woods and lakes of Minnesota with his sister, Alena.

In high school, Josef developed an interest in medicine by volunteering at a local hospital. He was active in music including choir, orchestra, and many rock band side projects. He also competed in athletics, including cross country skiing and running, rowing, and cycling. He graduated number 1 in his class from Duluth East High School and was a National Merit Scholar.

Josef attended college at Harvard University in Cambridge, Massachusetts. He graduated cum laude in Neurobiology with a secondary in Computer Science. His thesis described locomotory behavior in C. elegans. He then attended medical school at the Warren Alpert School of Medicine of Brown University in Providence, Rhode Island. He was elected to Alpha Omega Alpha and researched cartilage imaging in lubricin-deficient mouse models.

As a fourth year medical student, Josef was elated to learn of his match at the University of Iowa's prestigious orthopaedic surgery residency. His research interests have included a variety of projects, many of which have the common themes of resident education, surgical simulation, and the interface of technology and medicine.

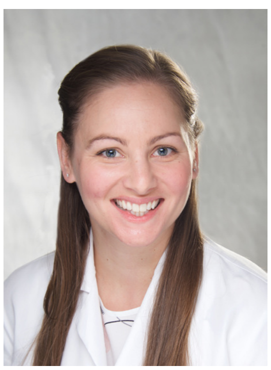
After moving to Iowa City, Josef met his future wife Bridget Shields. An Iowa City native, she had already matched in Dermatology at the University of Wisconsin. Though they lived away from each other for four years, Josef and Bridget enjoyed the process of commuting most weekends, first between Iowa City and Des Moines for Bridget's transitional year, then Madison, Wisconsin for the remainder of residency. Despite the distance, they found time to regularly run, bike, swim, ski race, build things, make music, and enjoy each other's company. They will pursue fellowships together in 2019-20 in hand surgery at the Philadelphia Hand to Shoulder Center (Josef) and medical dermatology at the University of Pennsylvania (Bridget).

Josef is incredibly thankful for the influences, motivation, and guidance of his wife, family, in-laws, and co-residents, as well as the exceptional mentorship and unmatched teaching he has found as a resident at Iowa.

2019 GRADUATING FELLOWS

Robert Cates, MD

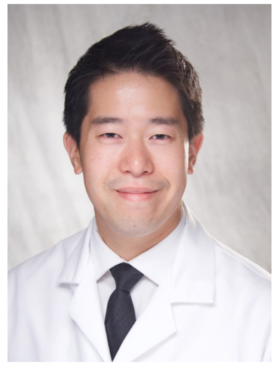
Robert grew up in Houston, Texas. He received his undergraduate degree in Kinesiology from Southwestern University in Georgetown, Texas and completed additional pre-medical work at the University of Houston. He completed his medical training in Fort Worth at the University of North Texas. He then headed north to Rochester, Minnesota for his Orthopedic training at Mayo Clinic. He is currently finishing his Orthopedic Sports Medicine Fellowship at the University of Iowa and is extremely grateful for all of the outstanding training and mentoring he has received. He is joined by his wife and two children who are now Hawkeye fans for life!



Elizabeth Weldin, MD

Elizabeth Weldin is the current hand surgery fellow. She was thrilled to stay on for the year after completing her residency at the University of Iowa. She is a proud wife to a fireman and mother of a one year old boy. Elizabeth and her family will be moving to Reno, Nevada for new adventures in the mountains after fellowship training is complete. Elizabeth hopes to focus on many types of upper extremity ailments, but has a particular interest in pediatric conditions and elbow pathology.

Elizabeth is grateful to all her mentors at the University of Iowa who have helped shape her into an orthopedic hand surgeon over the past 6 years. In particular, Dr Ericka Lawler has been a consistent source of support, mentorship and an excellent role model for women in orthopedics. Elizabeth aspires to provide mentorship to young people in the future and provide an example of work-life balance for mothers in medicine and women in orthopedic surgery.

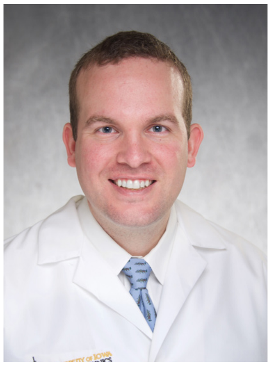


Benjamin Jong, MD

Dr. Benjamin Jong is an orthopaedic surgeon who is the current fellow in foot and ankle surgery. Ben was born and raised in Vancouver, BC, Canada. He earned his undergraduate degree in Kinesiology at Simon Fraser University in Burnaby in 2008. He then moved on to medical school at the University of British Columbia, graduating with his MD in 2013, and then finished his residency in orthopaedic surgery, also at UBC, in 2018.

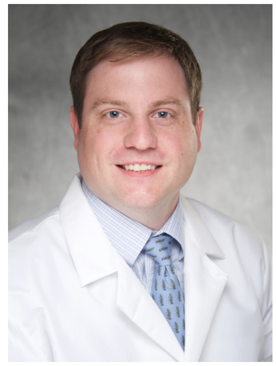
Ben would like to thank Dr. Femino for his guidance throughout the year. He is also grateful to the entire Department of Orthopedics and Rehabilitation at the University of Iowa for making his time in Iowa both educational and enjoyable. Ben will be heading back to Canada for a second fellowship in sports in Winnipeg, Manitoba.

NEW ORTHOPEDIC FACULTY



Kyle Duchman, MD

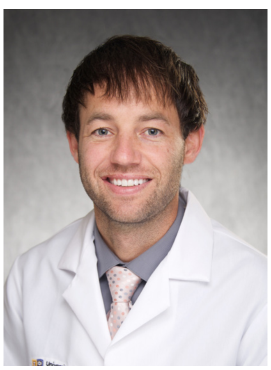
Dr. Kyle Duchman was born and raised in Cedar Falls, Iowa. He completed his undergraduate training at Wartburg College before completing both his medical school education and orthopedic residency training at the University of Iowa. Following residency, he completed an orthopedic sports medicine fellowship at Duke University in Durham, North Carolina. Upon completing fellowship, Dr. Duchman returned to the University of Iowa in the fall of 2018 to join the orthopedic faculty. He lives in Iowa City with his fiancée, Julia. His research interests include clinical outcomes following a variety of shoulder, knee, and ankle procedures as well as basic science research focused on tendon to bone healing.



Matthew Hogue, MD

Dr. Matthew Hogue is a Clinical Assistant Professor in the Department of Orthopaedics and Rehabilitation at University of Iowa Hospitals and Clinics. He completed his Orthopedic Traumatology Fellowship at the R. Adams Cowley Shock Trauma Center in Baltimore and his residency at the University of Iowa from 2012-2017. A Texas native, Matt obtained his bachelor's degree in Chemistry at Trinity University in San Antonio and his MD at the University of Texas at Houston Medical School.

In his free time, Matt enjoys basketball, college athletics and spending time with his wife, Shayna, and their daughters Caroline and Macey.



Joshua Holt, MD

Dr. Joshua Holt is an orthopaedic surgeon who specializes in scoliosis and child and adolescent hip pathology. He treats pediatric patients with a wide array or musculoskeletal conditions but has particular clinical and academic interest in developmental dysplasia of the hip, slipped capital femoral epiphysis (SCFE), Perthes disease, and scoliosis. Dr. Holt was born and raised in Salt Lake City, Utah where he earned his Bachelor's degree in Exercise Physiology from the University of Utah. He attended medical school at the University of North Carolina at Chapel Hill before completing residency training in Orthopaedic Surgery at the University of Iowa. He received specialized training in scoliosis and pediatric orthopaedics while completing fellowship at Rady Children's Hospital in San Diego, CA before returning to the University of Iowa as Assistant Professor in the Department of Orthopaedics and Rehabilitation. He received additional advanced training in pediatric spine and hip procedures while working with renowned international surgeons in New Zealand. He and his wife, Ali, and three boys (Boston, Nixon, and Ryker) are happy to now call Iowa home.

Mindy Trotter, MD

Dr. Mindy J Trotter is a Podiatrist who joined the Department of Orthopedics and Rehabilitation in the fall of 2018. An Iowa native, Dr. Trotter received her doctorate from Des Moines University and then completed a 3 year surgery residency with the Podiatry Institute in Atlanta, Georgia. She is board certified by the American Board of Podiatric Medicine and has special interest and training in advanced wound care. After 3 years in private practice in southeast Iowa she made the decision to join the University to promote advancing care and patient outcomes with complex wounds. Dr. Trotter serves as a faculty member of the Podiatry Institute in addition to being reappointed for a second term to the Iowa Board of Podiatry.

The 2019 Michael Bonfiglio Award for Student Research in Orthopaedic Surgery

The 2019 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.

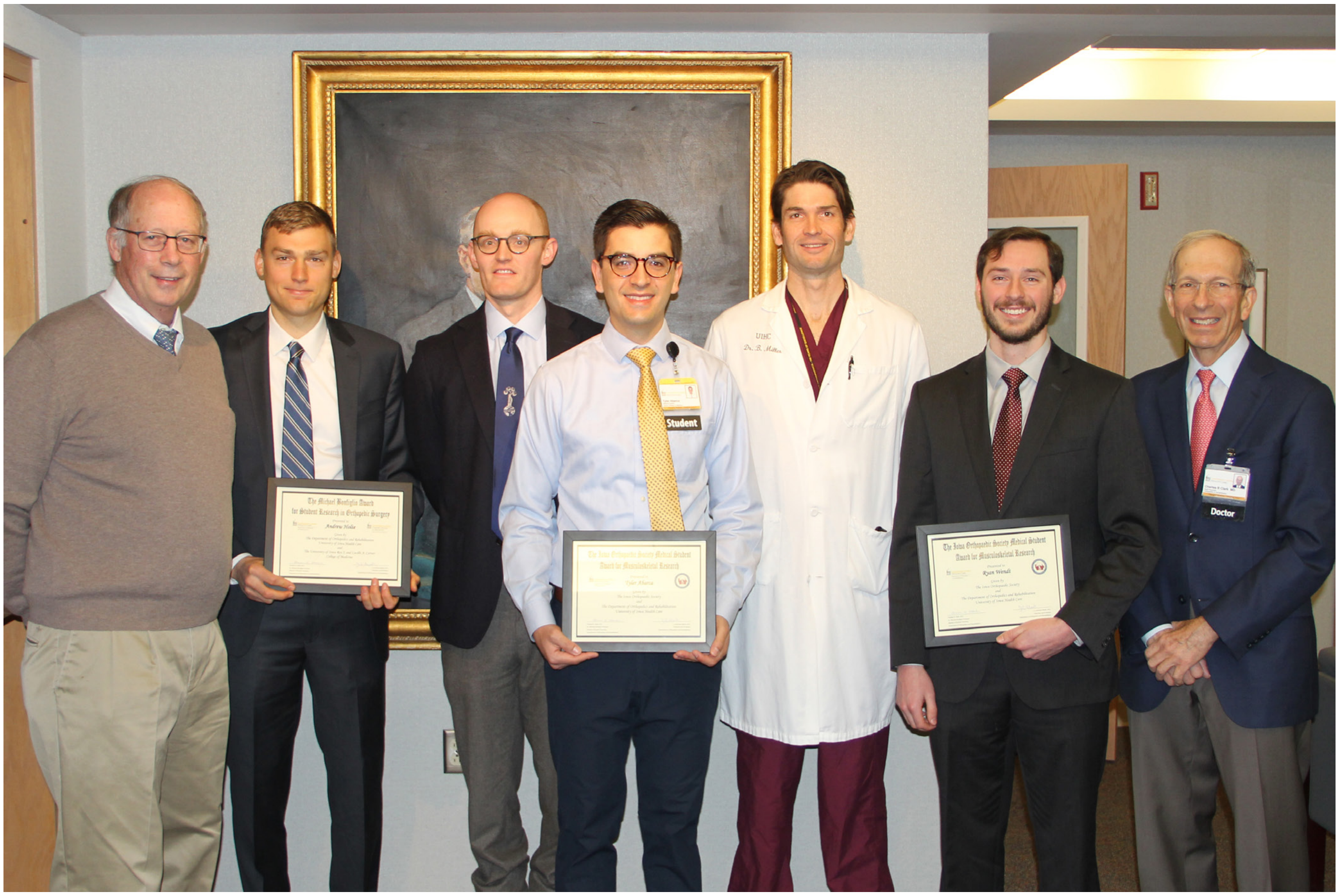
This year the selection committee consisted of Drs. Charles R. Clark, Timothy Brown, Joseph Buckwalter, Timothy Fowler, Cassim Igram, Craig Mahoney, and Jose Morcuende. They recommended that Andrew Holte, M4, receive the 2019 Michael Bonfiglio Student Research Award. Andrew's award was based on his project, "Restrictive Opioid Prescribing Protocols Following THA and TKA Are Safe and Effective". His advisor was Dr. Timothy Brown.

The selection committee recommended that the Iowa Orthopaedic Society Medical Student Research Award be given to Tyler Abarca, M3, for his research titled "Improved Survival for Extremity Soft Tissue Sarcoma Treated in High-Volume Facilities". His advisor was Dr. Benjamin Miller.

The selection committee recommended that the Iowa Orthopaedic Society Medical Student Research Award also be given to Ryan Wendt, M3, for his research titled "Rural Patients Are at Risk for Increased Stage at Presentation and Diminished Overall Survival in Osteosarcoma". 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. JL Marsh/Chairman, Andrew Holte/Michael Bonfiglio recipient, Dr. Timothy Brown/advisor of Andrew Holte, Tyler Abarca/IOS recipient, Dr. Benjamin Miller/advisor of the IOS recipients, Ryan Wendt/IOS recipient, Dr. Charles Clark/Director

DIVERSITY IN ORTHOPEDICS

This year, the Iowa Orthopedic Journal is proud to announce a new section of the journal that discusses diversity in Orthopedics. In future issues, we will feature at least one article annually on the topic of diversity in order to highlight this area of growing research and interest. We invite our readership and researchers to submit their work and insights to this forum in the coming years for publication.

The Department of Orthopedics and Rehabilitation is also excited to announce the initiation of a new Diversity Committee in 2018. The charter members of the committee successfully brought the Perry Initiative to Iowa City in the spring of 2019. Many women cite inadequate exposure and experience during the pre-medical and medical school years as a major deterrent from choosing orthopedics as a career. During the 4-hour session, medical students were taught the basics of intramedullary nailing and external fixation in a hands-on course in the Buckwalter Surgical Skills Laboratory. Female faculty and residents discussed the training process and reflected on the nuances of work and lifestyle as an orthopedic surgeon. We look forward to many more events promoting orthopedics as an exciting career path for young people of all backgrounds in Iowa.

Dr. Jessell Owens (PGY 4) teaches triangulation to a medical student during the Perry Initiative.

Two students practice external fixation techniques as part of an outreach program to increase exposure to orthopedics during the early years of medical school.

BREAKING BARRIERS: A BRIEF OVERVIEW OF DIVERSITY IN ORTHOPEDIC SURGERY

Molly A. Day, MD, ATC[1]; Jessell M. Owens, MD[1]; Lindsey S. Caldwell, MD[1]

ABSTRACT

Diversity within the field of orthopedic surgery has been slow to progress, even well into the 21st century. Despite the barriers broken in 1932 by Ruth Jackson - the first female member of the American Academy of Orthopedic Surgeons (AAOS) - gender, racial and ethnic diversity continues to be lacking. Research has shown there are clear advantages of a diverse physician population, not only in medicine and patient care but in commercial industry as well. Although the representation of females and underrepresented minorities (URM) in orthopedics is increasing, it is doing so at a slower rate as compared to other surgical subspecialties. Targeted efforts have been made to investigate and promote gender and cultural diversity in orthopedic surgery. New programs and initiatives have been developed to promote diversity in orthopedics through mentorship and enhancing visibility of females and URM in the field.

Keywords: minority, gender, orthopedic surgery, diversity

INTRODUCTION

The term "diversity" is not easily defined. The more traditional connotation of the word refers to the great variety of differences that exist between people, associated with race, language, culture or gender. In recent years, advocates have expanded the definition of diversity beyond the more obvious dimensions, to include individuals with a myriad of perspectives, social roles and experiences.[1-2] When considering diversity in its traditional sense, orthopedic surgery has the lowest percentage of females and minorities of all medical and surgical subspecialties.[3-5] While females comprise approximately 50% of medical school graduates, they represent only 14% of orthopedic surgery residents.[6] African Americans and Hispanics comprise 13.3% and 17.6% of the U.S. population, but only 4.1% and 2.7% of orthopedic trainees, respectively.[6] Furthermore, according to a 2010 study, there were 6.3 male applicants for every female, 13.5 white applicants for every African American, and 14.1 white applicants for every Latino applying to orthopedic surgery residency.[4] There is a well-documented paucity of diversity in gender as well as race and ethnicity that exist in surgical subspecialties, and this is magnified in orthopedics.

Why is Diversity Important?

The concept of diversity has been increasingly recognized and valued in academia and the workplace. Research in business and commercial industry has shown that diversity in the workplace broadens consumer markets and stimulates economic growth.[7-9] In a survey of over 1,700 companies examining diversity in management, it was found that companies with more diversity earned more revenue from new products and services, especially when females held >20% of positions.[10] In a 2010 study, Joy et al. found that Fortune 500 companies with females on the board of directors had better performance. Further, they found that two of the companies with the best stock market gains (DuPont, Kraft foods) had female CEOs.[11] These studies support the idea that within the corporate world, boards perform better when they include people who offer a wide range of skills, perspectives and backgrounds.

With the increased heterogeneity of modern America, many would agree that diversity in healthcare is of paramount importance. Within medicine, physician diversity provides well-documented benefits to patient care. URM have increased health disparities and decreased access to patient care.[12] For example, a recent study showed Hispanic and African American patients are almost 50% less likely to undergo total knee arthroplasty (TKA) than white patients.[13] Research has demonstrated that underrepresented minority physicians are more likely to serve uninsured patients and practice in underserved areas, leading to improved patient satisfaction and access to care for underserved groups.[14] Additionally, patients are more satisfied with their treatment and their ability to communicate with their provider when they are managed by a physician from their own culture.[14] Bickel et al. found that there are many benefits to recruiting female leaders including improved marketing efforts for the institution,

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additional healthcare provider options for patients, an increased number of role models for students and residents, enhanced institutional creativity and an enriched institutional culture.[15] Recruiting a diverse medical team is therefore important for the advancement of the medical profession and benefits the health of the population.

Ruth Jackson and the Ruth Jackson Orthopaedic Society

Dr. Ruth Jackson is known as the first practicing female orthopedist in the United States. She was born near Scranton, Iowa and later obtained her medical degree from Baylor College of Medicine in 1928, as one of four women in her class of 164 students. In training, females were not allowed to examine men and had to score 10 points higher to graduate with "equal standing."[16] After graduation, she pursued general surgery, but was rejected as no internships were available for females. With her path blocked for a career in general surgery, Dr. Arthur Steindler invited her to the University of Iowa to train in orthopedics. Dr. Jackson then decided to pursue a career in orthopedic surgery and finished her residency at the Worcester Massachusetts Memorial Hospital in 1932. She became board certified in 1937, and the first female member of the AAOS.[17] She practiced orthopedics for over 50 years. Dr. Jackson is known to many to be a pioneer who broke down many barriers for female physicians, surgeons and orthopedists alike.

The Ruth Jackson Orthopaedic Society (RJOS) was founded in 1983 as a support and networking group for female orthopedic surgeons. Founding members included Drs. Ruth Jackson, Liebe Diamond, Mary Morden, Sandra Thompson, Jacqueline Perry, and Mary Ann Shannon. Originally a sounding board and socializing group, RJOS has developed into a professional society amassing over 600 members devoted to advancing females in orthopedic surgery. Opportunities such as a mentorship, scholarships, research grants and awards, educational projects, an endowment with the Orthopedic Research and Education Foundation (OREF), and a traveling fellowship program are offered through the society. The mission of the RJOS is to "promote professional development of and for women in orthopaedics throughout all stages of their careers." RJOS serves as one of the major organizations that exist to promote diversity within the orthopedic community.

Where are we now?

Diversity within the field of orthopedic surgery has been slow to progress, even well into the 21st century. Despite the barriers broken, gender, ethnic and cultural diversity continues to be lag behind other industries and health care fields. The relative lack of diversity in orthopedics has been a popular topic of investigation over the past 20 years.

In an analysis of data from the American Association of Medical Colleges from 1970 to 2001, Blakemore et al found that the percentage of women in medical school increased from 0.6% in 1970 to 9.0% in 2001.[3] This percentage has drastically increased over the last two decades, with women representing nearly 51% of matriculating medical students in 2017.

Although medical schools have achieved balance in gender over the last decades, gender diversity in orthopedic surgery has remained disproportionately low. From 1981-2001, the percentage of female residents who chose orthopedic residency was consistently 0.6% .[3] This proportion increased to 0.92% in data from the 2016-2017 academic year.[18] Furthermore, in the years 2008-2009, although 58% of undergraduate students and 48% of medical students were female, only 13% of orthopedic residents and 4% of AAOS fellows were female. At that time, more than 50 orthopedic residencies had an average of less than 10% female trainees over 5 years,[19] which did not change in the following 5 years.[20] Currently, females represent only 6.5% of AAOS membership.[21]

Although historically surgical subspecialties are male-dominated, orthopedic surgery has the lowest proportion of female residents and has been the slowest to increase in proportion over time. Compared to other surgical subspecialties, between the 2005-2006 and 2016-2017 academic years, neurosurgery and thoracic surgery had 56.8% and 111.2% increases in female representation, respectively, whereas orthopedic surgery demonstrated a 27.3% increase. This study also revealed that women are much less likely to hold high-ranking academic titles and department chair positions.[18] Given the proportion of females in medical school increased over the time period, these data may imply that the percent increase in female orthopedic surgery residents may be more directly related to the increase in number and proportion of female medical students rather than increased interest in the field.

Studies show female orthopedic trainees perceive gender disparities. In a poll of orthopedic surgery residents about perceptions of gender differences in orthopedics, mentorship by the same gender was a more important positive factor for women as compared to men. Females were more likely to choose orthopedics during clinical rotations, while men were more likely to choose prior to clinical rotations.[22] Additionally, a 2010 survey of 76 ACGME-accredited orthopedic surgery programs reported that 2/76 (2.6%) residency program directors were female, with no female department chairs.[23] The findings suggest that mentorship, exposure, and experiences could increase the recruitment of female applicants in orthopedic surgery.

Diversity in orthopedics is not restricted to gender.

Throughout history, there has been a paucity of diversity in ethnicity and race as well, although this has been less studied and less clear data exists. Day et al. compared orthopedics to other surgical subspecialties to determine the composition of the workforce according to race, ethnicity and sex that make up medical students, orthopedics residents, faculty and full professors. They found that in the 2006 orthopedic workforce, there were significantly fewer minority orthopedic residents compared with medical school graduates, and comprised a significantly smaller proportion of orthopedic residents as compared to general surgery and neurosurgery residency programs. Furthermore, African-Americans, Hispanics/Latinos, and Asian-Americans were underrepresented among orthopedic faculty compared with their representation in orthopedic residency programs. Okike et al. found that in 2001-2008 females represented 14.5% of orthopedic surgery residents while Hispanics/Latinos represented 3.8%, African-Americans represented 4.0%, Asian-Americans 11.7%, American Indian/Alaskan Natives 0.4%, and 0.3% for Native Hawaiians/Pacific Islanders.[5] These studies are just a few that highlight the gender, ethnic and racial profile of orthopedic surgery compared to both the American population and the profile of U.S. medical students.

Although not exhaustive, this review is meant to provide a brief summary of the limited gender, racial and ethnic diversity in the field of orthopedics. In our overview, we note issues of gender diversity have been highlighted in literature and the media, while we found less clear and complete data on ethnic and racial diversity in orthopedics. Research supports that targeted efforts to decrease ethnic healthcare disparities by diversifying the U.S. physician workforce are needed to ensure high-quality, culturally competent care is provided to all patients.

Efforts to Increase Diversity in Orthopedics

Recent literature suggests that mentorship and early exposure are critical for increasing female and underrepresented minority interest in orthopedic surgery, and targeted efforts have been made to facilitate this change. Several programs have been developed to promote diversity in orthopedics, improving the perception of orthopedics and interest in pursuing a career in orthopedic surgery.[24] These programs, as well as RJOS, have been instrumental in supporting and encouraging diversity in the field.

Nth Dimensions was founded in 2006 with the mission of addressing the paucity of females and URM in orthopedic surgery through a longitudinal pipeline program. Pre-medical and medical students are provided with early exposure and hands-on experience, clinical and research opportunities, mentoring and professional development. The program revolves around an internship program targeted for junior medical students with hands-on surgical stimulation and skills workshops. This program has been shown to increase odds of applying to orthopedic surgery residency for females (OR 43.2, $p<0.001$) and URM (OR 14.5, $p<0.001$).[25]

The Perry Initiative is an outreach program founded in 2009, targeted for inspiring young women in high school, college and medical school to pursue careers in orthopedic surgery and engineering. Named for Dr. Jacqueline Perry, one of the earliest female orthopedic surgeons, a hands-on curriculum and lectures are designed to improve participant perception of lifestyle, demands, training and competitiveness of the field. The medical student program produced a match rate of 31% (5/16) in the first class and 28% (20/72) in the second class of participants.[24]

The J. Robert Gladden Orthopedic Society was founded in 1998 with the mission to increase diversity in orthopedics and eliminate discrepancies in musculoskeletal care. In 1950, Dr. J. Robert Gladden became the first, African American, board-certified orthopedic surgeon. Today, the Gladden Society has over 450 members and is responsible for providing mentorship and professional development opportunities for URM in orthopedic surgery. Initiatives include mock oral exams, research grants, scholarships, and traveling fellowships. Through advocacy efforts, the society promotes the elimination of healthcare disparities in patients with musculoskeletal disorders. Through research and education, the goal of the Gladden Society is to provide culturally competent musculoskeletal care for all patients they serve.

The Women Orthpaedist Global Outreach was founded in 2006 by five female orthopedic surgeons, with a mission of providing free orthopedic surgery to underserved communities worldwide. The group provides musculoskeletal reconstructive care to anyone in need, but focuses on women due to the barriers to receiving treatment and significant burden of life and work in rural communities. Previous mission trips have included various countries such as Nepal, Guatemala, Tanzania, Republic of Congo and Cuba. As part of the program, local orthopedic surgeons and healthcare professionals are trained in orthopedic skills and technologies to improve the health of their communities. Not only do participants in this program provide musculoskeletal care, but they also provide mentorship to young volunteers and diverse populations in the developing countries that they visit.

These programs have the common goal of promoting diversity in orthopedics, as a workforce exhibiting a variety of backgrounds and skillsets produces a more complete, well-rounded approach to healthcare. Stated simply, diversity "increases the overall collective intelligence of the team".[26]

CONCLUSION

The orthopedic community has been making efforts to encourage diversity in the field, yet, disparities continue to exist. Although the representation of females in orthopedics is increasing, it is doing so at a slower rate as compared to other surgical subspecialties. African-Americans, Hispanics/Latinos, Asian-Americans, American Indian/Alaska Natives and Native Hawaiians/Pacific Islanders are all significantly underrepresented in orthopedic surgery as compared to their prevalence in the U.S. population.[27] While multiple programs are working to promote diversity in orthopedic surgery through mentorship and enhancing the visibility of females and URM in the field, significant work has yet to be done.

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FACTORS IMPACTING INITIAL ARTHROSCOPY PERFORMANCE AND SKILL PROGRESSION IN NOVICE TRAINEES

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ABSTRACT

Background: Arthroscopy is one of the cornerstone skills learned during orthopaedic residency training. Previous studies have attempted to identify characteristics of arthroscopy naive individuals leading to superior initial arthroscopic performance with conflicting findings. Furthermore, other virtual reality simulator studies consisting of beginner trainees, have noted that certain individuals fail to progress at the rate of their peers despite rigorous training. Therefore the purpose of this study was to 1) identify trainee characteristics that may have an impact on initial arthroscopy skill and performance and 2) identify trainee characteristics affecting their ability to improve through training on an arthroscopy simulator.

Methods: Forty-three medical students with no prior arthroscopy experience performed a diagnostic knee arthroscopy using an anatomic virtual reality simulator. Prior to the procedure, information was collected about each participant regarding various demographics, sports involvement, hand dominance, specialty interest, 3-D video game use and experience assisting in the operating room. Their baseline performance was measured using the following outcomes: time (seconds), camera path length (CPL) (centimeters), and an overall composite score. A subgroup consisting of 22 students underwent training with a non-anatomic virtual arthroscopy simulator consisting of a series of 5 self-guided modules after their initial knee scope. This group was retested using the same diagnostic knee scope one to two weeks later. Participant background characteristics were correlated with initial performance on the knee scope and the change from the first to second knee scope in the sub-group that completed the training.

Results: At the time of the initial diagnostic knee arthroscopy, performance was most strongly correlated with how often an applicant currently plays video games and how often they have played video games in the past. However, this was only a weak correlation (r= 0.29 and 0.24, respectively). Interestingly, students pursuing a non-surgical residency outperformed those interested in a surgical specialty in all outcome measurements at baseline, although this did not reach a level of significance. Year of training in medical school, age, hand dominance, current or past participation in sports requiring hand-eye coordination, and number of surgical cases they have assisted in for did not influence initial performance. Participants that have operated another type of scope (e.g. bronchoscopy, laparoscopy) in the past showed a trend towards higher performance in composite score (21.6 vs 14.9, p = 0.07), although this did not reach a level of significance. Regarding the change in performance of those that completed the non-anatomic training prior to the second knee scope, change in time to complete the procedure was significantly different between participants in different years of medical school. Fourth year medical students improved by an average of 421 seconds compared to 98 seconds, 127, and 140 seconds for the other classes, p = 0.02. Those who have regularly participated in sports requiring hand eye coordination in the past improved their time (182 vs 78 seconds, p = 0.0245) and camera path length (96 vs 31 cm, p = 0.0372) significantly more than those were not involved in sports.

Discussion and Conclusions: Our study demonstrates that baseline arthroscopy performance correlates most highly with 3D video game experience. The ability of trainees to learn arthroscopy using a virtual reality simulator appears to be influenced more by those who have regularly participated in sports requiring hand eye coordination rather than video game use.

Level of Evidence: III

Keywords: arthroscopy, simulator, knee, non-anatomic, skill, video games, sports, training, medical student

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Table 1. Study Participant Demographics

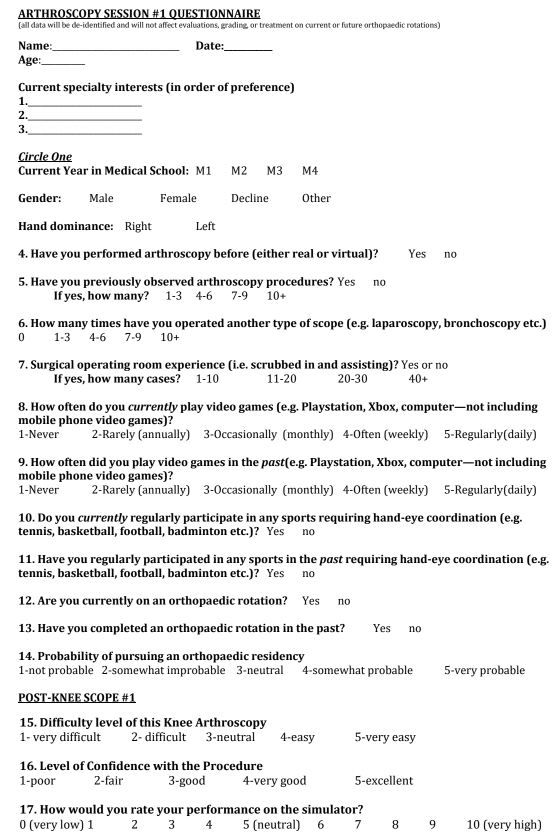
	Completed Simulation One	Completed Simulations 1 and 2 with training in between	P-value
Age	25.81 (2.94)	25.13 (1.42)	0.3513
Year in Medical School (1/2/3/4)	12/3/3/3	11/4/5/2	0.8789
Males/Female	14 / 7	15 / 7	0.9156
Right handed/Left handed	20 / 1	19 / 3	0.6069
Listed Surgical/Non-surgical specialty as #1 interest pre-test	10 / 11	16 / 6	0.0923
Time between knee scopes	9.48 days	8.86 days	0.1969
Total number of subjects	21	22	

INTRODUCTION

Arthroscopy is one of the cornerstone surgical skills learned during orthopaedic surgery residency training. Orthopedic surgery residents that graduated in the class of 2012 performed an average of 340 arthroscopic surgeries over the course of their residency training; this accounted for approximately 15% of all cases during residency.[1] Recent studies examining the trends in arthroscopic surgeries in the United States have demonstrated marked increases in the number of cases of hip arthroscopy, arthroscopic rotator cuff repair, and knee arthroscopy.[2-4] Practice and development of arthroscopic surgical techniques is of paramount importance in modern orthopedic residency training. Anatomic arthroscopy simulators have been demonstrated to be effective training tools for the development of arthroscopic technique that translates to increased skill in the operating room.[5-7]

Previous studies have attempted to identify characteristics of novice trainees, including residents and medical students, which are associated with superior initial arthroscopic performance.[5,8] These studies have demonstrated conflicting findings, with inconsistent associations between increased arthroscopic performance and activities such as video game experience and participation in sports.[5,8,9] Furthermore, other virtual reality simulator studies using cohorts of novice trainees have noted that a portion of trainees fail to progress at the rate of their peers despite equal rigorous training.[10] Identifying factors that may contribute to failure of progression would allow for identification of residents that may require additional intervention (i.e. focused training) to develop adequate arthroscopic skill.

The purpose of this study was twofold: (1) to identify trainee characteristics that may have an impact on initial arthroscopy skill and performance, and (2) to identify trainee characteristics affecting ability to demonstrate measured improvement through training on an arthroscopy simulator. We hypothesized that video game use, sports participation, and previous assistance in the operating room would correlate with improved initial performance, as well as a greater ability to improve with training.



ARTHROSCOPY SESSION #1 QUESTIONNAIRE
(all data will be de-identified and will not affect evaluations, grading, or treatment on current or future orthopaedic rotations)

Name:________________ **Date:**________
Age:________

Current specialty interests (in order of preference)
1.________________
2.________________
3.________________

Circle One
Current Year in Medical School: M1 M2 M3 M4

Gender: Male Female Decline Other

Hand dominance: Right Left

4. Have you performed arthroscopy before (either real or virtual)? Yes no

5. Have you previously observed arthroscopy procedures? Yes no
If yes, how many? 1-3 4-6 7-9 10+

6. How many times have you operated another type of scope (e.g. laparoscopy, bronchoscopy etc.)
0 1-3 4-6 7-9 10+

7. Surgical operating room experience (i.e. scrubbed in and assisting)? Yes or no
If yes, how many cases? 1-10 11-20 20-30 40+

8. How often do you *currently* play video games (e.g. Playstation, Xbox, computer—not including mobile phone video games)?
1-Never 2-Rarely (annually) 3-Occasionally (monthly) 4-Often (weekly) 5-Regularly(daily)

9. How often did you play video games in the *past*(e.g. Playstation, Xbox, computer—not including mobile phone video games)?
1-Never 2-Rarely (annually) 3-Occasionally (monthly) 4-Often (weekly) 5-Regularly(daily)

10. Do you *currently* regularly participate in any sports requiring hand-eye coordination (e.g. tennis, basketball, football, badminton etc.)? Yes no

11. Have you regularly participated in any sports in the *past* requiring hand-eye coordination (e.g. tennis, basketball, football, badminton etc.)? Yes no

12. Are you currently on an orthopaedic rotation? Yes no

13. Have you completed an orthopaedic rotation in the past? Yes no

14. Probability of pursuing an orthopaedic residency
1-not probable 2-somewhat improbable 3-neutral 4-somewhat probable 5-very probable

POST-KNEE SCOPE #1

15. Difficulty level of this Knee Arthroscopy
1- very difficult 2- difficult 3-neutral 4-easy 5-very easy

16. Level of Confidence with the Procedure
1-poor 2-fair 3-good 4-very good 5-excellent

17. How would you rate your performance on the simulator?
0 (very low) 1 2 3 4 5 (neutral) 6 7 8 9 10 (very high)

Figure 1. The questionnaire administered to participants prior to beginning the first knee arthroscopy attempt.

METHODS

After approval was obtained from the Institutional Review Board, 43 medical students were recruited from a single allopathic medical school for participation in this prospective study conducted from April 2016 to April 2017. Participants were excluded if they had previous simulated, live, or cadaveric arthroscopy experience or were unable to use an arthroscopy simulator. Study participant demographics including gender, year of medical school training, age, and hand dominance are seen in Table 1.

Upon agreement to participate in the study, all 43 subjects initially completed a questionnaire regarding demographics, background characteristics, educational status, and career specialty interests. Pre-test questionnaire is shown in Figure 1. They then viewed a video demonstrating a simulated diagnostic knee arthroscopy performed by a sports medicine fellowship-trained orthopaedic surgeon on the same simulator used in this study (ArthroS knee). After viewing the video, they completed a self-guided PowerPoint module on the basics of arthroscopy and how to use the virtual reality simulator. Once these steps were complete, they were then given one minute to familiarize themselves with the scope and subsequently proceeded with the first diagnostic knee arthroscopy.

Twenty-two subjects were randomized to undergo a series of five self-guided arthroscopic training modules on a non-anatomic simulator. These were performed on the Fundamentals of Arthroscopic Surgery Training (FAST) simulator. Self-guided modules included linear tracking, curved tracking, periscoping, palpation, and collecting stars using a grasping device all within a three dimensional virtual environment. In order to progress from one module to the next, subjects were required to obtain a 3

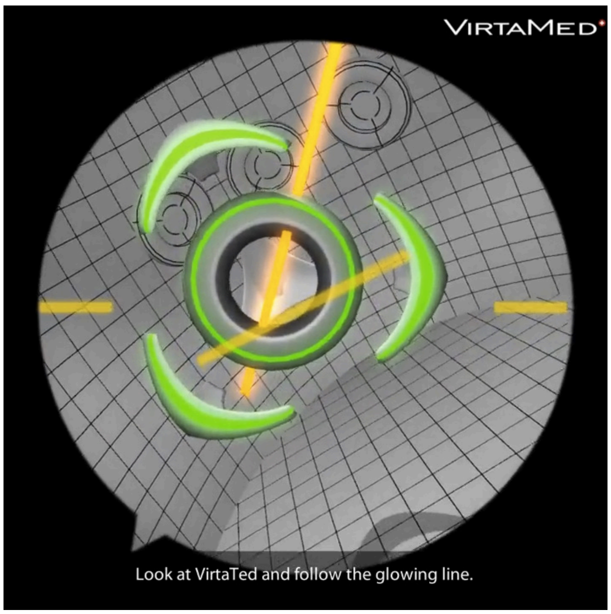


Figure 2. In this non-anatomic (FAST) module, the objective is to track along a line while keeping the scope centered at an appropriate distance.

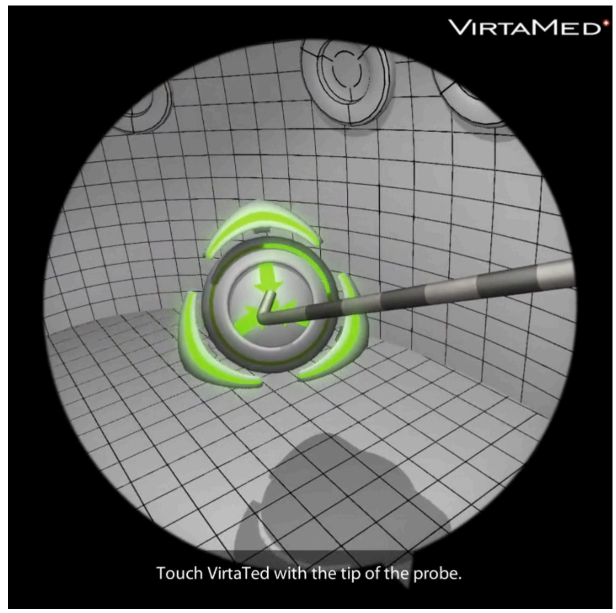


Figure 3. The palpation module uses a probe to touch the center of a freely moveable 3D ball in various spatial dimensions while under appropriate visualization from the arthroscope.

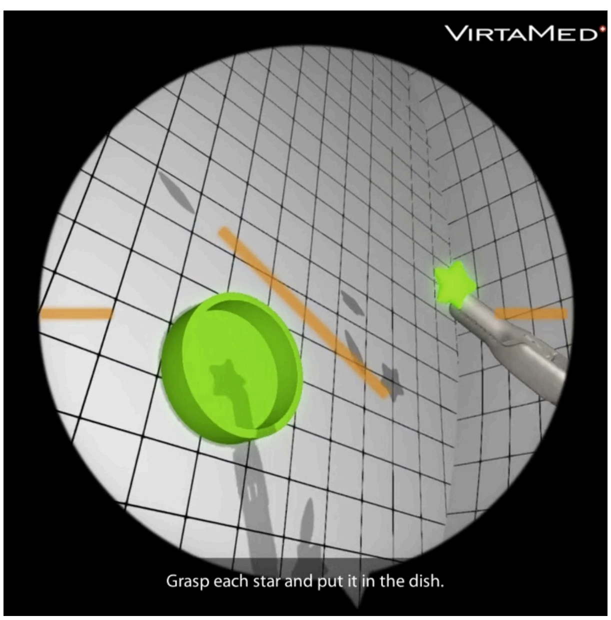


Figure 4. This modules utilizes a grasper in one hand while controlling the scope in the contralateral hand to pick up and place stars floating in 3D area into a bucket.

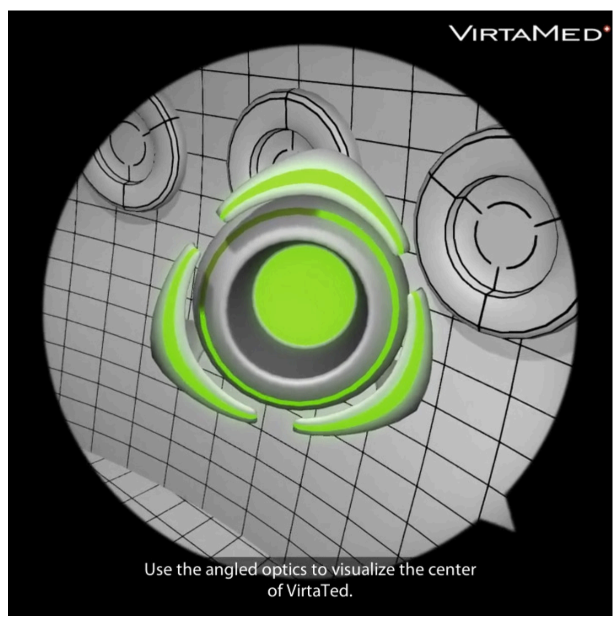


Figure 5. The objective of the periscoping module is to use the periscope to gain an appropriate view of the center of the green surface at various positions and angles within a 3D space.

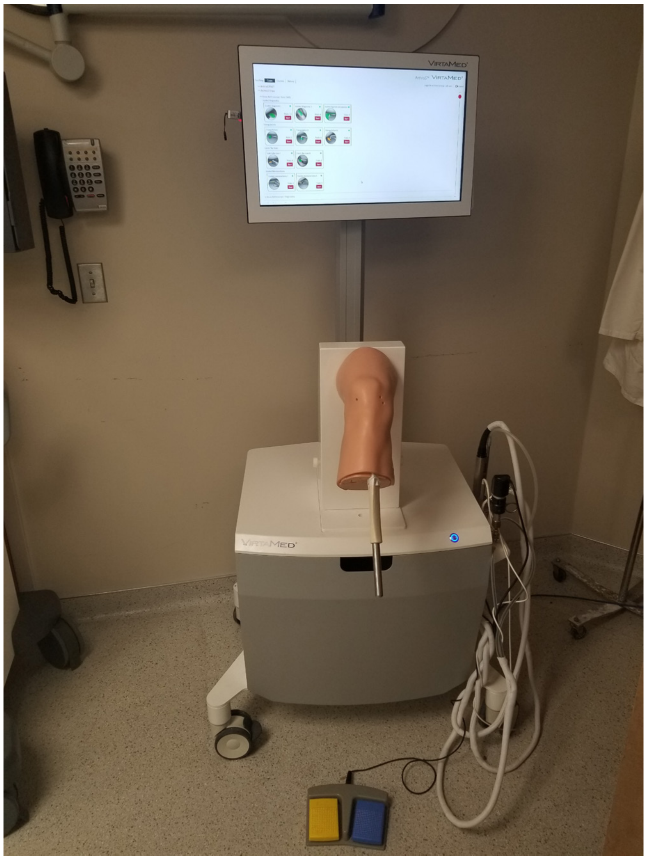


Figure 6. Demonstrates the anatomic knee virtual reality simulator set-up used for assessment in this study.

Figure 7. Demonstrates the non-anatomic FAST simulator used for training in this study.

out of 3 star rating. Sample images from these modules are shown in Figures 2 through 5. After the training was complete, participants returned between 7 and 15 days after later to complete the post-test (second diagnostic knee arthroscopy).

Arthroscopy simulation was performed in a supervised, distraction free environment. The anatomic knee simulator used for the pre and post-tests was the ArthroS knee (Figure 6). The non-anatomic simulator used in this study was the FAST virtual reality simulator (Figure 7). Participants did not receive tips or feedback on performance during the simulation, however, to eliminate the need knowledge of anatomy during the procedure each area of interest to be visualized was highlighted in yellow and would turn green with appropriate visualization as seen in Figure 8. Total time, camera path length, and overall composite score were recorded for the diagnostic knee arthroscopy attempts.

Data analysis was performed by using SAS software, version 9.4 (SAS Institute, Inc. of Cary, North Carolina). Statistical methods include Pearson correlations and two-group t-test or paired t-test for continuous variables and Chi-Square test for categorical variables. P value < 0.05 was considered statistically significant.

RESULTS

Twenty-nine males and fourteen females were enrolled in this study with a mean age of 25.1 years. Average length of time between the first and second knee arthroscopy was 8.9 days. Thirty-nine participants were right hand dominant and four were left hand dominant. Average time to complete the five FAST modules was 71 minutes. No subjects were lost to follow up in this study. Twenty-two of these students completed the self-guided non-anatomic arthroscopic fundamentals of arthroscopy training modules per randomization protocol.

Performance on the initial diagnostic knee arthroscopy most highly correlated with the frequency that an applicant played video games in the past followed by closely by how often an applicant currently plays video games, r = 0.29 and 0.24, respectively. Those who had operated another type of scope (e.g. bronchoscope, laparoscope) in the operating room setting tended to perform better compared to those who had not with an average composite score of 21.6 vs 14.9 p =0.07, time 273.4 vs 324.4 seconds p = 0.36, camera path length 121.1 vs 172.7 cm, p=0.13. Number of surgical cases assisted with as well as hand dominance, age, and year of medical training did not significantly influence initial performance. Interestingly,

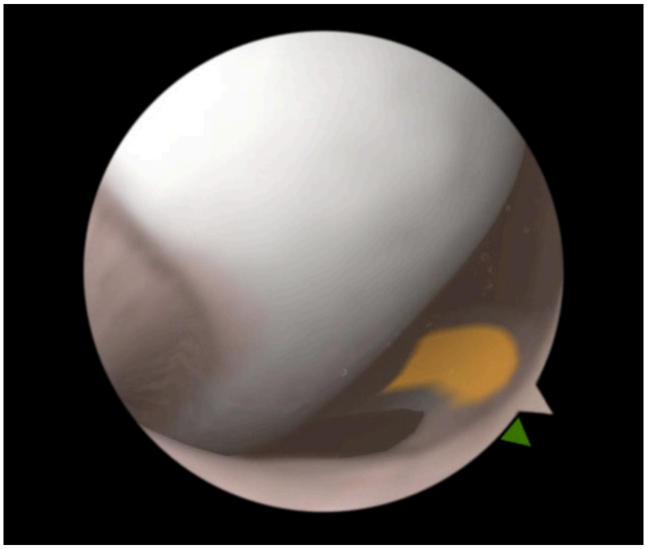


Figure 8. Is a sample view of the knee joint during the simulated diagnostic arthroscopy procedure in this study. Objectives are visualized in yellow and begin to turn green once appropriately visualized with the scope.

students planning to pursue a surgical residency tended to perform worse compared to those pursuing non-surgical residencies when comparing composite score (16.2 vs 19.2), time (325.1 vs 275.3 seconds), and camera path length (168.2 vs 131.1 cm), however these did not reach a level of significance.

Regarding the change in performance of those that completed the non-anatomic training prior to the second knee scope, change in time to complete the procedure was significantly different between participants in different years of medical school. Fourth year medical students improved by an average of 421 seconds compared to 98 seconds, 127, and 140 seconds for the other classes, p = 0.02. Those that reported they had regularly participated in sports requiring hand eye coordination in the past improved their time (182 vs 78 seconds, p = 0.0245) and camera path length (96 vs 31 cm, p = 0.0372) significantly

Table 2. Participant's Year of Training Compared with Change in Performance

Year of Training	Change in Composite Score (STD)	Change in Time, seconds (STD)	Change in Camera Path Length, cm (STD)
1 (N=11)	16.55 (9.8))	-140.45 (127.29)	-89.82 (102.39)
2 (N=4)	11.00 (7.48)	-127.00 (55.47)	-34.73 (41.76)
3 (N=5)	13.20 (12.72)	-98.60 (130.73)	-93.74 (136.15)
4 (N=2)	11.00 (1.41)	-421.50 (127.99)	-68.75 (63.29)
P-value	0.735	0.028	0.8

more than those were not involved in sports. Specialty interest, video game use, hand dominance, experience in operating room assisting cases did not correlate with the ability to improve with training. Results are summarized in Tables 2 and 3.

DISCUSSION

The results of this study suggest that of the variables examined, initial diagnostic knee arthroscopy performance was most highly associated with how often a student currently plays video games or how often they played video games in the past, i.e. cumulative video game experience. Participants that have operated another type of scope (e.g. bronchoscopy, laparoscopy) in the past showed a trend towards higher performance, although this did not reach a level of significance. A subject's ability to train and improve through self-guided modules was most highly associated with participation in sports requiring hand-eye coordination. Additionally, fourth year medical students improved significantly more in time and camera path length compared to other years of medical education, suggesting that experience and knowledge may be a factor in skill acquisition.

Jentzsch et al. previously suggested individuals that are skilled at 3-D video games are better arthroscopists

Table 3. Pearson Correlation Coefficients Between Questionnaire Responses and Change in Performance

Pearson Correlation Coefficient (p-value)	Age	Question 8	Question 9	Question 14	Change in Composite Score	Change in Time (seconds)	Change in CPL (cm)
Age	1	-0.35 (0.12)	-0.14 (0.52)	-0.43 (0.05)	0.16 (0.49)	-0.15 (0.5)	0.03 (0.90)
Question 8	-0.35 (0.12)	1	0.41 (0.05)	0.36 (0.10)	-0.20 (0.36)	-0.05 (0.8)	0.05 (0.81)
Question 9	-0.14 (0.52)	0.42 (0.05)	1	0.34 (0.12)	0.06 (0.79(	-0.04 (0.87)	0.024 (0.91)
Question 14	-0.43 (0.05)	0.36 (0.11)	0.34 (0.12)	1	0.15 (0.52)	0.05 (0.84)	0.05 (0.81)
Change in Composite Score	0.16 (0.49)	-0.20 (0.36)	0.06 (0.79)	0.15 (0.52)	1	-0.32 (0.14)	-0.47 (0.02)
Change in Time (seconds)	-0.15 (0.50)	-0.05 (0.81)	-0.04 (0.87)	0.05 (0.84)	-0.32 (0.14)	1	0.7 (0.0002)
Change in CPL (cm)	0.027 (0.90)	0.05 (0.81)	0.02 (0.91)	0.05 (0.82)	-0.47 (0.03)	0.71 (0.0002)	1

compared to inexperienced or poor 3-D gamers in a level II cross sectional study.[5] Their study consisted of 30 volunteers who were asked to play five different types of video games with increasing visuospatial demands and their performance was then correlated with a score on the ArthroS knee arthroscopy simulator. They reported a positive correlation of 0.63, $p < 0.001$, between knee arthroscopy simulator performance and 3D video game performance. Cumulative video game experience showed slightly less correlation at 0.50 ($p = 0.005$). Gomoll et al., however, did not find any correlation between shoulder arthroscopy simulator performance parameters and video game experience in a study consisting of 43 participants of varying surgical experience.[11]

Current literature examining laparoscopic surgical skill in novice medical students and junior residents suggests that novice laparoscopists with prior computer or console-based video game experience demonstrated better initial performance, greater overall proficiency, and faster time to achieve technical proficiency on laparoscopic training simulators.[12-16] Prior and current video game experience was associated with faster task performance and fewer errors.[12,14] Additionally, past video game experience was found to be predictive of laparoscopic surgical skill via regression analysis.[14,15]

The use of 3-D video games as a training tool aimed at improving spatial reasoning has been suggested within current laparoscopic simulation literature.[16,17] Schlickum et al. demonstrated greater overall proficiency using a laparoscopic simulator in a cohort after spatial training using 3-D video games compared to cohorts that participated in 2-D video game training as and no video game training.[16] The results of the current study echo the overall associations within laparoscopic simulation in part; current and past video game experience was associated with higher initial proficiency in the arthroscopy simulation. No association was found between video game experience and the ability to improve or progress in proficiency in this study. Hand dominance has also been found to be associated with higher initial proficiency in one laparoscopic simulation study; no such association was demonstrated in this study.[12] Within the current study, participation in sports that require hand eye coordination was associated with an ability to improve through self-guided modules. Following a review of current literature, this appears to be a novel association. Logically, such an association makes sense – sports requiring hand-eye coordination demand participants to be adept at repeatable gross and fine motor tasks, as does arthroscopy.

In the present study, no subjects were lost to follow-up. Participants were enrolled from all four years of medical school, with varying interests in surgical and non-surgical specialties. Additionally, this study was conducted in a prospective design. The outcome measures were collected objectively by the virtual reality arthroscopy simulator, and the manner of testing was standardized for all students.

Despite the above strengths, there are several limitations to this study. First, some of the factors may have reached statistical significance with a greater study population. However, numbers were limited by the maximum amount we were able to recruit. In addition, participants were not blinded as to which group they were assigned to (FAST versus control group). Finally, while arthroscopy performance was assessed using objective measurements recorded by the simulator, it is unable to precisely replicate the arthroscopy experience in the operating room.

Based on the findings of this study, potential characteristics of novice orthopaedic trainees with innate arthroscopy ability, which are different from those that are indicative of individuals that respond best to training, are identified. Future studies are needed to validate these findings in either actual operating room situations or cadaveric models. Additionally, since arthroscopy is just one cornerstone skill learned during orthopaedic residency it would be useful to see how these characteristics apply to other areas of fracture management in the operating room.

CONCLUSIONS

Our study suggests that baseline arthroscopy performance correlates most highly with how often the trainee currently uses or has used video games in the past. The ability of trainees to learn arthroscopy using a virtual reality simulator appears to be influenced more by those who have regularly participated in sports requiring hand eye coordination rather than video game use.

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VARIABILITY IN EXPERIENCE PERFORMING LOWER EXTREMITY AMPUTATIONS BETWEEN SURGICAL RESIDENTS: AN EXAMINATION OF ACGME CASE LOGS

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ABSTRACT

Background: There is a wide array of indications for lower extremity amputation (LEA) and inherent variability in operative experiences between surgical residents. Significant variation in resident surgical experience performing LEAs is possible.

Objective: To identify inter- and intra-specialty trends and variability in LEA experience in graduating orthopedic surgery, general surgery, and vascular surgery residents from 2007-2017.

Methods: Publicly available ACGME case log data for above knee amputation, below knee amputation, and transmetatarsal/digital amputation procedures from accredited orthopaedic surgery, general surgery, traditional (5+2) vascular surgery and integrated (0+5) vascular surgery residencies was reviewed from 2007-2017. Linear regression analysis was used to identify temporal trends, with statistical significance set at $p<0.05$.

Results: From 2007-2017, the mean number of total LEA, AKA, and BKA performed by graduating orthopaedic surgery residents did not change significantly. The mean number of total LEAs logged by graduating general surgery and integrated (0+5) vascular surgery residents did not change significantly over time ($p=0.98$, $p=0.23$, respectively). The mean number of total LEAs logged by traditional (5+2) vascular surgery residents increased from 16.0 to 32.6 ($p<0.01$). As study year increased, graduating integrated (0+5) and traditional (5+2) vascular surgery residents logged more LEAs relative to graduating orthopaedic surgery and general surgery residents ($p<0.01$).

Conclusions: There is significant variation in resident experience in LEAs between surgical specialties. Integrated vascular surgery residents logged the most LEAs, followed by traditional vascular surgery residents, orthopaedic surgery residents, and general surgery residents. Experience of orthopaedic surgery residents in LEAs has been relatively stable over time.

Level of Evidence: IV

Keywords: acgme, resident, education, amputation

INTRODUCTION

Lower extremity amputations (LEA) are a common surgical procedure in the United States, with an incidence of over 100,000 procedures occurring annually.[1, 2] Recent studies have demonstrated that the incidence of LEA is increasing over time; this trend is expected to increase in magnitude by 100% over the next 25-30 years.[1, 2] This increase is likely secondary to the growing incidence of disease processes that may be treated with LEA, including atraumatic ischemia (often secondary to peripheral artery disease), trauma, local tumors, and congenital anaomalies.[2]

LEA are unique procedures in that surgeons from multiple surgical specialties, including orthopaedic surgery, general surgery, and vascular surgery routinely perform amputations. At our institution, residents from orthopaedic surgery, general surgery, and vascular surgery are receive training on and perform LEAs. However, given the wide variety of indications for the procedure, as well as the inherent variability between operative experiences of surgical residents, significant variation in the level of exposure and experience of trainees performing LEAs is possible. Daniels et al.[3] demonstrated significant inter- and intra-specialty variability in the number of case logs of spine surgeries between graduating orthopaedic surgery and neurosurgery residents. These findings highlight current trends in residency training, and may prove valuable in programmatic design and the practice of training surgeons well-suited to meet the increased procedural demand.

At present, a formal examination of Accreditation Council for Graduate Medical Education (ACGME) case logs comparing the number of LEA between orthopedic surgery, general surgery, and vascular surgery has not been performed. The purpose of this study is to retrospectively review ACGME case logs was for 2 specific reasons: (1) identify inter- and intra-specialty trends in the

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Table 1. Trends in Demographics of ACGME Case Log Respondents, by Service and Graduating Year

	Orthopaedic Surgery		Vascular Surgery (5+2)		Vascular Surgery (0+5)		General Surgery	
Year	Programs	Residents	Programs	Residents	Programs	Residents	Programs	Residents
2007	149	616	86	111	†	†	248	1004
2008	148	621	78	94	†	†	246	1020
2009	148	635	90	116	†	†	244	1044
2010	147	653	92	120	†	†	242	1040
2011	148	650	96	124	†	†	240	1060
2012	149	675	94	124	†	†	242	1092
2013	150	678	91	121	10	11	240	1098
2014	151	684	89	122	16	19	243	1105
2015	151	699	96	130	23	26	246	1142
2016	153	705	88	116	27	32	248	1172
2017	156	709	90	114	36	41	251	1211
	$p<0.01$*	$p=0.002$*	$p=0.22$	$p=0.15$	$p<0.01$*	$p<0.01$*	$p=0.44$	$p<0.01$*

Year – year of resident graduation. †No data available for given year. *Statistically significant.

median number of resident case logs in LEA from 2007-2017; (2) evaluate for inter- and intra-specialty variability in resident case logs.

MATERIALS AND METHODS

Publically available ACGME case log data for accredited orthopaedic surgery, general surgery, traditional (5+2) vascular surgery, and integrated (0+5) vascular surgery residencies was reviewed from the 2006-2007 to the 2016-2017 academic years.[4] Collected data included the mean number of above knee amputations (AKA), below knee amputations (BKA), transmetatarsal and digital amputations (TM/Dig), and the mean total number of lower extremity amputations logged by graduating residents over the course of their previous five years of training. The number of LEA logged by residents in the 30th and 70th percentiles of operative volumes was collected for graduating orthopedic surgery residents. Differences between residents in the 30th and 70th percentiles of case logs were calculated and analyzed, with temporal trends identified. The total number of graduating residents and total number of ACGME accredited orthopaedic surgery, general surgery, and vascular surgery residencies were recorded for each academic year.

The ACGME assesses residency programs in orthopaedic surgery, general surgery, and vascular surgery based on the number of resident case logs in multiple defined categories.[5-7] Resident case logs are coded by procedural designations based on current procedural terminology (CPT) codes. These codes may be recorded by the resident at the time of the surgery, or may be distributed to residents by a program administrator. Levels are assigned to each case based on resident responsibility throughout the case. Cases in which the resident acts as either the primary resident surgeon, or acts in a direct supervisory role to another resident are designated and logged as level 1 cases. Cases in which the resident acted in an assisting role during the surgery are designated and logged as level 2 cases.[8] Level 1 and level 2 cases count equally towards fulfillment of categorical minimum case logs necessary for graduation.[8] For the purposes of this study, level 1 and level 2 cases were counted as equal.

Linear regression analyses was used to identify temporal trends, with statistical significance set at $p<0.05$. Statistical analysis software (SAS version 9.4, SAS Institute Inc., Cary NC, USA) was utilized for statistical analysis.

This study was exempt from institutional review board (IRB) approval.

RESULTS

From 2007-2017, the number of orthopedic surgery programs and graduating residents increased significantly, from 149 programs and 616 residents in 2007 to 156 programs and 709 residents in 2017 ($p<0.01$ for both) (Table 1). There was no significant change in the number of traditional vascular surgery (5+2) programs ($p=0.22$) and graduating residents ($p=0.15$) over the study period (Table 1). ACGME case log data for integrated vascular surgery (0+5) programs was available only for years 2013 to 2017. Significant increases in the number of integrated vascu-

Table 2. Mean Experiences in Lower Extremity Amputation of Graduating Orthopaedic Surgery Residents, 2007-2017

Year	AKA	BKA	TM/Dig	Total LEA
2007	3.4	6.7	6.5	16.6
2008	3.1	6.5	5.4	15.0
2009	3.0	5.9	5.9	14.8
2010	3.0	5.7	5.7	14.4
2011	3.4	6.0	5.9	15.3
2012	3.5	6.5	6.1	16.1
2013	3.7	6.3	6.1	16.1
2014	3.0	5.8	4.9	13.7
2015	3.3	5.9	5.4	14.6
2016	3.3	6.4	5.3	15.0
2017	3.5	6.5	5.2	15.2
Study Mean	3.3 ± 0.24	6.2 ± 0.35	5.7 ± 0.48	15.2 ± 0.84
	p=0.34	p=0.82	p=0.04*	p=0.74

Values reported as mean or mean ±standard deviation.
Year – year of resident graduation; AKA – above knee amputation; BKA – below knee amputation; TM/Dig – transmetatarsal or digital amputation; LEA – lower extremity amputation. *Statistically significant increase over study period.

lar surgery programs ($p<0.01$) and graduating residents ($p<0.01$) was observed over the study period (Table 1). The number of general surgery residency programs did not change significantly, while the number of graduating general surgery residents increased ($p<0.01$) (Table 1).

Over the study period, the mean number of total LEA, AKA, and BKA performed by graduating orthopaedic surgery residents did not change significantly; however, the mean number of TM/Dig amputations decreased ($p=0.04$) (Table 2). The mean number of total LEA, AKA, BKA, and TM/Dig amputations logged by traditional vascular surgery residents all increased significantly over the study period ($p<0.01$ for all) (Table 3; Figure 1). For integrated vascular surgery residents and general surgery residents, there was no significant change in the mean number of total LEA, AKA, BKA, and TM/Dig amputations performed by graduating residents (Table 3; Figure 1).

As study year increased, graduating integrated and traditional vascular surgery residents logged more LEAs relative to graduating orthopaedic surgery and general surgery residents ($p<0.01$) (Table 4). From year to year, there was no significant difference in the number of logged LEAs between graduating orthopaedic surgery and general surgery residents ($p=0.84$) (Table 4). The difference in the number of cases logged between graduating orthopaedic surgery residents in the 30th percentile and those in the 70th percentile decreased over the study period ($p=0.03$).

DISCUSSION

With an incidence of over 100,000 procedures annually, and a >100% increase projected by 2050, LEA are and will likely remain a common part of a modern surgical practice.[1] With vascular disease and trauma accounting for >98% of all indications for LEA, it is imperative that graduates of orthopaedic surgery, general surgery, and vascular surgery residencies be familiar with performing and caring for patients with LEA.[1] With the relatively recent introduction of integrated vascular surgery residency programs, as well as restrictions regarding resident work hours and the inherent variability in operative experience between residents, there is potential for deficiency in the volume of experience in LEA over the course of a surgical residency.[9-11] Iannuzzi et al.[12] demonstrated the association of general surgery resident involvement with LEA cases with a multitude of adverse outcomes, major complications, and prolonged time in the operating room. The authors concluded that the presence of this risk necessitates the tracking of potential effects or changes in the training of surgical residents, as poor clinical outcomes for patients may result.[12] Pugely et al.[13] demonstrated increased rates of patient morbidity and longer operative times associated with orthopaedic surgery resident involvement in lower extremity trauma cases. These studies illustrate the necessity to observe and understand recent trends in the experiences of surgical residents performing LEAs.

In the United States, there is significant variation in resident experience in LEAs between surgical specialties. Integrated vascular surgery residents logged the most LEAs, followed by traditional vascular surgery residents, orthopaedic surgery residents, and general surgery residents. This data seems to be relatively consistent with current trends, as atraumatic ischemia is by far the most common for LEA in the United States, accounting for over 80% of the total number of LEA cases.[2] Trauma is the second most common disease etiology, accounting for approximately 16% of LEA.[2] Congenital and cancer-related diagnoses account for less than one percent of LEA each.[2]

Importantly, the operative experience of orthopaedic surgery residents in LEA has been stable over time. The decrease in the number of case logs between orthopaedic surgery residents in the 30th percentile versus those in the 70th percentile suggests that LEA experience is becoming more uniform between orthopaedic surgery residents on a national level over time. Similarly, the growth of integrated vascular surgery programs seems to have had little impact on LEA experience of general surgery and traditional vascular surgery residents over the study period. One possible explanation may be that the

Table 3. Mean Experience in Lower Extremity Amputations of Graduating Surgical Residents, 2007-2017

Procedure	Orthopaedic Surgery	Vascular Surgery (5+2)	Vascular Surgery (0+5)	General Surgery
AKA	3.3 (3.0-3.7)	7.7 (4.7-11.2)*	12.9 (9.6-13.1)	4.1 (3.9-4.4)
BKA	6.2 (5.7-6.7)	8.9 (5.1-13.4)*	18.1 (13.4-19.8)	5.3 (5.0-5.7)
TM/Digit	5.7 (4.9-6.5)*	7.2 (4.5-9.3)*	18.5(16.8-21.1)	5.3 (5.0-5.6)
Total	15.2 (13.7-16.6)	23.7 (14.8-32.6)*	49.5 (39.8-52.8)	14.7 (14.1-15.3)

Mean values for 2007-2017 are shown, with range in parenthesis. Total values are inclusive of all lower extremity amputations performed by residents of respective services. AKA – above knee amputation; BKA – below knee amputation; TM/Digit – transmetatarsal or digital amputation. *Statistically significant change over study period.

practice of integrated vascular surgery residents is simply less diverse than those of general surgery or orthopaedic surgery residents, in that amputation for vascular disease represents an overall greater and/or increasing proportion of practice volume relative to other specialties.

Whether or not the current levels of case volume demonstrated in this study are sufficient for competency in performing LEA is unknown. Eardley et al.[14] performed a recent survey of orthopaedic surgery trainees throughout the United Kingdom. Respondents had similar case volumes in amputations relative to trainees in the present study; >75% of respondents thought of their training volume as satisfactory or greater.[14] Currently, there is no defined category or minimum number of LEA that are required for graduation from AGCME-accredited orthopaedic surgery, general surgery, and vascular surgery programs.[5-7] It may be worth considering there may be significant baseline post-operative morbidity and mortality in patients undergoing LEA; recent studies estimate 30 day mortality at 13-16% for patients undergoing AKA and 5-6% for patients undergoing BKA.[15,16] Bosse et al. in a series of 130 patients undergoing LEA secondary to lower extremity trauma, demonstrated an overall complication rate of 33.9%.[17] Wound complications, including infection, dehiscence, and failure to heal are commonplace.[15,17] The potential additive effect of resident inexperience on an already morbid surgery with high rates of complications raises the question as to whether or not there should exist a minimum number of LEA cases that should be required for resident graduation. However, the data in this study is not sufficient to answer such questions, and further studies are needed.

There are several limitations to this study. First are limitations imposed by the case logs themselves. Multiple studies have raised questions about the accuracy and reliability of reporting amongst case logs of residents and

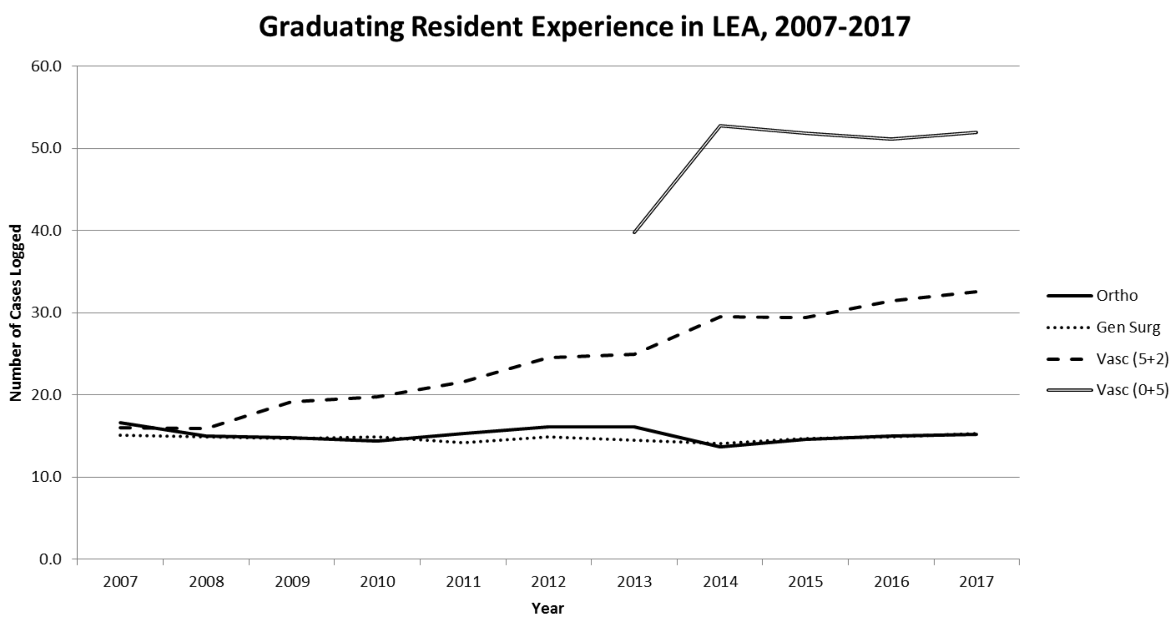

Figure 1. Mean number of total lower extremity amputations logged by specialty, 2007-2017.
A line graph depicting the temporal trends in resident experiences in LEA by respective specialty. LEA – lower extremity amputation; Ortho – orthopaedic surgery; Gen Surg – general surgery; Vasc(5+2) – traditional vascular surgery (5+2); Vasc(0+5) – integrated vascular surgery (0+5).

Table 4. Paired Inter-Specialty Differences in Mean Lower Extremity Amputation

Specialty Comparison	Difference between Means	95% CI		Sig.
		Lower	Upper	
Ortho – Vasc(0+5)	-11.44	-12.93	-9.93	***
Ortho – Vasc(5+2)	-2.97	-4.16	-1.78	***
Ortho – GS	0.13	-1.33	1.05	
Vasc (0+5) - GS	11.58	10.07	13.09	***
Vasc(0+5) – Vasc(5+2)	8.47	6.96	9.98	***
Vasc(5+2) – GS	3.11	1.92	4.30	***

***Statistically significant, $p<0.05$.
Sig – significance. CI – confidence interval.

fellows.[18-23] Critiques include inconsistent use, incorrect, omitted, or erroneously added CPT code designations, and overall widely variable logging practices.[18-23] As a group of procedures with no required minimum for graduation, case logs pertaining to LEA may be particularly susceptible to inaccuracy relative to procedures with a categorical minimum. Additional limitations include the retrospective nature of the study and the limited number of years of available data for residents of integrated vascular surgery programs. Strengths of the study include the large scale use of data obtained nationally, from a wide range of resident practices.

There is significant variation in resident experience in LEAs between surgical specialties. Integrated vascular surgery residents logged the most LEAs, followed by residents of traditional vascular surgery, orthopaedic surgery, and general surgery. The experience of orthopaedic surgery residents in LEAs has been relatively stable over the past 11 years. The growing number of cases logged by vascular surgery residents mirrors national trends in the incidence of peripheral arterial disease and LEA

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ANATOMIC SYNDESMOTIC AND DELTOID LIGAMENT RECONSTRUCTION WITH FLEXIBLE IMPLANTS: A TECHNIQUE DESCRIPTION

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ABSTRACT

The optimal fixation method for unstable syndesmosis (SYN) injuries remains a matter of debate between rigid screw fixation that stabilizes all three components of the syndesmosis but prohibits any motion, and flexible implants stabilizing by compression along the axis of the interosseous ligament. More recently additional repairs of the anterior or posterior SYN ligaments have been explored both clinically and biomechanically. The role for deltoid ligament (DL) repair or reconstruction in the setting of SYN injury remains controversial. However, the DL is increasingly recognized as having an important contribution to rotational stability of the ankle. A method of treatment is presented for unstable SYN injuries with flexible implants. An anatomic approach to reconstructing the DL with specific augmentation of the anterior and posterior bands of the deep deltoid ligament (DDL) is described for immediate restoration of medial ankle rotational stability.

Level of Evidence: V

Keywords: syndesmosis, deltoid

INTRODUCTION

Syndesmosis injuries occur in over 10% of all ankle fractures and in up to 20% of operative ankle fractures.[1, 2] Anatomic syndesmosis reduction is known to be essential for better outcomes.[3-5] The syndesmosis ligaments consist of the anterior inferior tibiofibular ligament (AITFL), the interosseous ligament (IOL) and the posterior inferior tibiofibular ligament (PITFL).[6] These are largely extra-articular and will heal primarily but require maintenance of anatomic reduction for a matter of months. Historically, rigid fixation with 1-2 syndesmotic screws has been considered the gold standard of treatment. Fixation strategies with more flexible implants, including suture buttons, have been recently investigated, with the rationale that they may allow for more physiologic motion in the syndesmosis with similar biomechanical strength.[7-9] Patient outcomes with suture button implants have been shown to be similar or superior to screw fixation[1, 5, 10-12] and may help ameliorate malreduction.[13] Recently, the role of the AITFL in resisting external rotation stress has been highlighted and augmentation suggested for syndesmotic injuries;[14] this is likely important in cases of greater instability.[15-17] This information serves to guide more anatomic reconstruction techniques.

Although not historically categorized as a component of the syndesmosis ligament complex, the contributions of the deltoid ligament (DL) as an important stabilizer and deterrent to external rotation force have been increasingly recognized.[14, 18-20] The indications, long-term utility, and optimal technique of treating associated DL instability are controversial and ill defined.[21-23] This is due to the complex anatomy and function of the DL, a lack of understanding of the patterns of injury, and lack of definition of clinically important DL instability. The DL consists of the superficial deltoid ligament (SDL) and deep deltoid ligament (DDL). The SDL acts to control the valgus stress associated with hindfoot eversion (tibiocalcaneal and tibiospring bands), anterior translation of the talus (tibionavicular band) and posterior translation of the talus (superficial posterior tibiotalar band in conjunction with the posterior band of the deep deltoid ligament). However, the anatomic presence of each component individually is variable.[24] The DDL which is also variable generally consists of an anterior band which primarily resists external rotation and a posterior band which resists posterior translation of the talus as the ankle dorsiflexes.[6, 25] Figures 1-3 demonstrate the anatomy of the medial and lateral ankle in a cadaveric specimen.

Various treatment methods for associated DL instability have been described.[26-30] While anatomic repair of the components of the superficial deltoid ligament (SDL) can achieve primary healing, the deep deltoid ligament (DDL), like the anterior cruciate ligament, is an intra-articular ligament with poor likelihood of primary healing. This is due to the effect of synovial cells, which express a gene for alpha smooth muscle actin, inducing myofibroblasts to form on the ends of the ruptured ligament and leading to retraction of the ruptured ends of the ligament.[31]

We describe a technique of repairing SYN and DL instability using suture button augmentation with

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flexible implants to anatomically stabilize the IOL and AITFL, with an augmented reconstruction of the DDL and suture anchor repair of the superficial deltoid. This technique describes the method that we currently use with implants made by Arthrex (Naples FL, USA), which include the TightRope suture button device, SwiveLock anchors (4.75 mm and 3.5mm) and FiberTape suture for flexible augmentation. However, there are several other manufacturers who make similar systems.

SURGICAL TECHNIQUE

Both medial and lateral exposures are performed initially and the tunnels for the posterior talar, anterior talar and tibial SwiveLock anchors are created while the ankle is maximally unstable. The posterior 3.5 mm SwiveLock anchor is placed with the FiberTape prior to reduction and fixation of the syndesmosis. The medial approach is described below in the technique for augmentation and reconstruction of the DL.

Technique for syndesmosis reduction and placement of suture button.

A longitudinal lateral approach to the distal fibula is made and at the tip of the fibula it is directed toward the base of the 4th metatarsal for 3-4 cm. The superior extensor retinaculum (SER) and anterior compartment fascia are sharply elevated off of the anterior edge of the fibula and the anterior compartment musculature is retracted medially to expose the syndesmosis. The anterior perforating peroneal artery is noted and protected although it is also traumatically disrupted in some cases and can be cauterized as the anterior angiosome is primarily supplied by the anterior tibial artery. The stability and displacement of the fibula are assessed, and the torn interosseous ligament fibers and any fibrinous clot are removed with a synovial rongeur. Care is taken not to strip all of the ligamentous attachments off of the tibia or fibula. In chronic cases, the AITFL fibers may appear intact but with stress can be seen to be attenuated in the reduced position. Fatty degeneration may be apparent on the underside of otherwise intact ligament fibers. These are also pie-crusted to allow for overlap of the ends when reduced. The unstable fibula in lower energy injuries tends to be subluxated in an anterolateral and externally rotated position relative to the incisura. A glide maneuver is performed and the reduced position is confirmed clinically and fluoroscopically.[32] A 2.0 mm wire is pre-positioned in the fibula under fluoroscopic guidance at the planned level for the TightRope suture button fixation, approximately 3-4 cm proximal to the tibial plafond; at a level ~5mm proximal to the superior margin of the interosseous portion of the SYN (Figure 4). The TightRope and clamp are not placed too far proximally; as they are compression devices, as opposed to a static device like a screw. The TightRope and/or the clamp can bend the fibula when placed proximally and lead to malreduction due to diastasis of the distal syndesmosis. With manual reduction held and medial-lateral compression the wire is advanced into the tibia in a posterolateral-to-anteromedial trajectory with respect to the axial plane and through the medial tibial cortex in the midline. A medial incision is made over this and the medial soft tissue structures, including the saphenous neurovascular structures, are retracted. The medial periosteum and overlying tibial insertion of the SER are cleared with cautery around the tip of the wire, so that the medial button can be seated directly on the cortical bone. A reduction clamp is then placed across the syndesmosis 4-5mm proximal to the 2.0 wire using a small pre-drilled hole in the fibula to assure stable placement of the pointed reduction clamp. The medial tine is placed 4-5 mm proximal to the tibial exit of the wire and single hand compression is applied with the clamp; there is often a shift of the fibula on the wire as it seats fully into the incisura. The 2.0 wire acts as a guide for medial-lateral compression, preventing any other displacement or rotation, so that the fibula remains in the anatomically reduced position. A smaller diameter wire such as a 1.6mm or 0.062" Kirschner wire may not be strong enough in some cases and could bend. A second 2.0 mm wire is then placed obliquely in the coronal plane, starting 2-3 cm distal to the first wire to hold reduction. The first 2.0 mm wire is then removed and the guide wire for the cannulated drill for the TightRope device is placed through this and then the 3.7 mm cannulated drill for the TightRope device is used over the guide wire. The TightRope is then passed and tensioned by pulling sequentially tighter on the two strands of suture, with longitudinal placement of the suture button medially. The suture strands are not cut until the conclusion of fixation; after the clamp and 2.0 wire are removed the tightrope is finally tightened.

In severe cases of gross multidirectional instability we would use screw fixation as the posterior SYN ligamentous sleeve would be completely ruptured off of the tibia or fibula. In most cases the posterior SYN ligaments act as a tension band with reduction of the fibula fracture and SYN; augmentation of the AITFL stabilizes anterior-posterior translation as well as resisting external rotation. Once reduced the posterior ligaments heal primarily.

Technique for augmented reconstruction of the AITFL:

The pointed reduction clamp and oblique wire remain in place during the augmented reconstruction of the AITFL. Augmentation is performed using a flat flexible non-absorbable suture, FiberTape (Arthrex, Naples FL,

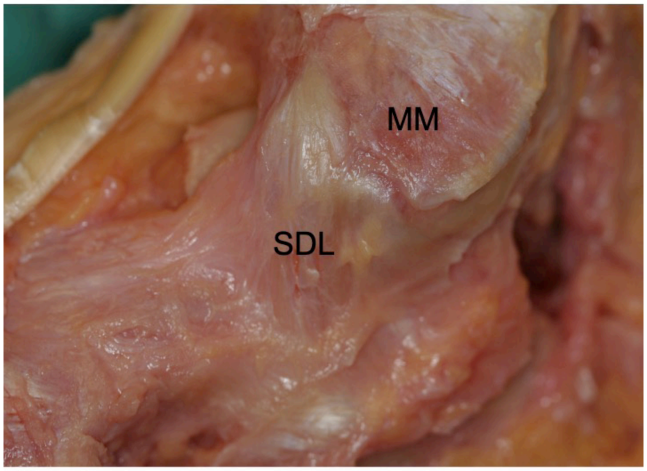

Figure 1. Medial view of dissected ankle specimen with flexor retinaculum removed demonstrating the superficial deltoid ligament (SDL). MM = medial malleolus

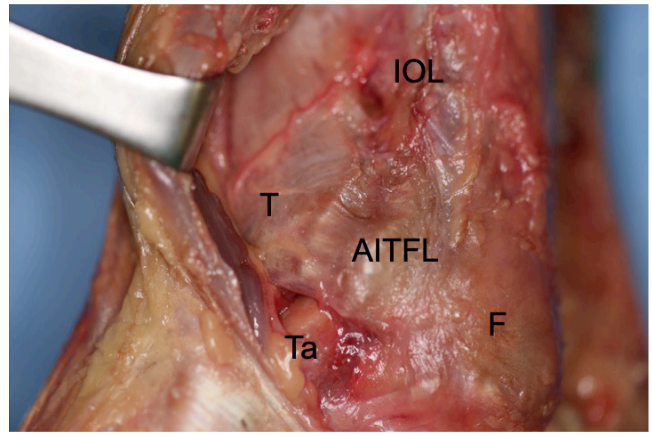

Figure 2. Lateral view of intact syndesmosis. AITFL = anterior inferior tibiofibular ligament, IOL = interosseous ligament, T = tibia, F = fibula, Ta = talus

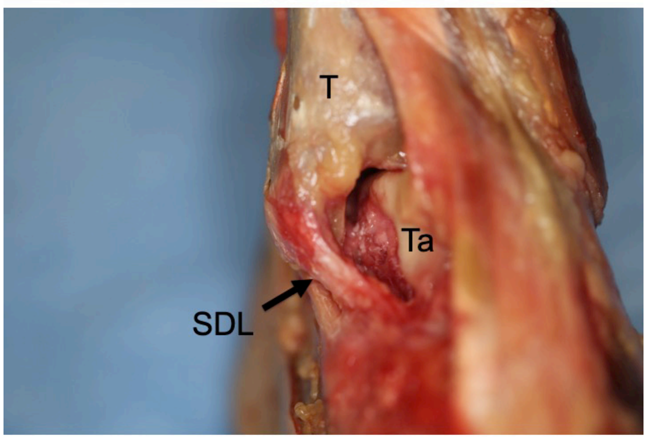

Figure 3. Medial ankle after sectioning of the deep deltoid ligament with superficial deltoid ligament (SDL) intact. T = tibia, Ta = talus

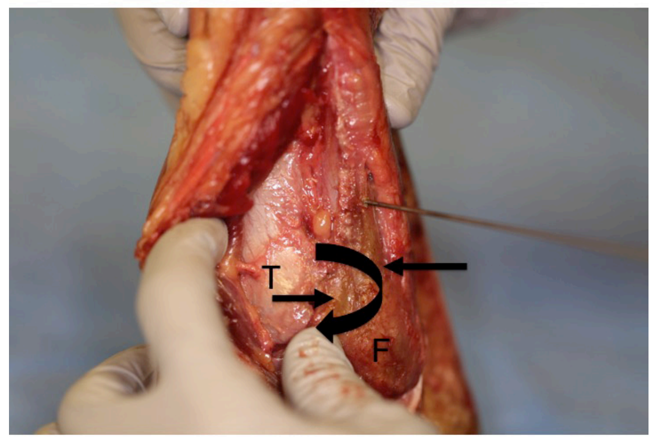

Figure 4. Placement of Kirschner wire in preparation for TightRope application. Arrows demonstrate reduction forces with compression and an internal rotation moment applied over the anterior fibula. T = tibia, F = fibula

USA) which is secured to the fibula and tibia with 3.5 mm and 4.75 mm intramedullary SwiveLock anchors (Arthrex, Naples FL, USA). The technique allows tension to be determined by the surgeon. The previously pie-crusted AITFL ligament ends will overlap to form a scaffold for primary ligament healing at a shorter length after reduction. With flexible interosseous fixation previously performed, a 3.5 mm SwiveLock anchor loaded with FiberTape is placed into the fibula, lateral to the tibial footprint of the AITFL origin; this is placed with a distal direction to utilize the wider metaphyseal bone as the fibular shaft becomes narrow above the syndesmosis and the 3.5mm SwiveLock requires 15mm of bone for placement. A hole is prepared for a 4.75 mm SwiveLock anchor in the tibial footprint, in an oblique direction to avoid violating the concavity of the tibial plafond. Both limbs of the FiberTape are tensioned equally and the anchor is inserted. We have found that this transverse orientation augmenting the more proximal fibers of the AITFL provides the strongest resistance to external rotation and anterior translation. The clamp and oblique 2.0 mm wire are removed and the Tightrope is tightened a final time and tightness is confirmed by stability of the button with hemostat pressure (Figure 5).

Technique for completion of flexible augmentation of Deep Deltoid Ligament and Anterior Superficial Deltoid Ligament following application of suture button and AITFL repair):

The initial incision is made longitudinal along the posterior 1/3 of the medial malleolus and at the tip of the malleolus it is then directed toward the navicular on a line dorsal to the posterior tibialis tendon Superficial dissection allows for mobilization and protection of the saphenous vein. In an acute setting the soft tissue dissection is minimal but in a chronic setting the anterior band

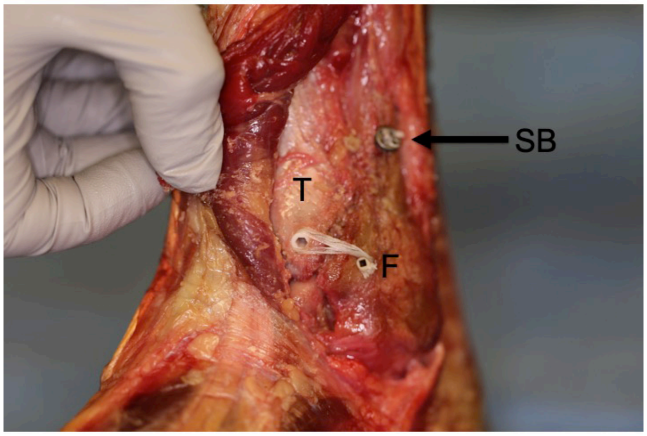

Figure 5. Complete syndesmotic reconstruction with a suture button (SB) and AITFL reconstruction with FiberTape. T = tibia, F = fibula

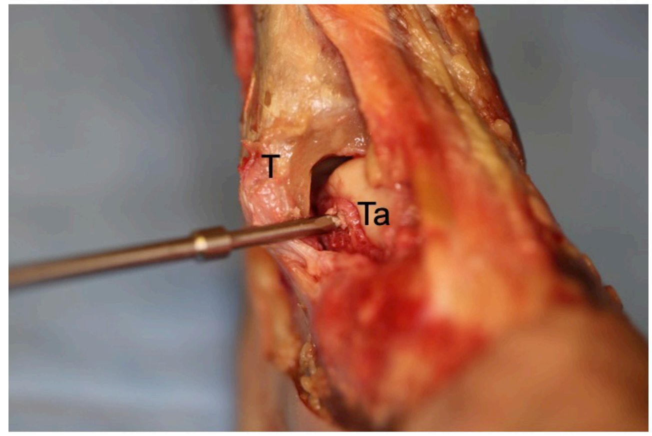

Figure 6. Position of drill for the placement of 3.5 mm SwiveLock anchor in the talus near the footprint of the posterior insertion of the deep deltoid for the posterior deep deltoid reconstruction. T = tibia, Ta = talus

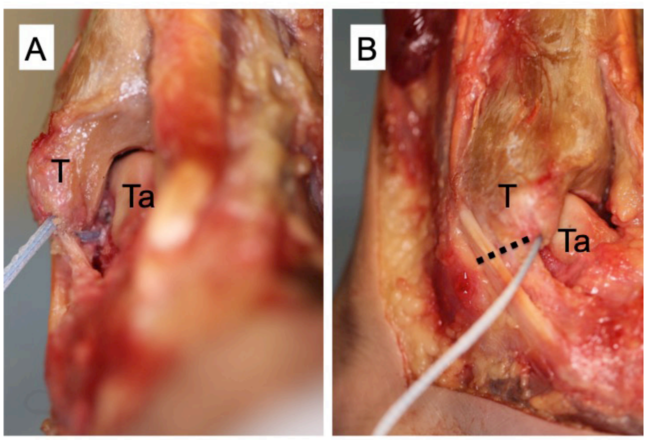

Figure 7. (A) Anterior posterior (AP) view of the ankle after completion of the posterior deep deltoid reconstruction with Fiber Tape (B) Lateral view of the medial ankle after posterior deep deltoid reconstruction. Dashed line demonstrates the trajectory of the reconstruction which is obscured by the superficial deltoid ligament. T = tibia, Ta = talus

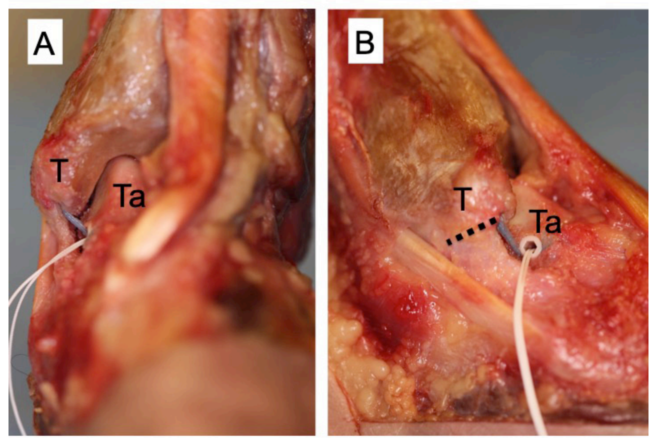

Figure 8. (A)Anterior posterior (AP) view of the medial ankle after the anterior deep deltoid reconstruction (B) Lateral view of the medial ankle after anterior deep deltoid reconstruction. Dashed line demonstrates the trajectory of the reconstruction which is obscured by the superficial deltoid ligament. T = tibia, Ta = talus

of the SDL is mobilized laterally with the superomedial band of the inferior extensor retinaculum (IER). In the unstable state the talus is easily mobilized anteriorly to allow placement of a 3.5 mm SwiveLock anchor with associated FiberTape suture into posterior footprint of the DDL on the talus, recreating the direction of the posterior fibers of the DDL (Figure 6). A drill hole for a 4.75 anchor is prepared in the intercollicular groove (more anteriorly than posteriorly) on the inferior surface of the medial malleolus. The reduction and fixation of the syndesmosis is then performed before returning to the DL reconstruction.

Once the syndesmosis reconstruction is completed, the FiberTape strands are placed into the eyelet of a 4.75 mm SwiveLock anchor. The tension is applied with the ankle in approximately 15 degrees of ankle equinus, and the anchor is inserted.

The ankle is then dorsiflexed to neutral, tensioning the posterior augment in the same way the intact posterior DDL is tensioned with ankle dorsiflexion and physiologic talar rollback into the mortise (Figure 7). A tunnel for an additional 4.75mm SwiveLock anchor is made in the anterior portion of the deep deltoid fossa on the talus and the fiberwire strands are then placed into the eyelet of the 4.75 mm SwiveLock anchor, and after tensioning in ankle neutral position, it is then inserted (Figure 8). This provides control of external rotation as the intact anterior fibers of the DDL would. The Fiberwire in the 4.75 anchor in the talus is can then be used to sew the superior tibiospring and tibionavicular bands of the deltoid to the medial talus as a direct repair of these fibers. In cases where the more proximal portion of the SDL is avulsed from the medial malleolus, additional smaller suture anchors can be used to reattach the ligament and overlying retinacular tissues to the convexity of the medial malleolus. These then will heal primarily back to the bone.

DISCUSSION

We present a method of reconstruction addressing the AITFL, IOL, DDL with SDL repair, using flexible implants.

These injuries are commonly addressed with one or two syndesmotic screws, but normal ankle kinematics require physiologic syndesmotic motion. Therefore, screw removal, loosening or breakage are deemed important after some months. Recently more flexible suture button implants have been increasingly used and studied with the goal of providing stability for ligament healing and allowing for early restoration of "normal" kinematics. Clinical outcomes are equivalent or improved with these flexible implants.[11, 12] but biomechanical studies have failed to show restoration of normal kinematics.[14] The SYN is notoriously difficult to reduce anatomically and it is established, as outlined earlier, that malreduction leads to worse outcomes. This highlights the paramount importance of the accuracy of reduction with either type of fixation. It has been demonstrated biomechanically that a suture button is able to better compensate for malreduction than screw fixation.[13] Perhaps this relates to the findings of improved clinical outcomes in some studies. Excellent outcomes remain elusive with current treatment strategies and recent attention to the importance of the DL and individual components of the SYN have emerged, with the goal of improving outcomes further.[15, 19, 20, 33]

The DL provides primary multifunctional medial stability to the ankle joint. The role of DL repair in the setting of ankle fractures or syndesmotic injuries is controversial. Biomechanical studies investigating contact pressures after syndesmotic sectioning have shown that abnormal ankle mechanics remain with isolated syndesmotic fixation in the presence of a sectioned deltoid ligament.[19] Another biomechanical study showed that there was no significant change in tibiotalar contact area or peak pressure after disruption of the syndesmosis if the deltoid remained intact, yet with the addition of deltoid ligament sectioning there was a 42% increase in peak pressure.[34] Both repair and reconstruction techniques for the deltoid ligament have been described in the literature- including direct repair, suture anchor repair, reconstruction with autograft or allograft, and repair with anchor to post suture reinforcement.[26, 35-38] The technique described in this article allows for flexible anatomic reconstruction of the IOL, AITFL, SDL and specific anatomic augmentation of the DDL, with an effort to restore the kinematic properties of the anterior and posterior components of the DDL. This reconstruction method uses anatomically oriented augmentations to attempt to further aid reproduction of the stability and kinematics found in intact ankle joint. Future biomechanical and clinical studies will be needed to further investigate this reconstruction technique.

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OVERLAPPING SURGERY IN PRIMARY TOTAL KNEE ARTHROPLASTY: ARE 6-WEEK COMPLICATIONS WORSE THAN SINGLE OPERATING ROOM SCHEDULING?

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ABSTRACT

Background: Overlapping surgery is common in high-volume total knee arthroplasty (TKA) practices and has come under recent scrutiny in the press. The aim of this study was to evaluate differences in 6-week clinical and radiographic outcomes for primary TKA patients between single and overlapping operating room (OR) days.

Methods: We retrospectively reviewed individual patient records of a consecutive series of primary TKAs with complete 6-week follow-up performed by a single academic surgeon between 2008-2016 (N= 452). Patients were stratified by single vs. overlapping OR days. 177 patients (39%) had an overlapping surgery. Age, body mass index (BMI), Charlson Comorbidity Index (CCI) and American Society of Anesthesiologists (ASA) class were recorded to assess for confounding variables. Outcomes included anesthesia time, 6-week readmission, unplanned return to OR, medical and surgical complication, and 6-week radiographic alignment.

Results: There were no significant differences in anesthesiology time (165.5 vs 164.5 min, p=0.85), medical or surgical complication rates (10.5% vs 6.2%, p=0.11), 6-week readmissions (4.4% vs 1.7%, p=0.12), or return to OR (1.8% vs 1.7%, p=1.00) before or after adjusting for age, BMI, gender, ASA and CCI. There was no difference between overlapping and single OR cohorts in rate of neutral coronal alignment (2°-8° valgus) (98.3% vs 98.9%, respectively, p=0.68) or presence of periprosthetic lucency (p=0.43).

Conclusions: This study demonstrates no differences in 6-week clinical or radiographic outcomes between patients undergoing primary TKA on single versus overlapping OR days. These results support the safe practice of overlapping surgical scheduling in high-volume primary TKA centers.

Level of Evidence: III

Keywords: concurrent surgery, overlapping surgery, patient safety, total knee arthroplasty, complications

INTRODUCTION

Overlapping surgery, or "running two rooms", has recently garnered public criticism following an October 2015 article published in the Boston Globe, titled "Clash in the Name of Care,"[1] that described a case in which a significant adverse event occurred while a surgical trainee operated without direct supervision, as the attending surgeon was concurrently operating in another operating room (OR).[1] This media attention triggered a senate inquiry into the efficacy and safety of the longstanding medical practice.[2,3] In response to widespread concern, Massachusetts General Hospital (MGH) and The American College of Surgeons (ACS) published definitions differentiating the practice of overlapping and concurrent operations and their proper use in academic medical centers.[4-7] The ACS defines concurrent operations as "Surgical procedures when the critical or key components of the procedures for which the primary attending surgeon is responsible are occurring all or in part at the same time".[4] In contrast, overlapping operations are defined as "the practice of the primary surgeon initiating and participating in another operation when he or she has completed the critical portions of the first procedure and is no longer an essential participant in the final phase of the first operation."[4] Critical or key components of each procedure are not universally defined, but rather depend on the expertise of the specific attending surgeon to make that decision. In addition to the formal guidelines published by the ACS, there are prominent opinion pieces in the surgical literature asserting that overlapping surgery is safe and efficient.[8-12] Concurrent operations are considered inappropriate, while overlapping operations are performed at the discretion of individual institutions. The American Academy of Orthopedic Surgeons has affirmed the ACS position on concurrent operations.

Overlapping surgery is appealing due to its increased

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Table 1: Six Week Patient Demographic Characteristics

Demographics	Overlapping Surgery (N = 177)	Non-Overlapping Surgery (N = 275)	P Value
Age (yr)*	59.7±11.2	60.4±10.0	0.469
Sex†			0.301
Female	104 (58.8)	176 (64.0)	
Male	73 (41.2)	99 (36.0)	
BMI†			0.179
<18.5 kg/m2	0 (0.0)	0 (0.0)	
18.5 to 24 kg/m2	11 (6.2)	10 (3.6)	
25 to 29 kg/m2	27 (15.2)	50 (18.2)	
30 to 34 kg/m2	52 (29.4)	62 (22.5)	
35 to 40 kg/m2	34 (19.2)	56 (20.4)	
>40 kg/m2	53 (30.0)	97 (35.3)	
ASA Rating†			0.369
1	3 (1.7)	8 (2.9)	
2	94 (53.1)	120 (43.6)	
3	42 (23.7)	75 (27.3)	
4	0 (0.0)	4 (1.5)	
Missing data	38 (21.5)	68 (24.7)	
Charlson Comorbidity Index sum score†			0.0025
0	96 (54.2)	118 (43.0)	
1	45 (25.4)	62 (22.5)	
2	12 (6.8)	25 (9.1)	
≥3	24 (13.6)	70 (25.4)	

*reported as mean ± standard deviation.
†reported as number of patients (percentage of cohort).

efficiency by maximizing surgeon's time operating and minimizing wait times for OR turnover, room set up, and anesthesia preparation. The primary surgeon delivers high quality care to a greater proportion of patients while training surgeons gain valuable experience and progressive independence. Participation of trainees in different surgical subspecialties has consistently been correlated with improved safety and patient care.[13-19] In addition, multiple surgical disciplines have demonstrated that overlapping surgery can be safely performed.[20-28] While the orthopedic literature is limited to short-term outcomes from hand, foot & ankle, and sports medicine procedures performed at an ambulatory surgery center, this study showed equivalent outcomes between overlapping and non-overlapping procedures.[20] In addition, a study of primary total hip and knee arthroplasty procedures with intraoperative complication rates, 90-day component revision rates, and 90-day postoperative complication rates showed no difference between overlapping and non-overlapping procedures.[28] We are aware of no studies to date reporting complication rates and individual radiographic analysis between overlapping and non-overlapping surgeries in primary total knee arthroplasty (TKA).

Primary TKA is commonly performed in overlapping operating theaters at high volume academic practices. We hypothesize there is no difference in clinical outcomes at six weeks. Therefore, the purpose of this study was to evaluate for any differences in 6-week clinical or radiographic outcomes for primary TKA patients between overlapping surgery and non-overlapping surgeries. We hypothesize that complication rates, patient reported outcomes, and radiographic outcomes will be similar, regardless of whether overlapping surgery was performed.

METHODS

Study Design

This project was reviewed by human subjects institutional review board and approved as exempt from informed consent. We performed a retrospective review of individual patient records in a consecutive series of eligible primary TKA performed by a single academic surgeon from April 2008 through April 2016. Patients with 6-week follow-up were included in the primary data analysis (n = 452). Cases were stratified by whether their surgery was performed on a day with non-overlapping ORs or overlapping ORs (n = 275 and 177, respectively). Although not randomized, cases were not systematically assigned to overlapping or non-overlapping days. On days with overlapping surgeries, cases were staggered to allow for the surgeon to complete the critical portions of a case and then transition directly to a second room for the critical portions of the next procedure. Critical portions were defined as initial incision through the completion of component cementing.

Patient Demographics and Clinical Indicators

Patient demographics as well as medical and operative data were obtained from electronic medical records. This information included age, body mass index (BMI), medical comorbidities, and American Society of Anesthesiologists classification (ASA). BMI was calculated from height and weight data and was stratified by the World Health Organization (WHO) classification. Charlson Comorbidity Index (CCI) was calculated as previously described using 16 comorbidities identified by the International Classification of Diseases codes, Tenth Revision (ICD-10).[29] Anesthesiology time was obtained from procedural documentation.

Table 2. Six Week Intraoperative and Postoperative Outcomes

Outcomes	Overlapping Surgery	Non-Overlapping Surgery	P Value
Intraoperative*			
Anesthesia time (min)	164.5±25.0	165.5±25.3	0.845
Postoperative†			
6-Week Readmissions	3 (1.7)	12 (4.4)	0.122
Return to OR	3 (1.7)	5 (1.8)	1.000
6-Week Complication	11 (6.2)	29 (10.5)	0.114

*reported as mean ± standard deviation.
†reported as number of patients (percentage of cohort).

Complications

Patient electronic medical records were accessed to review operative notes, progress notes, discharge summaries, clinic notes and postoperative admission notes to identify peri- and postoperative complications. Complications and revision surgery occurring within 6 weeks of the initial primary TKA were included. Complications included medical complications (deep venous thromboembolism/pulmonary embolism (DVT/PE), cardiac abnormality or arrhythmia, syncope, acute renal failure, stroke, pneumonia, or renal insufficiency), surgical complications (intraoperative fracture/ligament injury, wound dehiscence, wound drainage, cellulitis, hematoma, deep surgical site infection, or neuropathy), 6-week readmission, and return to OR. Indication for return to OR was documented in each case.

Patient Outcomes

Analysis of 6-week long leg radiographs included coronal alignment as previously described by The Knee Society.[30] Radiographic alignment was classified from long leg and lateral radiographs as neutral (2-8 degrees valgus alignment), varus (<2 degrees valgus alignment), or valgus (>8 degrees valgus alignment). One patient from the non-overlapping cohort and four patients from the overlapping cohort were excluded from radiographic analysis due to presence of post-traumatic deformity prior to surgery.

Statistical Analysis

Patient characteristics were described using means ± SD for continuous variables and proportions for categorical variables. The overlapping and non-overlapping cohorts were compared using t-tests for continuous and chi-square tests for categorical variables. Continuous variables that were not normally distributed were compared using the Wilcoxon Rank Sum test. This included age, BMI, ASA, CCI, anesthesiology time, WOMAC pain, and WOMAC functionality. Post-operative outcomes and complications were compared with logistic regression and generalized linear models with and without adjustment for age, BMI, comorbid conditions and ASA scores.

RESULTS

Overall, 177 of 452 primary total knee arthroplasty procedures with complete 6-week clinical and radiographic follow-up were performed with overlapping scheduling (39.2%). There was no significant difference in age ($p = 0.469$), sex ($p = 0.301$), BMI ($p = 0.179$), or ASA rating ($p = 0.369$) between patients who received an overlapping surgery versus those who received a non-overlapping surgery (Table 1). Patients who received an overlapping surgery had a lower Charlson Comorbidity Index sum score than patients receiving a non-overlapping surgery (1.0±1.7 vs 1.8±2.6; Table 1; $p=0.0025$).

There was no significant difference in anesthesiology time between overlapping and non-overlapping cases (164.5±25.0 vs 165.5±25.3; $p = 0.845$) (Table 2). Postoperative 6-week readmissions (1.7% vs 4.3%; $p = 0.12$), return to OR within 6 weeks (1.7% vs 2.2%; $p = 1.00$), and 6-week complications (6.2% vs 10.5%; $p = 0.11$) were not significantly different between overlapping and non-overlapping cases (Table 2). Surgical complications accounted for 70% of all reported complications (Table 3). Of the four patients with an intraoperative fracture or ligament injury, one patient suffered a peri-prosthetic intra-operative tibia fracture, one sustained a patellar tendon partial tear, another had a partial MCL avulsion that was reattached with two G2 suture anchors, and the fourth patient had a patellar tendon partial peel-off that was sutured to bone with #5 Ticron. In addition to specific intraoperative and postoperative complications, 3 patients (0.6%) received a manipulation under anesthesia for arthrofibrosis. All three of these patients made a full recovery within 6 weeks with no subsequent tendon tear or further complication at last follow-up.

Six-week radiographic outcomes showed similar rates of neutral coronal alignment ($p = 0.681$). Periprosthetic lucency was detected in 9 patients from the overlapping surgery group (9.3%), versus 11 patients in the non-overlapping group (6.5%, $p = 0.434$) (Table 4). In the

Table 3. Six Week Complications by Type

	Overlapping Surgery*	Non-Overlapping Surgery*
Medical Complication		
DVT/PE	1 (0.6)	7 (2.5)
Cardiac Abnormality or Arrhythmia	0 (0.0)	2 (0.7)
Syncope	0 (0.0)	0 (0.0)
Acute renal failure	1 (0.6)	1 (0.4)
Stroke	0 (0.0)	0 (0.0)
Pneumonia	0 (0.0)	0 (0.0)
Renal insufficiency	0 (0.0)	0 (0.0)
Surgical Complication		
Intraoperative Fracture/Ligament Injury	1 (0.6)	3 (1.1)
Wound dehiscence	4 (2.3)	8 (2.9)
Wound drainage	0 (0.0)	2 (0.7)
Deep surgical site infection[a]	1 (0.6)	1 (0.4)
Cellulitis	2 (1.1)	4 (1.4)
Neuropathy	0 (0.0)	0 (0.0)
Hematoma	1 (0.6)	1 (0.4)
All complications	11 (6.3)	29 (10.5)

DVT = Deep Venous Thromboembolism
PE = Pulmonary Embolism

* reported as number of patients (percentage of cohort).
[a] Deep surgical site infection defined as culture positive infection extending deep to fascial closure.

overlapping group there was one patient with varus alignment and in the non-overlapping group there were two patients with varus alignment (p=1.000). In the overlapping group, there were two patients with valgus alignment postoperatively, compared to one valgus in the non-overlapping group (p=0.562). Radiographic results of four patients in the overlapping group and one patient in the non-overlapping group were excluded from analysis due to preoperative deformity.

DISCUSSION

The current study is the first study evaluating the practice of overlapping surgery that we are aware of to include 6-week clinical and radiographic outcomes following primary total knee arthroplasty. Our analysis of 6-week outcomes of 452 consecutive primary TKA cases showed no significant differences in anesthesia time, 6-week readmissions, return to OR, 6-week complications, or radiographic long leg coronal alignment. Our outcomes in both overlapping and non-overlapping patient cohorts had favorable outcomes consistent with previous reports in the literature.[28,31] While we observed a significant difference in Charlson Comorbidity Index scores between overlapping and non-overlapping surgery groups, there was no difference in 6-week outcomes when controlling for this potential confounding variable. The observed difference in comorbidity, as measured by CCI, is potentially due to the random nature of case scheduling or thoughtful selection bias by scheduling personnel, although there is no protocol in place for scheduling higher-risk patients on non-overlapping OR days. Given the possible source of bias, we adjusted for patient demographics using logistic regression and generalized linear models, which did not detect a difference in clinical or radiographic outcomes between overlapping and non-overlapping scheduling.

Our overall conclusions are consistent with prior surgical analysis of overlapping outpatient orthopaedic,[20,28] neurosurgical,[21,22] spine,[23] thoracic,[24] otolaryngology[25] and pediatric procedures,[26] the results of each study showed no significant difference in clinical outcomes (complications,

Table 4. Six Week Radiographic Outcomes

	Overlapping Surgery	Non-Overlapping Surgery	P Value
Coronal Alignment†			
Neutral	170 (98.3)	271 (98.9)	0.681
Varus	1 (0.6)	2 (0.7)	1.000
Valgus	2 (1.1)	1 (0.4)	0.562

† reported as number of patients (percentage of cohort).

hospital readmission, and return to OR) among patients undergoing overlapping surgery versus non-overlapping surgery. This study adds to prior reports on the safety of overlapping surgery, which were thus far limited to 30-day or 90-day postoperative complications and/or were database-driven studies. Ours included analysis of radiographic outcomes and accuracy, in addition to 6-week complication metrics in an individualized review of over 450 consecutive patients at our institution. Furthermore, Hyder et al. published a large-scale retrospective review of 36,074 surgical cases from nationally standardized clinical data registries demonstrating that overlapping surgery does not place patients at greater risk of adverse outcomes.[27] Zhang also recently reported equivocal 30-day outcomes for 2,474 overlapping cases and 1,166 non-overlapping cases in sports medicine, hand and elbow, and foot and ankle procedures.[20] Hamilton reviewed 16,916 cases in overlapping and non-overlapping primary total hip and knee arthroplasty procedures, with no differences in intraoperative complication rates, 90-day component revision rates, or 90-day complication rates.[28] In contrast to certain procedures included in previous studies, large and elective inpatient procedures such as primary TKA may include a patient population with greater comorbidities and result in more substantial adverse events.

The safety and efficacy of overlapping surgery relies on the support of fellows, residents, and physician assistants. In academic medical centers, surgical trainee participation raises the question of whether additional risk is incurred by the patient. It has been repeatedly demonstrated that participation of trainees in different surgical subspecialties is correlated with improved safety and patient care.[13-19] Contrasting studies have demonstrated increased operative time, patients' length of stay, and non-home discharge associated with resident involvement.[34] Resident involvement is a highly imprecise term that is not captured identically across studies or specialties and is dependent on attending physician level of comfort and teaching abilities. At our institution, there is a surgical resident present in each operating room to assist the attending physician on an overlapping surgery day. The surgical team can additionally consist of a physician assistant and a medical student who play a complementary role to the attending physician and resident. Residents and fellows aid in the preoperative preparation as well as incision closure which may contribute to the safety, efficacy, and efficiency of overlapping surgery by allowing the attending surgeon to promptly begin the subsequent case.[8]

Surgeon variability in the definition of critical or key portions of surgical procedures presents a challenge for data interpretation. A recent study was conducted where 100 orthopaedic surgeons were surveyed with the goal of defining the critical portions of total hip arthroplasty and total knee arthroplasty procedures.[32] These two procedures were selected due to their prevalence and highly structured format. Despite these postulated advantages, overall critical portion agreement rates were 3.2% and 8.6% for hip and knee procedures, respectively. Poor intra-surgeon consensus demonstrates the necessity for the formal identification of critical portions in certain surgical procedures as suggested by the US Senate Finance Committee.[3] At our institution, standard protocol requires at a minimum that the attending surgeon be present from the initial incision through the completion of component cementing. Due to this institutional protocol, the uniformity in the degree of overlap for each case was not recorded. In addition to surgical trainee assistance on overlapping surgery days, proper patient disclosure about the possibility of overlapping surgery is a key component in delivering high quality patient care in an operational setting. Recent press reports highlighted the lack of disclosure in overlapping surgery cases and the public sentiments towards this issue.[1,33] To remedy this potential disconnect between the patient and the provider, MGH and other institutions, including our own, have implemented policies requiring the possibility of overlapping surgery to be disclosed on patient consent forms.[7,20-23] Proper disclosure and patient education in the practice of overlapping surgery aids in operational transparency while achieving comparable patient outcomes to non-overlapping surgery.

One limitation of our study is the retrospective nature involving a single academic medical center and a single provider. Although a prospective multicenter or multi-provider study has the potential to provide improved data, we elected to analyze a single attending surgeon's cases to maintain clinical and surgical consistency. In addition, our medical center services a diverse patient population. Patient electronic health record data outside of our institution was not available in all instances. Certain adverse outcomes including range of motion, postoperative pain, stiffness, and strength deficits are subjective measures and were not included if they did not result in a 6-week readmission, return to OR, or documented complication. Despite this, an individualized, detailed chart review was performed to analyze the nature of each complication. Finally, the results of overlapping surgery by a single academic surgeon may not be generalizable to other practices that lack involvement of surgical trainees, appropriate support, and adequate resources.

Information regarding the practice of overlapping surgery in primary total knee arthroplasty is currently limited and this study aims to strengthen earlier claims pertaining to its practice. The topic is emergent among the medical community, and this data will hopefully aid future policy decisions about delivering surgical care without compromising patient safety. Future research examining the potential long-term effects of overlapping surgery on patient outcomes is suggested in order to expand the knowledge of the medical profession.

CONCLUSIONS

The results of this study demonstrate no differences in 6-week clinical and radiographic outcomes between patients undergoing overlapping versus non-overlapping primary total knee arthroplasty and support the safe practice of overlapping scheduling in high volume total knee arthroplasty centers.

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EARLY PREDICTORS OF MICROSURGICAL RECONSTRUCTION IN BRACHIAL PLEXUS BIRTH PALSY

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ABSTRACT

Background: Microsurgical reconstruction is indicated for infants with brachial plexus birth palsy (BPBP) that demonstrate limited spontaneous neurological recovery. This investigation defines the demographic, perinatal, and physical examination characteristics leading to microsurgical reconstruction.

Methods: Infants enrolled in a prospective multicenter investigation of BPBP were evaluated. Microsurgery was performed at the discretion of the treating provider/center. Inclusion required enrollment prior to six months of age and follow-up evaluation beyond twelve months of age. Demographic, perinatal, and examination characteristics were investigated as possible predictors of microsurgical reconstruction. Toronto Test scores and Hospital for Sick Children Active Movement Scale (AMS) scores were used if obtained prior to three months of age. Univariate and multivariate logistic regression analyses were performed.

Results: 365 patients from six regional medical centers met the inclusion criteria. 127 of 365 (35%) underwent microsurgery at a median age of 5.4 months, with microsurgery rates and timing varying significantly by site. Univariate analysis demonstrated that several factors were associated with microsurgery including race, gestational diabetes, neonatal asphyxia, neonatal intensive care unit admission, Horner's syndrome, Toronto Test score, and AMS scores for finger/thumb/wrist flexion, finger/thumb extension, wrist extension, elbow flexion, and elbow extension. In multivariate analysis, four factors independently predicted microsurgical intervention including Horner's syndrome, mean AMS score for finger/thumb/wrist flexion <4.5, AMS score for wrist extension <4.5, and AMS score for elbow flexion <4.5. In this cohort, microsurgical rates increased as the number of these four factors present increased from zero to four: 0/4 factors = 0%, 1/4 factors = 22%, 2/4 factors = 43%, 3/4 factors = 76%, and 4/4 factors = 93%.

Conclusions: In patients with BPBP, early physical examination findings independently predict microsurgical intervention. These factors can be used to provide counseling in early infancy for families regarding injury severity and plan for potential microsurgical intervention.

Level of Evidence: Prognostic Level I

Keywords: palsy, plexus, obstetric, brachial, birth

INTRODUCTION

Brachial plexus birth palsy (BPBP) refers to paralysis of the upper extremity secondary to a traction or compression injury sustained to the brachial plexus during birth. The incidence of BPBP is approximately 0.9 to 2.0 out of 1,000 live births.[1-3] Risk factors include shoulder dystocia, macrosomia, difficult or instrumented delivery, and breech presentation.[1] BPBP varies in severity and the extent of plexus involvement, ranging from transient neuropraxia to complete cervical nerve root avulsion of part or all of the brachial plexus.[4-6]

The natural history of BPBP remains largely unknown, due to the paucity of studies of affected patients followed from birth to maturity. Historically, 80 to 90% of patients were thought to demonstrate spontaneous recovery within the first 2 months of life, with subsequent normal upper extremity function.[2,3,5,7-10] More recent investigation has suggested a much lower recovery rate, with only 66% of affected children recovering completely and 10% to 30% with considerable permanent weakness.[11,12] The variation in reported recovery rates may correlate with regional differences in injury severity, referral patterns, and treatment strategies.

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Table 1. Microsurgery by Site of Care

Site	#/N	(%)
1	31/163	(19%)
2	3/10	(30%)
3	48/78	(62%)
4	41/65	(63%)
5	3/35	(9%)
6	1/14	(7%)
All Sites	127/365	(35%)

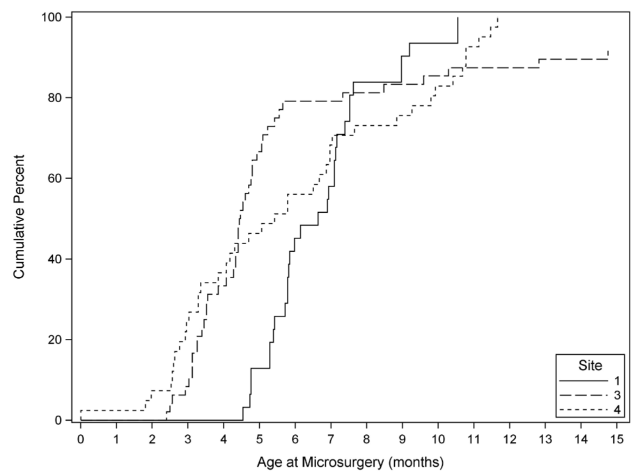

Figure 1. Distribution of microsurgical procedures over time. Cumulative percent of microsurgical procedures performed as a function of age by site of care. Displayed plot is truncated at 15 months, but procedures were performed at later ages at site 3. The sites not shown had three or fewer microsurgical procedures each. Microsurgical procedures at Site 1 were performed over a narrow age interval, generally between the fifth and eighth months of life, whereas procedures at Site 3 and Site 4 were often performed earlier, during the fourth and fifth months of life. Microsurgery at Site 3 was generally performed prior to 5 months although there were several procedures performed at much later ages. While some microsurgical procedures at Site 4 were performed at early ages, the timing was spread relatively evenly through 12 months of age.

Patients with persistent neurologic deficits after 3 to 6 months of age are at high risk for permanent neurologic dysfunction.[3,6,8,10,13-15] Microsurgical reconstruction with nerve grafting or transfers is indicated for infants that demonstrate limited spontaneous neurological recovery. Traditionally, return of antigravity biceps function by 3 to 6 months of age has been used to prognosticate long-term neurological recovery. In a small retrospective series, Michelow et al. reported that use of biceps function alone incorrectly predicted recovery in 12.8% of cases.[10] When elbow flexion as well as elbow, wrist, thumb, and finger extension at 3 months were combined into a single test score (the Toronto Test score), the proportion of patients whose recovery was incorrectly predicted was reduced to 5.2 percent.[10] Fisher et al. have also reported that elbow flexion alone cannot adequately predict spontaneous neurological recovery in BPBP.[16]

This investigation seeks to define the demographic, perinatal, and early physical examination characteristics of infants which led to microsurgical reconstruction in a large prospective multicenter study. We hypothesize that physical examination factors, but not demographic and perinatal factors, will independently predict microsurgical intervention in children with BPBP.

MATERIALS AND METHODS

A prospective multicenter cohort study of infants with BPBP was performed by the TOBI (Treatment and Outcomes of Brachial Plexus Injuries) Study Group, comprised of six regional medical centers. This investigation was performed as a secondary study aim, with the primary study aim directed towards determining the optimal timing for microsurgical intervention. Inclusion criteria for this investigation required enrollment prior to six months of age and follow-up evaluation beyond twelve months of age. In this cohort, microsurgery was performed at the discretion of the treating provider at each institution. The distributions of age at microsurgery at the three sites with at least thirty microsurgical procedures were compared with the Kruskal-Wallis test.

Demographic, perinatal, and physical examination characteristics were investigated as possible predictors of microsurgical reconstruction. The demographic and perinatal factors analyzed included gender, race (white, black, other), gravidity (1, 2, ≥3), parity (1, 2, ≥3), presence of gestational diabetes, history of preeclampsia, history of previous difficult delivery, duration of labor (0-4, 5-10, 11-16, ≥17 hours), type of obstetric provider (obstetrician, midwife), fetal presentation (vertex, breech, face), type of delivery (uncomplicated, difficult, forceps/vacuum extraction, Cesarean section), gestational age (≤37, 38 40, ≥41 weeks), birth weight (≤4000, 4000-4500, >4500 grams), Apgar scores at 1 and 5 minutes, neonatal asphyxia, respiratory complications, and neonatal intensive care unit (NICU) admission. Since the rate of microsurgery, demographic, and perinatal factors were expected to vary by site of care, these demographic and perinatal factors were examined for confounding by site of care. For all demographic and perinatal factors except Apgar scores, logistic models were used to test the association between microsurgery and each characteristic, with and without adjusting for site. Factors were screened for consideration in multivariable models by identifying those with p values <0.10 either in unadjusted analysis or when adjusted only for site. The logistic models were also used to estimate odds ratios (OR) and 95% confidence intervals (CI). Apgar scores were treated as continuous factors and a two

Table 2. Microsurgery by Demographic and Perinatal Characteristics.
Only characteristics with unadjusted or adjusted p values <.10 are shown.

				Unadjusted		Adjusted for Site	
Characteristic		#/N	(%)	OR (95% CI)	p	OR (95% CI)	p
All	(N=365)	127/335	(35%)				
Race	(N=304)						
White		68/220	(31%)	1.0	.002	1.0	.14
Black		33/59	(56%)	2.84(1.58, 5.11)		1.86(0.95, 3.66)	
Other		8/25	(32%)	1.05(0.43, 2.56)		1.75(0.62, 4.93)	
Gestational Diabetes	(N=354)						
No		94/290	(32%)	1.0	.02	1.0	.02
Yes		31/64	(48%)	1.96(1.13, 3.39)		2.08(1.11, 3.90)	
Hx Difficult Delivery	(N=348)						
No		91/281	(32%)	1.0	.06	1.0	.22
Yes		30/67	(45%)	1.69(0.98, 2.91)		1.48(0.80, 2.73)	
Obstetric Provider	(N=328)						
Obstetrician		102/291	(35%)	1.0	.06	1.0	.05
Midwife		7/37	(19%)	0.43(0.18, 1.02)		0.40(0.16, 1.02)	
Neonatal Asphyxia	(N=344)						
No		81/256	(32%)	1.0	.007	1.0	.001
Yes		42/88	(48%)	1.97(1.20, 3.23)		2.64(1.46, 4.75)	
Respiratory Issues	(N=347)						
No		69/217	(32%)	1.0	.09	1.0	.25
Yes		53/130	(41%)	1.48(0.94, 2.32)		1.35(0.81, 2.25)	
NICU Admission	(N=352)						
No		72/239	(30%)	1.0	.02	1.0	.01
Yes		49/113	(43%)	1.78(1.12, 2.82)		2.03(1.19, 3.47)	
Birth Weight (g)	(N=362)						
≤4000		50/152	(33%)	1.0	.39	1.0	.04
4000-4500		43/128	(34%)	1.03(0.63, 1.70)		1.11(0.63, 1.95)	
>4500		34/82	(41%)	1.44(0.83, 2.52)		2.27(1.17, 4.38)	

sample Wilcoxon test was used to compare the Apgar distributions between infants who did and did not undergo microsurgical reconstruction. The Van Elteren test, a stratified version of the Wilcoxon test, was subsequently used to control these comparisons for site of care. The demographic and neonatal factors were then evaluated with multivariable logistic regression.

The physical examination characteristics assessed included presence of a Horner's syndrome, maximum Toronto Test score in the first three months of life (<3.5, ≥3.5), 10 and maximum Hospital for Sick Children Active Movement Scale (AMS) scores for finger, thumb, wrist, and elbow flexion and extension *in the first three months of life*.[17] Of note, both a logistic regression analysis and a factor analysis of the eight studied AMS scores suggested the following five summary scores: hand/wrist flexion (average of finger, thumb, and wrist flexion scores), hand extension (average of finger and thumb extension scores), wrist extension, elbow flexion, and elbow extension. Each of these summary scores was dichotomized at <4.5 versus ≥4.5, corresponding to no motion against gravity versus motion against gravity. For all physical examination factors, logistic models were used to test the association between microsurgery and each characteristic, with and

Table 3. Multivariable Model Predicting Microsurgery from Demographic and Perinatal Characteristics (N=388)

	Unadjusted		Adjusted for Site	
Characteristic	OR (95% CI)	p	OR (95% CI)	p
Gestational Diabetes				
No	1.0	.04	1.0	.04
Yes	1.83(1.04, 3.21)		1.97(1.02, 3.78)	
Neonatal Asphyxia				
No	1.0	.02	1.0	.003
Yes	1.83(1.11, 3.02)		2.64(1.36, 4.48)	

without adjusting for site. The logistic models were also used to estimate odds ratios and 95% confidence intervals. The physical examination factors were then evaluated with multivariable logistic regression.

Finally, the demographic, perinatal, and physical examination characteristics were combined in a single multivariable logistic regression model to assess whether each factor contributed unique information toward predicting which patients would undergo microsurgery. The final model was illustrated by tabulating the percentages of patients undergoing microsurgery separately for patients with 0, 1, 2, 3, or 4 of the 4 factors in the model.

In all of these analyses, patients with missing values on particular variables were excluded from analyses of those variables, two sided tests were performed, and p-values less than 0.05 were considered statistically significant.

RESULTS

365 infants with BPBP met the inclusion criteria including 165 (45%) males and 200 (55%) females. The median age at initial evaluation for these patients was 2.2 months and 246 (67%) were examined within the first three months of life.

Rate and Timing of Microsurgery

127 (35%) infants underwent brachial plexus reconstruction, with microsurgery rates varying significantly by site ($p < 0.0001$) (Table 1). The median age at microsurgery was 5.4 months (interquartile range 3.8 to 7.5); however, the age distribution differed significantly between sites (p=0.003). Figure 1 shows the distribution at the three sites with at least 30 procedures. Microsurgical procedures at Site 1 were performed over a narrow age interval, generally between the fifth and eighth months of life, whereas procedures at Site 3 and Site 4 were often performed earlier, during the fourth and fifth months of life.

Analysis of Demographic and Perinatal Factors

In preliminary analysis, we identified demographic and perinatal factors demonstrating an association with microsurgery at a significance level of $\alpha = 0.10$ either in completely unadjusted analysis or adjusted only for site (Table 2). When these demographic and perinatal factors were considered in a multivariable logistic regression model, only gestational diabetes (OR 1.83, p = 0.04) and neonatal asphyxia (OR 1.83, p =0.02) were significant predictors of microsurgery (Table 3). Patients with gestational diabetes and/or neonatal asphyxia had a microsurgical rate of 48% (62/130), compared to 29% (60/208) for patients with neither.

Analysis of Physical Examination Factors

Univariate analysis suggested that all selected physical examination factors had strong associations with microsurgery (Table 4), and remained statistically significant when adjusting for site of care. When these physical examination factors were considered in a multivariable logistic regression model, only presence of Horner's syndrome (OR 4.43, p =0.04), AMS score for hand/wrist flexion (OR 4.57, p =0.008), AMS score for wrist extension (OR 2.77, p =0.004), and AMS score for elbow flexion (OR 11.32, p =0.02) were statistically significant predictors of microsurgery (Table 4).

Combined Analysis of Demographic, Perinatal, and Physical Examination Factors

The demographic, perinatal, and physical examination factors were combined in a single regression model to assess which factors contributed unique information toward predicting which infants underwent microsurgical reconstruction. The perinatal factors that were statistically significant when analyzed independent of the physical examination factors were not significant in this global model. This analysis suggested that only the physical examination factors presented above (multivariable model, Table 4) were statistically significant predictors of microsurgery, including presence of Horner's syndrome, AMS score for hand/wrist flexion, AMS score for wrist extension, and AMS score for elbow flexion. Microsurgical rates increased as the number of these four factors present increased from zero to four: 0/4 factors = 0%, 1/4 factors = 22%, 2/4 factors = 43%, 3/4 factors = 76%, and 4/4 factors = 93% (Table 5).

DISCUSSION

In this multicenter prospective cohort of infants with BPBP, several early physical examination findings independently predicted microsurgical brachial plexus reconstruction. Although perinatal factors, including gestational diabetes and neonatal asphyxia, were also as-

Table 4. Microsurgery by Physical Examination Factors[a]

		Unadjusted		Multivariable Model (N=224)	
Characteristic	#/N (%)	OR (95% CI)	p	OR (95% CI)	p
All (N=365)	127/335 (35%)				
AMS Score Hand/Wrist Flexion[b] (N=226)					
≥4.5	49/194 (25%)	1.0	<.001	1.0	0.008
<4.5	27/32 (84%)	15.98 (5.83, 43.77)		4.57 (1.49, 14.04)	
AMS Score Hand Extension[c] (N=232)					
≥4.5	31/153 (20%)	1.0	<.001		
<4.5	46/79 (58%)	5.49 (3.02, 9.96)			
AMS Score Wrist Extension (N=232)					
≥4.5	23/135 (17%)	1.0	<.001	1.0	0.004
<4.5	55/97 (57%)	6.38 (3.49, 11.64)		2.77 (1.38, 5.57)	
AMS Score Elbow Flexion (N=234)					
≥4.5	1/39 (3%)	1.0	0.002	1.0	0.02
<4.5	77/195 (39%)	24.79 (3.34, 184.3)		11.32 (1.48, 86.49)	
AMS Score Elbow Extension (N=233)					
≥4.5	29/141 (21%)	1.0	<.001		
<4.5	49/92 (53%)	4.40 (2.47, 7.85)			
Toronto Score (N=227)					
≥3.5	38/156 (24%)	1.0	<.001		
<3.5	48/73 (66%)	5.96 (3.25, 10.93)			
Horner's Syndrome (N=359)					
No	101/326 (31%)	1.0	<.001	1.0	0.04
Yes	26/33 (79%)	8.27 (3.48, 19.69)		4.43 (1.10, 17.78)	

[a]AMS and Toronto Test scores represent maximum score in the first three months of life
[b]Average of individual AMS scores finger, thumb, and wrist flexion
[c]Average of individual AMS scores for finger and thumb extension

sociated with microsurgery, these factors demonstrate no independent predictive value when physical examination characteristics are available in clinical decision-making. In this cohort, nearly half of patients with a history of asphyxia and/or maternal history of gestational diabetes underwent microsurgical reconstruction. Interestingly, one-third of infants without a history of either still underwent microsurgical reconstruction. This finding is supported by an investigation performed by Al-Qattan et al which demonstrated no difference in recovery among infants of diabetic and non-diabetic mothers.[18]

Among physical examination characteristics, Horner's syndrome as well as antigravity elbow flexion, wrist extension, and finger/thumb/wrist flexion *prior to three months of age* were the only factors to demonstrate independent predictive value. Since Horner's syndrome is highly associated with preganglionic injury and poor spontaneous recovery,[5,9,19] it logically follows that presence of a Horner's syndrome was strongly associated with future microsurgical reconstruction. This finding corresponds with the consensus that microsurgical reconstruction should be undertaken for infants with global lesions and Horner's syndrome, by 3 months of age.[4,6,8,9,20] Interestingly, in this investigation, the Toronto Test score demonstrated no independent predictive value when considered as either a continuous or a dichotomous variable. In contrast, AMS scores for elbow flexion, wrist extension, and finger/thumb/wrist flexion prior to three months of age did independently predict future microsurgical intervention.

Of all factors, the presence or absence of antigravity elbow flexion prior to three months of age was the most

Table 5. Microsurgery by Number of Exam Factors

# of Factors	#/N	(%)
0	0/35	(0%)
1	21/95	(22%)
2	25/58	(43%)
3	16/21	(76%)
4	14/15	(93%)
All		(34%)

predictive of future microsurgical reconstruction, suggesting that surgeons continue to utilize early return of biceps function as a marker of plexus recovery of from birth injuries. Multiple prior investigations suggest that infants with return of biceps function after 3 months rarely experience complete recovery without some persistent limitations in strength or motion. Global shoulder function worsens with increasing delay in return of biceps function,[15] as suggested by lower Mallet scores found in patients who recovered function after 6 months of life, compared with those who recovered between 4-6 months.[21] Interestingly, the average AMS score for finger, thumb, and wrist flexion—functions not scored by the Toronto Test—independently predicted future microsurgical reconstruction. Since these motor functions correspond to the C7 and C8 nerve roots, lower AMS scores suggest involvement of the middle and lower trunk. As noted, the prognostic value of the average AMS score for these functions is also supported by the general consensus that infants with Horner's syndrome or global injuries be targeted for early microsurgical reconstruction.[4,6,8,9,20]

The data from this cohort suggests that physical examination characteristics may be used to provide counseling in early infancy for families regarding injury severity and plan for potential microsurgical intervention. A previous investigation by Bae et al. suggests that there is excellent intraobserver and interobserver reliability for use of the Hospital for Sick Children Active Movement Scale and Toronto Test Score,[22] which supports reliance on physical examination for indicating microsurgical intervention. Since these classification systems grade strength with gravity eliminated, they are particularly useful for infants who cannot follow commands and, therefore, can only be prompted and observed.

The value of early counseling for families cannot be understated. More than 80% of parents utilize the internet to learn more about treatment and surgical options.[23] Counseling families as they embark on this process of self-education may improve understanding of the condition and increase the integrity of shared-decision making. Since early physical examination factors are used to indicate microsurgical intervention, referral of infants with persistent brachial plexus birth palsy to specialized treatment centers is recommended prior to two months of age.

The data analysis in this investigation was supported by prospective multicenter design, which permitted the enrollment of a large number of patients and the inclusion of 365 subjects. The large sample size permitted robust statistical analysis of broad set of demographic, perinatal, and physical examination characteristics when evaluating which factors were most predictive of microsurgical reconstruction. The multicenter design combined with a sample size large enough to be adjusted for site of care was a strength of this study, as the investigation was able to identify salient predictive characteristics across sites that varied with respect to racial composition, injury severity, and treatment paradigms.

The study had several important limitations. Although the study was designed to initiate enrollment in the first few months of life, only 66% of the subjects eligible for this analysis were enrolled prior to 3 months. As we were interested in the predictive value of physical examination characteristics present in the first three months of life, this data was not available for a substantial subset of patients. Moreover, missing data points limited comparisons, particularly when multivariate analyses were performed. We had to exclude 141 subjects from our final multivariable model because of missing data on one or more physical exam factors.

In this series, the four independently predictive physical examination characteristics were associated with a stepwise increase of about 20% to 30% in the rate of microsurgery with the addition of each additional factor. However, this result needs validation in a different set of patients to determine whether microsurgery can be predicted at three months of age. Nonetheless, awareness of perinatal and physical examination characteristics most predictive for microsurgery allows clinicians to focus on the most salient patient characteristics. This awareness can guide clinical decision-making for providers engaged with this unique, complex patient population.

One of the most controversial elements of brachial plexus management remains the timing of surgery for patients with post-ganglionic injuries, in which there are varying degrees of severity of injury and recovery. Although this investigation does not elucidate the optimal timing of microsurgical reconstruction, it does provide clinicians additional insights at an early age regarding which patients are likely candidates for microsurgical reconstruction, thereby permitting planning for microsurgical reconstruction and providing appropriate time for counseling and discussion with families.

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EFFECTIVENESS OF NONOPERATIVE TREATMENT OF THE SYMPTOMATIC ACCESSORY NAVICULAR IN PEDIATRIC PATIENTS

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ABSTRACT

Background: Initial management of symptomatic accessory navicular in pediatric patients is nonoperative. However, efficacy of nonoperative treatment has not been studied or established. If nonoperative treatment is frequently unsuccessful or does not give lasting pain relief, surgery could be offered as first line treatment. This study retrospectively reviewed outcomes of pediatric patients treated nonoperatively for symptomatic accessory naviculae in an effort to provide clinicians success rates for their discussion of treatment options with patients and their families.

Methods: A retrospective analysis of pediatric patients diagnosed and treated nonoperatively for a symptomatic accessory navicular bone at Cincinnati Children's Hospital Medical Center between dates August 1st, 2006 and August 24th, 2016 was performed. Outcome measures consisted of complete pain relief, partial relief without operative intervention, or need for operative intervention. Radiographic imaging for each patient was also used to identify the type of accessory navicular and presence of concurrent pes planus.

Results: A total of 169 patients were included, with 226 symptomatic accessory naviculae. Average age at diagnosis was 11.8 years, with majority females (78%). Type 2 accessory naviculae were most frequent (72.7%), with Type 1 and Type 3 in 9.7% and 17.4%, respectively. Average number of nonoperative trials was 2.1, with 28% experiencing complete pain relief, 30% requiring surgical intervention, and 41% that experienced partial pain relief and did not require surgical intervention, and were recommended as needed (PRN) follow-up based on clinical improvement. Of those that achieved complete pain relief, the average length of non-operative treatment was 8.0 months.

Conclusion: The results of this study can be used by clinicians to frame discussions surrounding treatment options for symptomatic accessory navicular bones with both patients and their families.

Level of Evidence: III

Keywords: accessory naviculae, nonoperative treatment, pediatric

INTRODUCTION

An accessory navicular is considered a normal anatomic variant. They are present in 4% to 21% of the population.[1,2] The accessory navicular was first described by Bauhin in 1605.[3] It has been known by several names including os tibiale, naviculare secundarium, pre-hallux, and bifurcated hallux. Most are asymptomatic and incidentally noticed on a radiograph. However, occasionally an accessory navicular can present with clinically evident symptoms, such as pain and tenderness. These symptoms typically present in the second decade of life which correlates with its ossification.[3] The navicular is the last of the tarsal bones to ossify with variable radiographic appearance between 2.7 to 4 years.[4] The secondary ossification center does not appear until 9 through 13 years of age, occurring two years earlier in females than males.[3,5] When this ossification center fails to fuse to the primary mass, it results in an accessory navicular which can cause medial foot pain.

The first proposed classification system for the accessory navicular was described by Dwight in 1907 and is still used today with only slight modification. Dwight's classification includes three categories of accessory navicular bones (Figure 1). In a Type 1 accessory navicular, the ossicle is completely independent from the navicular as a sesamoid bone in the tibialis posterior tendon.[3] It accounts for 30% of accessory navicular bones.[3,5] The Type 2 accessory navicular is the most common at 60% of accessory navicular bones, and is united to the navicular by a cartilaginous or fibrocartilaginous bridge.[3,5] Lastly,

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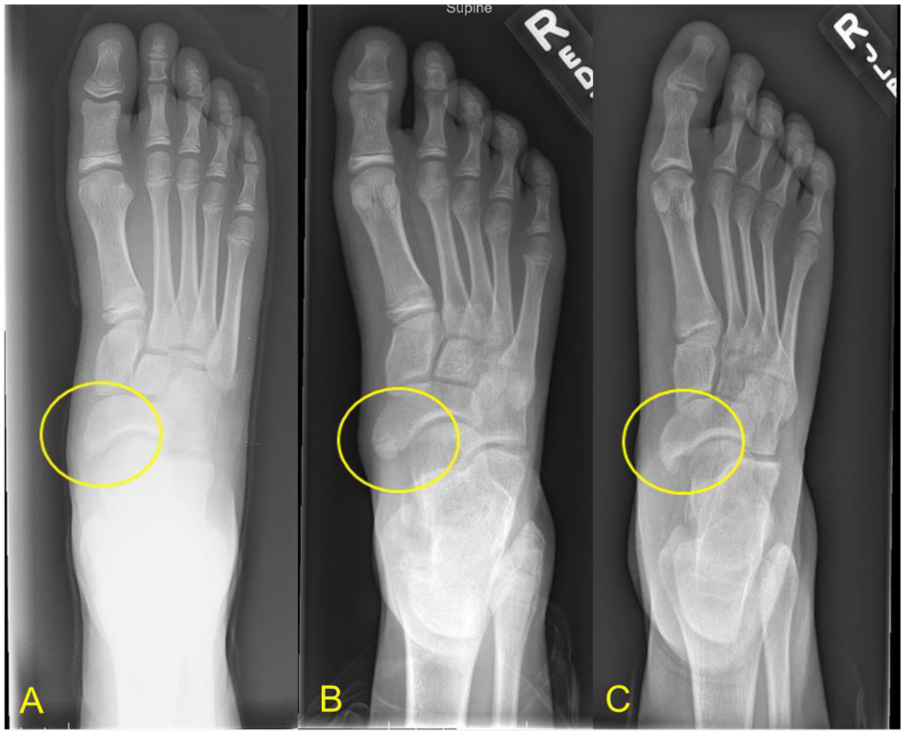

Figure 1. Examples of type 1, 2, and 3 accessory naviculae labeled as A, B, and C, respectively. Identified in external rotation view and represented within circle.

the Type 3 accessory navicular, which is only 10% of accessory naviculae, occurs when the secondary ossification center fuses during adolescence but leaves a very prominent medial projection.[3,5] Some authors argue that the Type 3 accessory navicular may represent the final stages of the Type 2. Medial sided foot pain is almost exclusively seen in the Type 2 accessory navicular.[2]

The initial management of a symptomatic accessory navicular in pediatric patients is nonoperative. The first line of treatment is shoe wear modification to wider, more comfortable shoes which alleviate the pressure on the medial side of the foot.[4] In addition, activity modification to limit or stop any strenuous activities along with nonsteroidal anti-inflammatories are common. Another conservative option is casting to assure compliance and prevent any repetitive microtrauma.[4] When nonoperative treatments fail to mitigate symptoms, surgery is indicated.

While operative outcomes and efficacy has been extensively studied in the accessory navicular, in contrast, the efficacy of nonoperative treatment for alleviating pain or preventing surgery in the symptomatic accessory navicular has not been established. If nonoperative treatment is frequently unsuccessful or does not give lasting pain relief, then surgery could possibly be offered as a first line treatment. This study retrospectively reviewed the outcomes of pediatric patients treated nonoperatively for symptomatic accessory naviculae which will provide clinicians success rates for their discussion of treatment options with patients and their families.

MATERIALS AND METHODS

After obtaining IRB approval, all accessory naviculae diagnosed and treated by the senior author (J.R.D.) and colleagues at Cincinnati Children's Hospital Medical Center between August 1st, 2006 and August 24th, 2016 were retrospectively reviewed. Medical records were used to identify demographic information, type of accessory navicular, duration, and total trials of nonoperative treatment, additional foot comorbidities, response to nonoperative management, and need for surgery if nonoperative management failed. To be included in this study, subjects were required to be under 18 years of age at presentation during the specified time frame, experienced medial sided foot pain, had radiographic evidence of an accessory navicular, and underwent at least one course of nonoperative treatment. Patients with a previously operated on accessory navicular or other diagnosed painful foot conditions were excluded. Outcome measures consisted of pain relief, no operative intervention, or need for operative intervention. Imaging for each patient was also reviewed to determine type of accessory navicular and identify presence of concurrent pes planus. Radiographic pes planus was determined using both Meary's angle (measuring greater than 10 degrees) and calcaneal pitch (measuring

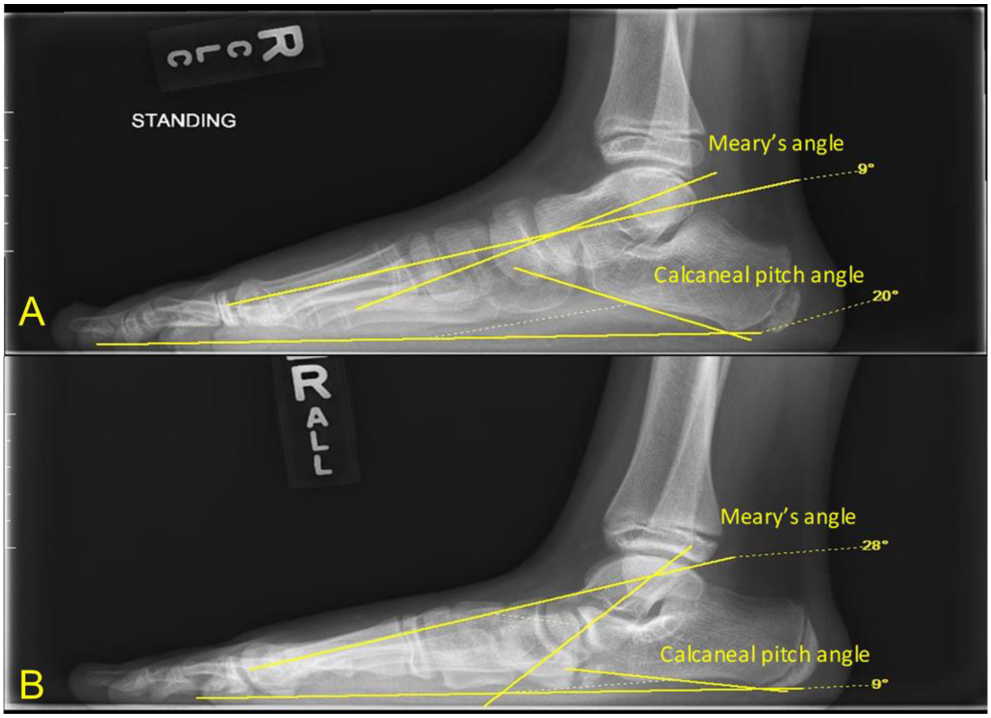

Figure 2. Measurement of Meary's (talar-1st metatarsal angle) and calcaneal pitch angles. A) Measurement of patient's right foot without pes planus demonstrating normal Meary's and calcaneal pitch angles. B) Measurement of patient's right foot with pes planus demonstrating abnormal Meary's and calcaneal pitch angles. Meary's angle was measured between the long axis of the talus and first metatarsal on a weight-bearing lateral view as shown. Calcaneal pitch angle was measured between plantar-most surface of calcaneus to inferior border of distal articular surface and transverse plane.

less than 15 degrees) (Figure 2).

Descriptive statistics were used to characterize the sample, including nonoperative treatment type, duration of nonoperative treatment, treatment response and need for additional surgery. The response to treatment was assessed by the patient's ability to return to baseline or sporting activities at described in follow-up visits, depending on activity level of patient. Treatment response was also judged by patient and families not seeking further treatment. A chi-squared test was used to analyze the different conservative treatments and the outcomes achieved. The percentage of patients failing conservative management and requiring surgery was also calculated.

RESULTS

A total of 169 patients with 226 symptomatic accessory naviculae were identified which met all inclusion criteria, and had complete medical records necessary for data analysis. Average age at diagnosis was 11.8 years, with 78% females and 22% males. Fifty-three (32%) were left symptomatic accessory naviculae, 56 (33%) right, and 60 (36%) bilateral. Type 2 accessory naviculae were most frequent (72.7%), with Type 1 and Type 3 accounting for 9.7% and 17.4%, respectively (Figure 1). Fifty-six percent of the symptoms were chronic in nature, with 31% due to acute injury. Average number of nonoperative trials was 2.1, with 28% experiencing complete pain relief, 30% requiring operative intervention, and 41% that experienced partial pain relief, did not require operative intervention, and were recommended PRN follow-up based on clinical improvement. Of those that achieved complete pain relief, average length of nonoperative treatment was 8.0 months. In contrast, of those patients who failed nonoperative treatment and went on to receive operative intervention, the average length of nonoperative treatment prior to receiving operative intervention was 11.7 months. A total of 47 (27.8%) patients underwent immobilization alone as nonoperative treatment, 40 (23.6%) underwent shoe inserts alone as treatment, and 82 (48.5%) underwent both immobilization and shoe inserts as treatment (Table 1).

Thirteen percent of patients received advanced imaging (CT or MRI) during their initial work-up. Associated pes planus was identified using radiographic measurements from available standing radiographs. There were 18 patients (17.6%) which demonstrated pes planus using Meary's angle, while 22 patients (21.5%) demonstrated pes planus using calcaneal pitch (Figure 2).

DISCUSSION

There is currently very little literature exploring nonoperative treatment outcomes of symptomatic accessory naviculae. Case reports make up the majority

Table 1. Type of Nonoperative Treatment and Associated Treatment Outcome

Type of Nonoperative Treatment	Pain Relief	No Operative Intervention£	Surgery
Immobilization+	19 (40%)	12 (26%)	16 (34%)
Shoe Inserts++	7 (18%)	31 (78%)	2 (5%)
Immobilization+ & Shoe Inserts++	25 (30%)	29 (35%)	28 (34%)
Total Patients	51 (30%)	72 (43%)	46 (27%)

£No operative intervention patients underwent nonoperative treatment and did not receive surgery.
+Immobilization defined as patient treated with CAM walker and/or cast.
++Shoe inserts defined as patient treated with orthotics and/or cushion inserts.

of current insight, and among those athletes tend to be the focus over the general population.[6,7] In a recent case report comparing two adolescent dancers, one treated operatively and the other treated nonoperatively, it was found that nonoperative treatment of bracing, taping, and foot orthotics provided substantial pain relief and return to activities similar to the patient treated operatively.[7] Despite reported cases of nonoperative treatment outcomes, overall effectiveness of nonoperative treatment and specific effectiveness of various treatment modalities have yet to be investigated. Our results provide further insight into effectiveness of not only nonoperative treatment, but also of specific treatment modalities. The results of our study are meant to provide baseline data for surgeons to utilize when discussing treatment options with patients and families.

Recent literature has suggested that not all symptomatic accessory naviculae respond similarly to nonoperative treatment.[7,8] A retrospective study by Jegal et al. found that athletes with symptomatic accessory navicular pain have symptoms that are more refractory to conservative treatment when compared to the general population.[8] This raises the question of whether surgery could be considered sooner in those patients whose symptoms seem to arise as a direct result of athletic activity. In our study, it is hard to determine cause due to athletic activity versus other trauma, as this is not a common question asked during initial work-up that would ultimately alter treatment decisions. Further, patients that are active in competitive sports may have a lower threshold in which to opt for operative intervention. Based on our results, an average of 2.1 nonoperative trials were required spanning an average of 8.0 months, which could have a big impact on return to sport for those involved in multiple competitive athletic activities.

It is often difficult to differentiate pain from symptomatic accessory navicular from other etiologies, such as tibialis posterior tendonitis. This distinction can be made more challenging when patients have difficulty pinpointing where pain is emanating from. To mitigate this in our study, particular attention was paid to the physical exam with emphasis placed on the patient feeling point tenderness over the navicular bone only rather than along the length of the tibialis posterior tendon. Concomitant pes planus was another contributing factor considered. There are several radiographic angles that have been described for determination of pes planus. The authors prefer to use both the Meary's angle and calcaneal pitch angle to determine pes planus radiographically. A Meary's angle greater than 10 degrees (normal range of 0 to 10°) or calcaneal pitch angle less than 15 degrees (normal range of 15 to 30°) was considered diagnostic of pes planus.[9-11] There were 17.6% of patients which demonstrated pes planus using Meary's angle, while 21.5% demonstrated pes planus using calcaneal pitch. Previous studies have reported prevalence rates of pes planus in the pediatric population ranging from 4 to 44%.[12-14] Rates of pes planus from the current study support these findings, however with the various methods practitioners use to diagnose pes planus there is some variation between studies. Literature also suggests that an accessory navicular does not play a role in the development of pes planus, and vice versa.[15,16] In addition, the degree of pes planus is not associated with severity of symptoms in patients with accessory naviculae.[15,16]

It is also difficult to determine success of nonoperative treatment given pain thresholds vary so greatly between individuals. In our study, 28% of patients experienced complete pain relief with nonoperative management while 31% required operative intervention. The remaining 41% of our patients initially underwent nonoperative treatment and on subsequent visits demonstrated partial pain relief and were recommended follow-up as needed based on clinical improvement. Effectiveness of non-operative treatment also likely varies based on factors such as baseline activity level and age, and subgroup analyses would be beneficial to determine more specific characteristics of those that achieved complete pain relief with nonoperative management. In addition, a more standardized approach to assessing pain relief in children is warranted. While patient reported outcome measures (PROs) have become standard of care in the adult population, in children there is limited evidence demonstrating the efficacy of PROs in pediatric orthopedic practice.[21]

A weakness of our study is the small number of patients from which to make recommendations. However, the patient population represented in this study can suggest trends which are useful in assessment and treatment planning.

There is currently nothing in current literature that explores the potential effectiveness of different nonoperative treatments for symptomatic accessory naviculae. There is also no current literature aimed to help guide discussions for decision-making about available nonoperative treatment. This study is a novel exploration into nonoperative treatment effectiveness in symptomatic accessory naviculae.

In summary, results of this study can be used by clinicians to frame discussions surrounding treatment options for symptomatic accessory naviculae with both patients and their families. Further research is warranted to determine the necessary duration and type of nonoperative treatment, among those most commonly used, that is most successful in providing pain relief.

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OPEN VS. CLOSED REDUCTION IN TYPE 2 LATERAL CONDYLE FRACTURES

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ABSTRACT

Background: Lateral condyle fractures are associated with high morbidity due to their risk of nonunion and avascular necrosis (AVN). This study aims to assess the outcomes between closed reduction and the more traditional open techniques for operative fractures.

Methods: All lateral condyle fractures that required operative fixation (pins or screws) over a ten-year period were included. We compared open versus closed reduction for OR time, infection rate, AVN, nonunion, premature physeal closure, ulnohumeral angle, and interepicondylar width (IEW).

Results: 28 patients were identified in the closed reduction group while 41 were identified in the open reduction group. Average displacement at surgery for these two groups was significantly different at 3.95mm for the closed group and 9.47mm for the open group (p<0.0001). Operating room time was significantly greater for the open reduction group by an average of 45 minutes (p <0.0001). Additionally, the closed reduction group was significantly less likely to require post-operative admission compared to the open reduction group (p=0.0004). There were no significant differences between the two groups with regard to abnormal ulnohumeral angles, infection rates, avascular necrosis, nonunion, lateral spur formation, premature physeal closure, or reoperation rate.

Conclusion: The significant differences in OR time and post-operative admission make closed reduction the preferred approach from a hospital system quality improvement standpoint.

Level of Evidence: IV

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Keywords: pediatric trauma, lateral condyle fracture, pediatric orthopedics

INTRODUCTION

Lateral condyle fractures are the second most common pediatric elbow fracture, comprising up to 20% of them.[1] Not only are they relatively common, but they are also associated with high rates of morbidity, including nonunion, avascular necrosis (AVN), and premature physeal closure.[2,3] Due to these risks, it has been recommended that they be managed operatively if they are displaced by more than 2mm based on the Jakob classification.[1,3-5]

Surgical fixation may be completed in a number of ways, including with an open approach, a closed approach, with K-wire fixation, or with screw fixation.[6-8] There has been debate concerning the adequacy of open versus closed fixation.[1] Some have classically thought that an open approach was necessary in order to be certain that the articular surface was properly reduced; however, there have been some studies that show a closed reduction was not inferior in outcomes when performed on patients with 4mm or less of maximal displacement.[1,7,8] As closed approaches continue to gain popularity, we seek to evaluate their cost-effectiveness and re-examine the 4mm cut-off as an indication of their use.

METHODS

After obtaining the appropriate Institutional Review Board approval, patients were identified for this retrospective chart review between the years 2003 and 2013 who were under the age of 18 and had the following ICD-9 codes: 812.42 for a closed lateral condyle fracture, 812.52 for an open lateral condyle fracture, and 812.44 for an unspecified condylar fracture. Patients were excluded if they received multiple fractures in the ipsilateral upper extremity. Information regarding patient demographics, surgical methods, and follow-up were collected from the chart. Fractures were classified based on the Jakob criteria.[4,9]

Operative cases were selected based on an initial maximum fracture displacement greater than 2mm, progression of maximum fracture displacement to greater than 2mm, or at least 21 days of cast immobilization with resulting non-union. The decision to approach fixation with an open or closed approach was at the discretion of

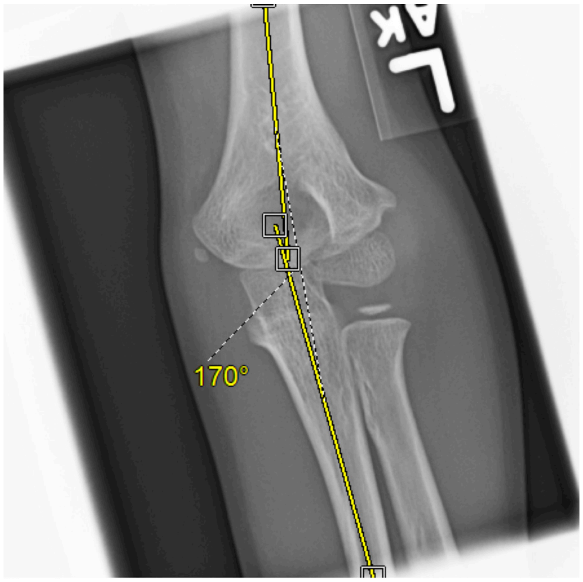

Figure 1. Measurement of ulnohumeral angle, which displays a normal value of 10˚.

Figure 2. AP elbow demonstrating a lateral spur. The interepicondylar width (IEW) was determined by measuring the distance of the metaphyseal spur from the medial epicondyle to the normal metaphysis.

Figure 3. Avascular necrosis. The capitellum demonstrates fragmentation and early closure of the lateral physis.

the operating orthopedic surgeon. The use of K wires or screws was also done at their discretion and the majority of them were unburied and removed in the office approximately one month after surgery.

Radiographic measurements, such as maximum fracture displacement, ulnohumeral angle, and interepicondylar width (IEW), were redone at the time of the study. Ulnohumeral angle was measured from the most recent AP of the ipsilateral elbow and was used as a measure of varus or valgus alignment. The range for the normal valgus alignment of the elbow used was 5°-15°. Measurements less than 5° were considered varus while angles more than 15° were considered valgus.

IEW is a measurement used to assess the severity of lateral spurring, which is a common radiographic abnormality after lateral condyle fracture.[10] IEW indicated mild spurring if it was between 100% and 110%, moderate spurring if it was between 110% and 120%, and severe spurring if it was greater than 120%.10

Additionally, the presence of avascular necrosis or premature physeal closure was identified on the most recent follow-up radiographs. AVN was defined as either the presence of a fishtail deformity or the loss of a previously developing capitellum. Premature growth arrest was defined as bony bridging across a physis.

Infection was monitored and was analyzed in total and after segmental analysis looking at superficial wound infections and septic arthritis.

In order to assess statistical significance between the open and closed groups, several tests were employed. The Student's T test was done when comparing mean values between the two groups. This was calculated with the use

Table 1. Patient Demographics and Original Injury Characteristics

	Closed (n = 28)	Open (n = 41)	P value
Age	5.16	6.0	0.08969
Gender	57.1% M	65.9% M	0.6135
Injured Side	71.4% L	63.4% L	0.6054
BMI	18.30	19.06	0.56277
Maximum Displacement	2.5 (range 0,6.32)	7.8 (range 1.17,24.3)	**<0.0001**
Jakob Criteria:			**<0.0001**
Jakob I	46.4% (n = 13)	7.3% (n = 3)	
Jakob II	32.1% (n = 9)	17.1% (n = 7)	
Jakob III	21.4% (n = 6)	75.6% (n = 31)	

of StatPlus in Microsoft Excel.[11] In addition, the Mann-Whitney U test was done to compare values in which the median was thought to be a better comparison of the average than the mean.[12] Finally, Fisher's Exact Test was computed for categorical data.[13] All p-values used were two sided and significance was noted when p<0.05. For cases where patients needed a reoperation, intent to treat analysis was used.

RESULTS

164 patients with lateral condyle fractures were identified in our search. Of those, 79 required surgical fixation. A total of 69 patients met our research criteria and were included in the study. 28 patients were identified in the closed reduction group while 41 were identified in the open reduction group. Median follow-up for the closed group was 9.5 months (1, 76), which was significantly longer than the open group, which was followed for 4 months (1.38, 43) post-operatively (p=0.02). Patient demographics are displayed in Table 1. The most common mechanism of injury was a direct fall onto the elbow with 43.6% of patients in the closed group and 41.4% of the open group reporting this. No patients in either group presented with an open fracture. Age at injury, gender, side of injury, and BMI were not significantly different between the two groups. The median maximum displacement at the time of presentation to our hospital system for the closed group was 2.5mm (range 0,6.32), which was significantly different compared to the open group, which had a median of 7.8mm (range 1.17, 24.3)(p <0.0001).

Table 2. Comparisons at the Time of Surgery

	Closed (n = 28)	Open (n = 41)	P value
Time to surgery (days)	9 (range 1,29)	2 (range 0,82)	**<0.0001**
OR Time (min)	78.64	123.29	**<0.0001**
Maximum Displacement	3.95 (SD = 1.61)	9.47 (SD = 5.71)	**<0.0001**
Fixation Type	78.6% Screws	17.1% Screws	**<0.0001**
Admitted to Hospital	7.1%	47.5%	**0.0004**

Comparisons at the time of surgery for the two groups are demonstrated in Table 2. Patients who underwent closed reduction of their fractures waited longer before surgery compared to the open reduction group with an average time of 9 days and 2 days, respectively (p <0.0001). At the time of surgery, the closed group had a

Table 3. Patient Follow-Up and Outcomes

	Closed (n = 28)	Open (n = 41)	P value
Follow-up Length (months)	9.5 (range, 1, 76)	4.0 (range, 1.38, 43)	**0.02**
Skin Infection	0%	10%	0.14
Septic Elbow	0%	5%	0.51
Nonunion	7.7%	0%	0.19
Avascular Necrosis	10.7%	12.2%	1.00
Premature Physeal Closure	7%	0%	0.164
Lateral Spurring	85.7%	78%	0.54
IEW:	n=23	n=32	0.42
Mild	21.74% (n=5)	34.38% (n=11)	
Moderate	69.56% (n=16)	50% (n=16)	
Severe	8.7% (n=2)	15.62% (n=5)	
Abnormal Ulnohumeral Angle	32.1%	39.5%	0.6106

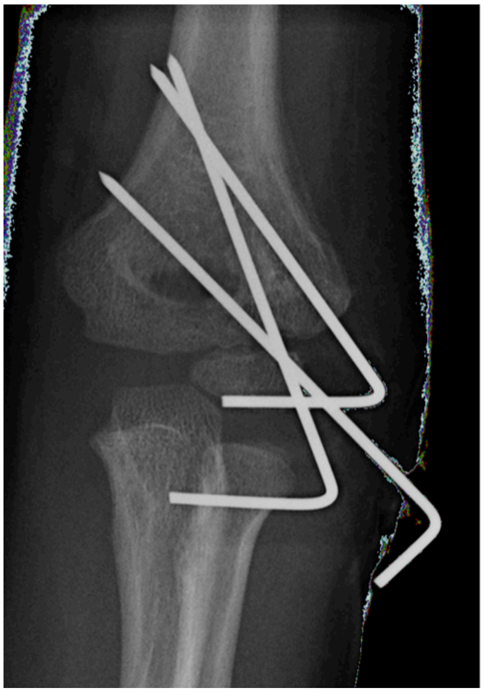

Figure 4. AP radiograph with pin fixation just prior to pin removal.

Figure 5. AP radiograph and last follow-up demonstrating a healed lateral condyle with retained implant. Apparently normal distal humerus growth is present despite persistent screw fixation.

median maximum displacement of 3.95mm, which was significantly different than the open group, which had a median maximum displacement of 9.47mm ($p < 0.0001$). Although 100% of patients received prophylactic antibiotics at the time of surgery, cefuroxime was the preferred antibiotic used for both groups with 96.2% of the closed group receiving it and 85% of the open group receiving it ($p=0.23$). Surgical fixation was completed with either pins or screws. 78.6% of closed reductions used screw fixation while only 17.1% of open reductions used screws ($p < 0.0001$). Additionally, the OR time required to complete the two surgical approaches was significantly different as the closed group needed just 78.6 minutes while the open group required 123.3 minutes ($p < 0.0001$). Moreover, patients who had an open reduction were more likely to require overnight observation compared to those who underwent closed reduction (47.5% vs. 7.1%, $p = 0.0004$).

Follow-up and outcomes data are illustrated in Table 3. Median follow-up time was 4 months for the open group and 9.5 months for the closed group ($p= 0.02$). There were no significant differences between the two groups with regard to abnormal ulnohumeral angles, infection rates, avascular necrosis, nonunion, lateral spur formation, interepicondylar width or premature physeal closure.

DISCUSSION

Both the relatively high volume and morbidity of lateral condyle fractures make it an injury that should be examined for quality improvement. Currently, there are different methods to fix them, including through an open approach or through a closed approach.[7,8]

When looking at the open and closed groups, their outcomes were quite similar, which has been described in other studies.[7,8] One difference encountered was the significant difference in the time to surgery with the closed group waiting 7 days longer than the open group ($p<0.0001$). In one systematic review, pediatric lateral condyle fractures displaced at a rate of 14%.[14] The difference in time to surgery is therefore likely due to non-operative fractures displacing into operative fractures.

Despite the difference in displacement, the long-term outcomes assessed during this study were not significant. This includes septic arthritis, avascular necrosis, lateral spurring, and the percent with abnormal ulnohumeral angles.

Although both groups ultimately had similar outcomes, there were some significant differences at the time of surgery. The closed group was significantly more likely to have screw fixation with 78.6% of them being treated with screws while only 17.1% of the open group received screw fixation ($p<0.0001$). The type of fixation used may significantly affect the outcomes, but after rearranging our sub-group analysis, there were no significant differences in long-term outcomes when our patient population was divided into screws vs pins.

The most important differences at the time of surgery were OR time and the rate of post-operative hospital admission. The closed group was in the OR for an average of 44.7 minutes less than the open group ($p<0.0001$). This most likely represents the time necessary to perform the open approach and perform a layered closure. It may also represent a failed attempt at closed reduction. A shorter operative time decreases unnecessary exposure to anesthesia and dramatically decreases the cost of care as OR time and hospital charges are directly correlated.[15] Aside from bringing down the cost of care for lateral condyle fractures, it would open up the OR, an important and limited resource, to be used for other patients. Additionally, patients who underwent closed reduction were significantly less likely to be admitted to the hospital after surgery. Only 7.1% of closed reduction patients were admitted after surgery while 47.5% of open reduction patients were admitted post-operatively ($p=0.0004$) for pain control. This difference likely represents a significant cost-savings from a healthcare perspective.

There were several limitations to this study. First, it was a retrospective chart review, so randomization, which would have increased the exchangeability of the patients in our groups of interest, was not conducted. Second, we used ICD-9 inpatient diagnostic codes to identify our study population. Errors with coding may have inadvertently limited the size of our study population. Lastly, the size of our study population was limited. While the significant values highlighted are likely true, there may have been true differences that were not significant due to lower power.

In conclusion, closed reduction in pediatric lateral condyle fractures has similar outcomes to open reduction. This, coupled with the significantly decreased OR times and decreased rate of post-operative hospital admission, make it the preferred approach from a hospital system quality improvement standpoint. Also, our paper highlights that the 4mm of maximum displacement is not a hard cut-off as approximately 1/3 of our patients treated with the closed approach had displacement greater than 4mm. With standard reduction techniques, their post-operative fracture gap was less than 2mm. Establishing a less stringent cutoff for attempting closed reduction maneuvers may be the subject of future research.

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DETERMINING THE PREVALENCE AND COSTS OF UNNECESSARY REFERRALS IN ADOLESCENT IDIOPATHIC SCOLIOSIS

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ABSTRACT

Background: Adolescent idiopathic scoliosis (AIS) has been associated with unnecessary referrals, but the provider and patient costs associated with these referrals remain unknown. The purpose of this study was to determine the prevalence and associated costs of unnecessary referrals for AIS in a university hospital-based orthopaedic clinic. These data are required to estimate the cost-efficacy of scoliosis screening programs.

Methods: We accessed the electronic medical records of all patients referred during 2013-2014 with suspected AIS. Spine radiographs were reviewed to determine whether the referral was "unnecessary," defined as a Cobb angle <20 degrees. Patient and provider costs were estimated. Patient costs included transportation expenses and parental lost wages. Provider costs included orthopaedic evaluation, diagnostic imaging, and overhead. Transportation costs were based on actual driving distances and the Internal Revenue Service standard mileage rate. Parental lost wages and the cost of evaluation by an orthopaedic surgeon were calculated with time-driven activity-based costing. Diagnostic imaging costs were calculated with a traditional activity-based costing methodology.

Results: Three hundred thirty-seven patients were included. The prevalence of unnecessary referrals was 39% (n=131). 17% of patients had a Cobb angle <10 degrees and 22% had a Cobb angle between 10-20 degrees. Males were more likely to be referred unnecessarily than females, 49% to 35% (p=0.02) as were non-Caucasians (54% vs. 37%, p=0.04). No difference was noted related to source of insurance (private or public, p=0.18). The average total cost of an unnecessary referral was $782.13 USD, including $231.07 in patient costs and $551.06 in provider costs.

Conclusions: Nearly 40% of all referrals for AIS were deemed unnecessary. The average cost of an unnecessary referral is approximately $780, imposing significant costs on both patients and the healthcare system.

Level of Evidence: III

Keywords: referrals, cost-efficacy, retrospective cohort, adolescent idiopathic scoliosis

INTRODUCTION

The United States spends more money on health care than any other nation in the world.[1] Increasing health care expenditures have become a major policy focus of politicians and health care administrators. One of the factors contributing to rising health care costs is the high number of unnecessary referrals to specialists. Barnett et al. demonstrated that referral rates in the United States nearly doubled between 1999 and 2009.[2] Changes in referral rates have led to increased health care costs, as patients referred to a specialist typically utilize more healthcare resources than those not referred.[3, 4] Minimizing costs associated with unnecessary referrals to specialists is critically important to improving value-based healthcare delivery.[5]

Data from a Canadian community without a school-screening program suggests adolescent idiopathic scoliosis (AIS) is associated with a high rate of unnecessary referrals to orthopaedic surgeons.[6] At the current time, there is limited data on the prevalence and cost of unnecessary referrals for AIS in the United States. This data is critical to determining the cost-efficacy of community-based programs and screening provided during primary care encounters.

This investigation seeks to define the prevalence and cost of unnecessary referrals for AIS in a United States community without a state-mandated screening program. All direct and indirect costs related to referral were con-

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sidered including transportation expenses, parental lost wages, orthopaedic evaluation, diagnostic imaging, and clinic overhead.

METHODS

Sample

This investigation is a retrospective review of all patients who presented to a single orthopaedic surgeon at a tertiary care hospital-based clinic during 2013 and 2014 for evaluation of AIS or possible AIS. Prospective cost accounting techniques were used to accurately capture all direct and indirect expenses associated with referral.

The records of all new patients, age 10-19 years, evaluated by a single pediatric orthopaedic surgeon during 2013 and 2014 with ICD-9 codes of 737.30, 737.8, 737.9, 738.5, 754.2, and V65.5 were reviewed. Any patient with a neuromuscular, congenital, or other non-idiopathic scoliosis was excluded, as was any patient with previous spinal surgery. Finally, all orders for scoliosis spine radiographs were reviewed to ensure no patient was missed due to errant coding. Only those records that noted 'scoliosis evaluation' as the reason for referral were retained in the study sample. Demographic data was abstracted. For all patients included in the investigation, spine radiographs were reviewed and Cobb angles were recorded.

In addition, a prospective cross-sectional survey of parents and caretakers was used to collect data needed for estimation of transportation costs and parental lost wages as these data were not available in the medical record. The survey was offered to all parents attending the clinic visit with a child being evaluated for scoliosis; no parent declined. For each patient, we recorded how many parents were present for the appointment and the gender of any parent in attendance. We also asked each parent to estimate how long it took to navigate to the clinic from the parking lot (wayfinding time).

Prevalence of Unnecessary Referrals

The patient's maximal Cobb angle determined whether a referral was necessary. Referral of patients with a Cobb angle less than 20 degrees was deemed unnecessary, and referral of patients with Cobb angles of at least 20 degrees was deemed necessary. The 20-degree threshold was based upon expert opinion and previous literature,[7] and also because treatment is not typically offered to patients with curves below 20 degrees. Unfortunately, we were unable to find recommendations from any major professional organization guiding referring physicians as to what constitutes an appropriate referral in terms of curve severity.

Patients were also stratified by gender, insurance status (public or private), and race (Caucasian or other). The impact of gender, insurance status, and race on the rate of unnecessary referrals and the presenting Cobb angle was assessed.

Transportation Costs

The costs associated with patient travel were estimated by using an online distance calculator along with standard mileage rates from the Internal Revenue Service (IRS).[8] The distance from the patient's home address to the hospital was calculated. If a patient's home address was not found in the distance-calculating program, the center of the patient's home city was used. Those residing more than 350 miles from the hospital were excluded due to both their outlier effects and the increased probability of the family using air travel. The calculated distance was multiplied by the standard mileage rates available from the IRS. The "business miles" rate was used. This rate includes all fixed and variable costs of operating a motor vehicle. For clinic visits occurring in 2013, the rate was 56.5 cents. For clinic visits in 2014, the rate was 56.0 cents.

Parental Lost Wages

The educational attainment, county of residence, and sex of each of the parents of each patient in the retrospective sample were extracted from the medical record. These variables were then cross referenced with earnings data from the U.S. Census Bureau to estimate each parent's annual salary.[9] The salary was divided by 2087 hours to determine the parent's hourly wage.[10]

To determine parent lost time, an estimate of driving time (determined by the distance calculating program) and wayfinding time was added to the time in office (patient's check-in time to check-out time). This lost time estimate was multiplied by the hourly wage to determine lost wages. Finally, these lost wages were multiplied by the probability of a parent of a specific gender was present at the clinic visit, which was estimated by the cross-sectional survey as described above. For example, Maternal Lost Wages = [(Driving time)+(Wayfinding time)+(Length of Clinic Appointment)]*(Mother's hourly wage estimate)*(Probability mother was present at the appointment).

Provider Costs

Orthopaedic physician costs were calculated with a time-driven activity-based costing (TDABC) methodology,[11] which accounts for all costs of employing a provider including salary, benefits, administrative support, and department overhead. The resulting per minute cost rate was multiplied by the time a provider dedicated to each patient's visit, measured prospectively with a stopwatch. Clinic overhead costs were calculated with a traditional activity-based costing methodology. These costs included hospital overhead, non-physician (e.g. medical assistant)

Table 1. Unnecessary and Appropriate Referrals by Sex, Race and Insurance

Total	n (%)	Mean Cobb Angle at Referral	Unnecessary Referral (0-19°) n (%)	Appropriate Referral (20°+) n (%)	p value
All Referrals	337 (100)	26.23	131 (39)	206 (61)	
Sex					
Female	248 (74)	28.00	87 (35)	161 (65)	0.02
Male	89 (26)	21.40	44 (49)	45 (51)	
Race					
Caucasian	290 (86)	26.63	106 (37)	184 (63)	0.04
Other	41 (14)	23.61	22 (54)	19 (46)	
Insurance					
Private	284 (84)	26.49	107 (38)	177 (62)	0.18
Public	48 (16)	23.83	23 (48)	25 (52)	

labor, and utilities. This costing methodology has been shown to be more accurate than traditional relative-value unit based methods in other areas of orthopaedic surgery.[12]

Radiography costs were estimated by a traditional activity-based costing methodology. In our clinic, outside radiographs are first screened by a staff member to assess if they were adequate to determine the diagnosis of AIS. If not, new spine radiographs were taken. Therefore, because adequate spine radiographs are necessary for the diagnosis of AIS, all spine radiographs taken at the clinic were deemed necessary. Hand radiographs were also taken of all new patients to determine the Sanders skeletal maturity stage and assist in AIS treatment decisions. However, in patients who were not consequently assigned a diagnosis of AIS, hand radiographs for bone age were considered unnecessary. Costs of unnecessary hand radiographs were included when calculating the cost burden of unnecessary referrals.

Statistical Analysis

The sample demographics and presenting Cobb angle are summarized using the average and percentage for the sample overall and stratified by type of referral. Differences in the average Cobb angle between gender, insurance and race by referral type were evaluated via independent t-tests; differences in sample proportions by referral type were evaluated using the Chi-square test. The threshold for statistical significance was set at alpha=0.05.

RESULTS

337 patients met the inclusion criteria for the retrospective sample and their electronic medical records were reviewed. 24 patients and 32 parents who accompanied AIS patients to a clinic visit were included in the cross-sectional portion of the study.

Sample Characteristics and Prevalence of Unnecessary Referrals

The proportion of unnecessary and appropriate referrals by sex, race and insurance (private or public) is summarized in Table 1. Of the 337 patients, 74% (n=284) were female, 86% (n=290) were Caucasian, and 84% (n=284) had private insurance. 39% (n=131) were referred unnecessarily, defined by a maximum Cobb angle of less than 20 degrees. 17% were referred with a Cobb angle of less than 10 degrees.

Females presented with an average Cobb angle of 28 degrees compared to 21 degrees for males (p = 0.001). Consequently, more males were unnecessarily referred (49%) than females (35%) (p=0.02). Caucasians were less likely to be unnecessarily referred than other racial groups (37% vs. 54%, p=0.04). Having private or public insurance was not significantly associated with the appropriateness of the referral (p=0.18).

Transportation Costs

The average family traveled 172.4 miles ± 124.8 (range 2.4 - 594 miles) to visit the clinic and return home, resulting in an average cost of $98.34 ± $70.20 (range $1.34 - $335.61).

Parental Lost Wages

Of the 24 patient visits included in the cross-sectional study, the mother was present in 96%, and the father was present in 38%. Combining data from these visits to data from the retrospective chart review, we estimated total parent lost time averaged 322.7 minutes and included an average of 177.9 ± 113.9 minutes of driving, 16.4 ± 12.0 minutes of wayfinding, and an average of 128.4 ± 38.0

minutes in clinic. This resulted in an average total wage loss per family of \$132.73 ± \$60.60 (range \$34.26 - \$512.31).

Hospital Costs

Patients were first seen by either a mid-level provider (44%) or a resident physician (56%), followed then by the staff physician. The mid-level provider spent an average of 32.0 minutes with each patient, the resident averaged 39.6 minutes, and the staff physician averaged 11.2 minutes. The labor cost of the orthopaedic healthcare providers for a single visit averaged \$118.96.

Clinic overhead costs were \$193.11 per patient, and the cost of unnecessary radiography, (hand films to establish skeletal maturity during an inappropriate referral), was \$239.00 per patient.

Cost Summary

In total, the average cost of an unnecessary AIS referral was \$782.13. Average patient costs (travel, lost wages) were \$231.07 and average provider costs (provider time, clinic overhead, radiography) were \$551.06.

DISCUSSION

Nearly 40% of referrals for AIS to our clinic were medically unnecessary, as defined by a Cobb angle of less than 20 degrees. The average cost of an unnecessary referral was \$782.13, with more than half that amount attributable to provider-side costs. Male and non-Caucasian patients were more likely to be referred unnecessarily. The insurance provider was not associated with the appropriateness of the referral.

Currently, there is not a consensus in the literature as to what constitutes an appropriate referral. The American Academy of Pediatrics released guidelines in 2014 for referral to a pediatric surgical specialist.[13] The guidelines include "infants, children, and adolescents with significant spinal deformity (scoliosis or kyphosis)" as grounds for a referral to a pediatric orthopaedic surgeon. However, the authors fail to define what "significant" means in this context. In addition, these guidelines do not distinguish between the type of scoliosis (e.g., infantile, juvenile, adolescent, neuromuscular, congenital) or the stage of the disease. While there is a question as to which AIS patients with curves of 21-30 degrees should be referred, most published literature agrees that referral of patients with less than 20 degree curves is unnecessary.[7,14,15] Since the present investigation only defines referrals as unnecessary for curves less than 20 degrees, the incidence may be somewhat underestimated. Further clarification from professional organizations as to which patients should be referred for specialist treatment could be instrumental in decreasing the number of unnecessary referrals.

The prevalence (39%) of patients presenting with curves less than 20 degrees noted in this sample is lower than other prior investigations. Hines et al. reported that 67% of patients at Texas Scottish Rite Hospital for Children presented with curves of less than 20 degrees, albeit based on a small sample (n=27).[16] In a Montreal study, Beauséjour et al. reported 42% of referred patients had curves of less than 10 degrees, and 67% had curves of less than 20 degrees.[6] It seems plausible that rates of unnecessary referrals may vary across investigations due to geographic variations and the presence or absence of community screening programs. The majority of patients included in the current study live in a predominately rural section of the Midwest. The long travel distances noted in this sample may explain the lower rate of unnecessary referrals.

In 2015, the Scoliosis Research Society, American Academy of Orthopaedic Surgeons, American Academy of Pediatrics, and the Pediatric Orthopaedic Society of North America called on the United States Preventive Services Task Force (USPSTF) to review its recommendation against screening for AIS in light of new research evidence supporting bracing, and to a lesser degree, screening.[17,18,19] Upon review, the USPSTF found insufficient evidence to recommend for or against the practice of screening, citing lack of evidence that screening leads to improved patient-reported outcomes in adulthood.[20] We anticipate that state health departments may cancel mandatory screening programs as a result of this review, but it is unlikely that primary care providers will eliminate spine and posture examinations during well child checks or sports physicals, and will instead continue to refer patients to orthopaedic surgeons when asymmetries are noted. Since Iowa does not have a statewide mandate to provide community screening, we do not foresee a significant decrease in referrals as a result of the updated recommendation, although its effect in other states remains to be seen.

It is important to consider the financial impact screening and consequent referrals can have on families. A single unnecessary referral can create a financial burden to a family. To put the patient cost of \$231.07 into perspective, one should consider that in 2011 the average family had only \$3050 in interest-earning assets at financial institutions and regular checking accounts.[21] While harm from unnecessary radiation or treatment are often discussed, our study suggests financial harms should also be recognized and taken into consideration. This emphasizes the need for a screening protocol with not only a high sensitivity, but a high specificity as well.

Our study is the first to examine the costs associated with unnecessary referrals for AIS using TDABC and primary data, in contrast to prior investigations relying on charges or reimbursements.[22] The accuracy of our cost estimates could have been improved if radiography and overhead costs were calculated with TDABC instead of activity-based costing. Prior work by Akhavan et al. suggests that the ABC methodology may overestimate actual costs.[12] Nonetheless, the cost data reported herein are essential to appropriately assessing the cost-efficacy of scoliosis screening programs. Establishing the value of community- and provider-based scoliosis screening programs is critical to value-based healthcare delivery in pediatric orthopaedics.

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THE INFLUENCE OF DIFFERENT ROTATOR CUFF DEFICIENCIES ON SHOULDER STABILITY FOLLOWING REVERSE SHOULDER ARTHROPLASTY

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ABSTRACT

Background: The primary indication for reverse shoulder arthroplasty (RSA) is rotator cuff arthropathy caused by a deficient rotator cuff. Cuff deficiency in patients is highly variable in its distribution and extent, with mechanical implications that may significantly affect post-operative recovery. This study investigated the effects of variable cuff deficiency on the propensity for impingement between the scapula and humeral component and resulting subluxation, the source of two common complications (scapular notching and instability).

Methods: Five different finite element models of an RSA were analyzed with varying degrees of rotator cuff deficiency: (1) baseline, with intact subscapularis, infraspinatus and teres minor, (2) no subscapularis, (3) no subscapularis or infraspinatus, (4) no infraspinatus, and (5) no infraspinatus or teres minor. The supraspinatus was not included in any models, as it is absent in rotator cuff arthropathy. Each model was moved through a prescribed arc of 45° internal/external rotation originating from neutral.

Results: Greater rotator cuff deficiency was associated with more impingement and larger magnitudes of subluxation. The largest subluxation (7.5 mm) and highest impingement-related contact stress (479 MPa) was in the model lacking all rotator cuff muscle groups. Posterior subluxation was present in most models lacking the infraspinatus, while anterior subluxation was present in all models lacking the subscapularis.

Conclusions: This study helps clarify how different rotator cuff deficiencies influence shoulder stability following RSA and can ultimately help predict which patients may be at greater risk for impingement-related scapular notching and subluxation.

Clinical Relevance: Surgeons should carefully consider the nature of the rotator cuff deficiency and its influence on impingement and instability when planning for RSA.

Level of Evidence: V

Keywords: contact stress, instability, finite element analysis, reverse shoulder arthroplasty, rotator cuff tear

INTRODUCTION

Since its FDA approval in 2003, reverse shoulder arthroplasty (RSA) has continually increased in popularity, accounting for 33% of all shoulder arthroplasties in 2007.[1,2] RSA reverses the ball-in-socket-design of the native shoulder by implanting a hemispherical component onto the glenoid surface and a cup/stem component into the humerus. By moving the center of rotation distally and medially, a larger moment arm is created, enabling the deltoid muscle to move the humerus with increased efficiency and stability.[3,4] RSA is performed primarily to restore pain-free function and range of motion for patients with rotator cuff arthropathy, shoulder arthritis resulting from rotator cuff deficiency and characterized by degenerative changes of the glenohumeral joint, superior migration of the humeral head, and often severe pain and disability.[5-8] Based on its success in relieving pain and restoring function, the indications for RSA have expanded to include younger populations with rotator cuff deficiency, arthritis, or previously failed shoulder implants.[9-17]

Despite the initial success associated with RSA, complications such as instability are common.[18,19] Instability, accounting for 38% of all complications, is due to an unbalanced force coupling associated with rotator cuff deficiency and often accompanies impingement.[20,21] Reduced control of motion associated with rotator cuff deficiencies leads to less predictable motion, increasing the risk of dislocation which can ultimately necessitate revision surgery.

The nature of the cuff deficiency varies considerably across rotator cuff arthropathy patients, with implications for shoulder stability and function after RSA. It is not simply a matter of whether a patient has muscle deficiency, since each patient presents with a variable

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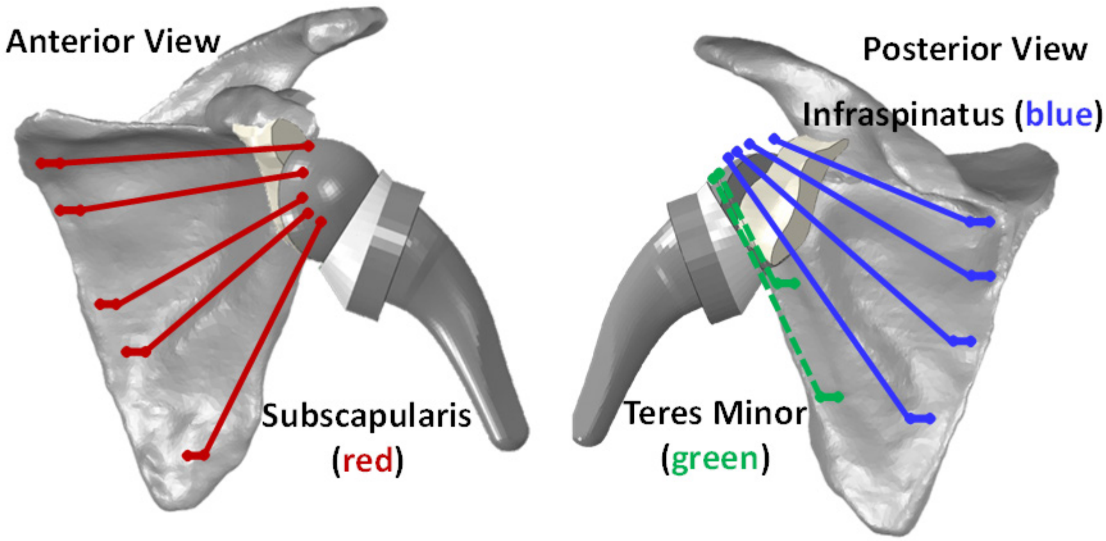

Figure 1. The rotator cuff muscles were modeled using slipring elements. Each set of colored slipring elements represented a different rotator cuff muscle group.

amount of intact cuff tissue. Numerous factors such as which muscles are deficient/intact, quality of muscle/tendon tissue, and strength of a given muscle may impact the overall stability and function of the shoulder before and after implantation. Orthopedic surgeons currently rely on their best judgement to accommodate these variable cuff deficiencies when deciding on implant positioning and tension.

This study built upon previous work using finite element analysis of RSA to investigate the influence of specific rotator cuff deficiencies on impingement-related contact stress and shoulder stability during a full external/internal rotation motion. With RSA still being relatively new, the association between rotator cuff deficiency and its influence on motion post-operatively can serve to identify the role that each muscle group plays and their contribution to instability and contact stress at the impingement site. Results can also provide guidance on which muscles could benefit most from muscle transfer, and how implants should be positioned based on which muscles are intact. Ultimately, this can provide a better understanding of stability and functionality post-op. We hypothesized that a complete lack of the rotator cuff musculature would produce the most subluxation and highest contact stress values at the impingement site, and that subluxation would occur on the same side of the joint as the cuff deficiency.

METHODS

A finite element (FE) model of an RSA-implanted shoulder previously implemented in Abaqus/Explicit 6.14-2 (Dassault Systêmes, Paris, France)[22,23] was modified to simulate varying degrees of rotator cuff deficiency. The scapula was segmented from CT scans of the Visible Human Female (National Library of Medicine; https://www.nlm.nih.gov/research/visible/visible_human.html) using OsiriX software (Pixmeo, Geneva, Switzerland). The FE model incorporated a contemporary RSA implant design (Tornier Aequalis Ascend Flex Reversed; Wright Medical, Memphis, TN) placed according to manufacturer-supplied guidelines. The FE model consisted of a deformable 15 mm section of the lateral-most portion of the scapula, a rigid glenosphere and humeral stem, and a deformable polyethylene insert. All FE meshes were generated using hexahedral meshing software (TrueGrid; XYZ Scientific Applications, Livermore, CA).

Points representing where the lines of action of rotator cuff muscle groups traverse over the bony surfaces were mapped onto the RSA-implanted shoulder model using Geomagic Studio software (3D Systems, Rock Hill, USA). The surface geometry of the implant and scapular bone were combined in Geomagic by a shoulder surgeon specializing in RSA to simulate the correct positioning of the device.[24,25] Slipring elements were used in the FE model to produce cable and pulley systems that approximated the lines of action of individual rotator cuff muscle groups, with in-line stiffness values taken from prior studies to represent the associated active resistance to elongation for each of the muscle groups (Figure 1).[24,25] The deltoid was also modeled using slipring elements, with in-line stiffness values taken from prior work and the proximal end held fixed against displacement to support loading while undergoing motion.[26,27] Point of reference locations on the ends of the muscles and the implant were chosen using a combination of geometric calculations to determine spacing and location, based upon the anatomy of

Table 1. Subluxations Present Through 45° of External/Internal Rotation from the Neutral Position for Five Models Varying in Cuff Deficiency

Cuff Deficiency	Antero-Posterior Sublux. (mm)	Supero-Inferior Sublux. (mm)	Medio-Lateral Sublux. (mm)	Total Sublux. at 45° (mm)
Baseline (No Sup)	-3.8	0.7	-4.5	6.0
No Sub	4.0	-0.5	-6.3	7.5
No Inf	-4.0	-0.9	-3.3	5.3
No Sub or Inf	4.0	-0.6	-6.3	7.5
No Inf or TM	-4.0	-1.0	-3.3	5.3

Sublux. = subluxations, No Sub = No Subscapularis, No Inf = No Infraspinatus, TM = Teres Minor

the human shoulder, to ensure contact points accurately portrayed the location of each muscle group. Slipring elements were distributed evenly within each muscle, dividing the outermost edges of the area into lines of action with equal spacing to one another for each muscle group. The numbers of elements used for each muscle group were based on their cross-sectional area: 5 elements for the subscapularis, 4 for the infraspinatus, and 2 for the teres minor. The insertions of all muscles were tied to the humerus, while their origins were fixed on the scapula.

Five different models with varying degrees of rotator cuff deficiency were created. Because the vast majority of rotator cuff arthropathy patients lack the supraspinatus, it was not included in any model. A baseline model included all muscles except the supraspinatus, while four additional models were created using varying combinations of intact muscle tendon units: no subscapularis (No Sub), no subscapularis or infraspinatus (No Sub or Inf), no infraspinatus (No Inf), and no infraspinatus or teres minor (No Inf or TM).

An internal/external rotation motion was simulated, as these motions have been shown to produce the most impingement/subluxation and would likely be the most affected by muscle deficiencies.[28] Prior to simulating any arm motion, the sliprings were pre-tensioned by pulling the medial-most ends to represent in-vivo active muscle tensioning. Sliprings representing deltoid and rotator cuff musculature were kept at this position throughout the movement. A 40 N load was applied to the distal end of the humerus to represent the weight of an arm.[22] The motions prescribed for the FE model simulated an external/internal rotation with the shoulder abducted 25° from the neutral position. Humeral rotation was defined about its long axis. The model was rotated from neutral to 45° of external rotation, and then back through the neutral position to 45° of internal rotation.

Subluxation of the humeral component was defined by a vector connecting the normally concentric centers of rotation of the humeral polyethylene liner and the glenosphere. The magnitude and direction of subluxation were tracked, with decomposition into antero-posterior, supero-inferior, and medio-lateral displacements. The location of any impingement and the maximum impingement-related contact stress were recorded.

RESULTS

The nature of the impingements and subluxations varied with the type of rotator cuff deficiency modeled (Table 1). Whereas a posterior subluxation of 4 mm was observed in most models lacking the infraspinatus, an anterior subluxation of 4 mm was observed in all models lacking the subscapularis. All models had inferior subluxation, except for the baseline model, which had 0.7 mm superior subluxation. The No Inf or TM model and No Inf model contained the highest magnitudes of supero-inferior subluxation at 1 mm and 0.9 mm inferior subluxation, respectively. No Sub or Inf model exhibited 0.6 mm of inferior subluxation, while No Sub had 5 mm of inferior subluxation. No Sub and No Sub or Inf each contained the highest amount of antero-lateral subluxation with 6.3 mm lateral subluxation. This was followed by Baseline with 4.5 mm lateral subluxation, No Inf or TM with 3.3 mm lateral subluxation, and No Inf with 3.3 mm lateral subluxation. Larger magnitudes of subluxation were seen in all models lacking a subscapularis, while minimal changes in subluxation were seen whether the teres minor was present or not. Elevated amounts of subluxation were found with increased rotator cuff deficiency, with the No Sub or Inf model and No Sub model both having a total subluxation of 7.5 mm. The baseline model had a total subluxation of 6 mm, followed by the No Inf or TM model with 5.3 mm and then the No Inf model at 5.2 mm. The model lacking all rotator cuff musculature experienced the most subluxation and greatest impingement-related contact stress.

Impingement of the poly insert on the scapula in models lacking only posterior muscles occurred medially relative to the baseline model lacking only the supraspinatus, while for all models lacking anterior musculature impingement sides were located laterally to the baseline

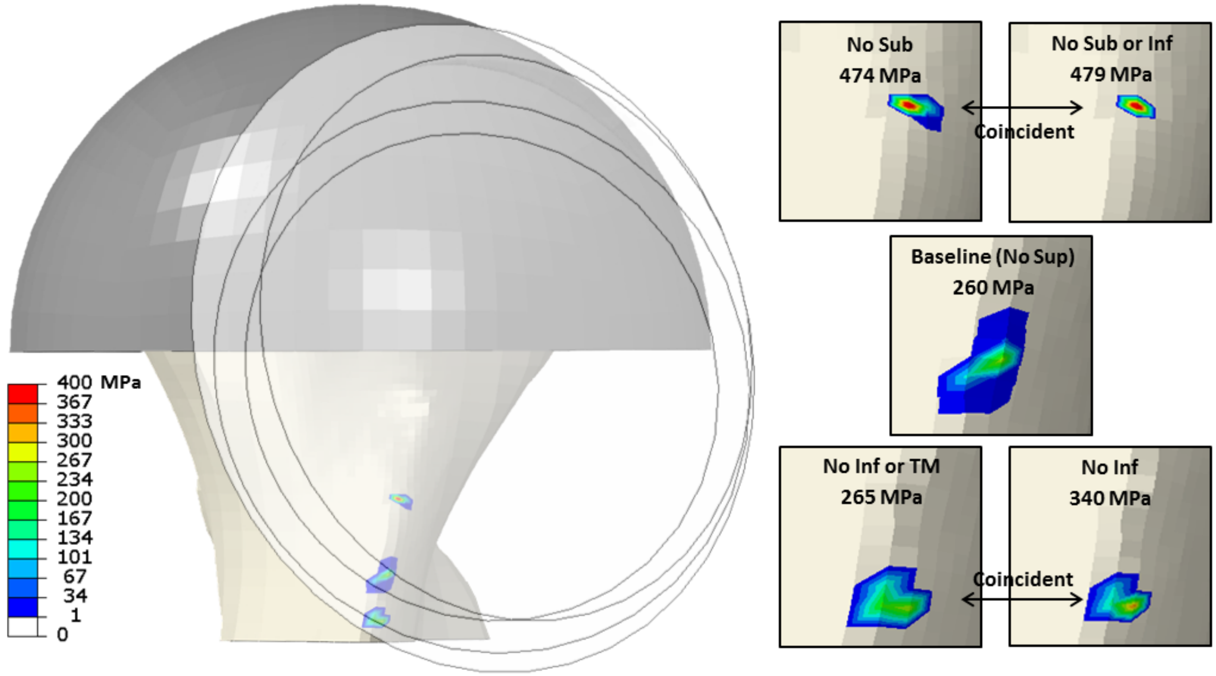

Figure 2. Inferior glenoid view of impingement-related contact stress during external rotation plotted on a single scapula for all models. The No Sub model impinged in the same region as the No Sub or Inf model, while the No Inf or TM model impinged in the same region as the No Inf model. No Sub = No Subscapularis, No Inf = No Infraspinatus, TM = Teres Minor

model (Figure 2). Absence of the supraspinatus, subscapularis, and infraspinatus produced a maximum contact stress of 479 MPa. Absence of the supraspinatus and subscapularis gave a maximum stress of 474 MPa, absence of supraspinatus and infraspinatus gave a maximum stress of 340 MPa, absence of the supraspinatus, infraspinatus and teres minor gave a maximum stress of 265 MPa, and the absence of only the supraspinatus gave a maximum stress of 260 MPa.

DISCUSSION

Rotator cuff arthropathy is the primary indication for RSA, yet the mechanical effects of rotator cuff deficiency in the context of RSA are still not fully understood. This study aimed to build upon previous FE studies[22,23,29] to examine the effects of variable rotator cuff deficiencies on subluxation and impingement after RSA. As expected, increasing cuff deficiency led to greater amounts of subluxation. Integrity of the subscapularis had the greatest influence on subluxation, whereas the teres minor had the least effect. These findings aligned with data from prior studies indicating that the subscapularis is the primary contributor to internal rotation, while the teres minor played a minor role in that movement.[30-34] Contrary to our expectation, anterior muscle deficiency was associated with anterior subluxation and posterior deficiency was associated with posterior subluxation. This is most likely due to the presence of the muscle, lacking compressive force in this direction, blocking the subluxation path as it moves closer to the muscle group. Differences between subluxation found with anterior versus posterior muscle deficiency can be attributed to the relative control of specific rotation directions by certain muscles as well as this blocking characteristic.

The FE analyses also showed that absence of the subscapularis produced higher, more focal contact stress at the impingement site as opposed to the baseline model (lacking only a supraspinatus). Elevated amounts of stress found in this study ranging from 260 MPa to 479 MPa, which would likely result in high wear rates at the impingement site. As a point of reference, the compressive yield stress of polyethylene is on the order of 15 MPa,[35] suggesting that the polyethylene component could be damaged by this impingement.

Internal rotation is primarily controlled by the subscapularis; hence, absence of the primary muscle involved with internal rotation movement might be expected to create larger amounts of stress. The sites of impingement for models without a subscapularis were located superiorly to those with an intact subscapularis. The smallest contact stress values were observed in the baseline model. This supported the consensus that the subscapularis, infraspinatus, and teres minor play a role in internal/external motion.[30-34]

Several factors limited the scope of this study. Mapping the rotator cuff musculature in the models required some degree of subjectivity due to the lines of action being placed along the geometry of the bone. This may have produced minor discrepancies in the direction of the pulling force and location of the coordinates. Use of only one implant geometry and scapular surface precluded any study of possible influences on scapular contact stress and shoulder subluxation owing to individual variation in geometry. Mechanical properties of each muscle group were taken from prior studies using intact shoulders from subjects aged 58 to 98 years, which may not be the case for all rotator cuff arthropathy patients. The modeling approach also does not account for fatty and epithelial tissue surrounding the shoulder, or pain experienced during major subluxations, both of which might limit the amount of subluxation experienced by patients. Forcing the shoulder to rotate through a prescribed range of motion with no regard for the amount of muscle force that would be required to do so could result in impingement-related contact stresses and accompanying subluxations greater than would actually be experienced. Variation in soft tissue composition, musculature, and the specific nature of the cuff tears may also affect the results between individuals.

This study determined the influence of variable rotator cuff deficiency on shoulder stability following RSA. Future studies may include physical testing of material properties in each rotator cuff muscle for validation. Testing the models through different types of motion other than internal/external rotation may provide further insight as to how the muscle deficiencies affect subluxation and contact stress. The results of this study can aid in understanding how different rotator cuff deficiencies influence shoulder stability following reverse shoulder arthroplasty, and the results can ultimately help predict which patients may be at greater risk for dislocation and impingement-related subluxation.

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PREDICTORS OF CLINICAL BENEFITS AND ONE-YEAR FUNCTIONAL OUTCOMES FOLLOWING SHOULDER ARTHROPLASTY

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ABSTRACT

Background: Shoulder arthroplasty has been shown to improve function in patients with advanced shoulder disease. However, the response to surgery and final outcomes are not easily predictable. This study assessed the effect of residual pain, age, sex, diabetes, hypertension, and depression on changes and status at one-year following arthroplasty with respect to shoulder function and overall physical and mental health status.

Methods: A retrospective analysis of a prospective cohort of 140 patients tested preoperatively and one-year following shoulder arthroplasty was conducted at our tertiary hospital. Pearson's correlations and multiple regression analysis were performed to test the impact of predictors on shoulder pain and function assessed using the American Shoulder and Elbow Surgery (ASES) questionnaire, and on physical and mental health assessed using the Short Form-12.

Results: Pain and female sex were significant predictors of poorer function at one-year (R = .56, *p* = .001); and with other predictors, they explained 32% of the variability in function. The explained variability of changes in function scores was 15% with pain being the only significant predictor. Physical health was lower in older patients (*r* = -.31, *p* < .05) and was less predictable for physical health change scores (12%) and the physical status at one-year (14%).

Conclusions: Residual pain is associated with poorer function status and less clinical benefits. Female sex is not associated with less change in function which suggests that men and women get equal benefit from the surgery. Advanced age relates to poorer physical health and to a lesser extent physical change over the year.

Level of Evidence: III

Keywords: shoulder arthroplasty, function, physical health status

INTRODUCTION

Shoulder arthroplasty is widely used to treat patients with severe arthritic changes in the joint.[1] This surgical procedure has been shown to be effective in reducing pain, improving shoulder function and increasing range of motion (ROM).[2,3] However, the overall improvement in shoulder functional outcomes is not always predictable and can be influenced by several factors.[4] These factors were examined by several studies;[2,4,5] however, the results of these studies have conflicted with one another. Young age was associated with better shoulder function on constant score at one-year follow-up after hemiarthroplasty performed for patients with proximal humeral fracture.[6] Further, the improvement over time on shoulder clinical scores was associated with young age at the time of shoulder arthroplasty surgery but not with the later follow-up years in patients with rheumatoid arthritis.[5] In contrast, advanced age was associated with greater improvement (change) in shoulder function as demonstrated on the Simple Shoulder Test (SST) following total shoulder arthroplasty (TSA).[2] However, other studies found no correlations between age and the improvement in shoulder function.[4,7] Lastly, studies that assessed the effect of gender on the improvement in shoulder function found that men had better post-operative function assessed using SST.[4,7]

Physical health is expected to decline with age[4] and be adversely affected by comorbidities.[8] However, factors that influence physical health following shoulder arthroplasty have rarely been examined. Advanced age is negatively associated with physical function (r = -.23) and the better pre-operative physical health is associated with better post-operative physical function (r = .4) as demonstrated on the Short Form-36 (SF-36) survey following TSA.[4]

The presence of comorbidities, including diabetes and hypertension, has been shown to have no effect on post-operative shoulder function,[7,9] except for internal rotation ROM (R = -.2) which was decreased with diabetes.[9] How-

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ever, depression has been associated with lower shoulder function assessed using the American Shoulder and Elbow Surgery (ASES) in 176 patients two-year following TSA.[10]

There is a limited pool of studies which addressed the factors that influence postoperative functional outcomes following shoulder arthroplasty. In addition, a number of these studies do not report regression coefficients or explain the effect size attributable to these predictors. This makes it difficult to determine how much these should influence decision-making. Finally, comorbidities such as diabetes, hypertension and depression are rarely examined although they are present in 20-60 % of patients undergoing shoulder arthroplasty.[1]

Identifying preoperative factors that are predictive of one-year outcomes could assist surgeons and health care providers in providing patients more realistic expectations on outcomes and may help plan postoperative pain management and rehabilitation. Therefore, the current study was designed to address the following questions: 1) Do age, sex, diabetes, hypertension, and depression predict patient-reported outcomes including shoulder pain and function, and physical and mental health status one-year following shoulder arthroplasty? 2) Do these factors predict the clinical benefits following surgery as reflected in the change of outcome scores? Is residual pain (pain at one-year) associated with poorer functional outcomes?

MATERIALS AND METHODS

Study design and patients

A retrospective query of prospective collected data of patients who underwent shoulder arthroplasty was conducted at a tertiary care referral hospital. Demographic data were collected and recorded into a computerized database for 477 patients with shoulder arthroplasty. All patients who completed the ASES (n = 140) and the SF-12 (n = 103) questionnaires at baseline and at one-year follow-up visits and who completed a self-reported comorbidity survey (n = 140) were included in this analysis. This cohort included all patients treated with shoulder arthroplasty regardless of the type of surgery based on a previous study[11] that showed non-significant differences in ASES and SF-12 scores between patients with different surgical intervention (TSA, reverse TSA, hemiarthroplasty). Exclusion criteria included an inability or refusal to complete tests/measures. The University Ethics board approved the protocol and written consents was obtained from all patients.

Outcome measures

The dependent variables included the ASES,[12] which assessed shoulder pain and function, and the SF-12 which assessed physical and mental health status.[13] Both questionnaires have been shown to be valid and reliable self-reported assessment tools[13,14] and have been previously used to assess patients after shoulder arthroplasty.[10] In this study, self-reported pain severity (VAS: 0-10) and activities of daily living (maximum 30 scores) information were obtained from the ASES. The Physical Component Summary Score (PCS) and the Mental Component Summary Score (MCS) scores were obtained from the SF-12. A full description of ASES and SF-12 questionnaires is published.[12,13] Both questionnaires were administered preoperatively and at one-year follow-up visit. Next, scores from both questionnaires were averaged and were compared among patients based on their age, sex, and the presence of diabetes, hypertension, and depression (Table 1). To estimate the clinical benefits of shoulder arthroplasty, we calculated the change in scores from baseline (preoperative) to the one-year follow-up visit for the ASES function and SF-12 PCS.

Predictors (independent variables)

The predictive variables of interest included patient demographics: age and sex, and comorbidities: diabetes, hypertension and depression. Patients with a preoperative self-report of diabetes, hypertension, and depression were identified and were designated to the study cohort. The prediction effect of these factors has been examined twice; first on the final scores at one-year for ASES pain and function and for SF-12 PCS and MCS, and second on the change of scores from baseline to one-year follow-up visit for ASES function and SF-12 PCS.

Statistical analysis

Statistical analyses were performed using SPSS software, version 23 (SPSS Inc., Chicago, IL, USA). A p value of <0.05 was considered statistically significant. Independent sample *t-test* was used to detect differences in the ASES and the SF-12 scores between patients based on the predictive variables: patients demographics (age and sex) and the presence of comorbidities (diabetes, hypertension, depression). All values are reported as mean and standard deviation (SD). Pearson's correlation coefficients (r) were calculated between the dependent and predictive variables and between the predictive variables. The effect size of Pearson's correlations were classified as follow: r = +/- .1= small effect, r = +/- .3 = medium effect, r = +/- .5 = large effect.[15] Next, a multivariable enter regression analysis was performed to examine the effect of the predictive variables on the improvement in ASES and SF-12 one-year following shoulder arthroplasty. For ASES, pain at one-year was added to a second multivariable enter regression model as a predictive variable to examine its effect on function. To predict the clinical benefits of shoulder arthroplasty, we calculated the change in ASES function and SF-12 PCS scores by subtracting scores at

Table 1. Patient Demographics and its Influence on ASES and SF-12 One-year Following Shoulder Arthroplasty

Patient's demographics		ASES (n = 140)				SF-12 (n = 103)			
		Number of patients (%)	Age Mean (SD)	Pain: (VAS:0-10) Mean (SD)	Function: (scores: 0-30) Mean (SD)	Number of patients (%)	Age (years) Mean (SD)	PCS (scores: 0-100) Mean (SD)	MCS (scores: 0-100) Mean (SD)
Sex:	Male	57 (41)	68 (12)*	1.5 (2)	20 (8)*	45 (44)	72 (7)	42 (11)	55 (8)
	Female	83 (59)	73 (9)	2 (2)	17 (7)	58 (56)	73 (8)	38 (11)	52 (10)
Diabetes:	Yes	28 (20)	75 (9)*	2 (2)	18 (6)	20 (19)	73 (9)	38 (8)	53 (6)
	No	112 (80)	70 (11)	2 (2)	18 (8)	83 (81)	73 (8)	40 (12)	53 (10)
Hypertension:	Yes	54 (39)	74 (8)*	2 (2)	18 (7)	39 (38)	74 (7)	38 (11)	51 (10)
	No	86 (61)	69 (12)	2 (2)	19 (7)	64 (62)	72 (8)	41 (11)	54 (9)
Depression:	Yes	17 (12)	64 (8)*	3 (3)	18 (6)	11 (11)	65 (9)*	39 (8)	48 (12)*
	No	123 (88)	72 (11)	2 (2)	18 (8)	92 (89)	74 (7)	40 (11)	54 (9)

Independent sample *t-test* was used to detect differences between groups for each predictor (mean (SD)). *Significant difference between groups at $p < 0.05$. ASES: American Shoulder and Elbow Surgeons, SF-12: Short Form-12 survey, PCS: physical component summary, MCS: mental component summary.

one-year follow-up visit from baseline scores. Then, a multivariable enter regression analysis was performed on the change scores of ASES function and SF-12 PCS. All the assumptions of multiple regression including the test of normality, heteroscedasticity, multicollinearity and linearity were examined prior to the regression analysis.

RESULTS

Descriptive statistics

Within this cohort, 140 patients completed the ASES and 103 patients completed the SF-12 survey. The average age of patients was 71 years (range, 47-89 years). 57% of patients underwent TSA, 33% underwent reverse TSA and 10% underwent hemiarthroplasty.

Table 1 represents the influence of the patients' demographics on ASES and SF-12 scores one-year following shoulder arthroplasty. For ASES, age was significantly different between patients in all subgroups (p <.05). Males and patients with depression were younger than females and patients without depression while patients with diabetes and hypertension were older than patients without these two conditions. Males had significantly better function compared to females (r = -.27, p = .001) (Table 2). For the SF-12, patients with depression were younger and had worse mental health status compared to patients without depression (Table 1).

Pearson's correlations

Pearson's correlation between dependent variables and predictors are summarized in Table 2. The coefficients ranged from -.31 to .20. There were significant correlations (p <.05) with a small effect size between ASES pain and depression, ASES function and sex, MCS and sex, MCS and depression, and a medium effect size between PCS and age. Patients with depression reported higher pain and worse mental health status, male patients had better shoulder function and mental health status, and younger patients had better physical health status (Table 2).

When pain at one-year was added as a predictor to examine its effect on function, results revealed a moderate relationship between residual pain and function (r = -.51, p <.001) indicating that patients with higher pain had poorer shoulder function. In addition, there was a negative association between the change in function scores and residual pain (r = -.36, p <.001) indicating that patients who reported pain at one-year follow-up visit had less improvement in shoulder function.

Pearson's correlations were performed to examine collinearity between predictors. For ASES pain and function, results revealed significant correlations between diabetes and hypertension (r = -.25, p < .002) and between age and depression (r = .26, p < .001). For SF-12 PCS and MSC, results revealed significant correlations between diabetes and hypertension (r = -.33, p < .001) and between age and depression (r = -.34, p < .001). However, these correlations are weak.[15] We concluded that there is no collinearity within our data.

Multivariable regression analysis

The regression model is summarized in Table 3. In predicting pain, depression was the only significant predictor of pain (b = 1.5, SE = .63, $t_{(140)}$ = 2.4, p = .02) indicating that the presence of depression increases pain by 1.5 units. Together, all predictors explained 6% of the variability in pain.

For shoulder function, sex was a significant predictor

Table 2. Pearson's Correlations Between Predictors and Dependent Variables One-year Following Shoulder Arthroplasty

Dependent variables	Predictors				
	Age	Sex	Diabetes	Hypertension	Depression
ASES:					
Pain at one-year	.1	.11	.01	.06	.2*
Function: Model 1					
Demographics+ comorbidities	-.02	-.27*	-.07	.01	-.03
Function: Model 2					
Demographics+ comorbidities + residual pain	-.02	-.27*	.01	-.07	-.03
Change in function scores	.03	-.09	.11	-.01	-.02
SF-12:					
PCS at one-year	-.31*	-.14	-.08	-.14	-.03
Change in PCS scores	-.17*	-.17	.07	-.12*	-.07
MCS at one-year	.08	-.18*	.01	-.15	-.21*

Change in scores was calculated by subtracting scores at one-year follow-up visit from baseline scores
Function Model 1 predictors: age, sex, diabetes, hypertension, and depression.
Function Model 2 predictors: pain at one-year, age, sex, diabetes, hypertension, and depression
* Significant at $p < .05$. ASES: American Shoulder and Elbow Surgeons, SF-12: Short Form-12 survey, PCS: physical component summary, MCS: mental component summary.

of function ($b = -4.2$, $SE = 1.3$, $t_{(140)} = -3.2$, $p = .002$) indicating that being a male improves shoulder function by 4.2 scores on ASES index. All predictors explained 8% of the variability in function. When pain at one-year was added as a predictor in the final model, results revealed that both sex and pain ($b = -1.6$, $SE = .24$, $t_{(140)} = -6.7$, $p < .001$) were significant predictors of function. This indicated that as pain increases by one unit, shoulder function decreases by 1.6 scores. The explained variability in function increased to 32% with a greater contribution of pain.

In predicting the clinical benefits of shoulder arthroplasty, only residual pain was a significant predictor of the change in function scores ($b = -1.1$, $SE = .26$, $t_{(140)} = -4.4$, $p < .001$). This indicated that with 1 unit increase in residual pain, the improvement of shoulder function decreases by 1.1 scores. Together, all predictors explained 15% of the variability in the improvement in function.

In predicting SF-12 physical and mental health status, age was a significant predictor of physical health status ($b = -.48$, $SE = .15$, $t_{(103)} = -3.3$, $p = .001$). With one-year increase in age, physical health status decreases by 0.5 scores. Depression had a trend to predict mental health status ($b = -6.1$, $SE = 3.2$, $t_{(103)} = -1.9$, $p = .058$). Together, all predictors explained 14% of the variance in physical health status and 10% of the variance in mental health status.

In predicting the change in PCS, none of the predictors were significant. However, there was a trend for both age and hypertension to predict the change in PCS ($p = .055$). The explained variability in PCS change scores was 12%.

DISCUSSION

This study found that residual pain at one-year after shoulder arthroplasty is associated with poorer shoulder function. In addition, residual pain is the most significant predictor of function, and with other predictors, it explains 32% of the variability in shoulder function one-year after shoulder arthroplasty. Furthermore, residual pain is found to be the only predictor of improvement in shoulder function and clinical benefits following shoulder arthroplasty.

It is well established that shoulder pain can significantly affect function and the ability to perform activities of daily living[16] and pain relief is the primary goal of patients who undergo shoulder arthroplasty.[17] However, for some patients, post-surgical pain persists one to two years after shoulder arthroplasty, being most problematic for patients with fractures or osteoarthritis.[18] Our study found that residual pain at one-year is reported by 61% of patients who underwent shoulder arthroplasty but is highly variable in intensity (range: 0.2 - 10, VAS scale). In addition, higher pain is associated with worse shoulder function. Higher pain may be related to arthritis in the contralateral shoulder or in other parts of the arm since often outcome measures do not differentiate the location of the pain. However, it is also possible that closer attention to pain peri-operatively and during rehabilitation could improve these outcomes.

In our study, statistically significant poorer shoulder function is associated with female sex. In addition, although female sex is associated with lower functional

Table 3. Regression Model Summary for Dependent Variables One-year Following Shoulder Arthroplasty

Dependent variables	R	R^2	Adj. R^2	SE	F-statistics	Sig
ASES:						
Pain	.25[a]	.06	.03	2.3	1.7	NS
Function: Model 1						
Demographics+ comorbidities	.28[a]	.08	.05	7.3	2.3	.05
Function: Model 1						
Demographics+ comorbidities + pain at one-year	.56[b]	.32	.28	6.3	10	.001
Change in function	.38[b]	.15	.11	6.8	3.9	.0001
SF-12:						
PCS	.37[a]	.14	.09	10.5	3.0	.01
Change in PCS	.34[a]	.12	.07	10	2.5	.033
MCS	.31[a]	.10	.05	9.0	2.0	NS

Dependent variables at one-year
[a]Predictors: (constant), age, sex, hypertension, diabetes, depression
[b]Predictors: (constant), pain at one-year, age, sex, hypertension, diabetes, depression
Change in scores was calculated by subtracting scores at one-year follow-up visit from baseline scores
Function Model 1 predictors: age, sex, diabetes, hypertension, and depression.
Function Model 2 predictors: pain at one-year, age, sex, diabetes, hypertension, and depression
ASES: American Shoulder and Elbow Surgeons, SF-12: Short Form-12 survey, PCS: physical component summary, MCS: mental component summary, NS: nonsignificant.

scores, it is not associated with less change in function which suggest that men and women get equal benefit from the shoulder arthroplasty. Furthermore, women are more likely to have a negative change in mental health following surgery in comparison to men (Table 2). We showed that pain is highly related to poor shoulder function and, although not significant, women tend to report higher pain (Table 1). This may explain the poorer shoulder function for women. These findings are consistent with previous studies in which male patients had better improvement in function at a longer follow-up periods ranged from two to six years following TSA.[2,7]

In the present study, age is not a significant factor in predicting the change in shoulder scores nor the one-year shoulder function. However, age relates significantly to physical health status, in which younger patients had better physical health status, and to a lesser extent physical change over the year but not to mental health.

These findings are consistent with the study of Donigan et al. (n = 106) who reported a non-significant correlations between age and improvement in shoulder function[7]. However, advanced age was associated with significant better change in shoulder function in one study two-year after TSA (n = 102)[2] and with less improvement in shoulder function at the time of surgery[5] and at one-year follow-up[6] after shoulder arthroplasty. Advanced age was also associated with lower physical health status in the study of Matsen et al.[4] In addition, Matsen et al.[4] reported that the overall well-being of patients before TSA is strongly correlated with the quality of the outcomes.[4]

These conflicting findings might be related to the conflicting mechanisms by which age can mediate outcomes. Advanced age is associated with lower occupational and life demands for most people. Further, shoulder disorders and pathologies are common in older adults and are associated with general decline in physical health and quality of life.[8,19] However, in our regression analysis, we showed that age is not a significant predictor of the change in physical health status. This may indicate that physical health status is expected to improve following shoulder arthroplasty regardless to age. Other reasons for the conflicting conclusions among studies may include the use of different patient-reported assessment tools, the differences in the inclusion criteria, and the various sample sizes.

In general, comorbidities including diabetes, hypertension, and depression did not affect the final outcome status nor the amount of improvement gained with surgery for shoulder function, and physical and mental health status of this cohort' patients following shoulder arthroplasty. However, depression is associated with higher levels of pain and there is a trend toward worse mental health status (p = .058). Our lack of ability to show significant correlations between function and comorbidities is consistent with previous research.[7,9] These results are also consistent with our previous research[11] in which we showed that patients with and without diabetes recovered to the same functional level at one-year following shoulder arthroplasty despite significantly worse pre-operative function in diabetic patients. We concluded that patients with diabetes achieve large clinical benefits from shoulder arthroplasty, with follow-up outcomes equally positive to those without diabetes.[11] However, the non-significant association between depression and shoulder function may be due to our low sample size of patients with depression (n = 17). This lack of association differs with the study of Werner et al.[10] who reported significant effect of depression on shoulder function in 88 patients with depression assessed using ASES scale.[10] Our regression model showed a significant effect of depression on ASES pain in which depression, with other predictors, explained 6% of the variability of pain. However, the low percentage of the explained variability in pain might not have a clinical importance. Werner et al.[10] did not include a subscale of ASES pain for comparison.

This study provides new information about the impact of age, sex, diabetes, hypertension and depression on shoulder pain and function, and physical and mental health status one-year following shoulder arthroplasty. The data of this study were collected prospectively from a large cohort of patients who underwent shoulder arthroplasty. Shoulder pain and function, and physical and mental health status were evaluated using valid and reliable outcomes measures which have been used previously by several studies.[4,10] However, this study has several limitations. As with all regression models, a significant statistical relationship does not imply causation. Further, in some of our models the explained variation was quite small and thus the clinical importance of even to statistically significant correlations must be questioned. Our data was derived from a single specialty upper extremity program and may not be generalize to other clinical practices. We cannot distinguish the location of pain and thus residual pain is not necessarily related to the operated shoulder. However, none of these limitations diminish the value of this study which presented important information in a way that allow clinicians to incorporate its findings into their decision-making when planning for this surgical procedure.

CONCLUSION

This study found that residual pain is associated with poorer shoulder function at one-year and less clinical benefits over time. Female sex is associated with worse shoulder function at one-year but not with less change in function over time which suggest that men and women get equal benefit from the surgery. Comorbidities do not affect the final outcomes status and the amount of improvement gained with surgery. Advanced age relates to poorer physical health status and to a lesser extent physical change over the year. Lastly, patients with depression had higher pain than patients without this condition. Identifying risk factors for poor functional outcomes following shoulder arthroplasty can assist clinicians in counselling patients on the expected outcome following shoulder arthroplasty.

ACKNOWLEDGMENT

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RARE POST TRAUMATIC KYPHOSCOLIOSIS OF THE THORACOLUMBAR SPINE AFTER POSTERIOR FUSION FOR ADOLESCENT IDIOPATHIC SCOLIOSIS: A CASE REPORT AND REVIEW OF THE LITERATURE

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ABSTRACT

Background: Vertebral fracture after posterior arthrodesis and instrumentation for idiopathic scoliosis is a rare occurrence with limited reported cases in the literature.

Case Presentation: A 16-year-old female patient surgically treated for adolescent idiopathic scoliosis with T2-L1 posterior spinal fusion was in a low-energy fall resulting in fracture of L1 and new kyphosis and scoliosis of the thoracolumbar spine at the distal aspect of the fusion. The fracture was initially managed conservatively, however pain persisted and thus she was indicated for extension of the fusion and correction of the post-traumatic kyphosis.

Conclusions: Fractures after posterior spinal fusion for idiopathic scoliosis are rare and evidence for the appropriate management remains limited in the literature.

Level of Evidence: V

Keywords: spine, trauma, scoliosis, kyphosis

INTRODUCTION

Vertebral fracture after posterior arthrodesis and instrumentation for idiopathic scoliosis is rare; only a few cases have been reported in literature.[1-5] The authors present a case of traumatic fracture of the first lumbar vertebra (L1) at the distal aspect of the fusion construct. The L1 fracture resulted in a new kyphotic and scoliotic deformity initially treated conservatively however eventually necessitating surgical intervention.

CASE REPORT

A 16-year-old Caucasian female was referred for evaluation for adolescent idiopathic scoliosis (AIS). She reported chronic back pain resistant to oral anti-inflammatory medication and physical therapy. Plain standing radiographs showed a 46 degrees right-going thoracic curve and 34 degrees left-going lumbar curvature; MRI was negative for intra-spinal pathology. She underwent T2 to L1 posterior spinal fusion with instrumentation (PSFI) (Figure 1). The operative and postoperative periods were uneventful. At her first follow-up she was doing well with regards to pain management and deformity correction. Forty days after the surgery, she fell down a flight of stairs in her home and landed on her left buttocks. She went to a local emergency department due to significant low back pain as well as left lateral flank paresthesias and pain. Spine X-rays obtained were initially interpreted as negative and she was released with pain medications. Two days after the fall, her pain persisted and she re-presented. Repeat plain radiographs showed a compression fracture of L1 with kyphotic deformity as well as left scoliotic deformity (40 degrees and 19 degrees respectively) of the thoracolumbar spine, without evidence of mechanical failure of the instrumentation (Figure 2). She was placed in a thoracolumbar brace acutely. At the first follow-up, 6 days after her injury, she stated that the pain was stable and constant in nature. She had pain when upright and significant night pain. She also continued to have left flank numbness. A comprehensive neurologic examination was normal. A CT scan was acquired, which showed a non-displaced L1 body fracture that extended about the left pedicle screw with an acute kyphosis at the distal aspect of the fusion construct without evidence of hardware fracture or failure (Figure 3). The fracture was considered stable, in the absence of hardware failure or neurologic deficit. At this time, conservative management was recommended, encompassing oral anti-inflammatory medications, cold therapy and full-time brace. After 3

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Informed Consent: Informed consent was obtained from all individual participants included in this study.

Authors' Contribution: CC, JTC and LMH analyzed and interpreted the patient data and were major contributors in writing the manuscript. LL and KY contributed in writing the manuscript and in the literature review. SLW, the senior author, took care of the patient and performed the surgery, reviewed and supervised the manuscript preparation. All authors read and approved the final manuscript.

Disclosures: The authors report no potential conflicts of interest related to this study.

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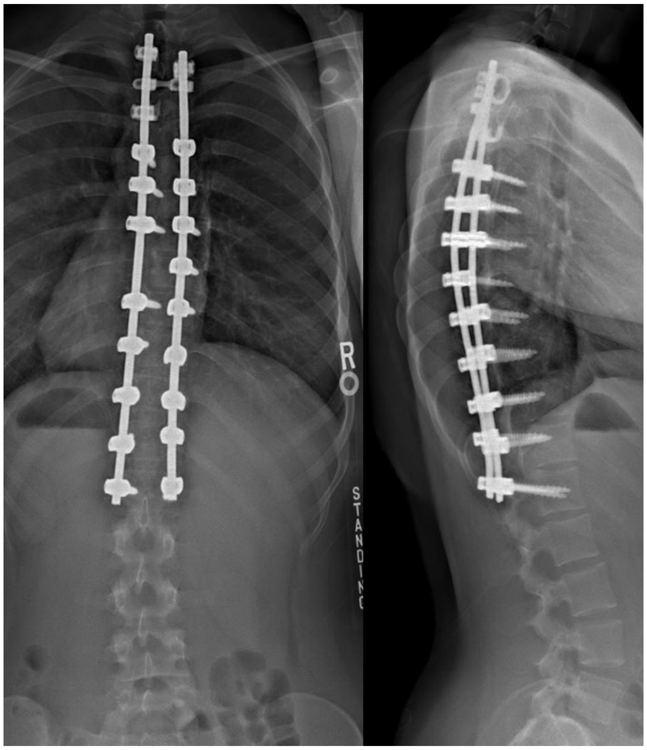

Figure 1. Radiographs show the radiological status of the patient before the injury: a posterior spinal fusion from T2 to L1 with the hardware is in stable alignment without evidence of complications.

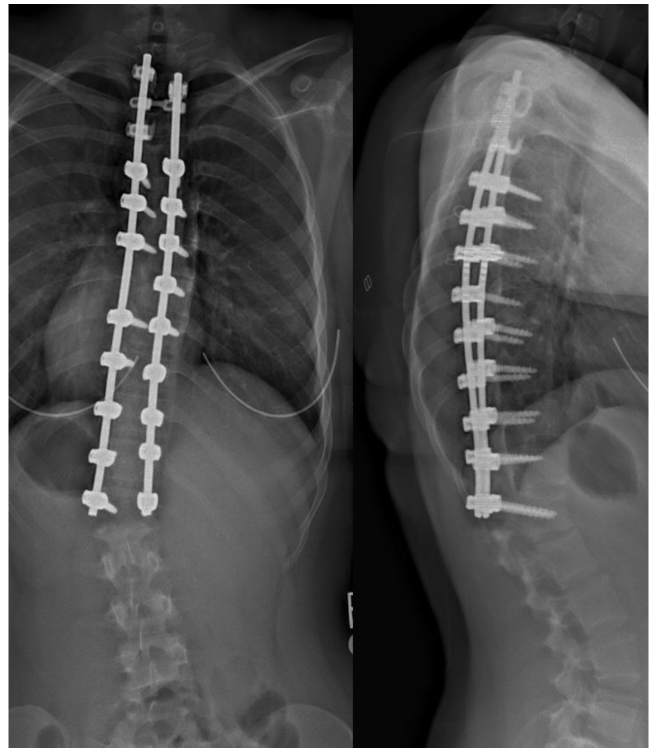

Figure 2. Radiographs show vertebral height loss at L1, concerning for acute fracture. Interval increased 19 degrees thoracolumbar left scoliosis and 40 degrees thoracolumbar kyphosis.

months follow-up radiographs were stable, however the patient's symptoms showed no improvement in symptoms. The patient complained of pain that limited her activities and sleep quality. For these reasons, she was indicated for partial hardware removal, correction of the thoracolumbar kyphosis and extension of the fusion to L4.

The revision surgery was performed 10 months after the patient's injury (approximately 11 months after index surgery). The spine was exposed T9 to L4. The rods were manually cut just above the T10 level. These rods and the pedical screws at L1 were removed. Two Ponte osteotomies were performed at levels T12-L1 and L1-L2 to achieve the correction of the kyphosis. Pedical screws were placed at L2-L4 and new rods were placed and connected to the old rods using an in-line connector at the right side and a side-to-side connector at the left side. The residual scoliotic and kyphotic deformities were corrected additionally with in situ rod benders. The operative and the postoperative hospital course were uneventful and she was discharged at the third postoperative day.

Radiographs acquired two and six months after surgery showed stable alignment without evidence of hardware complications. Her back pain improved by the second postoperative month and was completely resovled at six months after surgery. She was released to full activity without restrictions. At one-year follow-up, the patient was in excellent overall condition without any concerns of pain or functional limitation and radiographs demonstrated no further complications (Figure 4).

DISCUSSION

Fractures of the thoracolumbar spine represent around 90% of traumatic spine fractures in adults.[6] Most of these fractures do not manifest neurological complications, and thus can be treated conservatively with brace and rest. In these cases, persistent pain and kyphotic deformity are the most common indications for surgical correction.[7-8]

However, thoracolumbar fractures after PSFI for AIS are very rare. In this case, the traumatic fracture was initially stable and the patient was neurologically intact; thus, conservative management was initially trialed. The persistence of pain and the presence of a kyphotic deformity rendered surgical intervention a reasonable option for this patient's symptoms after 10 months of conservative management. Due to the length of intervening time between injury and surgical intervention, two Ponte osteotomies were required to successfully correct the rigid kyphotic deformity. The instrumentation below the fracture from L2 to L4 was considered necessary to maintain the reduction of the kyphosis and the scoliosis.

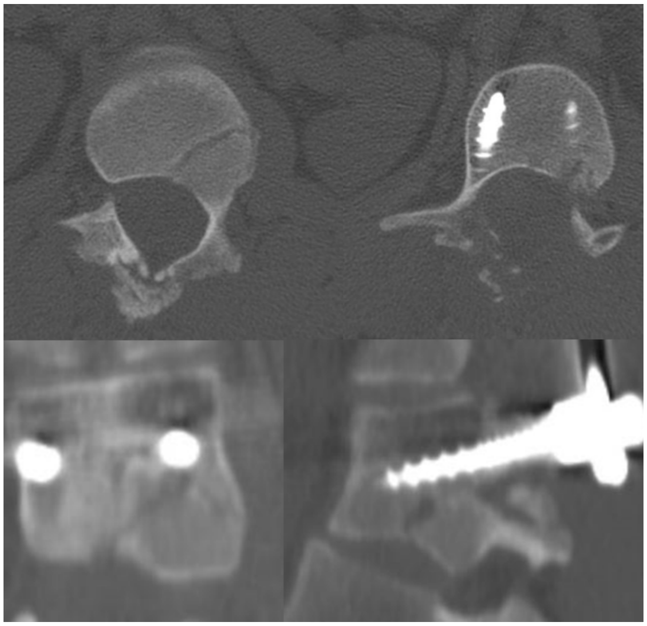

Figure 3. The CT images show the fracture line of the L1 body that start from the screw track.

Only few similar cases have been reported in literature,[1-5] and each differs from our case. To the best of our knowledge, this is the first report in literature of a vertebral body hyper-flexion fracture that involved the distal-most vertebra of a construct with pedicle screws.

In 2014, Pirris and Kimes reported a case of a 12-year old patient with PSFI for AIS treated with Harrington's rodding technique. At the age of 43 years, she developed adjacent-segment disease that was treated with extension of the PSFI from L3 to ileum. After 8 months, the patient fell and reported a compression fracture of L2, which was within the fusion mass cranial to the new pedicle screw construct. After 2 weeks of observation a balloon kyphoplasty was performed because of pain and kyphosis. In this case report, the procedure was unsuccessful and she developed pseudarthrosis and relapse of the kyphosis.[1]

Neyt and Weinstein, in 1999, reported a fracture-dislocation three years after a patient underwent PSFI with Cotrel-Dobousset instrumentation for idiopathic scoliosis. The patient was involved in a car accident and L2 was injured, which was the first free vertebra below the prior arthrodesis. In that case, the fracture was determined to be unstable with risk of neurologic compromise. The authors extended the arthrodesis to L4 with two cross-linked side-to-side rods by a posterior approach.[2]

Bago et al., in 1998, reported a case of a 30-year-old woman who underwent anterior and posterior fusion for AIS with Cotrel-Dobousset instrumentation. She was involved in a car accident two years after her index surgery, sustaining a wedge fracture of T11 with deformity of the rod and loss of correction. Because the fracture was stable and within a solid fusion mass, conservative treatment was successful.[3]

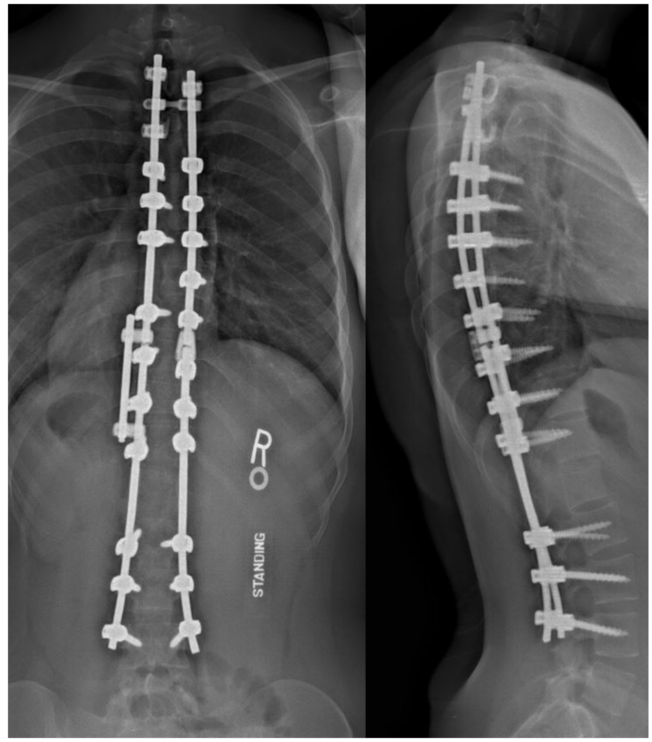

Figure 4. Twelve month post-operative radiographs show distal extension of posterior spinal instrumentation with hardware extending from T2 to L4, removal of the L1 pedicle screws and the correction of the thoracolumbar kyphosis and scoliosis.

King and Bredford, in 1980, reported on a fracture-dislocation of T11 in a patient involved in motor-vehicle collision two years after PSFI with Harrington's rod. They chose an operative approach because the angulation of the rod interfered with stable closed reduction.[5]

Other similar reports in literature refer to older or a geriatric population. Various authors reported fractures in fused segments with or without minor trauma,[9-10] after the removal of the implant,[11] or in patients with other comorbidities like idiopathic skeletal hyperostosis.[12]

The literature posits that these fractures are unusual because the fusion mass and instrumentation protect fused spinal segments. This hypothesis was namely coined by by King and Bago.[3,5] No current reports in the literature involve segments with pedicle screw instrumentation. Pedicle screws are biomechanically superior to previously ubiquitously utilized hooks, providing better pull-out strength, higher stiffness and stability to the construct.[13] After immobilization and arthrodesis of a long spinal segment, there is an increased mobility between the upper and the lower adjacent segments.[14-15] We hypothesize that, in this case, fracture occurred at the end vertebra of the construct for three reasons: first, there is greater mobility of the caudal adjacent segment at the junction of the rigid thoracic spine and the mobile lumbar spine; second, the injury occurred only 40 days after the surgery and there was not yet a solid fusion mass; and third, the fracture occurred through the weakened bone of the screw track because of time course and relatively recent screw insertion. The presence of the pedicle screw construct gave enough stability such that the fracture did not grossly change during 10 months of observation.

CONCLUSION

We present an unusual case of vertebral fracture through a pedicle screw track 40 days after AIS surgery. Thoracolumbar fractures in patients who are status post PSFI for AIS are very rare and mainly the consequence of high-energy injuries. Secondary kyphosis with persistence of pain should be considered an indication for extension of the fusion and to restore normal sagittal balance.

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THE DEFORMITY TLIF: BILATERAL FACETECTOMY AND OSTEOTOMY CLOSURE WITH A HINGED TABLE

Christopher T. Martin, MD[1]; Kristen E. Jones, MD[2]; David W. Polly, Jr., MD[1,2]

ABSTRACT

Background: Increasing emphasis has been placed on segmental lordosis correction, even in short segment constructs. However, the majority of reports on TLIF indicate that lordosis correction is modest at best. TLIF with bilateral facetecomy has been described with better lordosis correction, but is usually performed with the spine in extension throughout the case. This report presents a new technique for lordosis correction during TLIF with the use of bilateral facetectomy and osteotomy closure using a mechanically hinged operative table.

Methods: A 78-year-old male presented with claudicatory back and leg pain due to foraminal stenosis and spondylolisthesis at L4-5 and L5-S1, and was operated on with bilateral facetectomies and TLIF while positioned on a motorized-hinged table, which started in flexion for the decompression and was brought into extension at the end of the case for osteotomy closure.

Results: Segmental lordosis from L4-S1 increased from 15° pre-operatively to 42° post-operatively.

Conclusions: A comparison of pre- and post-operative lateral radiographs showed 27° segmental lordosis correction, and intra-operative fluoroscopy showed correlation between extension of the table and segmental lordosis correction. Bilateral facetectomy and TLIF allows for segmental lordosis correction. Use of the hinged table allowed for ideal positioning during the decompression and controlled osteotomy closure with close correlation between table position and segmental alignment.

Level of Evidence: V

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Keywords: transforaminal lumbar interbody fusion, tlif, smith peterson, osteotomy, lordosis, hinged table, bilateral facetectomy

INTRODUCTION

Short segment kyphosis increases the amount of lordosis required at adjacent segments. This adjacent hyperextension compensates for a short time, but as the adjacent segment deteriorates the effect is lost and global imbalance can subsequently occur.[1] Thus, lordosis correction has been emphasized even in short segment constructs.[2]

TLIF with bilateral facetectomy (Smith-Peterson osteotomy, SPO) is a well-described technique for lordosis correction,[3] but the procedure is usually performed with the spine in extension.[4,5] This position narrows the canal diameter,[6] which makes the decompression more challenging and may limit the size of the interbody that can be placed.

Here, we report a new TLIF technique combined with SPO using a mechanically hinged table. The technique starts with the table in flexion to facilitate the decompression, and ends with controlled osteotomy closure through the mechanical hinge, with close correlation between table position and intra-operative segmental alignment.

METHODS

Case Report

This experimental protocol and was approved by our institution's accredited Institutional Review Board, which allowed for review of interbody fusions with an osteotomy that were presented in a de-identified fashion. The IRB did not require individual patient consents for retrospective presentation of de-identified data. A 78-year-old male presented with progressively worsening claudicatory back and leg pain. Imaging revealed spondylolisthesis at L4-5 and spondylosis at L5-S1 with foraminal stenosis at both levels (Figures 1 and 2). After failure of non-operative management, he proceeded to surgery.

Surgical Technique

The patient was placed prone on a hinged table (ProAxis® Spinal Surgery Table, Mizuho OSI, Union City, CA). The table was then flexed to 10° and brought into reverse-trendelenburg to level the spine. Sub-periosteal exposure was performed out over the facet joints just enough to

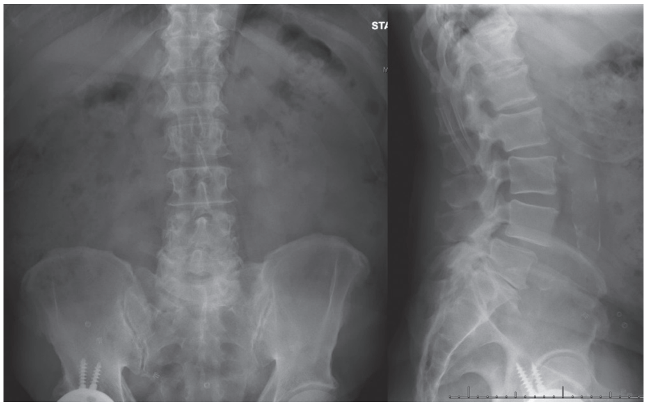

Figure 1. Pre-operative standing radiographs showing L4-5 spondylolisthesis and L5-S1 spondylosis.

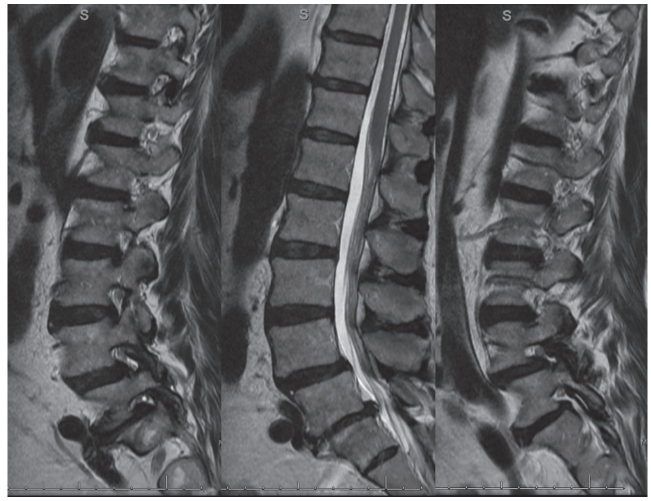

Figure 2. Mid-sagittal and both left and right para-sagittal T2 MRI images showing foraminal stenosis at L5-S1 and L4-5.

expose screw start points. Pedicle screws were then placed in the standard fashion (Figure 3A). The interspinous ligament was removed and a laminar spreader was used to distract the spinous processes. If the spinous process is absent or broken, then pedicle-based distraction is used. The bilateral inferior articular processes were removed with an osteotome. A curved curette was used to define the lateral border of the superior articular process (SAP) and the bone was removed outside-in with a combination of the rongeur and the kerrison. Bone removal continued medially until the traversing nerve root was visible and bleeding was controlled with bipolar electrocautery. Disc space prep proceeded with pituitary and currettes, followed by the turn-and-rotate distractors to serially dilate the disc space (Figure 3B). The SAP was removed on the contralateral side, thus completing the SPO, and contralateral disc prep was performed. A trial was used to select the appropriately sized cage. The disc space was irrigated and packed with local autograft from the facetectomies. 2-3 cc of bone can usually be inserted. An appropriate sized bulleted TLIF cage was then inserted (Figure 3C). The distractor was then removed from the contralateral side, further bone graft impacted, and a second cage inserted. Fluoroscopy was obtained to verify the cage position. Any remaining midline flavum was then removed with a kerrison to complete the decompression, but the lamina was preserved.

The hinged table was then brought into extension in 5° increments until it reached a total of 10° extension (Figure 4). Rods and set screws were placed and compression across the pedicle screws was used to further increase lordosis (Figure 5). The midline lamina was then decorticated and packed with a mixture of allograft and the remaining autograft bone.

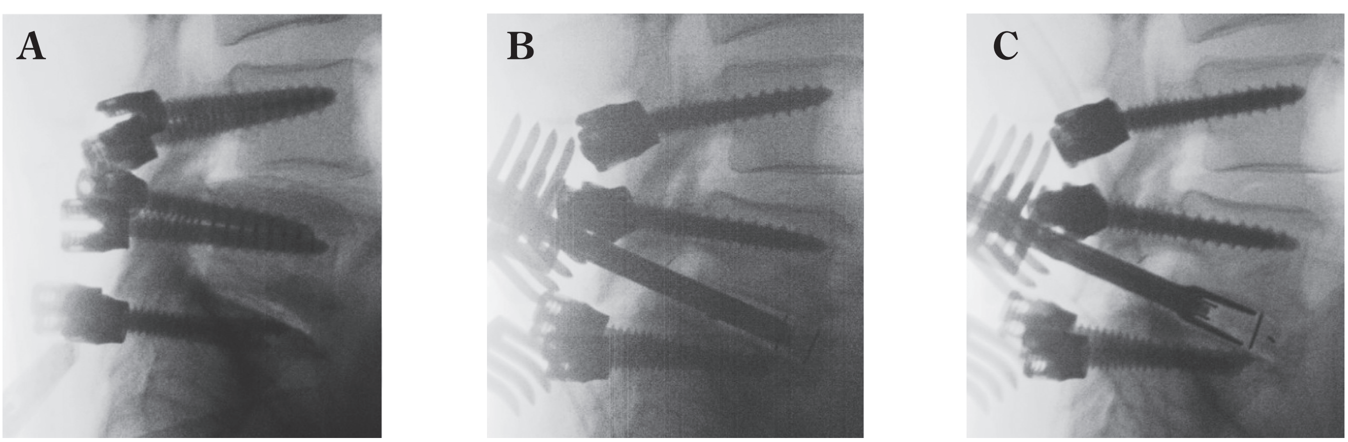

Figure 3. Performance of bilateral TLIF. (A) Pedicle screws are placed in the standard fashion. (B) After completion of the osteotomy, the disc space is prepared and turn-and-rotated distractors are used to serially dilate the disc space. The trial is used to select an appropriate height cage. (C) After cage insertion, fluoroscopy is obtained to verify cage position.

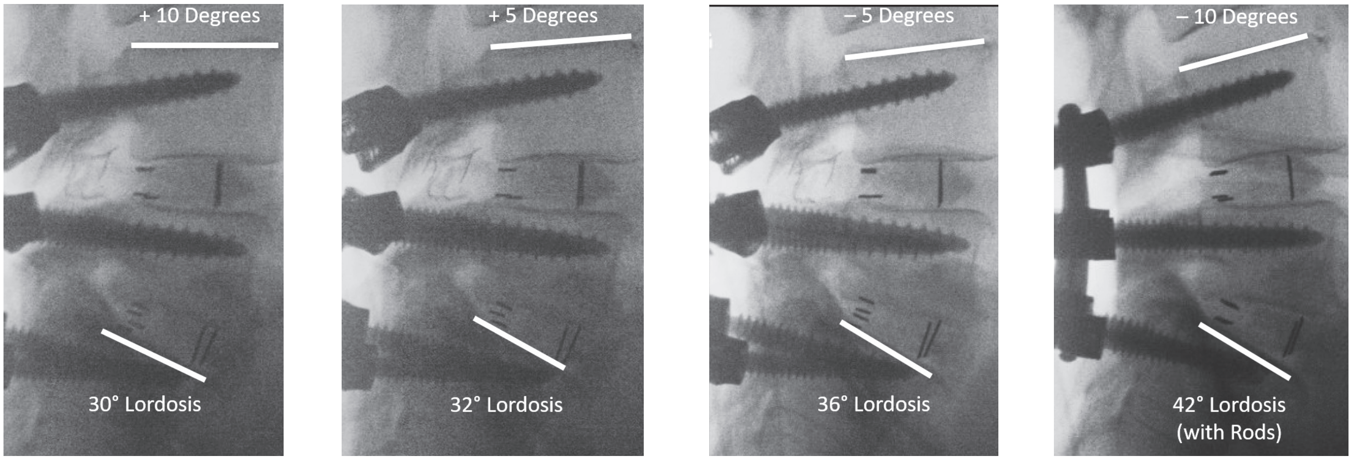

Figure 4. Serial osteotomy closure with the hinged table.

RESULTS

Based on comparison of pre- and post-operative lateral radiographs, segmental lordosis from L4 S1 increased from 15° pre-operatively to 42° post-operatively, for a total of 27 segmental lordosis correction. Intra operative fluoroscopy showed close correlation between extension of the table and segmental lordosis correction alignment.

DISCUSSION

TLIF with SPO is a well described technique for segmental lordosis correction.[3] Here, we describe the first report of positioning on a motorized hinged table, which carries several advantages. First, the table starts in a flexed position, which allows for optimal visualization during the decompression. Further, this positioning facilitates segmental distraction during the TLIF which allows for larger cages to be inserted. Second, because the interspace is distracted, very little midline lamina needs to be removed to complete the decompression, which allows for midline bony fusion, and avoids the need for wide lateral gutter dissection/grafting with its associated muscle trauma. Third, the canal is not entered until after it has already been widely distracted by cage insertion, which helps minimize dural tear risk. Lastly, substantial lordosis correction is possible. 16-18 mm high cages with 18° of lordosis can be routinely inserted, and intra-operative table extension allows for controlled osteotomy closure. In this case, 27° segmental lordosis was achieved across the two operative levels (Figure 6), which compares favorably against prior literature reports for TLIF.[7-10]

CONCLUSION

TLIF with bilateral facetecomy on a motorized-hinged-table allows the surgeon to perform the decompression and TLIF with the spine in flexion and the disc space distracted, which is an ideal situation. Closure of the osteotomy through the mechanical hinge in the table allows for substantial lordosis correction.

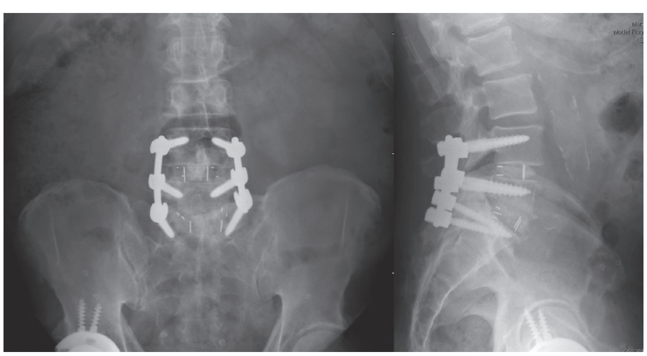

Figure 5. Standing post-operative AP and lateral radiographs showing improved segmental and global alignment.

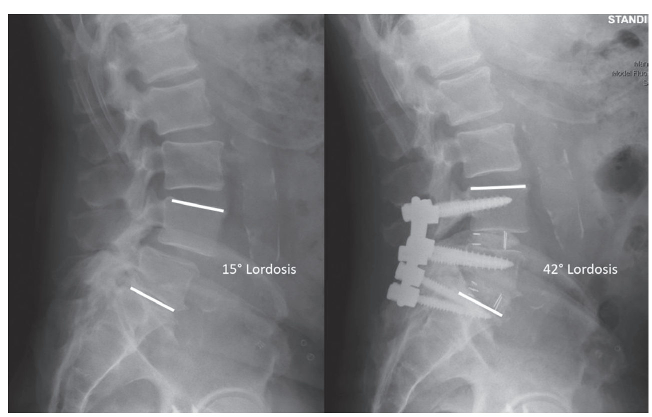

Figure 6. Comparison of pre- and post-operative lateral radiographs showing 27° segmental lordosis correction.

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ACUTE ONSET ATYPICAL SEVERE SCOLIOSIS: A CASE REPORT

Luca Labianca, MD[1,2,3]; Cosma Calderaro, MD[1,2]; Stuart L. Weinstein, MD[1]

ABSTRACT

Background: Although most cases of scoliosis are idiopathic, scoliosis may also be congenital or associated with other diseases. Herniated Nucleus Pulposus (HNP) has been reported as a potential cause of non-structural scoliosis. HNP is unusual in adolescents and the clinical features are typically different from those in adults.

Case Presentation: An 18-year-old Caucasian male was referred to our ambulatory service for evaluation of scoliosis after orthopedic evaluation at another center. He had noticed left-sided low back pain in the previous 6 months, which had worsened over the last two months with the development of limp and left lower extremity (LLE) paresthesias. After an accurate clinical evaluation, the acute onset of the curvature with mild back pain and associated neurological findings were suggestive of an intraspinal lesion. The MRI examination showed an L4-L5 HNP compressing L4 nerve root and displacing the distal L5 nerve root. An L4-L5 laminectomy and discectomy were performed. His left leg pain was completely relieved the day after surgery. At 3 months follow-up complete resolution of scoliosis deformity and return to full activity was achieved.

Conclusions: Every child who presents with atypical scoliosis should have a complete physical examination and appropriate imaging studies seeking an underlying cause.

Level of Evidence: V

Keywords: herniated nucleus pulposus, scoliosis, atypical scoliosis, acute onset scoliosis, MRI, laminectomy, discectomy

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INTRODUCTION

Adolescent idiopathic scoliosis (AIS) is a musculoskeletal disorder of unknown etiology.[1-3] Idiopathic scoliosis has standard recognizable patterns.[3] Although most cases of scoliosis are idiopathic, scoliosis may also be congenital or associated with neuromuscular diseases, spondylolysis/ spondylolisthesis, infections, syringomyelia, syndromes, and tumors.[4-14]

Herniated Nucleus Pulposus (HNP) has been reported as a potential cause of postural, non-structural scoliosis.[15-18] HNP is unusual in adolescents and the clinical features are typically different from those in adults and there are only a few studies in the literature about scoliosis secondary to HNP.[19-21]

The rapid development of a severe curve in the presence of back pain and neurological features, suggests non-idiopathic scoliosis.[22-25] We report a rare case of an otherwise healthy 18-year-old male presenting with the acute onset of atypical severe scoliosis due to HNP.

CASE PRESENTATION

An 18-year-old Caucasian male was referred to our ambulatory service for evaluation of scoliosis after orthopedic evaluation at another center. He had noticed left-sided low back pain in the previous 6 months, which had worsened over the last two months with the development of limp and left lower extremity (LLE) paresthesias. He had also noticed a truncal shift, which had not been present previously. His discomfort was never severe enough to require medication, and he had never undergone physical therapy.

The clinical examination showed a left-sided thoracic rib prominence with a significant truncal shift to the right. He had level shoulders and pelvis, normal strength in all muscle groups, intact sensation and symmetric abdominal and deep tendon reflexes; Babinski's manuever resulted in plantarflexion of the toes. Supine straight leg raise (SLR) however was positive on the left side, with radicular symptoms at 20 degrees of hip flexion.

Standing scoliosis films showed 37° right long atypical thoracic curve, and 33° left thoracolumbar curve, with loss of lumbar lordosis. There was a significant right truncal shift. He was a Risser stage 5 (Fig.1).

Clinical and radiological findings suggested a secondary cause of scoliosis. Therefore, an MRI was performed.

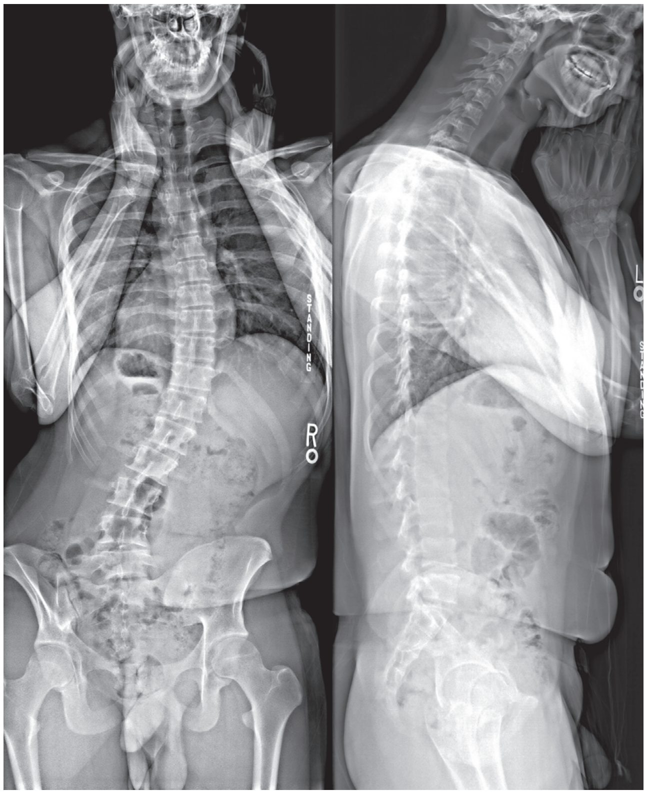

Figure 1. Standing x-rays demonstrating an atypical right thoracic curve measuring 37°, and a left thoracolumbar curve measuring 33°, with a significant truncal shift to the right, The patient also has loss of normal sagittal contours. The patient is Risser 5.

The MRI showed an L4-L5 left paracentral HNP compressing L4 nerve root and displacing the distal L5 nerve root (Fig. 2).

Due to his neurological symptoms and the severity of the curve, an L4-L5 laminectomy and discectomy were performed. His left leg pain was completely relieved the day after surgery. At 3 months follow-up complete resolution of scoliosis deformity and return to full activity was achieved (Fig.3).

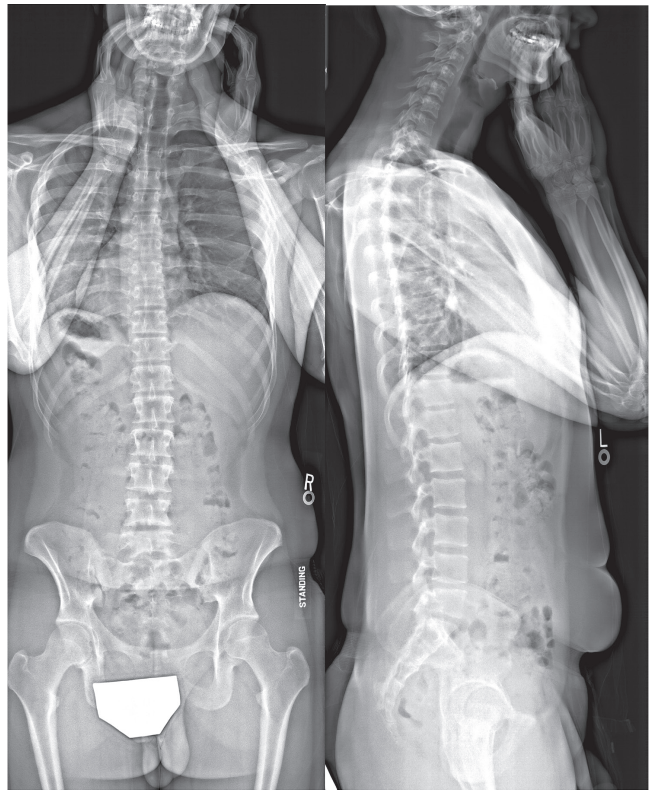

Figure 3. Standing scoliosis films obtained at the three months follow-up show almost a complete resolution of scoliosis.

DISCUSSION

This case report represents the most severe atypical scoliosis case secondary to an HNP reported in the literature.[21] The acute onset of the curvature in association with mild back pain and neurological findings were suggestive of an intraspinal lesion causing scoliosis.

Our patient was referred to us by another orthopedic surgeon with an AIS diagnosis and asking us to provide for treatment.

Pain may be a warning sign in patients presenting with

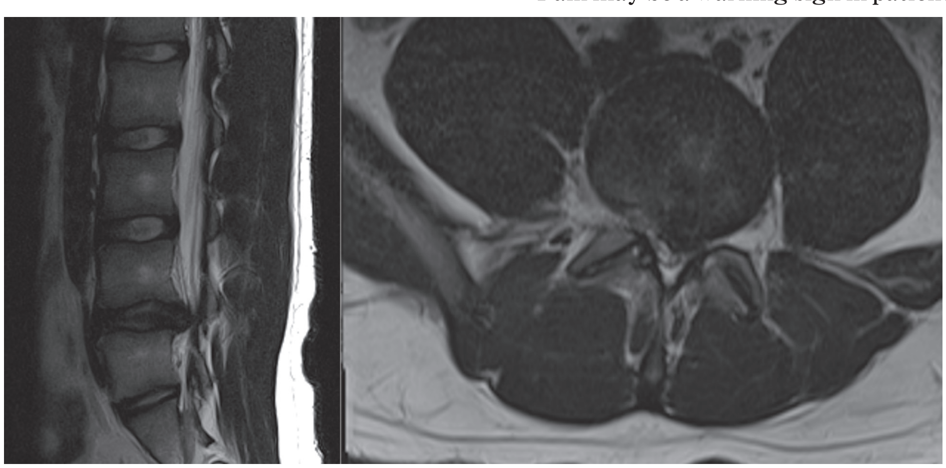

Figure 2. MRI T2-weighted shows herniated nucleus pulposus (HNP) with superimposed central/left paracentral disc protrusion at the L4-L5 level which likely contacts the exiting left L4 nerve root and posteriorly displaces the distal descending left L5 nerve root.

a scoliosis curve, as most patients complain of little or no discomfort. [22-25] Ramirez reported mild back pain in 23% out of 2442 patients diagnosed for AIS and 9% of them resulted in a different etiologic condition.[22] Likewise, progression rate, onset age, neurological symptoms, and signs should raise the index of suspicion for a non-idiopathic etiology.[4-14] In these cases, MRI is the most useful adjunctive diagnostic tool.[4,26-28]

The diagnosis in this patient was problematic for the initial evaluator because of the patient's lack of significant pain and failure to check the SLR in the face of severe scoliosis as well as the uncommon occurrence of HNP in adolescents.[21,25,29]

The etiology, pathophysiology, and patterns of the scoliotic posture in cases secondary to HNP remain debated. Zhu hypothesized that the trunk shift on the opposite side of the HNP reduces the weight-bearing on the involved leg, improving the symptoms of the nerve root irritation.[21] Finneson speculated that the opposite trunk shift allows decreasing the nerve root compression. Conversely, Suk hypothesized that the trunk shift side is opposite to the HNP side and not related to the inflammation.[30-31]

HNP in children and adolescents are less responsive to non-operative management with pharmacologic and physical therapy[18,32-35] and are more likely to undergo surgery with reported good to excellent results.[15,32,36]

CONCLUSION

We present here a case of an HNP in an adolescent with a secondary severe atypical scoliosis misdiagnosed as AIS. This case exemplifies that every child who presents with atypical scoliosis should have a complete physical examination and appropriate imaging studies seeking an underlying cause.

LIST OF ABBREVIATIONS

AIS: Adolescent idiopathic scoliosis
HNP: Herniated Nucleus Pulposus
LLE: Left lower extremity
SLR: Straight Leg Raising Test

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OUTCOMES OF HIP ARTHROSCOPY IN THE MEDICARE PATIENT: A GROWING POPULATION

Elizabeth J Scott, MD[1]; Nicholas A. Bedard, MD[1]; Christopher West, MD[1]; S. Blake Dowdle, MD[1]; Steve S. Liu, MD[1]; John J. Callaghan, MD[1]

ABSTRACT

Background: Although the results of hip arthroscopy in the elderly have been inferior to the results in younger patients, there have recently been some encouraging reports in carefully selected series of older patients. The purpose of this study was to identify the utilization of hip arthroscopy in the Medicare population and to determine the rate and timing of revision arthroscopy and/or total hip arthroplasty (THA) with the goal of identifying risk factors for secondary procedures based on patient demographics, comorbidities and the diagnosis at the time of arthroscopy.

Methods: The Medicare Standard Analytic Files were reviewed from 2005-2014 for all patients undergoing hip arthroscopy allowing for minimum 2 year follow-up (100% sample). Patients were tracked through the dataset for the occurrence of an ipsilateral THA or revision hip arthroscopy. Rates and timing of the subsequent procedures were then determined within 6 month intervals. Patients less than 65 years old were excluded. Multivariate logistic regression analysis was performed to determine the impact of patient age, sex, obesity or a diagnosis of hip osteoarthritis on need for revision procedures.

Results: 3,320 Medicare patients had a hip arthroscopy during 2005-2014 (0.3% compared to THA). 73 patients (2.2%) underwent reoperation during the follow-up period. Two-thirds (n = 46) of all revision procedures occurred within one year of primary hip arthroscopy. A pre-operative diagnosis of hip osteoarthritis significantly increased the odds of reoperation (OR = 5.3). (Conclusion: Relatively few numbers of Medicare patients underwent hip arthroscopy during the time interval evaluated (0.3% when compared to THA utilization). 2.2% underwent a subsequent revision arthroscopy or THA with many occurring soon after the procedure and for the diagnosis of hip OA demonstrating the need to better define indications in this population. This study should provide baseline utilization and outcome trends for future studies.

Level of Evidence: IV

Keywords: database, medicare, hip arthroscopy, arthroscopy

INTRODUCTION

The use of hip arthroscopy has increased exponentially in the last decade.[1-4] Recent research on hip arthroscopy trends using large national databases demonstrate an overall increase from 3.6 procedures per 100,000 in 2005 to 16.7 per 100,000 in 2013.[3] Although the largest increase has been observed in ages 35-44, enrollees in the 60 years and greater age group demonstrate a 200% increase in hip arthroscopies from 2007 to 2011.[1] With this rapid increase in hip arthroscopy, concerns regarding indications for the procedure, particularly in older patients, has risen. Initial results of hip arthroscopy in the elderly have been inferior to results in younger patients, with increasing age associated with greater subsequent risk of THA.[5] Multiple previous studies found that osteoarthritis was the biggest predictor of failed survivorship after hip arthroscopy in this population.[5,6] Recent evaluation of private insurer databases found a 25.2% rate of conversion to THA in patients over 60, and a mean of 25.0 months to THA.[3] Success, however, has been demonstrated in carefully selected series of older patients.[7,8]

Most studies evaluating the procedure in older patients have been limited by small cohorts, older data, or both.[1,5,9] Additionally, the Medicare population which represents the largest insurer for ages >65 has not been singularly evaluated. The purpose of this study was to evaluate the utilization of hip arthroscopy in the Medicare population from 2005 to 2014 and to (1) determine the rate of revision arthroscopy and total hip arthroplasty (THA) after initial hip arthroscopy, (2) determine how soon after hip arthroscopy a revision procedure was performed, and (3) identify factors that may predict the need for THA after arthroscopic surgery of the hip. Specifically, we targeted risk factors suggested by prior studies including age, gender, obesity status, and presence of osteoarthritis at the time of index arthroscopy.

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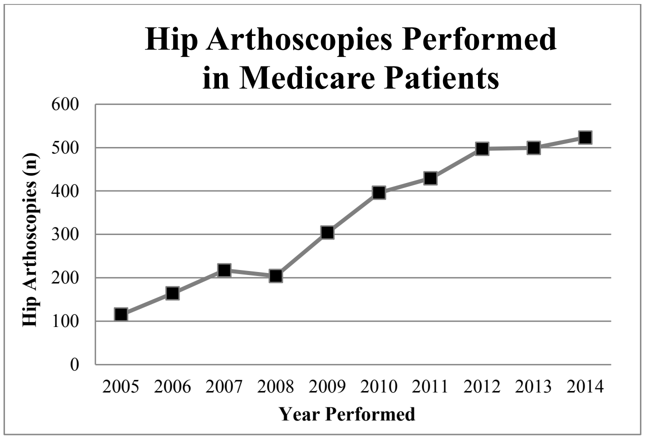

Figure 1. Hip arthroscopies performed in medicare patients per year.

Table 1.
Demographics of Hip Arthroscopy Patients

Demographic	Total (n)	Percent (%)
All Patients	3320	100
Male	1243	37.5
Female	2077	62.5
Obese	329	9.9
Non-Obese	2991	90.1
Age breakdown (years)	**Total (n)**	**Percent (%)**
65-69	1779	53.5
70-75	891	26.8
76-79	434	13
80-84	167	5
85+	57	1.7
Year Performed	**Total (n)**	
2005	115	
2006	164	
2007	217	
2008	204	
2009	304	
2010	396	
2011	429	
2012	497	
2013	499	
2014	523	

MATERIALS AND METHODS

The PearlDiver Research Program (www.pearldiverinc.com; PearlDiver Inc, Fort Wayne, IN) was used to query the Medicare Standard Analytic Files for the information presented in this study. The Medicare Standard Analytic Files represents 51 million covered lives and includes 100% of inpatient and outpatient facility records billed to Medicare in this period. All data within this database are health Insurance Portability and Accountability Act compliant and were thus deemed exempt from institutional review board approval by our institutions Human Subjects Office.

Patients undergoing hip arthroscopy were identified using the Current Procedural Terminology (CPT) codes 29861, 29862, 29863, 29914, 29915, 29916. The CPT code for diagnostic hip arthroscopy (CPT-29860) was specifically excluded as it was felt that this code would bias the results of conversion to THA. Patients less than 65 years of age were additionally excluded. Laterality modifiers were used to ensure ipsilateral revision procedures were captured and thus, records without laterality designation were excluded. Patients were then tracked longitudinally through the dataset at six month intervals for 5 years following index procedure, or for two to five years in those patients operated on after December 2011 for the occurrence of an ipsilateral THA or revision hip arthroscopy procedures. This allowed for determination of the incidence and timing of subsequent THA or revision hip arthroscopy procedure.

To evaluate the impact of specific patient factors on incidence of revision procedures, cohorts were filtered into subgroups based on demographic data including age, gender, and obesity status. Age subgroups included; 65-69 years, 70-74 years, 75-79 years, 80-84 years, and 85 or older. Obesity was determined by an International Classification of Diseases 9th Revision (ICD-9) diagnosis code representing body mass index 30 kg/m2. Additional subgroup analysis was performed to determine if odds of subsequent revision or THA were different with the presence of hip osteoarthritis, using ICD-9 codes for primary (715.15), secondary (715.25), or unspecified (715.35 and 715.95) osteoarthritis of the hip. The chi-square test was used to compare categorical variables, and odds ratios (ORs) with corresponding 95% confidence intervals were used to evaluate differences in rates of subsequent THA. Multivariate logistic regression analysis was performed to determine the impact of each of these groups (age, sex, obesity, or hip osteoarthritis) on need for revision procedures. Statistical significance was set at $P < .05$ for all tests.

Table 2.
Rate and Time to Revision Arthroscopy or Total Hip Arthroplasty (THA) after Hip Arthroscopy

Months after Hip Arthroscopy	Number of Patients undergoing Revision Arthroscopy	Percent of Total Revisions	Number of Patients Undergoing THA	Percentage of Total THA
6	19	44.2%	7	21.80%
12	28	65.1%	20	62.50%
18	34	79.1%	25	78.10%
24	36	83.7%	27	84.30%
30	37	86.0%	29	90.60%
36	39	90.7%	31	96.80%
42	41	95.3%	31	96.80%
48	42	97.7%	32	100%
54	42	97.7%	32	100%
60	42	97.7%	32	100%

RESULTS

Overall 3,916 Medicare patients underwent a hip arthroscopy between 2005 and 2014. After the application of laterality modifiers to the hip arthroscopy CPT codes, 3320 (84.7%) hip arthroscopy patients were remaining for longitudinal analysis of a subsequent ipsilateral arthroscopy or THA. Except from 2007 to 2008 there was an increasing number of arthroscopies performed each year, with a 454% increase in procedures from 2005 to 2014 (Figure 1). Of the 3320 arthroscopies included, 2077 (62.5%) were female and 1243 (37.5%) were male. There was a decreasing incidence of hip arthroscopy with age (Table 1), with the majority of procedures (53.5%) being done in patients aged 65-69 (1,779), and 891 (26.8%) in patients aged 70-74. The remaining 20% included 434 procedures in ages 75-79 (13.0%), and 167 procedures (5%) in ages 80-84. There were 57 hip arthroscopies done in patients 85 or older. The most common procedure documented was chondroplasty (CPT-29862), which was documented in 2,425 (73.0%) of procedures. A preoperative diagnosis of hip osteoarthritis of the hip was present for 30.9% of the hip arthroscopy patients.

Longitudinal tracking of hip arthroscopy patients found that 73 patients (2.2%) went on to require an additional ipsilateral THA or revision hip arthroscopy procedure. 32 patients (1.0%) underwent an ipsilateral THA, and 43 (1.3%) received a revision arthroscopy. Of patients who had a diagnosis of osteoarthritis at the time of their index procedure, 4.5% (n = 46) went on to require revision scope or THA. There was a significantly increased odds of subsequent procedure for the osteoarthritis group with an OR of 1.73 (1.46-1.99, $P < .001$). Of the 1% (n=32) of patients who underwent an ipsilateral THA, 84% occurred within two years of the index arthroscopy, and 100% occurred within 4 years of the index procedure. Similarly, 84% of revision arthroscopy procedures occurred within two years of the index arthroscopy, and 97.7% (n=42) were within four years (Table 2).

Multivariate regression analysis was performed to evaluate the potential effects of osteoarthritis, obesity, age sub-group, and gender on need for subsequent procedure. Obesity, gender and age were not associated with need for a revision hip arthroscopy or ipsilateral THA on multivariate analysis. A pre-operative diagnosis of hip osteoarthritis significantly increased the odds of a subsequent procedure with OR of 5.3 (95% CI: 3.2-9.1, $p<0.001$).

DISCUSSION

Of 3,320 Medicare patients analyzed in this study, following hip arthroscopy approximately 2.3% went on to require a subsequent procedure after hip arthroscopy with 1% undergoing THA and 1.3% undergoing a revision arthroscopy during the years 2005 to 2014. A preoperative diagnosis of hip osteoarthritis was present in 30.9% of patients, and patients with a pre-operative diagnosis of osteoarthritis had significantly higher odds of requiring an additional procedure (OR: 1.73, $p<.001$). Conversion to THA and revision arthroscopy both occurred quickly after index hip arthroscopy, with over half of secondary procedures occurring within 12 months, and 78-79% occurring within 18 months. Additionally, 100% of THAs and 97.7% of revision arthroscopies occurred within four years. The rate of hip arthroscopy in Medicare patients rose exponentially with an overall 450% increase in the number of hip arthroscopies during the 9 years of the study period.

Limitations of this study include those inherent to administrative claims database studies, which are dependent on coding and documentation accuracy. In addition, Health Insurance Portability and Accountability Act-compliant databases are unable to provide exact numbers when a value lies between 0-10, making analysis of smaller subgroups difficult. Also, patients undergoing arthroscopy towards the end of the study (after 2011) did not have a full five years of post-arthroscopy surveillance. Additionally, the arthroscopy CPT codes 29914, 29915, 29916 (femoroplasty of a cam lesion, acetabuloplasty of a pincer lesion, and labral repair, respectively) were introduced halfway through the study period in 2011, making it difficult to analyze the association of specific procedure codes with subsequent outcomes in this population. Finally, indications for repeat surgery and outcomes other than the need for repeat arthroscopy or hip replacement, including patient reported outcomes and radiographic outcomes can not be obtained from this type of database.

Strengths of the study include the very recent time period of data and large population of older patients able to be assessed. The use of a laterality modifier also allows for identification of true conversions to THA or revision arthroscopy; this addition is critical and sometimes not taken into account in other database studies. The use of the Medicare database gives an excellent sample of older adults in which to study while many studies of arthroscopy are innately limited by the overall small numbers of eligible older participants, using lower thresholds of age 40 or 50 as their cutoff which create an inherently different patient population.

Overall, the results of this study are encouraging for the use of hip arthroscopy in the older population with only 2.2% of patients requiring repeat arthroscopy or total hip replacement. Bedard et al. found a conversion rate to THA after arthroscopy of 9.7% in patients over 50, while Sing et al reports a rate of 17% for patients over 50 for the years 2007 to 2011.[1,10] Neither of these studies evaluated revision arthroscopy as a second indicator of treatment failure. Other recent meta-analyses evaluating hip arthroscopy in adults over 40 additionally emphasize increased re-operation rates compared to younger counterparts. Griffin et al.[8] reported overall conversion rate to THA of 18.5% at a mean of 17.5 months following hip arthroscopy; Horner et al.[7] cites an aggregate conversion to THA rate of 18.1% in patients over 50, and 25.2% in patients over 60 with a mean of 25.0 months to THA. Although substantially higher than rates of conversion observed in our study, both meta-analyses found overall a statistically significant improvement in outcome after hip arthroscopy if the indication included femoral osteochondroplasty, labral repair, or was unspecified.[5,8] Labral debridement, alternatively, has less predictable results.

Our finding of osteoarthritis as a predictor of failure is also well supported in literature. Phillipon et al. in an analysis of 203 patients >50 treated with hip arthroscopy for labral tears and femoroacetabular impingement found a joint space of <2mm to be a major predictor of subsequent THA.[11] Alternatively, when patients with osteoarthritis are excluded, results from hip arthroscopy in the older patient are very good. Bryan et al evaluated 201 patients without radiographic evidence of arthritis aged 55 or greater who underwent arthroscopy for FAI; although their ADL scores were below their younger counterparts at 2 years, there was significant improvement in mean Harris Hip Score (mHHS) compared with preoperative values.[7]

Although THA remains the clearest endpoint, inclusion of revision arthroscopy in our statistical evaluation of index treatment failure provides important additional data for consideration. A systematic review of >6000 patients of all ages by Harris et al.[12] found the most common reason for reoperation after hip arthroscopy to be conversion to THA while our study found a higher rate of revision arthroscopies (1.3%) than conversions to total hip arthroplasty (1.0%). One explanation for this finding in those >65 may be increased caution when selecting senior patients for hip arthroscopy; many elderly patients presenting with hip pain perhaps are simply directed towards the certain finality of a THA over the possibility of multiple procedures with arthroscopy. Those who are candidates for joint preservation, i.e. FAI with no or minimal arthritic change, may be the very select few who would therefore also consider revision arthroscopy before proceeding with THA. This low rate overall of conversion to THA in the 65+ age group compared to studies evaluating mostly 40-60 year olds need continued study.

Shared decision-making between patient and surgeon is especially valuable for the older patient in whom multiple procedures may be particularly unfavorable. Overall, however, our data suggests that the large majority of Medicare patients indicated for arthroscopy do not go on to require a revision arthroscopy or ipsilateral THA (only 2.2% of 3320 patients). It does suggest that when hip arthroscopy fails, it does so relatively quickly after the index procedure. As supported by prior literature, patients who have osteoarthritis at the time of hip arthroscopy are more likely to go onto conversion to THA and/or revision arthroscopy. These results provide needed age-specific data for hip arthroscopy failure rates in senior adults, and emphasize that risk factors such as osteoarthritis should be carefully taken into consideration when indicating those >65 for hip arthroscopy.

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RATES AND RISK FACTORS FOR REVISION HIP ARTHROSCOPY

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ABSTRACT

Background: Revision hip arthroscopy often serves as a measure for a failed primary hip arthroscopy procedure. The purpose of this study was to examine the rate, timing, and risk factors for revision hip arthroscopy using a large national database.

Methods: The Humana administrative claims dataset was reviewed from 2007 through the second quarter of 2015 to identify patients undergoing hip arthroscopy using Current Procedural Terminology (CPT) codes and laterality modifiers. Patients with subsequent ipsilateral revision hip arthroscopy were identified and the rate and timing of these revisions determined. Subgroup analysis was performed to determine effects of gender, age, body mass index (BMI), osteoarthritis diagnosis, and specific hip arthroscopy procedure on revision rates.

Results: There were 1807 hip arthroscopy procedures identified with a revision rate of 4% (total of 72 procedures). Of the revision procedures, 43% occurred within 6 months after the index procedure, and 86% occurred within 18 months. Age < 50 years was the only significant predictor of revision hip arthroscopy (OR 2.03, CI 1.17-3.53) with an even distribution across younger age groups. An osteoarthritis diagnosis, gender, and BMI did not represent significant risk factors for revision (OR 0.87, 0.98, 0.9 and CI 0.5-1.51, CI 0.6-1.59, CI 0.37-2.12, respectively). Chondroplasty was the most common procedure leading to revision (46%) followed by labral repair (37%). The most common revision procedures were chondroplasty (44%) followed by femoroplasty (38%).

Conclusion: Overall, 4% of hip arthroscopy procedures underwent revision arthroscopy over the 8-year period. Revision was associated with age < 50, and revisions were most frequently performed for femoroacetabular impingement. The majority of revisions occurred within 18 months after the index procedure.

Level of Evidence: IV

Keywords: femoroacetabular impingement, hip replacement, hip arthroscopy, hip

INTRODUCTION

Arthroscopic visualization of intraarticular structures in the hip was described as early as 1931.[1] The advent of hip arthroscopy as standard practice for treatment of various pathologies in the hip is a relatively recent phenomenon and has gained traction particularly over the last two decades with an exponential increase in utilization and indications.[2-5] The increase in hip arthroscopy over this time period has been shown to be in large part due to increasing recognition and treatment of femoroacetabular impingement (FAI) syndrome.[2] Recent studies have shown a 365% increase in utilization from 2004-2009, and this rise has continued with a 250% increase from 2007-2011.[4,5] These studies have also shown that although the longest component of this increase has been demonstrated in age groups under 30, there has been a significant increase in hip arthroscopy procedures in all age groups, including those over 60.[5]

In light of this increase in the use of hip arthroscopy, there has been an increasing focus on outcomes, reoperation rates, and complications associated with these procedures.[6-10] Following hip arthroscopy, subsequent procedures that have been consistently monitored include revision hip arthroscopy or arthroplasty. Conversion to total hip arthroplasty (THA) has been the subject of multiple investigations ranging from small cohorts to large national database studies with rates ranging from 2.9%-16%.[11-16] One of these studies that queried the same database that is the subject of the current work found a conversion rate of 5.3% with most of those occurring within 18 months after the index procedure.[11]

Causes of failed hip arthroscopy include FAI, iatrogenic chondrolabral injury, adhesions, and postoperative microinstability to name a few. Reoperation rates following hip arthroscopy have been reported with a wide range from 1.3% to greater than 50%.[6,15,17-19] Revision hip arthros-

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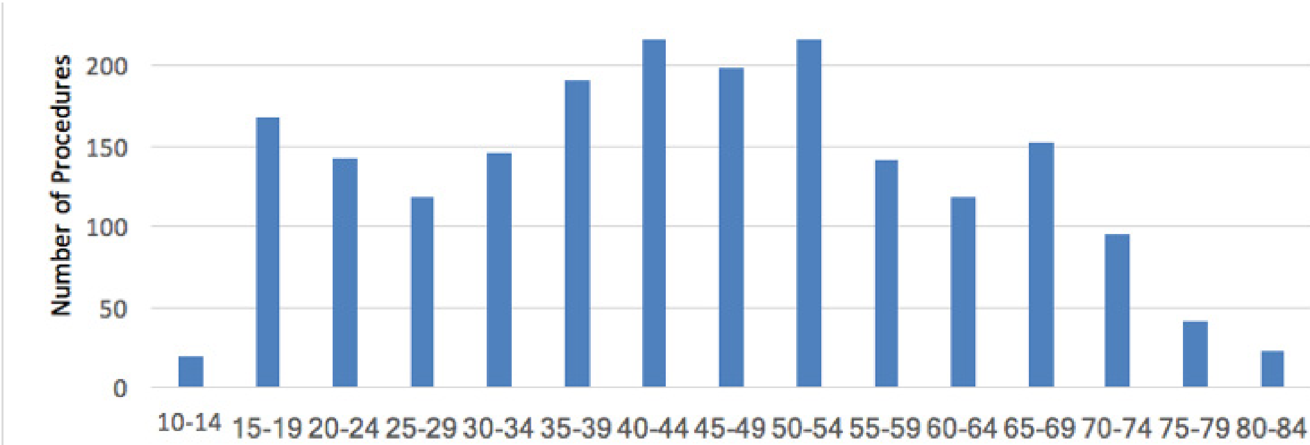

Figure 1. Hip arthroscopy procedures for given age groups.

copy is among the more common procedures performed after primary hip arthroscopy. Harris et al., in their large systematic review of 6,134 hip arthroscopy procedures, found that among 6.3% of patients that required reoperation, which included conversion to THA, 30% of those went on to need a revision arthroscopic procedure.[14]

With the continued increase in hip arthroscopy procedures and the subsequent increase in revision hip arthroscopies, the purpose of the present study was to use a large national database to evaluate the rate, timing, and potential risk factors for revision hip arthroscopy. We hypothesized that the overall rate of revision hip arthroscopy would be low, and would be predicted by obesity, female sex, advanced patient age.

METHODS

The data for the present study were obtained from the Humana Inc administrative claims database using the PearlDiver Research Program (www.pearldiverinc.com; PearlDiver Inc, Fort Wayne, IN). This data set represents over 16 million covered lives between 2007 and 2015 composed of private/commercially insured patients as well as Medicare/Medicare Advantage plans. These data are compliant with the Health Insurance Portability and Accountability Act and therefore were exempt from institutional review board approval.

Patients undergoing hip arthroscopy were identified using the Current Procedural Terminology (CPT) codes 29861, 29862, 29863, 29914, 29915, 29916. The CPT code for diagnostic hip arthroscopy (29860) was excluded. Laterality modifiers were used to determine whether the index procedure was done on the left or the right and records without laterality were excluded. Patients were then tracked longitudinally for the occurrence of an ipsilateral hip arthroscopy using the same CPT codes and laterality modifiers to ensure that the revision procedure was performed on the same hip as the index hip arthroscopy. The database was queried for ipsilateral hip arthroscopy at 6 month intervals for a period of 5 years postoperatively. We evaluated subsequent arthroscopy after index arthroscopy procedures and did not consider other revision procedures, preservation procedures such as periacetabular osteotomy, or conversion to THA. Further subgroups of these cohorts were then assessed for their effect on the rate of revision hip arthroscopy including specific procedure, gender, age, diagnosis of osteoarthritis, and body mass index (BMI). Revision rates were assessed for ages 0-90 years old divided into 5 year age ranges. Diagnosis of osteoarthritis at the time of index procedure was assessed using International Classification of Diseases 9th Revision (ICD-9) codes 715.15, 715.25, 715.35, 715.95 to include primary, secondary, or unspecified osteoarthrosis of the pelvic region and thigh. Effects of BMI were assessed with obesity defined as BMI > 30 with ICD-9 codes 27800, V853, V8530, V8539, 27801, V854, V8541, and V8545. Basic demographic data (age and gender) of the entire cohort were also identified. Odds ratios (ORs) with corresponding 95% CIs were used to evaluate differences in rates of subsequent revision hip arthroscopy. Statistical significance was set at $p < 0.05$.

RESULTS

During the years included in the time period investigated, 1,807 hip arthroscopy procedures coded for laterality were identified and used for longitudinal analysis. Within this group, the most common procedure performed was chondroplasty at 46.1% (n=833) followed by femoroplasty at 37.2% (n=673) and labral repair at 31.8% (n=575). Overall, 668 patients (37%) were male and 1139 (63%) were female. Hip arthroscopy was most commonly performed between the ages of 30 and 60 (61%) with the largest age groups being 40-44 (12%), 50-54 (12%), and 45-49 (11%) (Figure 1). Of this cohort 63% (n= 1132) were < 50 years old and 37% (n=675) were > 50. Obese patients comprised 9.1% (n=164)

Table 1. Procedures and Demographics of Total Number of Procedures (n = 1807)

Procedure	Number of Procedures	%
Loose Body Removal (29861)[a]	136	7.5
Chondroplasty (29862)	833	46.1
Synovectomy (29862)	317	17.5
Femoroplasty (29914)	673	37.2
Acetabuloplasty (29915)	424	23.0
Labral Repair (29916)	575	31.8
Demographics		
Male	668	37.0
Female	1139	63.0
Obese	164	9.1
Non-Obese	1643	90.9
Diagnosis of osteoarthritis	678	37.5
No diagnosis of osteoarthritis	1129	62.5

[a]Current Terminology Procedural Codes

Table 2. Comparison Between Revision and Non-Revision Groups[a]

		Revision	No Revision	
Age	> 50	55	1022	OR - 2.03
	< 50	17	641	CI: 1.17 - 3.53
Diagnosis of Osteoarthritis	Yes	20	638	OR - 0.87
	No	38	1053	CI: 0.5 - 1.51
Obesity	BMI > 30	6	152	OR - 0.9
	BMI < 30	66	1511	CI: 0.37 - 2.12
Gender	Male	45	1049	OR: 0.98
	Female	27	614	CI:0.6 - 1.59

[a]Data are reported as number of index procedures coded.
OR, Odds Ration. CI, Confidence Interval

of hip arthroscopy patients, and 90.9% (n=1643) had a BMI < 30. A diagnosis of hip osteoarthritis was present at the time of the index procedure in 37.5% (n=678) of patients, and 62.5% (n=1129) did not carry that diagnosis (Table 1).

Longitudinal tracking of patients identified 72 patients (4.0% of 1,807 patients) that underwent a subsequent ipsilateral hip arthroscopy. Among these revisions, 43.1% were performed between 6 and 18 months postoperatively, and 86.1% were performed within the first 18 months postoperatively. Of the total number of revisions, 55 (76%) were < 50 years old, and 17 (24%) were > 50 years old. Of the criteria that were evaluated for subgroup analysis, age < 50 years was the only significant predictor of revision hip arthroscopy (OR 2.03, CI 1.17-3.53).

Osteoarthritis, gender, and BMI were not associated with the need for revision arthroscopy (OR 0.87, 0.98, 0.9 and CI 0.5-1.51, CI 0.6-1.59, CI 0.37-2.12 respectively) (Table 2). Procedures performed at the time of revision arthroscopy included chondroplasty in 44% and femoroplasty in 38%.

DISCUSSION

The present study presents data collected from a large national database representing a large patient population, which is helpful when investigating relatively uncommon procedures such as revision hip arthroscopy. There was a 4.0% incidence of revision hip arthroscopy. This is comparable to revision rates reported by others. Harris et al. reported 1.8% of patient underwent revision hip arthroscopy in a systematic review of over 6,000 patients that underwent hip arthroscopy.[14] Truntzer et al showed a 5.31% revision hip arthroscopy rate within 6 months of the index procedures.[20] By comparison, those that have investigated indications and outcomes after revision hip arthroscopy have found that after revision hip arthroscopy there is a 5-8% re-revision rate.[21, 22] As has been shown in other studies, our data supports the conclusion that the most common reason for revision arthroscopy is residual femoroacetabular impingement with chondroplasty and femoroplasty being the most common revision procedures.[6]

Revision hip arthroscopy is associated with younger age which was the only significant variable in the current work. Interestingly, BMI, a preoperative diagnosis of osteoarthritis, and gender were not significant predictors of revision. While others have shown a female predominance for revision hip arthroscopy,[22] our data did not reveal gender as a significant risk factor. These findings may be partially explained by a treatment bias applied to those with arthritis and age > 50 as they may be more likely counseled toward arthroplasty. [11]

In a previous study, the conversion from hip arthroscopy to THA was evaluated in similar data set.[11] In that study, conversion rate to THA was 5.3% after failed hip arthroscopy, and conversion to THA was found to occur mostly in older patients with osteoarthritis. Both the timing and age of patients undergoing conversion to THA correlate to the findings for revision hip arthroscopy reported in the present study.

This work has limitations that are inherent to all database studies that are reliant on insurance administrative claims data and therefore accurate CPT and ICD-9 coding. Indications for individual procedures, intraoperative findings and complete descriptions of the procedures were not available using deindentified registry data and so associating specific treatments with specific diagnoses is not possible using these data. This is further complicated by the fact that CPT codes have expanded in recent years to more specific codes for femoroplasty (29914), acetabuloplasty (29915), and labral repair (29916), although older codes are still routinely used. No outcome data are available using this data set other than reoperation rates for the population. This study only evaluated subsequent arthroscopy after index arthroscopy procedures and did not consider other revision procedures, preservation procedures such as periacetabular osteotomy, or conversion to THA.

In summary, with rates of hip arthroscopy continuing to rise, there is a need to identify factors that increase the risk for revision procedures. Our ability to detect significant variables affecting outcomes with large database cohorts as in the present study should improve with the recent addition to the number of codes for operative treatment and the conversion to ICD-10 diagnostic coding. This information should help surgeons and patients be better informed in their shared decision making when deciding on hip arthroscopic procedures.

Overall, 4% of hip arthroscopies underwent revision arthroscopy over the 8-year period. Revision was associated with age less than 50, and revisions were most frequently performed for femoroacetabular impingement. The majority of revisions occurred within 18 months after the index procedure.

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INTRA-ARTICULAR PATHOLOGY ASSOCIATED WITH ACUTE AND CHRONIC ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

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ABSTRACT

Background: Concomitant meniscal and chondral pathology is common at the time of anterior cruciate ligament reconstruction (ACL-R). The purpose of the present study was to report the prevalence of concomitant intra-articular pathology for patients undergoing acute or chronic anterior cruciate ligament reconstruction.

Methods: This study represents a prospective, consecutively collected cohort of 255 patients undergoing both primary and revision ACL-R between January 2012 and December 2014 at a single institution. The cohort was divided into an acute surgical group, defined as surgery within six weeks of injury, and a chronic surgical group, greater than six weeks removed from injury. The median time from injury to surgery for the entire cohort was 37 days (range: 4 days to 855 days). Variables of interest included patient demographic characteristics, concomitant meniscal and chondral pathology, and meniscus treatment.

Results: Patients treated in the chronic setting were slightly older (28.7 ± 11.6 years vs. 23.1 ± 8.6 years, P=0.001), had a higher prevalence of complex tears of the medial meniscus (37.2% vs. 7.7%, P=0.012) and cartilage injury (16.5% vs. 7.8%, P=0.03). After excluding revision ACL-R procedures, complex medial meniscus tears in chronic ACL-R were higher than in acute ACL-R (medial= 27.3% vs. 3.0%, P=0.022), however when age was considered, these tears were no longer more frequent than in the acute setting (P=0.056). Similarly, the prevalence of cartilage injury was equivalent between groups after correcting for age (P=0.167). Among primary ACL-R, there were more medial meniscus repairs in the acute surgical group compared to the chronic group (60.6% vs. 24.2%, P=0.003). After excluding complex tears, medial meniscus repair rates were no longer performed more frequently in patients undergoing acute ACL-R (59.4% vs. 33.3%, P=0.054).

Conclusions: Data from this prospective cohort suggest that with increasing time from ACL injury to ACL-R, medial meniscus pathology increases, with a lower likelihood of meniscal repair in all patients undergoing ACL-R. However, this finding is no longer statistically significant when considering only patients undergoing primary ACL-R. Age appears to play an important role in whether concomitant pathology develops following ACL rupture. Given these findings, early intervention may increase the ability to repair medial meniscus tears in the setting of ACL-R, but this conclusion is less supported in primary ACL-R.

Level of Evidence: II

Keywords: anterior cruciate ligament, reconstruction, meniscus, acute, chronic

INTRODUCTION

The incidence of anterior cruciate ligament (ACL) rupture is as high as 7% in active, at risk populations.[1-3] ACL injuries predispose the knee to abnormal forces and kinematics that result in subsequent cartilage and meniscal injury that may lead to the development of osteoarthritis.[4,5]

ACL reconstruction (ACL-R) is commonly performed for treatment of ACL tears. The surgery has been shown to decrease the time to return to sport and improve patient reported outcomes.[6] However, the timing of ACL-R remains a topic of debate. One proposed approach promotes delaying surgery, with a focus on early range of motion to reduce the risk of postoperative arthrofibrosis.[7] On the other hand, delayed ACL-R has been associated with increased risk of chondral and meniscal damage.[8-12] The purpose of the present study was to report the prevalence of concomitant intra-articular pathology for patients undergoing acute or chronic ACL-R using prospectively collected data in a consecutively collected cohort of patients. It was hypothesized that chronic ACL-R portends greater intra-articular pathology at the time of surgical intervention.

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Table 1a. Patient Demographics of ACL-R Groups

	<6 weeks	>6 weeks	P value
N	128	127	
Age, yrs	23.1±8.6 24 (14-49)	28.7±11.6 25 (14-60)	0.001
Female	63 (49%)	59 (46%)	0.667
BMI	25.3±4.4 24.5 (15.7-39.9)	27.1±5.5 25.9 (18.6-44.8)	<0.001
Primary ACL-R	118 (92.2%)	89 (70.1%)	<0.001
Graft Type			
Allograft	14 (11.0%)	25 (19.7%)	0.052
Hamstrings	79 (61.7%)	74 (58.3%)	0.570
Bone-patellar-bone	35 (27.3%)	28 (22.0%)	0.333
Noncontact	111 (86.7%)	111 (87.4%)	0.877
Sport	103 (80.4%)	78 (61.4%)	<0.001
Time to surgery, d	25.31±10.29 25 (4-41)	164.0±176.5 88.5 (43-855)	Group

Table 1b. Patient Demographics of Primary ACL-R Groups with Complex Tears Excluded

	<6 weeks	>6 weeks	P value
N	118	89	
Age, yrs	23.1±8.9 19 (14-49)	28.9±12.1 25 (14-60)	0.001
Female	58 (49%)	40 (45%)	0.550
BMI	25.3±4.5 24.5 (15.7-39.9)	26.8±5.6 25.9 (18.6-44.8)	<0.001
Graft Type			
Allograft	12 (10.2%)	19 (21.4%)	0.026
Hamstrings	75 (63.6%)	58 (65.2%)	0.811
Bone-patellar-bone	31 (26.3%)	12 (13.5%)	0.025
Noncontact	102 (86.4%)	78 (87.6%)	0.800
Sport	98 (83.1%)	62 (69.7%)	0.023
Time to surgery, d	24.62±10.66 24 (4-41)	147.4±157.9 87.5 (44-768)	Group

METHODS

Prior to patient enrollment, this study was approved by the Institutional Review Board. All patients (n=255) undergoing primary (n=207, 81.2%) or revision (n=48, 18.8%) ACL-R were prospectively and consecutively enrolled from January 2012 to December 2014 at a single institution. All surgical procedures were performed by five sports medicine fellowship trained orthopaedic surgeons. Participating surgeons recorded the presence of meniscal pathology, including tear type and location, as well as the presence, location, and grade of chondral injury, when applicable.

Patients were divided into two groups based on time from injury to surgery. The acute surgical cohort was defined as having surgery within six weeks of the injury while the chronic surgical cohort underwent surgery greater than six weeks after the initial injury. All patients recalled a distinct injury event that was consistent with the mechanism of ACL injury. A time frame of six weeks was selected for the cutoff between acute and chronic surgical intervention based on previous studies which have shown increased risk of developing intra-articular lesions as time from injury to surgery increases.[13-15]

Collected data elements included patient demographics (age, gender, body mass index [BMI]), mechanism of injury (contact vs. non-contact), intraoperative findings (chondral injury, defined by the Outerbridge classification system with grade III or IV being considered significant[16] and meniscal injury, as defined by presence of a complex tear),[17] surgical variables (ACL graft choice [allograft, hamstrings, bone-patellar tendon-bone], ACL graft size, graft fixation methods, and meniscal treatment [repair vs. meniscectomy]).

Statistical Analysis

Demographic, injury and intraoperative data were compared between patients undergoing acute (≤6 weeks post-injury) or chronic (>6 weeks post-injury) ACL-R. Statistical analysis included chi-square and Fisher's exact tests and Student's t-test for categorical and continuous variables, respectively. When non-normal distributions were present, the Wilcoxon rank sum test was utilized. Age-adjusted comparisons were made using logistic regression. A p-value <0.05 was considered statistically significant. All analyses were completed using SAS statistical software version 9.4 (SAS Institute Inc., Cary, NC).

RESULTS

A total of 255 participants were enrolled, of which 122 (47.8%) were women and 207 (81.2%) were primary procedures. The mean patient age was 25.9 ± 10.6 years and mean BMI was 26.2 ± 5.0 kg/m^2. The majority of ACL tears occurred due to a non-contact injury mechanism, as described by the patient (n= 222, 87.1%). A majority also occurred while participating in a sporting event (n=181, 70.9%). Distribution of graft choice was as follows: hamstrings (n=153, 60%), bone-patellar tendon-bone (n=63, 24.7%), and quadriceps (n=39, 15.3%).

There were 128 (50.2%) patients who underwent acute ACL-R and 127 patients (49.8%) who underwent chronic ACL-R. The chronic group differed from the acute group

Table 2a. Intra-articular Pathology at Time of ACL-R

	<6 weeks	>6 weeks	P value
Meniscus tears	84 (65.6%)	77 (60.6%)	0.41
Medial meniscus tear	39 (30.5%)	44 (34.9%)	0.45
Lateral meniscus tear	60 (40.9%)	51 (40.2%)	0.28
Medial meniscus tear length, mm	11.5	17.5	0.74
Lateral meniscus tear length, mm	8.4	10.6	0.68
Medial, complex tear type	3 (7.7%)	16 (37.2%)	0.012*
Lateral, complex tear type	8 (13.3%)	11 (21.2%)	0.922*
Cartilage injury	10 (7.8%)	21 (16.5%)	0.03

*adjusted for age

Table 2a. Intra-articular Pathology at Time of ACL-R. (Excluding Revision ACL-R)

	<6 weeks	>6 weeks	P value
Meniscus tears	78 (66.1%)	60 (67.4%)	0.843
Medial meniscus tear	33 (28.0%)	33 (37.1%)	0.164
Lateral meniscus tear	58 (49.2%)	41 (46.1%)	0.660
Medial meniscus tear length, mm	12.1±6.1	17.5±16.3	1.00
Lateral meniscus tear length, mm	8.4±4.2	8.2±2.2	0.964
Medial, complex tear type	1 (3.0%)	9 (27.3%)	0.056* (0.022 if unadjusted)
Lateral, complex tear type	7 (12.1%)	9 (22.0%)	0.561*
Cartilage injury	9 (7.6%)	12 (13.5%)	0.167

*adjusted for age

in that they were slightly older (28.7 years vs. 23.1 years, P=0.001), had higher BMI (27.1 kg/m^2 vs. 25.3 kg/m^2, P<0.001), and more frequently underwent revision ACL-R procedures (29.9% vs. 7.8%, P<0.001) (Table 1a). No graft type was used disproportionately between the acute and chronic groups (P>0.05 for all comparisons). The mechanism of injury was more commonly due to a sports injury in the acute surgical group compared to the chronic group (80.4% vs. 61.4%, P<0.001). The median time from injury to surgery for the entire cohort was 37 days (range: 4-855 days). The median time to acute surgical reconstruction was 25 days (range: 4-41 days) and to chronic ACL-R was 88.5 days (range: 43-855 days).

After excluding patients undergoing revision ACL-R and those with complex meniscus tears, there were 118 patients in the acute group and 89 patients in the chronic group (Table 1b). The demographic trends in this group were similar to those in the entire cohort except that allograft (21.4% vs. 10.2%, P=0.026) and bone-patellar tendon-bone graft (26.3% vs. 13.5%, P=0.025) were more commonly used in the acute group compared to the chronic group. The difference in age between patients with complex tears in chronic ACL-R was also greater than those with complex tears in the acute ACL-R group (36.7±3.4 vs. 24.6±1.4). The median time to acute ACL-R was 24 days (range: 4-41 days) and to chronic ACL-R was 87.5 days (range: 44-768 days) for those undergoing primary surgery.

Does the timing of surgical intervention influence intra-articular pathology at the time of ACL-R?

Meniscal pathology was evaluated at the time of ACL-R for the entire cohort (Table 2a). There were similar numbers of meniscal tears in the acute and chronic surgical groups (65.6% vs. 60.6%, P=0.41) with no differences between the medial (30.5% vs. 34.9%, P=0.45, respectively) and lateral sides (40.9% vs. 40.2%, P=0.28, respectively). Although the tear lengths were longer in the chronic group, the difference was not significant (medial- 17.5 vs. 11.5 mm, P=0.74; lateral- 10.6 vs. 8.4 mm, P=0.68). Complex tears, however, were more frequently observed in both the medial and lateral compartment for patients undergoing chronic ACL-R (medial- 37.2% vs. 7.7%, P=0.003; lateral- 21.2% vs. 13.3%, P=0.022). After correcting for patient age, complex medial meniscus tears were still identified more frequently in patients undergoing chronic ACL-R (P=0.012), although this difference was no longer appreciated for complex tears in the lateral compartment (P=0.922). Chondral injury also occurred more frequently for patients undergoing chronic ACL-R with more areas of Outerbridge grade III and IV chondromalacia noted in the chronic group (16.5% vs. 7.8%, P=0.03).

After revision ACL-R procedures were excluded (Table 2b), complex tears in the medial compartment in chronic ACL-R were higher than in acute ACL-R (27.3% vs. 3.0%, P= 0.022). After this was adjusted for age, chronic complex medial meniscus tears observed in primary ACL-R did not significantly outnumber those observed in acute primary ACL-R (P=0.056). Chondral injury in the chronic surgical group was no longer significantly greater than that in the acute surgical group (13.5% vs. 7.6%, P=0.167).

Was the operative decision influenced by time from injury?

Operative decisions with respect to meniscus treatment were analyzed in the setting of acute and chronic primary ACL-R (Table 3a). Medial meniscus repair rates

Table 3a. Operative Decisions in Acute and Chronic Primary ACL-R

	<6 weeks	>6 weeks	P value
Medial			
Meniscectomy	7 (21.2%)	15 (45.5%)	0.037
Repair	20 (60.6%)	8 (24.2%)	0.003
Lateral			
Meniscectomy	19 (32.8%)	19 (46.3%)	0.171
Repair	17 (29.3%)	9 (22.0%)	0.412

Table 3b. Operative Decisions in Acute and Chronic Primary ACL-R with Complex Tears Excluded

	<6 weeks	>6 weeks	P value
Medial			
Meniscectomy	7 (21.9%)	7 (29.2%)	0.533
Repair	19 (59.4%)	8 (33.3%)	0.054
Lateral			
Meniscectomy	15 (29.4%)	15 (46.9%)	0.107
Repair	16 (31.4%)	7 (21.9%)	0.347

were higher in the acute surgical group compared to the chronic surgical group (60.6% vs. 24.2%, P=0.003). Meniscectomy rates were higher in the chronic reconstruction group relative to the acute surgical group (45.5% vs. 21.2%, P=0.037). When complex tears were excluded from analysis (Table 3b), medial meniscus repair rates in the acute surgical group were no longer different than those in the chronic surgical group (59.4% vs. 33.3%, P=0.054). Additionally, meniscectomy rates showed no difference (P=0.533).

DISCUSSION

This study examines the differences in intra-articular concomitant pathology for patients undergoing acute or chronic ACL-R. The key findings of this study include a higher prevalence of complex medial meniscus tears in the chronic ACL-R group and a higher rate of medial meniscus repair in the acute ACL-R group. However, these differences diminish when the effect of age is considered and revision ACL-Rs are excluded.

The demographic characteristics of the acute and chronic surgical cohorts were compared to better understand potential factors contributing to increased pathology with delayed surgical reconstruction. Although the overall age of the cohort was relatively young, the chronic surgical group was older than the acute surgical group by over five years. Moreover, the average age of the primary ACL-R group with chronic complex tears was greater than 10 years older than that of the acute ACL-R cohort with complex tears, suggesting that age may play a significant role in predicting complex tear development. As has been previously noted, age alone may serve as a risk factor for meniscal pathology and chondral injury.[17] These demographic trends illustrate the difficulty in isolating the effect of acute or chronic ACL-R because patients in the chronic surgical cohort are often older and have lower activity levels than those in the acute surgical cohort.

Additionally, the number of revision ACL-R procedures included in the delayed surgical group was higher than in the acute surgical group. Knees undergoing revision ACL reconstructions more frequently have concomitant intra-articular injuries than knees undergoing primary reconstruction.[19-21] We subsequently performed a subgroup analysis in which we excluded revision procedures to mitigate any selection bias towards increased intra-articular pathology in the chronic group and demonstrated a greater incidence of medial meniscus complex tears in chronic ACL-R compared to acute ACL-R.

In regard to the frequency of concomitant pathology, there was a greater prevalence of complex medial and lateral meniscus tears in patients undergoing chronic ACL-R. The increased incidence of complex medial meniscus tears persisted when correcting for age. Moreover, when subgroup analysis was performed with revision procedures excluded, a statistically significant higher rate of complex medial meniscus tears was observed for patients undergoing primary ACL-R in the chronic setting (P= 0.022). However this was no longer observed after correcting for patient age (P=0.056). Although this did not reach significance, the difference should be at least considered in this specific cohort of primary ACL-Rs. This finding suggests that patient age plays an important role in predicting development of intra-articular pathology following ACL rupture. Further studies with larger sample size are required in order to properly evaluate this relationship. There was no difference in the prevalence of complex tears observed in the lateral meniscus between the acute and chronic surgical groups when revision procedures were excluded. Our findings are supported by Church et al., who demonstrated an association between delayed surgical intervention, defined as taking place 12 months after an injury, and an increased frequency of medial meniscus tears.[22] Our study suggests that intra-articular pathology in the knee develops in chronic ACL injuries. However, this may in part be due to the higher frequency of revision ACL-R procedures being performed in the chronic setting, as suggested by subgroup analysis.

Intra-articular cartilage injury was noted to be greater in the chronic group when revision procedures were included. However, this trend did not persist when revision procedures were excluded. This finding is supported by Borchers et al, who showed that there is an increased odds ratio of Outerbridge grade III or IV articular cartilage injury at the time of revision ACL-R compared with primary ACL-R in the lateral and patellofemoral compartments.[20] Our findings, along with this study, suggest that there is likely progression of chondral damage following failed primary ACL-R. Moreover, Krutsch et al. published a study that showed no significant difference in chondral pathology between early and delayed ACL repair, using a time point of six months as a cutoff.[23] Our findings further support the idea that chondral injury may not be exacerbated by delayed intervention, although it does appear to occur more frequently in the revision setting.

Our study reported that meniscal treatment decisions differed between the acute and chronic primary ACL-R surgical cohorts. We found that the medial meniscus was more frequently repaired in the acute group compared to the chronic group while meniscectomy rates were higher in the chronic surgical cohort. After complex tears were excluded, which are historically considered irreparable by many surgeons, meniscal repair rates and meniscectomy rates were no longer different between the acute and chronic surgical groups. Differences in medial meniscus repair rates between the acute and chronic groups did not achieve statistical significance when complex tears were excluded (P=0.054), but were noted to be higher in the acute surgical cohort. Krutsch et al reported that medial meniscus lesions had significantly higher repair rates in early intervention, defined as undergoing surgery within six months of injury, compared to delayed ACL-R.[22] Meniscectomy rates were no longer higher in the acute ACL-R group compared to the chronic group after excluding complex tears. This is most reasonably explained by the fact that complex tears are indicated for treatment with meniscectomy and were more prevalent in the chronic ACL-R cohort. Age was not stratified in this group, however it is likely that the younger age of the acute surgical cohort influenced the surgeon's decision to repair the meniscus rather than perform a meniscectomy. As previously discussed, age, BMI, and revision ACL procedures may serve as risk factors for increased intra-articular pathology in this cohort, and further study into these potential risk factors is warranted.

There are several important limitations to consider. First, the paucity of follow-up data in this cohort makes it difficult to speculate about the utility of different treatment decisions. The time-zero analysis elucidates a number of interesting findings about meniscal pathology as it relates to injury chronicity, but it fails to provide information on outcomes of surgical intervention. Long-term follow-up data is required in this cohort in order to suggest further benefit to acute surgical intervention. The results of this single-institution study make for a smaller sample size than a large, multicenter study. A higher-powered study may reveal an increased prevalence of complex tears in the medial meniscus and lower medial meniscus repair rate associated with chronic ACL-R. Additionally, this study was performed at a single institution, thus the results are less generalizable. Moreover, the treatment decisions in this study were not randomized. Activity level of patients has been shown to influence outcomes. While subjective activity levels were not reported in the present study, injuries were characterized as sporting or non-sporting injury, which may at least suggest the activity level of the patients. While our study cannot identify all risk factors for development of chondral damage following primary ACL-R, it emphasizes the importance of further study on the effect of surgical timing on chondral injury in the ACL deficient knee. Finally, the five surgeons involved in the study controlled the graft selection as well as the decision to repair the meniscus or perform meniscectomy. While treatment decisions were not randomized, the ability of surgeons to classify meniscal pathology and render potential treatment decisions is reported to be relatively consistent.[17]

CONCLUSIONS

The present study identified a greater prevalence of complex medial meniscus tears and chondral injury associated with chronic ACL-R. These findings diminished when primary ACL-Rs were exclusively examined and corrected for age. Despite the inability to fully randomize treatment decisions at the time of ACL-R, the present study found that medial meniscus tears were more frequently considered reparable in patients undergoing acute ACL-R. However, when complex tears were excluded from analysis, this trend was no longer found to be significant. While further follow-up of these treatment decisions is warranted, consideration should be given to early surgical intervention for patients undergoing operative treatment of ACL injuries in order to allow for meniscal preservation.

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THE EFFECT OF NON-STEROIDAL ANTI-INFLAMMATORY DRUGS ON TENDON-TO-BONE HEALING: A SYSTEMATIC REVIEW WITH SUBGROUP META-ANALYSIS

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ABSTRACT

Background: There is some concern that non-steroidal anti-inflammatory drugs (NSAIDs) may impair the healing of certain musculoskeletal tissues. However, the effect of NSAIDs on the specialized fibrocartilaginous transition at the tendon-to-bone interface remains largely unknown. Thus, the purpose of the present study is to investigate the effect of NSAIDs on tendon-to-bone healing following acute injury or surgery.

Methods: A systematic review was performed according to the 2009 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The PubMed (MEDLINE), Embase, Cumulative Index to Nursing and Allied Health (CINAHL), and SportDiscus databases were searched from the time of database inception to May 14, 2018 to identify all clinical and basic science studies investigating the effect of NSAIDs on tendon-to-bone healing. Methodological quality was assessed using the Methodological Index for Non-Randomized Studies (MINORS) and SYstematic Review Center for Laboratory animal Research (SYRCLE) risk of bias assessment tools for clinical and basic science studies, respectively. A qualitative synthesis of the literature was performed with a subgroup meta-analysis of homogeneous basic science studies.

Results: A total of 13 studies, including three clinical and 10 basic science studies, were included. The overall methodological quality of the included clinical studies was poor, while assessment of the basic science studies revealed consistent areas at high or unclear risk of bias. Of the included clinical studies, a single study reported a higher rate of rotator cuff repair failure with selective (COX-2) NSAID use compared with non-selective NSAID use, while no clinical failures were noted with NSAID use following distal biceps tendon repair. Basic science studies had heterogeneous outcome reporting. A subgroup analysis of homogeneous animal studies revealed no significant effect of all NSAIDs (Standard Mean Difference [SMD] -1.05, 95% Confidence Interval [CI] -2.39-0.30, p=0.13) or non-selective NSAIDs on load to failure (SMD -0.62, 95% CI -1.26-0.02, p=0.06).

Conclusions: The current literature does not provide sufficient evidence for or against the use of NSAIDs following acute injury or surgical repair of the tendon-bone interface.

Level of Evidence: IV

Keywords: bone healing, tendon healing, nsaid, non-steroidal anti-inflammatory drugs

INTRODUCTION

Acute and chronic injuries to the tendon-bone interface are a common cause of pain and dysfunction.[1-4] While a myriad of surgical procedures aimed at re-establishing the complex tendon-to-bone interface at various anatomic locations have been described for both acute and chronic conditions,[5-9] surgery fails to fully restore the unique composition and mechanical properties of the native tendon-to-bone interface.[10-13] In hopes of better recreating the native tendon-to-bone interface following surgical intervention, local biologic augmentation,[14-19] systemic pharmacotherapy,[20-22] and avoidance of pharmaceuticals that may inhibit tendon-to-bone healing[23] have been proposed as potential options to improve healing at the tendon-bone interface. However, consistent high-level evidence to support their clinical use is lacking.

Nonsteroidal anti-inflammatory drugs (NSAIDs) are frequently used for their analgesic and anti-inflammatory properties in acute and chronic musculoskeletal conditions. While there is some concern that NSAIDs may impair the healing of certain musculoskeletal tissues, including bone and tendon in isolation,[24-28] the effect of NSAIDs on the specialized fibrocartilaginous transition at the tendon-to-bone interface remains largely unknown.

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Table 1. Selectivity of Included NSAIDs

Non-Selective	Selective
Diclofenac	Celecoxib
Flubiprofen	Parecoxib
Ibuprofen	Valdecoxib
Indomethacin	
Licofelone*	
Meloxicam	
Naproxen	
Piroxicam	

NSAID, Non-steroidal anti-inflammatory drug
*Combined cyclooxygenase/lipoxygenase (COX/LOX) inhibitor

Definitively determining the potentially negative effect of NSAIDs on tissue healing is further complicated by the different mechanism of action of NSAIDs at the cellular level, including cyclooxygenase-1 (COX-1) and/or cyclooxygenase-2 (COX-2) inhibition,[29] and the temporal relationship between drug administration and healing.[26, 30, 31]

To date, there remains no consensus within the literature as to the effect of NSAIDs on tendon-to-bone healing. While NSAIDs have been used postoperatively following orthopaedic procedures to limit inflammation,[32] heterotopic ossification,[33, 34] and pain, thus reducing opioid demand,[35, 36] these beneficial uses must be considered in light of the potentially deleterious effect on healing. The purpose of the current review is to investigate the effect of NSAIDs specifically on tendon-to-bone healing by systematically reviewing the available basic science and clinical literature.

METHODS

This study was performed according to the suggested methods within the *Cochrane Handbook for Systematic Reviews of Interventions*[37] and reported using the 2009 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[38]

Study Eligibility

Inclusion criteria were established *a priori* and included the following: all English-language, full-text, original clinical or basic science studies investigating tendon-to-bone healing in the acute injury or surgical setting that utilized NSAIDs as part of a defined post-injury or postoperative protocol, reported a clinical, biochemical, and/or biomechanical assessment of healing, and utilized a co-culture model consisting of bone or osteoprogenitor cells and tenocytes or fibroblasts for *in vitro* studies.

Exclusion criteria included the following: non-English studies, case reports, review articles, editorials, letters to the editor, studies using only survey data, studies that failed to report a clinical, biochemical, and/or biomechanical assessment of healing, *in vitro* studies using isolated tenocyte or fibroblast cultures, studies describing the effect of NSAIDs on intra-tendinous healing after acute injury or surgery, isolated muscle healing, studies describing the effect of NSAIDs following nonoperative management of chronic or degenerative tendon conditions, studies that included surgical procedures that did not aim to repair the tendon of interest to its normal anatomic footprint, such as tendon transfer or anterior cruciate ligament reconstruction, and studies that did not provide a clear description or protocol for post-injury or postoperative NSAID utilization (type, duration, and/or dose).

Search Strategy

Independent searches of the PubMed (MEDLINE), Embase, Cumulative Index to Nursing and Allied Health (CINAHL), and SportDiscus databases were performed using optimized search strategies for each database (Appendix 1). All searches were performed from the time of inception of the database of interest through May 14, 2018. After completing the search, duplicates were removed and an abstract and title screen performed. A full-text review was then performed independently by three authors (KRD, DBL, SHP). In the event of a disagreement between the three independent reviewers, the senior author (JCR) made the final decision on study inclusion. References in the reviewed manuscripts and review articles identified during the search were scrutinized to identify any studies not captured by the initial search parameters.

Quality Assessment of Included Studies

Included randomized clinical studies were evaluated for bias using the Cochrane Collaboration's bias assessment tool for randomized clinical trials.[39] All non-randomized clinical studies were evaluated for bias using the Methodological Index for Non-Randomized Studies (MINORS) scoring system.[40] The MINORS scoring system allows a score to be assigned to non-randomized studies, with a higher score indicating less bias. Using the MINORS scoring system, the highest possible score for non-comparative and comparative clinical studies is 16 and 24, respectively. MINORS scores were provided as an absolute point value as well as a percentage of the total possible score.

All included animal studies were evaluated for bias using the SYstematic Review Center for Laboratory animal Research (SYRCLE) risk of bias assessment tool,[41] an adaption of the Cochrane Collaboration's bias assessment tool for randomized clinical trials.[39] The SYRCLE bias assessment tool asks 10 questions which are scored as "yes", "no", or "unclear", with "yes" answers indicating

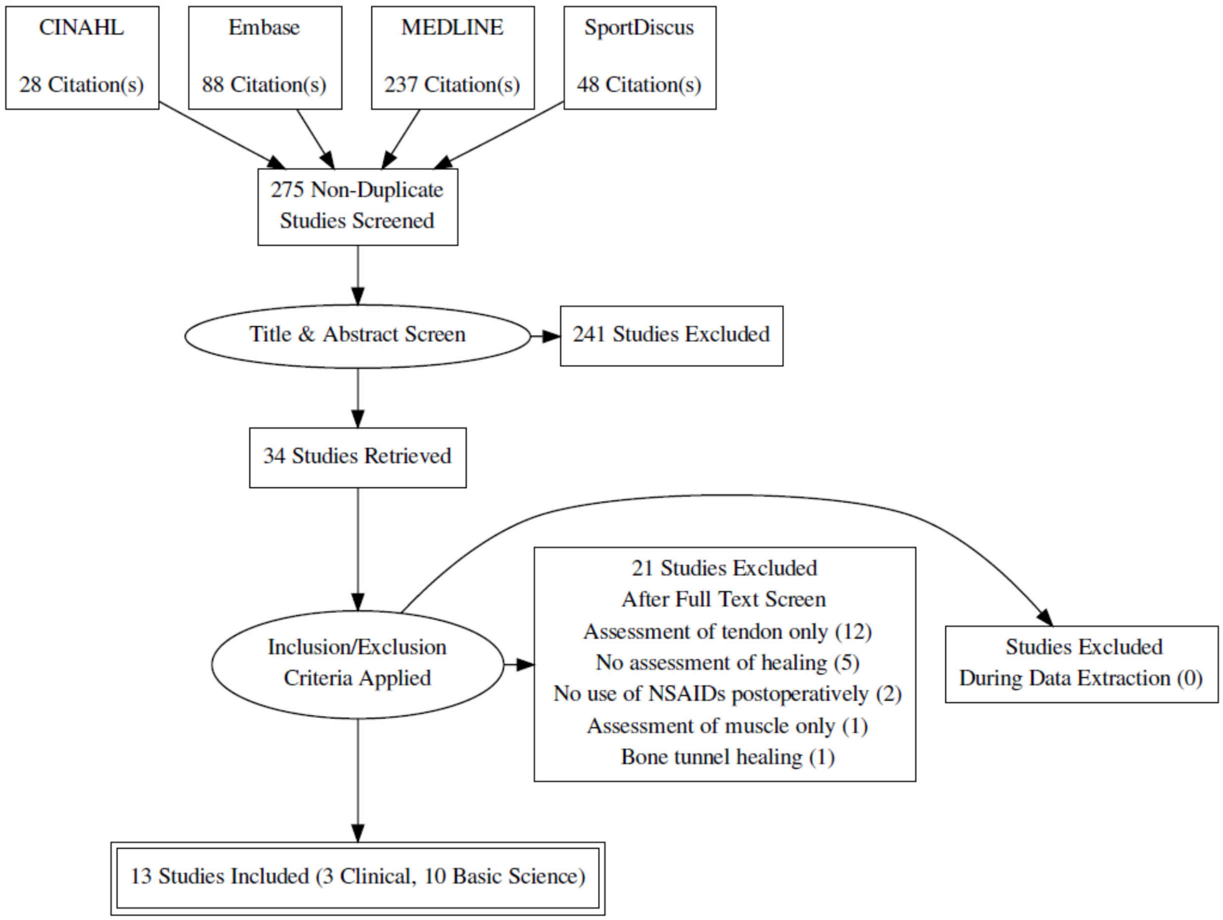

Figure 1. PRISMA flowchart for systematic study inclusion.

a low risk of bias, "no" answers indicating a high risk of bias, and "unclear" answers indicating insufficient details to adequately assess.

To date, there are no validated or consistently utilized risk of bias assessment tools for *in vitro* studies, including the *in vitro* co-culture studies included in this systematic review.

Data Abstraction

Data from all included studies were abstracted independently by three reviewers (KRD, DBL, SHP) and organized within Excel (Microsoft Corp., Redmond, WA). Studies were classified as "clinical" or "basic science" with basic science studies further categorized as "animal" or "*in vitro*". In addition to categorization by the generic pharmaceutical name, NSAIDs were further categorized as "non-selective" (COX-1 and COX-2 inhibition) or "selective" (COX-2 inhibition) based on the mechanism of action defined within the National Institute of Health's PubChem database[42] (Table 1). If a study included multiple treatment arms, only arms that investigated the effect of an NSAID in isolation were abstracted. Clinical studies were also categorized according to level of evidence.[43] Ultimately, data elements that were reported by at least three studies were included for qualitative and/or quantitative analysis, where appropriate.

Statistical Analysis

Due to the limited number, low level of evidence, and heterogeneity of clinical and *in vitro* studies, outcomes of interest were described with a qualitative synthesis. Similarly, a high degree of heterogeneity and inconsistency of outcomes reporting was noted in the included animal studies. However, a small subset of animal studies, specifically studies investigating the effect of a variety of NSAIDs on the load to failure of acute rotator cuff repair in an established rat model, were homogeneous in nature and meta-analysis was performed using a random effects model with inverse variance weighting. Standardized mean difference was used as the summary statistic to account for measurement and unit variability between studies. For the meta-analysis, if a study included multiple NSAID treatment arms, arms were combined to allow a single pairwise comparison to the control arm

Table 2. Clinical Study Characteristics

Author (Year)	Study Design (LOE)	Intervention	Sample Size	Age ± SD	NSAID	Dose	Initiation	Duration (days)*	Follow-up (mths)	Repair Assessment	Failures†
Anakwenze (2011)	Case Series (IV)	Distal Biceps Repair	34	45.6	Indomethacin	75 mg QD	POD 0	42	6-102‡	Clinical	0 (0%)
Costopoulos (2017)	Retrospective Comparative (III)	Distal Biceps Repair	104	50.3 ± 20.0	Indomethacin	75 mg QD	POD 0	10-42	NA	Clinical	0 (0%)
Oh (2018)	Randomized Controlled Trial (I)	Rotator Cuff Repair	30	NA	Celecoxib	200 mg BID	POD 1	14	24 ± 2‖	MRI/US	11 (36.7%)
			27	NA	Ibuprofen	385 mg TID	POD 1	14		MRI/US	2 (7.4%)

LOE, Level of Evidence; SD, Standard Deviation; NSAID, Non-steroidal Anti-inflammatory Drug; mths, Months; QD, Daily; BID, Twice Daily; TID, Three Times Daily; POD, Postoperative Day; NA, Not Available; MRI, Magnetic Resonance Imaging; US, Ultrasound

*Duration of NSAID administration; †Listed as number (percent); ‡Listed as range; ‖Listed as mean ± standard deviation

using weighted means and standard deviations, thus preventing a unit-of-analysis error.[37] Additionally, only treatment arms that initiated NSAID therapy immediately postoperatively (postoperative day zero or one) were included in the meta-analysis. If a study evaluated load to failure at multiple timepoints, only the latest (farthest from surgery) timepoint was included (range, 28-56 days). Separate meta-analyses were performed to include all NSAIDs (selective and non-selective) as well as only non-selective NSAIDs. Due to insufficient studies, a separate analysis was not performed for only selective NSAIDs. Descriptive statistics were prepared using IBM SPSS for Windows, version 25 (IBM Corp., Armonk, N.Y., U.S.A) and meta-analysis performed using Review Manager version 5.3 (The Cochrane Collaboration, Copenhagen, Denmark). Statistical comparisons with p-values <0.05 were considered statistically significant.

RESULTS

Search Strategy

The initial search yielded 401 studies, with 126 studies immediately removed as duplicates, leaving 275 studies available for review (Figure 1). No studies were identified from other sources. After systematic screening, a total of 13 studies, including three clinical[22, 44, 45] and 10 basic science studies,[21, 23, 28, 31, 46-51] met the inclusion and exclusion criteria.

Clinical Studies

Study Characteristics

The effect of NSAIDs on rotator cuff repair was reported in a single study[22] while distal biceps repair was assessed in two studies.[44, 45] Both celecoxib and ibuprofen were evaluated in separate treatment arms in the rotator cuff repair study while both distal biceps repair studies used indomethacin 75 mg daily as the postoperative NSAID for heterotopic ossification prophylaxis (Table 2). All clinical studies initiated NSAIDs immediately postoperatively, continuing for 14 days postoperatively following rotator cuff repair and ranging from 10-42 days following distal biceps repair. In the rotator cuff repair study by Oh et al., tendon-to-bone healing was a secondary outcome, and only 82/180 patients (45.6%) were assessed for healing using magnetic resonance imaging (MRI) or ultrasound at 24 ± 2 months postoperatively. Further demographic data for the subset of patients undergoing healing assessment was not reported.[22] The mean age of patients in the included distal biceps repair studies was 45.6[44] and 50.3[45] years, with follow-up duration described in a single study (range, 6-102 months).[45]

Quality Assessment of Clinical Studies

The rotator cuff repair study by Oh et al. was the only included randomized controlled trial (level I evidence) for the primary outcome of early postoperative pain. However, methodological quality was poor for the secondary outcome of tendon-to-bone healing given incomplete reporting of the secondary outcome and high risk of bias with selective reporting of the outcome (Figure 2). Scores for risk of bias assessment for non-randomized studies measured using the MINORS scoring system were 8 and 16 for the non-comparative[44] and comparative[45] studies investigating distal biceps repiar, representing 50.0% and 66.7% of the total possible MINORS score, respectively. The study by Costopoulos et al. was originally designed as a retrospective comparative study (level III evidence)[45] for the primary endpoint, development of heterotopic ossification, while the study by Anakwenze et al. was a case series (level IV evidence).[44]

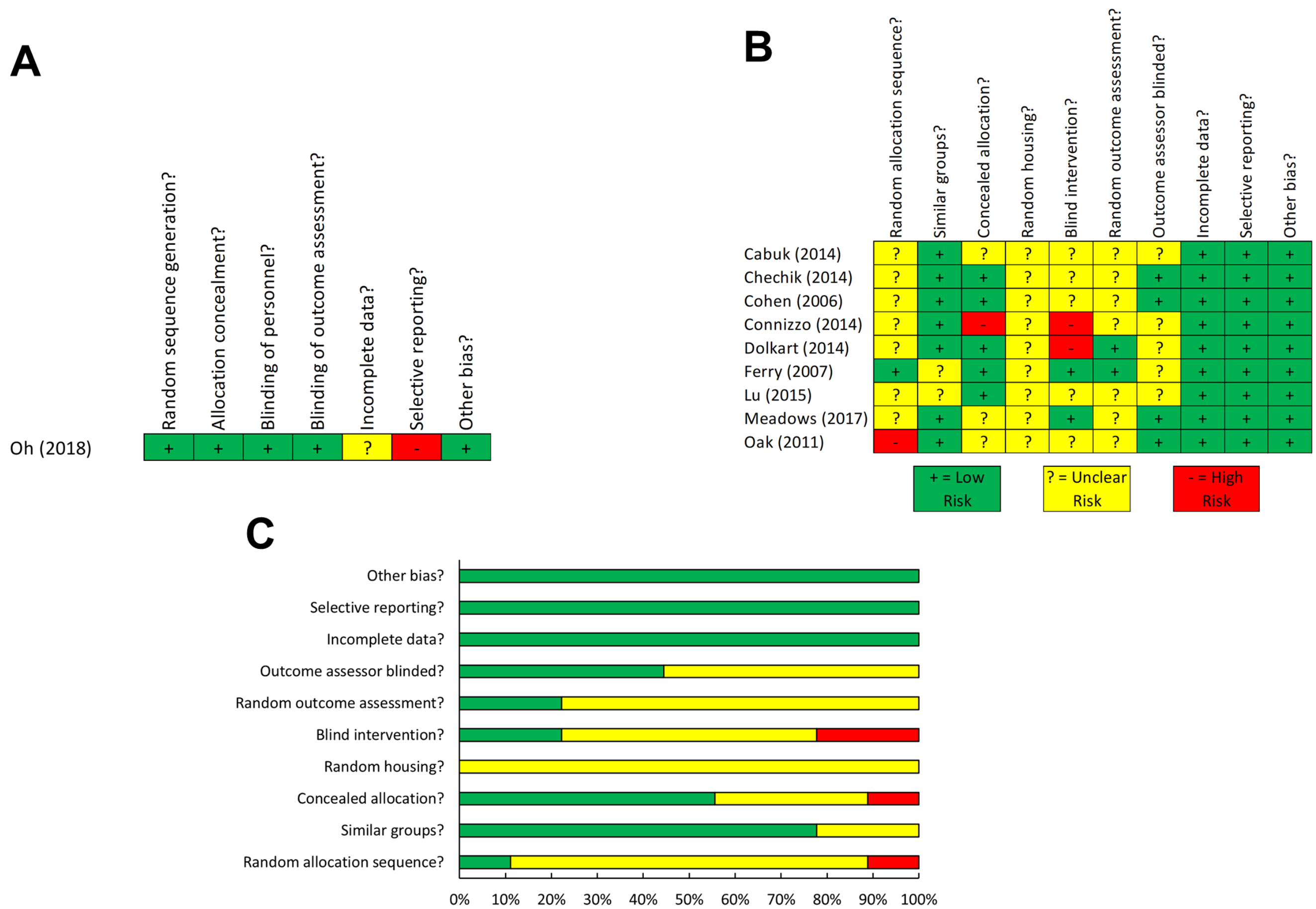

Figure 2. Risk of bias assessment for a) randomized controlled clinical trials and b) animal basic science studies c) The proportion of animal basic science studies with various forms of bias.

Clinical Study Outcomes

The method of assessing tendon-to-bone healing in the rotator cuff repair study was a combination of MRI and ultrasound. Overall, 2/27 patients (7.4%) receiving ibuprofen postoperatively and 11/30 patients (36.7%) receiving celecoxib postoperatively experienced clinical failures at the tendon-to-bone interface. The rate of failure was significantly higher with postoperative celecoxib use compared with ibuprofen and the control arm of patients receiving tramadol. The method of assessing tendon-to-bone healing in both distal biceps repair studies was limited to a clinical assessment. In aggregate, none of the 138 distal biceps patients receiving NSAIDs postoperatively experienced a clinical failure, nor did any of the eight patients in the control arm of the study by Costopoulos et al.[45]

Basic Science Studies

Study Characteristics

Of the 10 included basic science studies, nine were categorized as animal studies[21, 23, 28, 31, 46-49, 51] and one as an *in vitro* study[50] (Table 3). Within the animal studies, acute rat rotator cuff repair was used as the model in six studies,[21, 23, 28, 31, 46, 51] acute rabbit rotator cuff repair in a single study[48], chronic rat rotator cuff repair in a single study,[49] and acute rat patellar tendon repair in a single study.[47] All basic science studies included a control arm, six included a single NSAID treatment arm,[21, 28, 31, 46, 49, 51] and four included multiple NSAID treatment arms.[23, 47, 48, 50] Overall, 11 different NSAIDs were investigated, with celecoxib (4/10 studies)[21, 23, 47, 48] and ibuprofen (3/10 studies)[28, 47, 48] the most frequently studied NSAIDs. All animal studies included treatment arms with immediate initiation of NSAIDs postoperatively (postoperative day zero or one), while two animal studies additionally included treatment arms that delayed NSAID treatment until postoperative day eight[28] and 11.[31] The duration of NSAID therapy within the studies ranged from 7-42 days. All animal studies performed biomechanical assessment of healing, three studies performed biochemical assessment of healing,[46, 47, 49] and six performed a histologic assessment.[23, 28, 31, 47-49] Within the animal studies, the final assessment of

Table 3. Basic Science Study Characteristics

Author (Year)	Model	NSAID	Initiation	NSAID Duration (days)	Euthanasia (days)
Animal Studies					
Cabuk (2014)	Acute Rat RCR	Diclofenac	POD 0	Euthanasia*	7; 21; 42†
Chechik (2014)	Acute Rat RCR	Meloxicam	POD 0	10	21
			POD 11	10	21
Cohen (2006)	Acute Rat RCR	Celecoxib	POD 0	14	14; 28; 56†
		Indomethacin	POD 0	14	14; 28; 56†
Connizzo (2014)	Acute Rat RCR	Ibuprofen	POD 0	7	7; 14; 28†
			POD 8	7	14; 28†
Dolkart (2014)	Acute Rat RCR	Celecoxib	POD 1	20	21
Ferry (2007)	Acute Rat PTR	Celecoxib	POD 0	14	14
		Ibuprofen	POD 0	14	14
		Naproxen	POD 0	14	14
		Piroxicam	POD 0	14	14
		Valdecoxib	POD 0	14	14
Lu (2015)	Acute Rabbit RCR	Celecoxib	POD 0	7	21; 42; 84†
		Flurbiprofen	POD 0	7	21; 42; 84†
		Ibuprofen	POD 0	7	21; 42; 84†
Meadows (2017)	Acute Rat RCR	Indomethacin	POD 0	14	21
Oak (2011)	Chronic Rat RCR	Licofelone	POD 0	14	14
In Vitro Studies					
Schwarting (2015)	Co-Culture	Ibuprofen	Immediate	NA	NA
		Parecoxib	Immediate	NA	NA

NSAID, Non-steroidal anti-inflammatory drug; RCR, Rotator cuff prepair; PTR, Patellar tendon repair;
POD, Postoperative day; NA, Not available
*NSAID administration continued until euthanasia timepoint(s); †Multiple timepoints assessed

healing was performed 14-84 days after surgery, with four studies investigating multiple timepoints.[23, 28, 46, 48] In the *in vitro* experiment, a biochemical assessment of healing was reported using a variety of assays.[50]

Quality Assessment of Animal Studies

All studies had components at high risk or unclear risk of bias using the SYRCLE risk of bias assessment tool (Figure 3). Incomplete reporting of data, selective reporting of data, and other types of bias were consistently at lowest risk of bias, while random sequence allocation, blinding of intervention to investigators, and random housing assignments were most consistently at unclear or high risk of bias.

Animal Study Outcomes

Biomechanical outcomes were most consistently reported, with load to failure, stiffness, cross-sectional area, and maximum stress reported by at least three studies. Comparative results of the studies, which included 18 total treatment arms, are listed in Table 4.[21, 23, 28, 31, 46-49, 51] Of these studies, four studies (8/18 treatment arms)[23, 31, 47, 48] reported a decrease in load to failure with NSAID administration when compared with the control arm at the latest follow-up. Delayed NSAID administration (postoperative day 11) resulted in decreased load to failure in a single study when compared with the control arm,[31] while another study investigating delayed NSAID administration revealed no effect on load to failure with delayed administration.[28] Of the 18 treatment arms, 13 investigated non-selective NSAIDs,[23, 28, 31, 46-49, 51] with 4/13 (30.8%) demonstrating a decrease in load to failure compared with control arms.[23, 31, 47, 48] Five treatment arms investigated selective NSAIDs,[21, 23, 47, 48] with 4/5 (80.0%) demonstrating a decrease in load to failure.[23, 47, 48] In the subgroup meta-analysis,[23, 28, 46] load to failure was not sig-

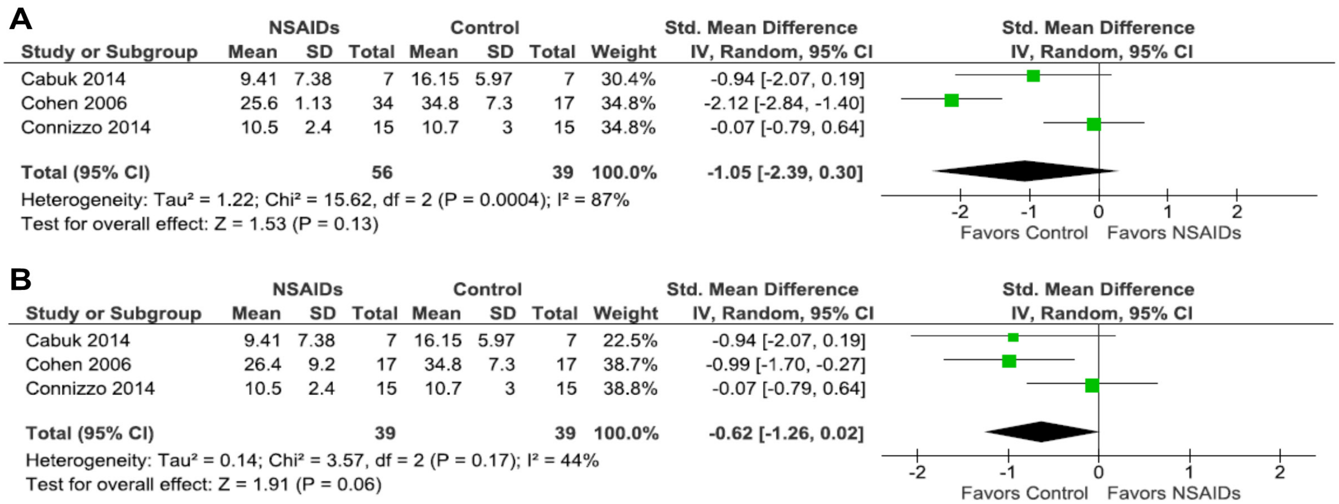

Figure 3. Forest plot comparing postoperative administration of non-steroidal anti-inflammatory drugs (NSAIDs) with controls for homogeneous studies (acute rat rotator cuff repair) using a) any NSAID and b) non-selective NSAIDs.

nificantly affected when comparing the use of all NSAIDs (Standard Mean Difference [SMD] -1.05, 95% Confidence Interval [CI] -2.39-0.30, p=0.13) or non-selective NSAIDs (SMD -0.62, 95% CI -1.26-0.02, p=0.06) with controls (Figure 3). Of the eight studies reporting results on stiffness,[21, 23, 28, 31, 46, 47, 49, 51] including 15 treatment arms, stiffness was significantly reduced in 2/15 treatment arms (13.3%), both of which included immediate administration of non-selective NSAIDs. Tendon cross-sectional area was decreased following NSAID administration in 1/10 treatment arms (10%) in the four studies reporting data,[23, 28, 47, 49] while maximum stress was decreased following NSAID administration in 2/11 treatment arms (18.2) in the four studies reporting data.[21, 28, 47, 49] Histologic outcomes were reported in six studies.[23, 28, 31, 47-49] Collagen orientation was reported in four studies, including 11 treatment arms,[23, 28, 31, 47] and was the only histologic metric to warrant qualitative synthesis. At the latest assessed timepoint, NSAID administration resulted in significantly poorer collagen orientation in 3/11 treatment arms (27.3%) when compared with control arms. Biochemical outcomes were only reported in three studies,[46, 47, 49] and there were no consistently reported biochemical metrics between studies to warrant qualitative synthesis.

In vitro Study Outcomes

A single *in vitro* study reported biochemical, cell viability, and cell migration results in a tendon-bone co-culture model using mouse MC3T3-E1 pre-osteoblasts and 3T3 fibroblast cell lines. Both ibuprofen and parecoxib were investigated. Ibuprofen led to reduced expression of bone gamma-carboxyglutamate protein (*Bglap*) within the osteoblasts and reduced expression of runt-related transcription factor (*Runx2*) within the osteoblast, fibroblast, and interface regions. Parecoxib similarly reduced *Runx2* expression in all three regions while also reducing alkaline phosphatase (*Alp1*) and fibromodulin (*Fmod*) expression in all three regions. Ibuprofen administration resulted in a dose-dependent decrease in viability of osteoblasts, while parecoxib decreased viability in fibroblasts in a non-dose-dependent fashion. Both ibuprofen and parecoxib administration led to increased cell migration from the osteoblast region into the interface region compared with control cultures.

DISCUSSION

Orthopaedic procedures to re-establish the tendon-to-bone interface are some of the most frequently performed ambulatory surgery procedures in the United States.[52, 53] Thus, optimizing the outcomes of these procedures would serve to positively affect a large patient population. As highlighted by this review, the current literature on the effect of NSAIDs on tendon-to-bone healing is limited, not only when measured by the number of available publications, but also when considering the methodological quality of the available clinical and basic science studies. Furthermore, translating the more readily available basic science studies, most of which utilize an acute rotator cuff repair model, to clinical practice poses several challenges that must be considered before drawing strong conclusions as to the effect of NSAIDs on tendon-to-bone healing.

The dilemma to use or prohibit NSAIDs following surgical repair of the tendon-bone interface may best be illustrated by considering rotator cuff repair. Due to the relatively high failure rate following repair of large and massive rotator cuff tears,[54-56] there has been a great deal of focus on optimizing the biomechanical and biologic environment to allow restoration of the unique proper-

Table 4. Comparison of Relevant Treatment Outcomes to Controls in Animal Studies

Author (year)	NSAID	Load to Failure	Stiffness	Cross-Sectional Area	Maximum Stress	Collagen Orientation
Cabuk (2014)	Diclofenac	↔	↓			
Chechik (2014)	Meloxicam - T0	↔	↔			↔
	Meloxicam - T1	↓	↔			↓
Cohen (2006)	Celecoxib	↓	↔	↔		↓
	Indomethacin	↓	↔	↓		↓
Connizzo (2014)	Ibuprofen - T0	↔	↓	↔	↔	↔
	Ibuprofen - T1	↔	↔	↔	↔	↔
Dolkart (2014)	Celecoxib	↔	↔		↔	
Ferry (2007)	Celecoxib	↓	↔	↔	↓	↔
	Ibuprofen	↔	↔	↔	↔	↔
	Naproxen	↔	↔	↔	↔	↔
	Piroxicam	↓	↔	↔	↓	↔
	Valdecoxib	↓	↔	↔	↓	↔
Lu (2015)	Celecoxib	↓				
	Flurbiprofen	↓				
	Ibuprofen	↔				
Meadows (2017)	Indomethacin	↔	↔			
Oak (2011)	Licofelone	↑	↑	↔	↑	

NSAID = Non-steroidal anti-inflammatory drug; T0 = immediate administration; T1 = delayed administration
↔ = statistical equivalence to control; ↓ = statistical decrease compared with control; ↑ = statistical increase compared with control

ties of the enthesis. Despite the lack of evidence, this concern may cause some providers to avoid the use of NSAIDs following procedures such as rotator cuff repair that are already at a high risk of structural failure. This approach is at odds with the potential pain-relieving benefits of NSAIDs, particularly in an era where multimodal pain management strategies are being encouraged due to the opioid epidemic.[35, 36] Therefore, the need for further high-quality clinical studies is necessary. At the time of this systematic review, a single randomized controlled trial investigating the effect of NSAIDs on rotator cuff repair integrity as a secondary outcome was available. The study found that the use of a non-selective COX-2 inhibitor, celecoxib, led to significantly more failures at the tendon-to-bone interface compared with ibuprofen or the control arm receiving tramadol. While the study was appropriately randomized for the primary outcome and blinded, <50% of patients were available for the repair integrity outcome, thus raising concerns with incomplete reporting and selection bias. The other two included clinical studies, consisting of level III and IV evidence, evaluated distal biceps repair, which have an inherently low failure rate when compared with rotator cuff repair, making it difficult to delineate clinical factors that may lead to failure given the low event rate.[57-59] While several factors pose challenges when designing clinical studies, including choosing the optimal method to assess or define clinical failures,[60] future randomized controlled studies could serve to significantly impact practice given the high rate at which these procedures are performed as well as the relatively widespread use of NSAIDs for the treatment of musculoskeletal pain.

Compared with clinical studies, basic science studies often provide logistical advantages, including ease of randomization and inclusion of an adequate number of specimens. However, translation of findings from basic science models into clinical practice can create challenges. For example, in the included basic science studies for this review, all but one study used an acute tendon-bone repair model. Particularly when considering rotator cuff tears, this is rarely the clinical scenario. Additionally, the clinical applicability and relevance of testing methods and results, such as biomechanical testing, often are not feasible in the clinical setting, and the clinical significance of the reported results may be limited. While most of those limitations will remain inherent to the majority of basic science studies, this review highlights several modifiable areas for improvement. First, while methodological quality is often only considered in clinical trials, the methodological quality of basic science studies focusing on the effects of NSAIDs on tendon-to-bone healing is poor. In the future, making efforts to appropriately randomize specimens while blinding animal caregivers and outcome assessors would serve to significantly improve the methodological quality of basic science research on the subject. Second, the heterogeneity of outcomes reporting, including biomechanical, biochemical, and histologic outcomes, and the variability of postoperative NSAID initiation and duration, limits aggregate analysis of a homogeneous cohort. The findings from this study can hopefully serve to provide guidance for future basic science studies, providing details on reporting of relevant outcomes and areas where future research efforts, such as the temporal effect of NSAID administration, can be focused.

The current study does have several limitations, including the quality of studies available in the current literature. At the time of this review, only three clinical studies, consisting of level I, III, and IV evidence, were available for review.[22, 44, 45] Basic science studies, comprised primarily of animal studies, were of low methodological quality and at high risk of bias using the SYRCLE risk of bias assessment tool, due in part to inadequate randomization and lack of blinding of animal caretakers and investigators. Additionally, the ability to translate individual findings within basic science studies to clinical practice remains limited. Despite the number of basic science studies available for review, many of which included multiple treatment arms, the heterogeneity of outcome reporting limited a high-level aggregate analysis. While three animal studies did utilize homogenous methodology and were subsequently selected for a subgroup meta-analysis, the conclusions from the analysis are limited by the small number of included studies, the unknown clinical significance of load to failure as an outcome, and the variable timepoints at which load to failure was measured postoperatively, although standardized measures were used. Despite these limitations, it is important to understand the current state of the literature in order to improve study design moving forward.

CONCLUSIONS

The current literature does not provide sufficient evidence for or against the use of NSAIDs following acute injury or surgical repair of the tendon-bone interface. Due to the low methodological quality of currently available literature, future high-quality studies on the effect of NSAIDs on tendon-to-bone healing are warranted while addressing the limitations identified in the current review in order to guide both clinicians and patients moving forward.

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APPENDIX 1: Search Strategy Report

Date: Database Inception – May 14, 2018

Database: PubMed (MEDLINE)

Set #		Results
1	"Anti-Inflammatory Agents, Non-Steroidal" [Pharmacological Action] OR "Cyclooxygenase Inhibitors" [Pharmacological Action] OR "Nonsteroidal anti-inflammatory drugs"[tiab] OR "Nonsteroidal anti-inflammatory drug"[tiab] OR "non-steroidal anti-inflammatory drugs"[tiab] OR "non-steroidal anti-inflammatory drug"[tiab] OR NSAIDs[tiab] OR NSAID[tiab] OR "Anti-Inflammatory Agents, Non-Steroidal"[mesh] OR "cyclooxygenase inhibitors"[tiab] OR "cyclooxygenase inhibitor"[tiab] OR "Cyclooxygenase Inhibitors/adverse effects"[mesh] OR "cox inhibitors"[tiab] OR "cox inhibitor"[tiab] OR cyclooxygenase[tiab] OR "cox-1"[tiab] OR "cox-2"[tiab] OR "cox1"[tiab] OR "cox2"[tiab]	259,439
2	"Wound Healing"[Mesh] OR "Wound Healing/drug effects"[Mesh] OR healing[tiab] OR heal[tiab] OR repair[tiab] OR repairing[tiab] OR remodeling[tiab] OR remodel[tiab]	553,302
3	"Tendons"[Mesh] OR Tendon[tiab] OR tendons[tiab] OR "Tendon Injuries"[Mesh] OR "patellar ligament"[MeSH Terms] OR "ligament"[tiab] OR "ligaments"[tiab] OR "patellar ligament"[tiab] OR "rotator cuff"[MeSH Terms] OR "rotator cuff"[tiab] OR "osteotendinous junction"[tiab] OR "bone-tendon"[tiab] OR "tendon-to-bone"[tiab]	130,443
4	#1 AND #2 AND #3	273
5	#4 NOT (Editorial[ptyp] OR Letter[ptyp] OR Case Reports[ptyp] OR Comment[ptyp])	258
6	#5 AND English[lang]	238
7	#6 AND 2017/10/02:2018/05/14[edat]	16

Database: SportDiscus

Set #		Results
1	DE "NONSTEROIDAL anti-inflammatory agents" OR TI ("Nonsteroidal anti-inflammatory drugs" OR "Nonsteroidal anti-inflammatory drug" OR "non-steroidal anti-inflammatory drugs" OR "non-steroidal anti-inflammatory drug" OR NSAIDs OR NSAID OR "cyclooxygenase inhibitors" OR "cyclooxygenase inhibitor" OR "cox inhibitors" OR "cox inhibitor" OR cyclooxygenase OR "cox-1" OR "cox-2" OR cox1 OR cox2) OR AB ("Nonsteroidal anti-inflammatory drugs" OR "Nonsteroidal anti-inflammatory drug" OR "non-steroidal anti-inflammatory drugs" OR "non-steroidal anti-inflammatory drug" OR NSAIDs OR NSAID OR "cyclooxygenase inhibitors" OR "cyclooxygenase inhibitor" OR "cox inhibitors" OR "cox inhibitor" OR cyclooxygenase OR "cox-1" OR "cox-2" OR cox1 OR cox2) OR KW ("Nonsteroidal anti-inflammatory drugs" OR "Nonsteroidal anti-inflammatory drug" OR "non-steroidal anti-inflammatory drugs" OR "non-steroidal anti-inflammatory drug" OR NSAIDs OR NSAID OR "cyclooxygenase inhibitors" OR "cyclooxygenase inhibitor" OR "cox inhibitors" OR "cox inhibitor" OR cyclooxygenase OR "cox-1" OR "cox-2" OR cox1 OR cox2)	1,923
2	DE "WOUND healing" OR TI (healing OR heal OR repair OR repairing OR remodeling OR remodel) OR AB (healing OR heal OR repair OR repairing OR remodeling OR remodel) OR KW (healing OR heal OR repair OR repairing OR remodeling OR remodel)	18,142
3	(((DE "TENDONS -- Wounds & injuries" OR DE "ACHILLES tendon -- Wounds & injuries") OR (DE "TENDONS")) OR (DE "LIGAMENTS -- Wounds & injuries" OR DE "COLLATERAL ligament -- Wounds & injuries" OR DE "CRUCIATE ligaments -- Wounds & injuries" OR DE "PATELLAR ligament -- Wounds & injuries") OR (DE "LIGAMENTS") OR (DE "SHOULDER joint -- Rotator cuff" OR DE "SHOULDER joint -- Rotator cuff -- Wounds & injuries")) OR TI (tendon OR tendons OR ligament OR ligaments OR patellar ligament OR rotator cuff OR osteotendinous junction OR bone-tendon OR tendon-to-bone) OR AB (tendon OR tendons OR ligament OR ligaments OR patellar ligament OR rotator cuff OR osteotendinous junction OR bone-tendon OR tendon-to-bone) OR KW (tendon OR tendons OR ligament OR ligaments OR patellar ligament OR rotator cuff OR osteotendinous junction OR bone-tendon OR tendon-to-bone)	26,453
4	#1 AND #2 AND #3	54
5	#4 AND Peer Reviewed; Language: English	47
6	#5 AND	

APPENDIX 1: Search Strategy Report

Database: Embase

Set #		Results
1	‘antiinflammatory agent’/exp OR ‘cyclooxygenase 2 inhibitor’/exp OR Nonsteroidal anti-inflammatory drugs:ab,ti,kw OR Nonsteroidal anti-inflammatory drug:ab,ti,kw OR non-steroidal anti-inflammatory drugs:ab,ti,kw OR non-steroidal anti-inflammatory drug:ab,ti,kw OR NSAIDs:ab,ti,kw OR NSAID:ab,ti,kw OR cyclooxygenase inhibitors:ab,ti,kw OR cyclooxygenase inhibitor:ab,ti,kw OR cox inhibitors:ab,ti,kw OR cox inhibitor:ab,ti,kw OR cyclooxygenase:ab,ti,kw OR “cox-1”:ab,ti,kw OR “cox-2”:ab,ti,kw OR cox1:ab,ti,kw OR cox2:ab,ti,kw	70,179
2	‘wound healing’/exp OR healing:ab,ti,kw OR heal:ab,ti,kw OR repair:ab,ti,kw OR repairing:ab,ti,kw OR remodeling:ab,ti,kw OR remodel:ab,ti,kw	712,235
3	‘tendon’/exp OR Tendon:ab,ti,kw OR tendons:ab,ti,kw OR ‘tendon injury’/exp OR “ligament”:ab,ti,kw OR “ligaments”:ab,ti,kw OR “patellar ligament”:ab,ti,kw OR ‘rotator cuff’/exp OR ‘rotator cuff injury’/exp OR “rotator cuff”:ab,ti,kw OR “osteotendinous junction”:ab,ti,kw OR “bone-tendon”:ab,ti,kw OR “tendon-to-bone”:ab,ti,kw	162,782
4	#1 AND #2 AND #3	87
5	#4 NOT (‘case report’/exp OR ‘case study’/exp OR ‘editorial’/exp OR ‘letter’/exp OR ‘note’/exp)	87
6	#5 AND [English]/lim	86
7	#6 AND Published Date: 20171001-	2

Database: CINAHL

Set #		Results
1	MH “Antiinflammatory Agents, Non-Steroidal+” OR TI (“Nonsteroidal anti-inflammatory drugs” OR “Nonsteroidal anti-inflammatory drug” OR “non-steroidal anti-inflammatory drugs” OR “non-steroidal anti-inflammatory drug” OR NSAIDs OR NSAID OR “cyclooxygenase inhibitors” OR “cyclooxygenase inhibitor” OR “cox inhibitors” OR “cox inhibitor” OR cyclooxygenase OR “cox-1” OR “cox-2” OR “cox1” OR “cox2”) OR AB (“Nonsteroidal anti-inflammatory drugs” OR “Nonsteroidal anti-inflammatory drug” OR “non-steroidal anti-inflammatory drugs” OR “non-steroidal anti-inflammatory drug” OR NSAIDs OR NSAID OR “cyclooxygenase inhibitors” OR “cyclooxygenase inhibitor” OR “cox inhibitors” OR “cox inhibitor” OR cyclooxygenase OR “cox-1” OR “cox-2” OR “cox1” OR “cox2”)	31,039
2	MH “Wound Healing+” OR TI (healing OR heal OR repair OR repairing OR remodeling OR remodel) OR AB (healing OR heal OR repair OR repairing OR remodeling OR remodel)	89,109
3	MH “Tendons+” OR Tendon OR tendons OR MH “Tendon Injuries+” OR MH “Ligaments+” OR TI (“ligament” OR “ligaments” OR “patellar ligament” OR “rotator cuff” OR “osteotendinous junction” OR “bone-tendon” OR “tendon-to-bone”) OR AB (“ligament” OR “ligaments” OR “patellar ligament” OR “rotator cuff” OR “osteotendinous junction” OR “bone-tendon” OR “tendon-to-bone”)	36,096
4	#1 AND #2 AND #3	70
5	#1 AND #2 AND #3 AND Limiters - Research Article; English Language	34
6	#5 AND Published Date: 20171001-	1

COMPUTER NAVIGATION FOR PEDIATRIC FEMORAL ACL TUNNEL PLACEMENT

Charles A. Popkin, MD[1]; Charles M. Chan, MD[1]; Jared A. Nowell, BA[2]; Stephen G. Crowley, BS[3]; Margaret Wright, MD[1]; Christopher S. Ahmad, MD[1]

ABSTRACT

Background: To compare accuracy, time and radiation exposure of pediatric femoral tunnel placement using computer navigation with a traditional freehand technique.

Methods: A single all-epiphyseal femoral tunnel was placed in the distal femur of 20 Sawbones™ adolescent knee models. Ten tunnels were drilled using standard fluoroscopic guidance (FG). An additional 10 tunnels were drilled using 3D fluoroscopic computer navigation (CN). Both techniques aimed to match an exact point described by the quadrant system of Bernard. Time to perform the procedure was recorded as were number of single shot fluoroscopic images and approximate effective radiation doses.

Results: The deviation from ideal femoral tunnel position was on average 6.4 ± 4.2 mm for FG tunnels and 2.7 ± 3.1 mm for CN tunnels ($p<0.05$) . There was no violation of the femoral growth plate using either technique. The surgeon was exposed to 17 ± 5.3 and 3 ± 0.66 single fluoroscopy exposures for FG and CN guidance, respectively ($p<0.05$). However, the effective dose for the CN because of the acquisition of 3D images was 0.52±.003 mSv and for FG was only 0.09mSv ± .027 ($p <0.001$). CN however required on average 12.5 ± 3.4 min compared to 4.6 ± 1.7 for FG ($p<0.05$) to complete drilling of the tunnel.

Concluson: CN achieves a more accurate epiphyseal femoral ACL tunnel position but requires more time to complete and has a higher effective radiation dose than FG. Whether the CN ACL tunnels can translate to improved clinical outcomes is still unknown.

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Level of Evidence: V

Keywords: ACL, skeletally immature, computer navigation, femoral tunnel, pediatric

INTRODUCTION

The decision to treat conservatively or surgically reconstruct a torn anterior cruciate ligament in a skeletally immature patient remains controversial.[1-4] Fear of injury to the growth plate[2, 3, 5-7] has prevented many surgeons from proceeding with routine ACL reconstruction in this population. Furthermore, a prospective cohort study from Norway followed a non-operative treatment algorithm and found that ninety percent of the children were able to participate in sports at the two year follow up, with a small number of surgical operation for new meniscal injuries (13%).[8] While nearly 40% of the children followed in this study had to decrease activity level, this study suggests that ACL deficient children can be physically active and may be an adequate treatment option in some patients.[8] However, other studies have demonstrated that activity modification and bracing is associated with a poor prognosis and these children have a high rate of irreparable meniscal tears, chondral injury, pain and accelerated joint arthrosis.[1-4, 9-12]

Many advocate early ACL reconstruction with specialized techniques to minimize growth plate violation.[1-3, 6, 13-15] Treatment of an ACL tear in young children requires recognizing the patient with symptomatic instability and tailoring the surgical approach to the skeletal maturity of the patient.[2, 3, 16] Two main options exist for skeletally immature athletes with more then 3 years of growth remaining: all-epiphyseal reconstruction[13] and the MacIntosh iliotibial band reconstruction.[6] The MacIntosh surgical technique is advocated to reconstruct and stabilize the knee in the very immature athlete, but this is a non-anatomic procedure.[6] An all-epiphyseal reconstruction technique follows many of the adult principles for ACL reconstruction with regards to tunnel placement and attempting to re-create normal anatomy.[13] This surgical technique is technically challenging and carries a risk of injury to the physis.[13, 17, 18] With the growing trend to put in larger grafts, there is simply a small amount of space for accurate placement of the tunnels in small, skeletally immature patients.

The accuracy of drilling with computer navigation has

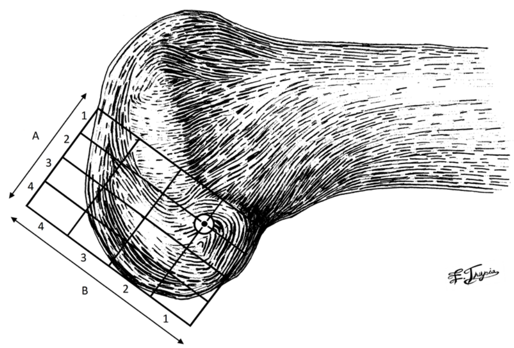

Figure 1. Quadrant system as described by Bernard et al for determining location of the femoral tunnel position.[27] This point is approximately one-fourth of the distance from posterior to anterior along Blumensaat's line and one-fourth of the distance down from Blumensaat's line.[13]

Drawing by Evan P. Trupia, MD (New York, New York)

been shown to be very high in the laboratory setting.[19] Clinical studies also exist highlighting the precision possible with these systems, which are used for total knee arthroplasty, total hip arthroplasty, high tibial osteotomies and anterior cruciate ligament surgery.[20-23] To date computer navigation has shown ability to produce more accurate tunnel placement, but no significant functional benefit or improvement in knee stability in adult patients in many studies.[7, 23-25] However, computer navigation to date has not been used or described to reconstruct ACL in the skeletally immature population. It has been described in standard ACL reconstruction as a way to enhance accuracy with placement of the femoral tunnel.[24] Proper tunnel position is thought to be an essential factor to a successful ACL reconstruction.[26] Unfortunately, there are studies in the literature that place the incidence of misplaced tunnels as high as 40%.[25]

For the skeletally immature patient, tunnel accuracy is extremely important to avoid iatrogenic injury to the growth plate and for proper ACL function.[2, 3] The purpose of this study was to compare placement of an all-epiphyseal femoral tunnel using standard fluoroscopic guided and with computer navigation. In this study, we compare the accuracy, safety, time, and radiation exposure of Computer Navigation (CN) versus fluoroscopy guided (FG) ACL femoral tunnel placement. We hypothesize that computer navigation will improve accurate placement of the epiphyseal tunnels and minimize injury to the growth plate.

MATERIALS AND METHODS

20 pediatric left knee sawbones (Sawbones™, Vashon, WA) covered with foam soft tissue envelopes were used for this study. 10 knees underwent the procedure using FG for tunnel drilling with the remaining 10 using CN. All 20 tunnel drilling procedures were done by the same sports medicine fellowship trained surgeon. The study was performed in two sessions of 10 knees each. The order for the technique used for tunnel drilling was decided by the surgeon. In the first session the order was 2 FG, 6 CN and lastly 2 FN. In the second session 6 FG were performed followed by the remaining 4 CN. No set amount of time was required between tunneling attempts. The surgeon performing the procedure also obtained all the measurements.

The technique for the FG group followed the protocol recommended by Anderson.[13] The image intensifier was brought in from the opposite side of the table. AP and lateral fluoroscopic images were obtained. The location used to define the optimal placement of the all-epiphyseal femoral tunnel was determined to be a point that is one-fourth of the distance from posterior to anterior along Blumensaat's line and one-fourth of the distance distal from Blumensaat's line (Figure 1).[13, 27] The guide pin was then percutaneously inserted and directed toward the predefined optimal starting point with fluoroscopy in the lateral position. The C-arm was then brought into an AP view and the guide pin position verified to be below the distal femoral growth plate. The C-arm was then taken back to a perfect lateral and the pin advanced 2-3 mm with care taken to avoid anterior and posterior angulation. Additional AP and lateral views were taken as required to place the pin in the desired location. Once the position was verified, a 7mm femoral tunnel was drilled with a 7mm reamer (Arthrex™, Naples, FL) using an outside-in technique. A 7mm diameter tunnel was selected based on work of Anderson[13] that identified the range of the quadrupled hamstring diameter in this age population between 6 and 8mm.

BrainLab® Curve Spine and Trauma 3D version 2.0 with 3D C-arm integration (Computer Assisted Surgery, Feldkirchen, Germany) was the computer assisted navigation platform and software used in this study. Most of the previous surgery and techniques utilizing this company's CAS technology was for total knee arthroplasty or spine.[28] Two pins from the BrainLab set were drilled into the distal femur and the reflective marker balls were attached (Figure 2). The reflective markers were registered and visualized by the Brain Lab Curve platform system. The foam covered pediatric knee model complete with growth plates (Sawbones™ Vashon, WA) then underwent a multi-exposure 3D fluoroscopy spin to image the knee. During the spin, the C-arm rotated 190° around the model knee to acquire 100 single 2D images, which are processed by the attached computer platform to a 3D image set.[29] The navigated straight pointer was then used to confirm proper registration of structural landmarks within the

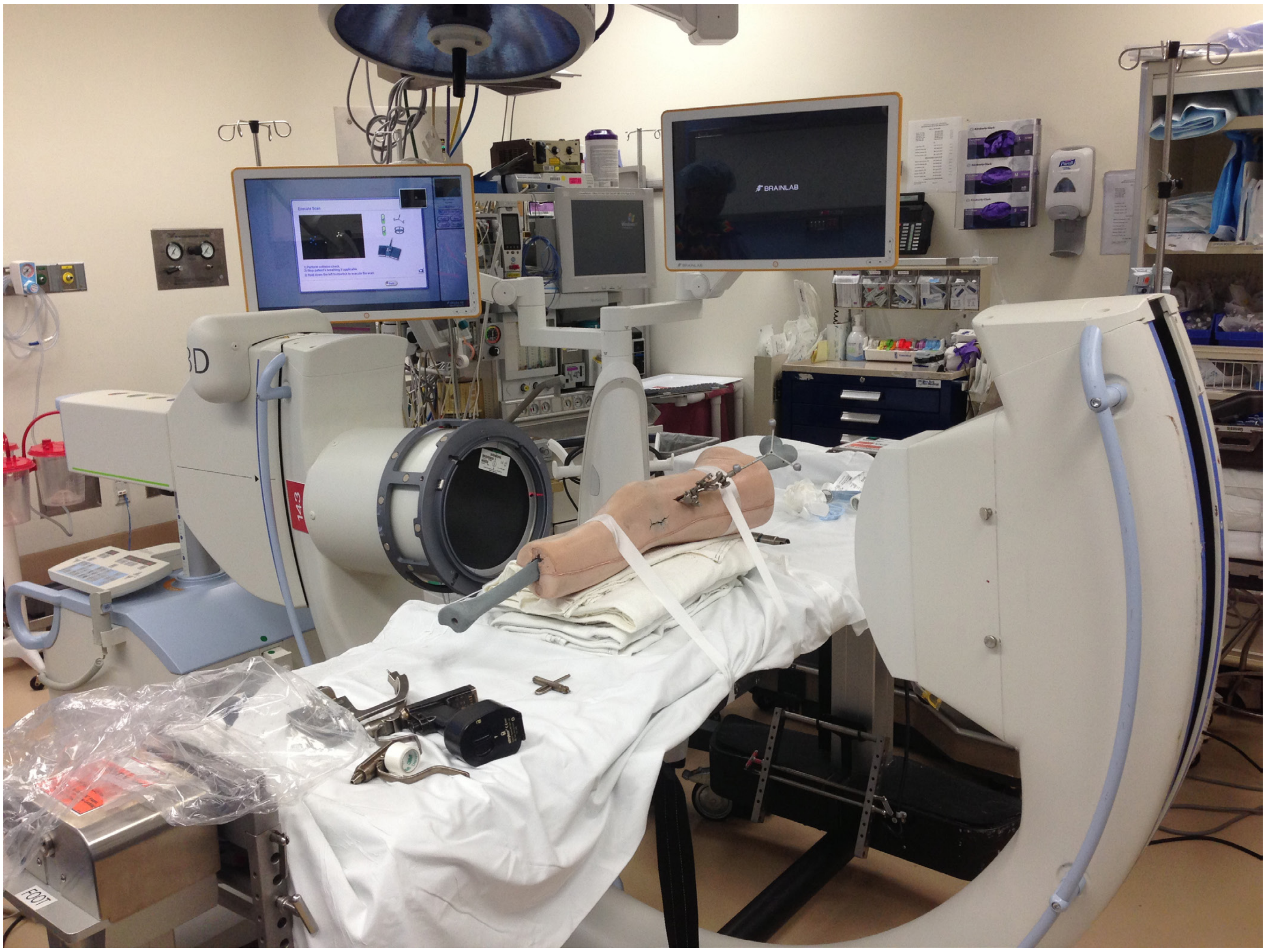

Figure 2. Shows the first part of the set up to use the BrainLab system. Two pins from the set were drilled into the saw bone femur and the reflective marker balls were attached. These reflective markers need to registered and recognized by the BrainLab platform system.

knee including the medial and lateral part of the notch wall (Figure 3). The desired tunnel size of 7mm was entered into the BrainLab software. The drill pin was then calibrated using the BrainLab instrument calibrator. With the use of the computer assisted surgery BrainLab system the optimal location of the femoral tunnel was determined according to the quadrant system described by Bernard[27] using real-time information about the anatomy of the femur and alignment of the drill (Figure 4). The tunnel was then drilled with a 7mm reamer (Arthrex™ Naples, FL). Deviation from ideal tunnel placement, distance from the growth plate, violation of the physis or blow out of the backwall, number of fluoroscopy images taken, effective radiation dose and time for completion of tunnel were recorded for the FG and CN groups.

Each sawbone was then removed of its overlying foam soft issue envelope. The ideal femoral center was determined from a perfect lateral fluoroscopic image with the superimposed quadrant system of Bernard.[27] The distance between the center of the ideal femoral tunnel and the center of the drilled tunnel either by FG or CN was then measured using a digital caliper (Mitutoyo 6" Absolute; Kangawa, Japan). The direction of deviation and violation of the simulated distal femoral physis were recorded. This was done by direct visualization of the knee model and then verified by fluoroscopy. Finally the distance from the outer femoral tunnel and intra-articular femoral tunnel to the nearest part of the distal femoral growth plate were also measured with the digital calipers.

Effective dose of radiation assumed each 2D fluoroscopic image of the knee to have 0.005 millisievert (mSv).[30] The effective radiation dose for the 3D scan was based on work of Kraus et al using the Brainlab 3D platform and software acquiring 100 2D images (0.5mSv).[29] Student's t-test was used for statistical analysis and the Statistical Analysis Software v9.3 (SAS Institute Cary, North Carolina) was used to perform the analysis.

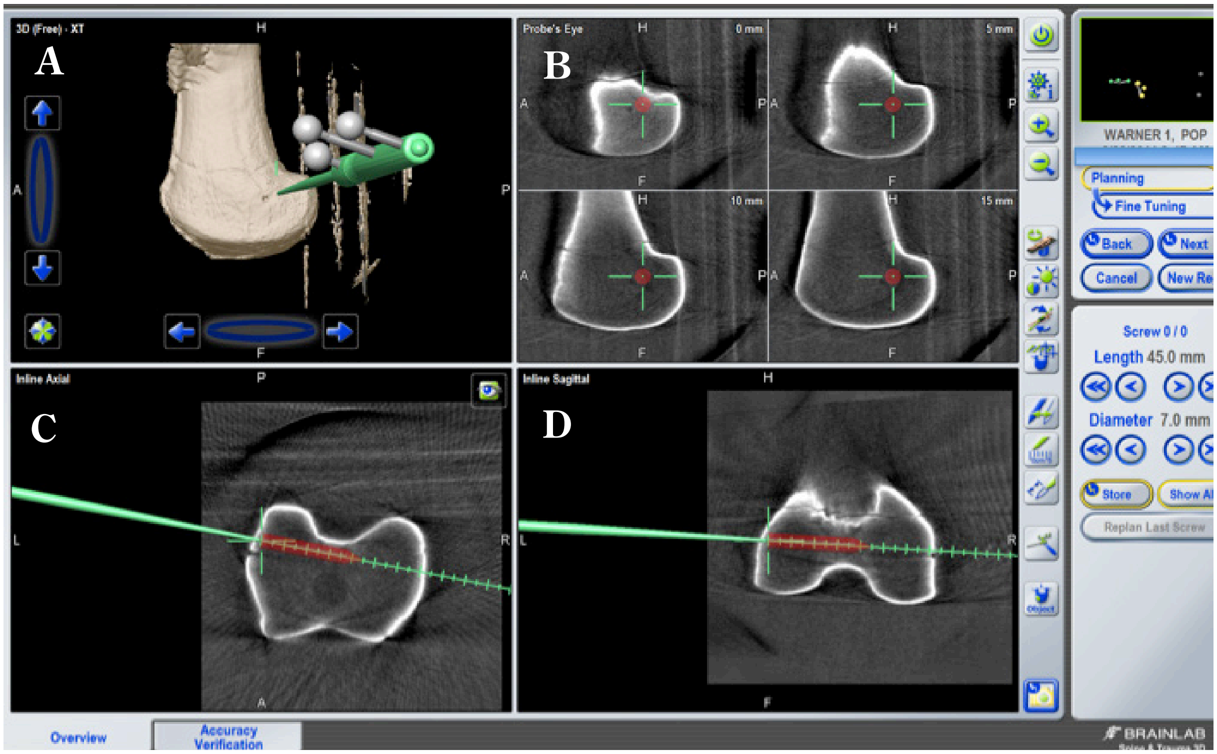

Figure 3. (A) is an image using the navigated straight pointer to confirm landmarks and then in subsequent sequences (B) Probe's eye view(C) Sagittal and (D) Axial images the pointer can be used like a drill to gauge trajectory of the femoral tunnel.

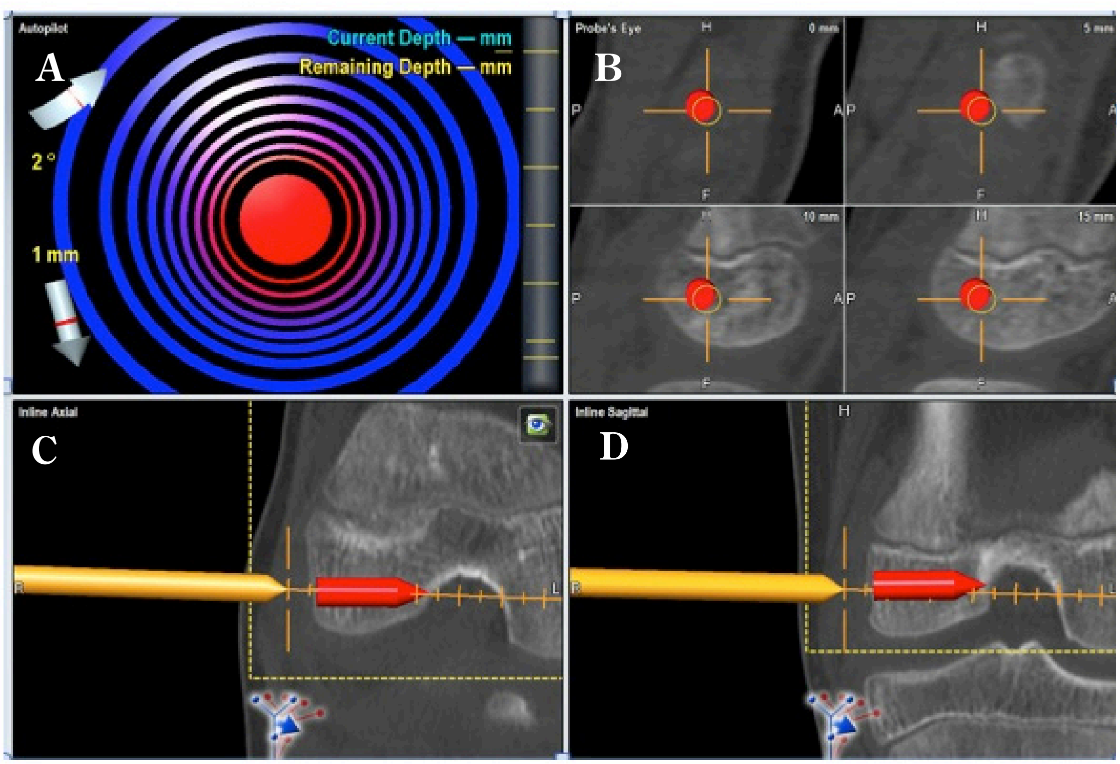

Figure 4. Images taken from a real surgical case using computer navigation from BrainLab to place the femoral all-epiphyseal tunnel in a 10 year old male. (A) is an image from the CN used to calibrate the drill to the desired location. (B) is a view from the Probe or drill called the Probe's eye view to localize your tunnel placement (C) and (D) are views from coronal CT slices with the projected tunnel location. The 7mm flipcutter has been calibrated by the BrainLab instrument calibrator and appears yellow in images (C) and (D).

Table 1. Computer Navigation Technique Tunnel Results

Knee Number	Technique Number	Deviation from ideal placement (mm)	Fluoroscopy exposures	Effective doses (mSv)	Time to complete technique (min)
3	1	0.04	3	0.515	16.58
4	2	3.07	2	0.51	9.58
5	3	1.8	4	0.52	8
6	4	6.94	3	0.515	7.4
7	5	9.79	2	0.51	11.83
8	6	0.79	4	0.52	11.5
17	7	0.59	3	0.515	15
18	8	1.65	3	0.515	14
19	9	3.02	3	0.515	16
20	10	0.05	3	0.515	15

Computer Navigation Technique Tunnel Results. Knee number is the order completed in the full set of twenty knees.

RESULTS

The deviation from the defined optimal all-epiphyseal femoral tunnel position was 6.4 ± 4.2 mm for FG tunnels and 2.7 ± 3.1 mm for CN tunnels ($p<0.05$). No violation of the distal femoral growth plate occurred using either the FG or CN technique for placement of the all-epiphyseal femoral tunnel. There was no back wall blowout for either technique verified by direct visualization and fluoroscopy of the knee models. The distance from the femoral tunnel to the growth plate with the CN group was 14.9 ± 3.95 mm from the outer diameter of the tunnel compared to 13.1 ± 5.72 mm in the FG ($p < 0.24$.) .The distances to the growth plate from the intra-articular part of the tunnel was 17.8± 4.47 mm in the CN group compared to 17.1 ± 4.9 mm ($p <0.74$).

The CN group received a higher effective dose of radiation because of all the images required for the 3D reconstruction. The effective dose for the CN because of the acquisition of 3D images was 0.52±.003 mSv and for FG was only 0.09mSv ± .027 ($p <0.001$). However, after the 3D scan it took the surgeon only 3 ± 0.66 extra fluoroscopy exposures to drill the guide pin for the epiphyseal femoral tunnel. The surgeon required 17.4 ± 5.3 single fluoroscopy exposures using the freehand technique ($p<0.05$). The computer navigation group also required on average close to eight more minutes to obtain the femoral tunnel position 12.5 ± 3.4 min compared to 4.6 ± 1.7 for FG ($p<0.05$).

The data for each individual tunnel by technique is listed in Table 1 and 2. Comparison of tunnel data for each technique is shown graphically in Figure 5.

Table 2. Fluoroscopic Guidance Technique Tunnel Results

Knee Number	Technique Number	Deviation from ideal placement (mm)	Fluoroscopy exposures	Effective doses (mSv)	Time to complete technique (min)
1	1	2.21	14	0.07	4.9
2	2	9.08	20	0.1	5
9	3	5.78	15	0.075	3.5
10	4	2.12	28	0.14	9.08
11	5	9.23	14	0.07	4
12	6	1.97	17	0.085	3.45
13	7	10.4	16	0.08	5
14	8	14	18	0.09	3.83
15	9	6.78	23	0.115	4.17
16	10	2.67	9	0.045	2.83

Fluoroscopic Guidance Technique Tunnel Results. Knee number is the order completed in the full set of twenty knees.

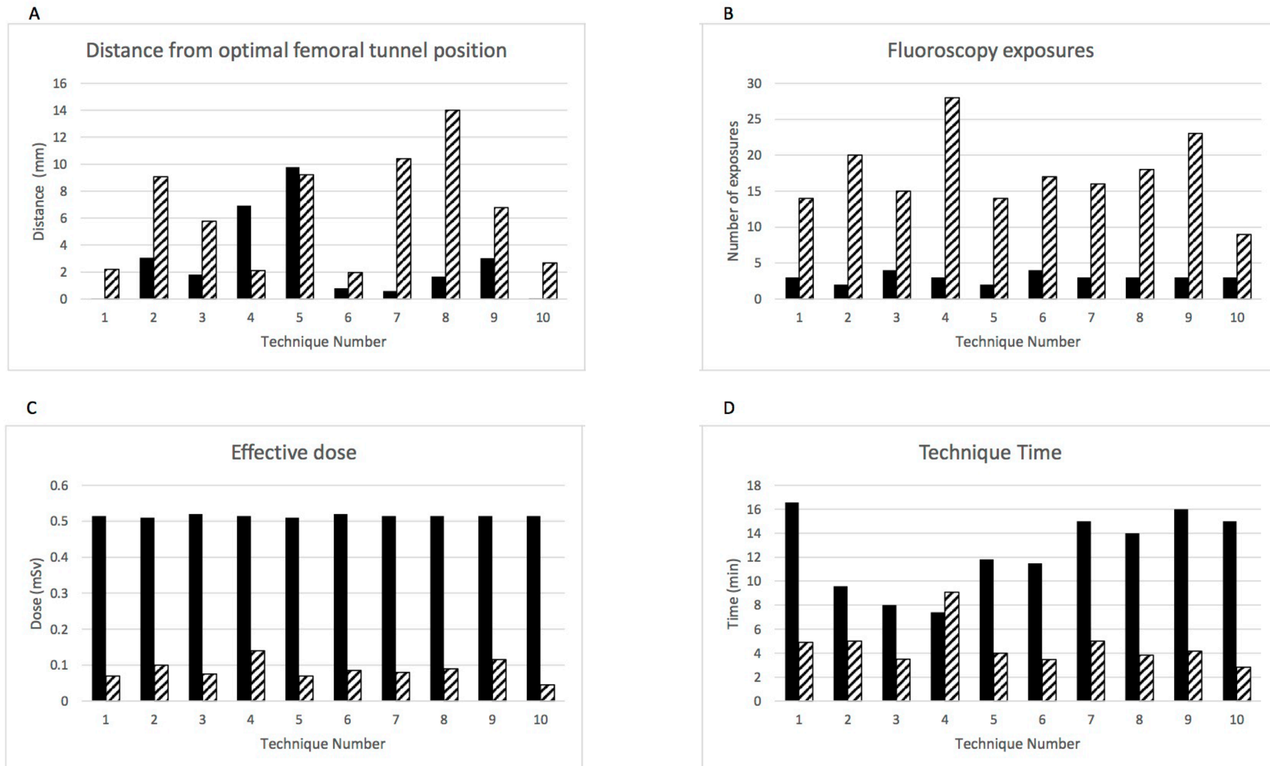

Figure 5. Direct comparison of CN vs FG by order performed in each subset. (A) is distance from optimal femoral tunnel position. (B) is number of fluoroscopy exposures. (C) is effective dose and (D) is time required to complete the technique. CN data is solid bars, FG data is striped bars.

DISCUSSION

Placement of tunnels in the correct position is one of the most essential factors for success with anterior cruciate ligament reconstruction.[25, 26, 31] The need for accurate tunnel placement has driven interest in computer navigation to improve consistent accurate tunnel placement.[24] All of the computer navigation or Computer-Assisted Orthopedic Surgery (CAOS)[32] to date have explored tunnel accuracy in an adult knee. This study is the first to assess accuracy of all-epiphyseal femoral tunnel placement with CAOS in an adolescent knee model. With the rising number of ACL injuries in the skeletally immature population, more surgical reconstructions are being performed in this age group.[2, 3, 16] The skeletally immature athlete brings additional concerns regarding iatrogenic growth plate injury causing deformity and arrest around the knee.[2, 5] In a study by Kocher et al, they looked at the results of a questionnaire given out to the members of the Herodicus Society.[33] 11% of the responding members had seen a case of growth arrest resulting from an ACL reconstruction performed in a skeletally immature athlete. Additionally a recent review paper surveying PRISM members reported 29 new cases of growth disturbance due to ACL reconstruction.[18] The most common disturbance seen was closure of the lateral distal femoral physis causing a valgus deformity. The true prevalence of growth disturbance with skeletally immature ACL surgery is not known at this time. While not common, the concern for injury to the growth plate is real and reinforces the need for careful attention to technical details during ACL reconstruction in the young athlete, especially with placement of the tunnels.

This study supports computer navigation for guiding more precise placement of epiphyseal femoral ACL tunnels. From our study, CN ACL tunnels were more accurate- but also required more time. The distance from the ideal tunnel placement in this study (2.7+ 3.1 CN and 6.4+ 4.2mm FG) compared favorably to the findings in the literature of distance from the ideal position using CN as opposed to traditional ACL techniques. Picard et al, compared a randomized control study of CN and traditional technique for ACL reconstruction in 20 foam knees as well, and found the distance from ideal femoral tunnel position with CN was 2.7mm + 1.9 compared to 4.2 + 1.8 mm for the traditional method.[25] A group from the Netherlands looked at accuracy of computer navigation for drilling anteromedial (AM)and posterolateral bundles (PL) of the ACL and found their accuracy to be within 2.7 mm AM and 3.2mm for PL.[31] Another advantage of this technique is the ability to have real-time guidance, allowing for correction of trajectory errors prior to complete placement of the guide pin (Figure 3). While CN ACL femoral tunnels can be more accurately placed, whether this can translate to improved clinical outcomes is still unknown.[24, 32]

Computer navigation brings improved accuracy and precision to the drilling of the tunnel, but what are the disadvantages of this technique? There are a few pertinent negatives to using computer navigation. First, the effective radiation dose is significantly higher with all the images required to make the 3D image for viewing. This is an almost 6 fold difference (0.09 vs 0.52 m Sv) in the effective radiation dose and is not inconsequential when dealing with a pediatric and adolescent patient population. There was also a statistically significant increase in time for the CN group, almost 8 minutes to complete the tunnel drilling. This number is consistent with previous publications on the CN set up for ACL surgery requiring a range from an extra 9 to 27 minutes.[23, 34, 35] While we did not measure the exact time for drilling after the 3D image reconstruction was complete, it took on average only 3 extra 2D fluoroscopic images to confirm the start point compared to 17 exposures necessary for the freehand technique. It can be inferred that the good majority of the extra time is spent with the set up, placement of pins with the reflective balls for the computer platform to recognize and the acquisition of the hundred 2D fluoroscopic images to create the 3D image. All these factors are responsible for the extra time required to use the computer navigation. Another significant weakness to computer navigation is the extra drilling into pediatric bone for the pins and reflective markers to register with the computer navigation platform.

There are several limitations worth mentioning with regard to this study. The first is that our model is not physiologic. While the soft tissue foam envelope encloses the sawbones pediatric knee model, it does not reproduce the feel of the soft tissues and the challenge to obtaining the start point with the freehand Anderson technique. Second, while this study may show improved accuracy of tunnel placement with CN, there remains no clear consensus that this accuracy translates to improved clinical outcomes following ACL reconstruction. There is a significant learning curve with regards to the set up and use of the CN so some of the increased time required to obtain the correct start point could be decreased with additional surgeon experience. In addition, newer techniques also use arthroscopic guides in combination with fluoroscopy to create and position the femoral tunnel. This was not studied. All the knee models in this study were left knees. This could have an effect on surgeon timing, skill and number of fluoroscopy exposures as this may be a dominant or non-dominant side. The computer navigation system we used in this study from BrainLab (Computer Assisted Surgery, Feldkirchen, Germany) has previously published work on total knee arthroplasty but has not been validated or published on previously with regards to anterior cruciate ligament surgery. Also, we chose to study the femur because it is more critical than the tibia but the tibia deserves future attention and study. We also did not plan for any additional tunnels to be drilled in the femur as part of a double bundle ACL reconstruction technique. We did not measure effective radiation dose with radiation badges or a thermoluminscence dosimeter (TLD), rather we used previously published numbers of effective radiation doses. Finally, computer navigation may not be available to those who wish to use it. Specifically the cost per case may be a limiting factor for using this technique. Previous studies in spine surgery and total knee arthroplasty highlighted the possible cost effectiveness of computer navigation.[36, 37] However the cost of our technique in a clinical setting was not studied.

In conclusion, the use of computer navigation contributed to more accurate femoral tunnel placement for an all-epiphyseal technique. However, it did require more time to drill the tunnel then the free hand technique and was associated with a higher effective radiation dose. While the tunnel placed with CN may be more accurate then the freehand technique, whether this will translate into better clinical results is not known. Therefore it is difficult to state that CN should be used routinely for every case without postoperative follow up data.

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A BIOMECHANICAL COMPARISON OF VARYING BASE KNOT CONFIGURATIONS WITH DIFFERENT OVERHAND/UNDERHAND COMBINATIONS OF REVERSING HALF-HITCHES ON ALTERNATING POSTS AFTER BASIC INSTRUCTIONAL TRAINING

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ABSTRACT

Background: Constructing a durable arthroscopic knot is critical for secure tissue fixation. The effect of various arthroscopic base knot configurations paired with various overhand/underhand stacking combinations of three reversing half-hitches on alternating posts (RHAPs) on knot strength and integrity remains unanswered.

Methods: Three common base knots (Surgeon's, Weston and, Tennessee Slider) followed by different overhand/underhand stacking combinations of three RHAPs were evaluated. Ten knots of each combination were tied by four subjects with varying levels of experience, resulting in the analysis of 480 total knots. A single load-to-failure test was performed to evaluate knot strength and integrity. The ultimate clinical failure load and mode of failure were recorded.

Results: All knots created surpassed the estimated minimum required load per suture. There was, however, statistically large inter-subject variability for each base knot configuration. The Surgeon's base knot was found to vary the least in knot strength, while the Tennessee base knot was found to vary the most. Knot security was mostly influenced by the base knot configuration than the different overhand/underhand RHAP stacking combinations. Knot slippage failure mode was higher with knots tied with the Weston base knot compared to the other two configurations.

Conclusions: Arthroscopic base knot configurations paired with different overhand/underhand stacking combinations of RHAPs yielded knot capable of secure tissue fixation. A short instructional training period appears to be sufficient for inexperienced individuals to learn easier base knot configurations, more challenging and complicated knots, however, may require training in a more gradual fashion.

Clinical relevance: The findings of this study provide information that the importance of hands-on experience for inexperienced individuals, such as residents, in performing arthroscopic knot tying, and that can lead to improving the securely constructed arthroscopic knots, which increase positive outcomes related to strengthened soft tissue to bone fixation of post-operative patients.

Level of Evidence: V

Keywords: arthroscopic knots, experience, reversing half-hitches on alternating posts, overhand and underhand half-hitches, loop and knot security

INTRODUCTION

With the rise in popularity of arthroscopic surgery, arthroscopic knot tying has become a critically important skill for orthopedic surgeons to master.[1-6] Surgeons should understand the unique challenges of tying a knot capable of yielding secure soft tissue fixation through a cannula with a knot pusher. While reviewing the literature, one will be exposed to an array of knot configurations, techniques, sequences, and circumstantial methodologies used across many practice settings and academic institutions. Tying secure arthroscopic knots, defined by their ability to resist slippage or breakage as a load is applied, can be time consuming and tedious. Arthroscopic knots are classified as either sliding or non-sliding, and either locking or non-locking. Complex sliding locking knots, which are commonly used in surgery, have been developed to maximize knot security by their internal resistance and friction.[7] Surgeons and residents must be skilled in tying a variety of knots because different knots are indicated for certain situations.

Previous studies have indicated that three reversing

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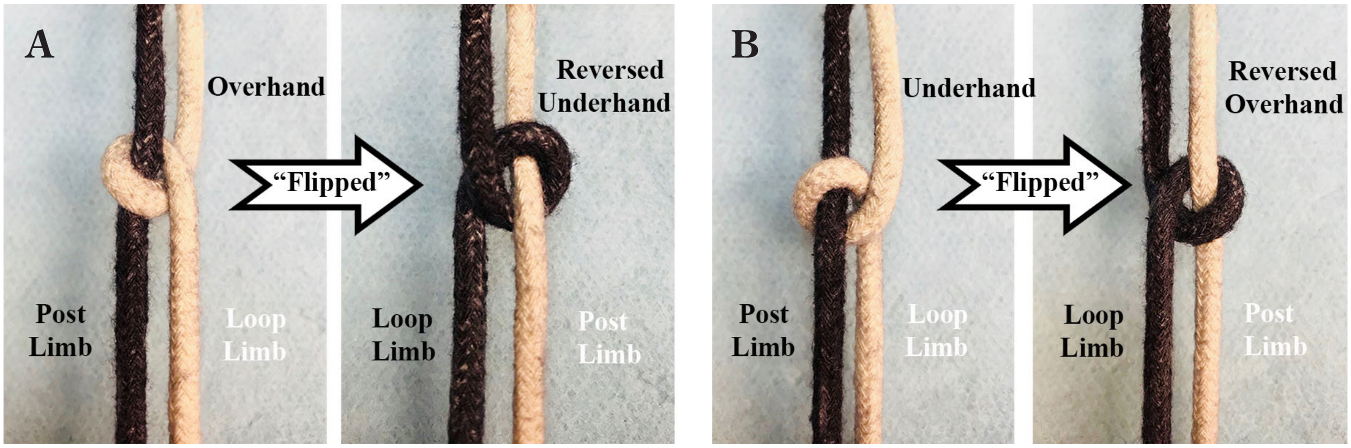

Figure 1. Chan et al.[16] switching post technique that the post suture limb "flips" to become loop suture limb. (a) Overhand configuration "flipped" to "reversed underhand" configuration; (b) Underhand configuration "flipped" to "reversed overhand" configuration.

half-hitches on alternating posts (RHAPs) are necessary to secure sliding locking knots.[8-14] Half-hitches can be created in either an "underhand" or "overhand" throw. An underhand half-hitch is completed by sliding the loop suture limb under and then over the post suture limb, whereas an overhand half-hitch is done by sliding the loop suture limb over and then under the post suture limb.[15] To accomplish flipping half-hitches to switch posts, Chan et al.[16] described a technique for switching posts by alternating tension on suture limbs, whereby the knot "flips" and the loop limb becomes the post limb. Half-hitches created by an overhand throw when "flipped" form a "reversed underhand" half-hitch (Figure 1a). Similarly, the underhand half-hitch when "flipped" forms a "reversed overhand" half-hitch (Figure 1b). Many orthopedic surgeons have been taught to construct the three RHAPs sequence in an 'underhand, overhand, underhand' configuration. However, because of this "flipping" phenomenon,[16] they may proceed without realizing that the final RHAPs sequence is converted to a 'reversed overhand, overhand, reversed overhand' configuration. The question remains whether this final RHAPs combination will affect arthroscopic knot holding strength.

Notably, many orthopedic residency-training programs across the United States have not developed a standardized training protocol for arthroscopic knot tying.[2, 17-22] Resident education has traditionally been based on apprenticeship, didactic learning, literature review, skills lab, and surgical experience. Arthroscopic knot tying is difficult to teach and to assess objectively. Comparing experienced and inexperienced residents' skills could identify potential shortcomings in the educational process. Hanypsiak et al.[23] performed a study demonstrating that even experienced practicing surgeons are relatively inconsistent when it comes to arthroscopic knot tying. Cronin et al.[24] and Chong et al.[25], however, suggests that after

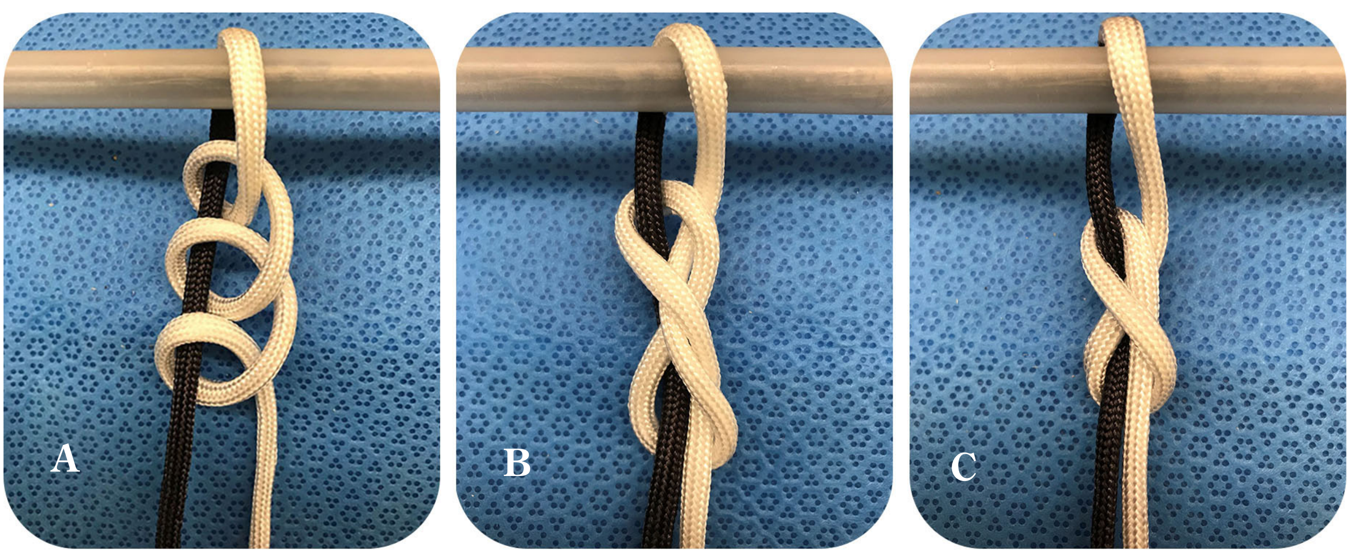

Figure 2. Three base knot configurations evaluated (black: post suture limb). (a) Surgeon's Knot; (b) Weston Knot; (c) Tennessee Slider Knot

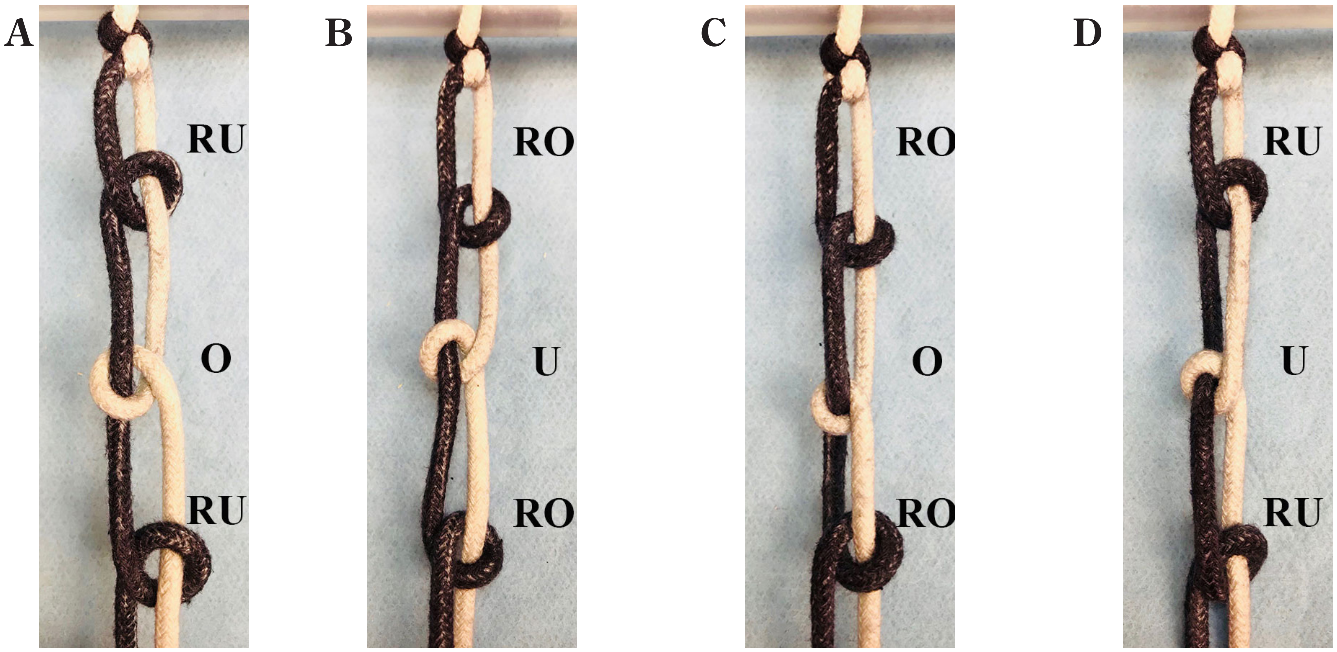

Figure 3. Four reversing half-hitches on alternating posts (RHAPs) stack combinations evaluated. (a) Configuration 1: reversed underhand (RU)–overhand (O)–reversed underhand (RU); (b) Configuration 2: reversed overhand (RO)–underhand (U)–reversed overhand (RO); (c) Configuration 3: reversed overhand (RO)–overhand (O)–reversed overhand (RO); (d) Configuration 4: reversed underhand (RU)–underhand (U)–reversed underhand (RU).

an adequate educational period is attained, any resident, at any level, can tie arthroscopic knots with acceptable knot security. Because of the complexity and large variety of knots to master, residents often feel confused and frustrated.[2, 17, 19] It is still undetermined how arthroscopic knot-tying skills can be best taught to reduce frustration, streamline education, and enhance outcomes. The specific aims of this study were to 1) evaluate the effect of various arthroscopic base knot configurations paired with different overhand/underhand stacking combinations of three RHAPs on knot strength and integrity, and 2) analyze after a short instructional training period on variations of knot integrity and security seen between test subjects.

METHODS

Three commonly used base knot configurations for arthroscopic knots were evaluated in this study (Figure 2): the Surgeon's, the Weston,[26] and the Tennessee Slider.[11] The Surgeon's knot, a non-sliding "static" knot with a simple stack design of three half-hitches, is most frequently used in arthroscopic surgery because this knot configuration is the easiest to learn.[24, 25] The Weston knot is a complex sliding and locking knot, and is among the more difficult knot configurations to master.[2] This configuration can easily be prematurely locked while advancing the knot if improper tension is applied to the wrong suture limb.[27] The Tennessee Slider is a much simpler sliding configuration and one of the easier arthroscopic knots to learn. Its figure-of-eight design makes its construction easy for surgeons to recall.[28]

Once the base knot was tied, one of the four overhand/underhand stacked RHAPs configurations was added to secure the base knot. The four RHAPs configurations tested were (Figure 3):

- Configuration 1: reversed underhand – overhand – reversed underhand
- Configuration 2: reversed overhand – underhand – reversed overhand
- Configuration 3: reversed overhand – overhand – reversed overhand
- Configuration 4: reversed underhand – underhand – reversed underhand

The suture material used for all knots in this study was a 356 N (80 lbs) tested braided fishing line (Power Pro Microfilament Braided Line, Irvine, CA). This material was chosen based on its similarity to commercially available arthroscopy suture material in terms of line diameter (0.46 mm vs. arthroscopy suture: 0.50 mm), manufacturer's tested strength (356 N vs. arthroscopy suture: 228 N), and the braided design. A length of 45 cm (18 inches) of the suture was used for tying all knots. A custom-designed arthroscopic knot-tying apparatus was used for tying knots with a standard knot pusher using standard arthroscopic technique in a dry laboratory environment, similar to other published studies (Figure 4).[29-35]

Four subjects, who were verbally informed about the purpose of the study, voluntarily participated in this study. Three of the subjects had no prior knot arthroscopic

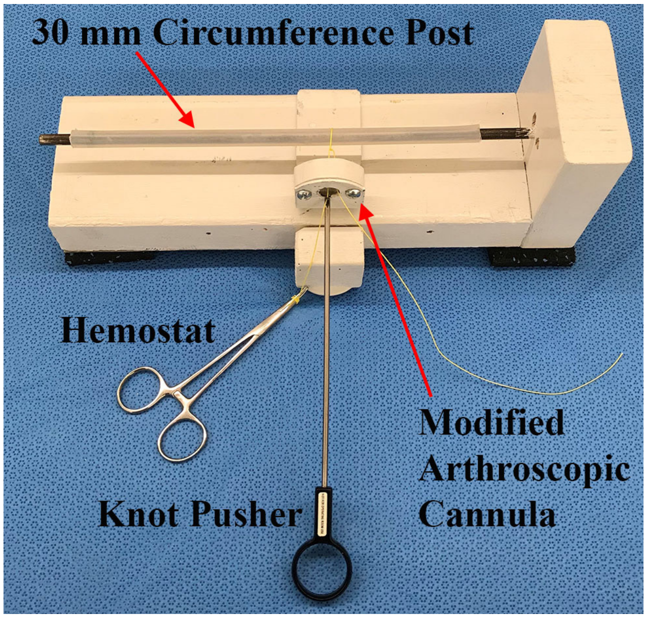

Figure 4. Arthroscopic knot tying setup.

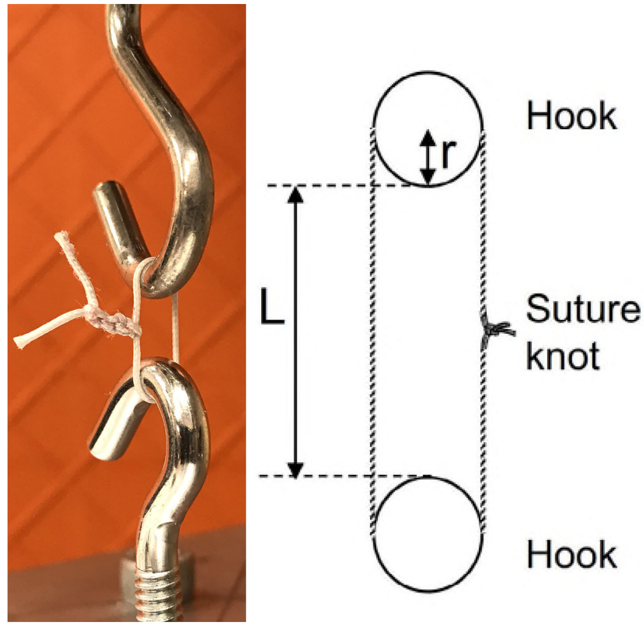

Figure 5. Load-to-failure experimental setup.

knot tying experience, while one subject had over 10 years of arthroscopic knot tying experience in a dry lab setting. Each subject received proper knot-tying technique instructional training with short training videos describing step-by-step instruction on how to appropriately tie each knot configuration. Each knot was also demonstrated by an instructor, while verbally explaining how the knot is tied. The instructor was available during the practice period to answer questions and assist the subjects with knot tying. Once the subjects felt sufficiently prepared and demonstrated competence, the base knot was constructed and fastened to a standardized 30 mm circumference post to provide a consistent starting circumference for each knot. The base knot was then followed by three RHAPs from one of the aforementioned configurations. The knotted suture loop was then removed from the post and was trimmed, leaving approximately 6 mm length tags from the most distal end of the knot. Ten knots were tied for each base knot configuration and for every RHAPs configuration. Therefore, each subject tied 120 knots, resulting in the analysis of 480 total knots.

A single load-to-failure test was performed to evaluate knot tensile strength and integrity by using a servohydraulic material testing system (model 8874; Instron, Norwood, MA). The experimental setup and test protocol used were similar to those described in the literature.[11, 12, 25, 29, 30-36] The knots were mounted around two 3.9 mm diameter hooks that attached to the actuator and the load cell (Figure 5). Each suture loop was initiated with five preconditioned loading cycles from 6 N to 30 N at 1 Hz to avoid potential errors produced from slack in the loops and stretching of the suture materials. The loops were then preloaded to 6 N to provide a well-defined starting point for data collection. Next, the loops were continuously loaded at an across-head speed of 1.0 mm/sec until either complete structure failure occurred or a 10 mm relative crosshead displacement was reached. Load and displacement data were collected at 100 Hz, and the mode of knot failure was recorded. This study defined three modes of knot failure: 1) failure by the suture material, 2) knot loop elongated but the loop and knot remained intact, and 3) knot slippage.

Clinical failure was defined as the knot slippage of 3 mm (crosshead displacement), which has been supported by previous evaluations of different suture/knot configurations.[5, 11, 13, 14, 21, 25, 32, 36, 37, 38] The "fail" criteria for this study were defined as 1) the ultimate tensile knot strength at crosshead displacement less than 3 mm with less than 100 N load, as previous studies have determined that 100 N is the estimated minimum required ultimate load per suture during maximum muscle contraction.[37, 38] And 2) the initial loop circumference at 6 N preload with more than 33 mm (circumference of the standardized post from the knot-tying apparatus: 30 mm). The initial loop circumference of the loop was calculated according to the formula as:

$$CL = (2^*L) + (4^*r) + Cr \qquad \text{Eqn 1}$$

Where CL represents loop circumference, L represents crosshead displacement, r represents rod radius, and Cr represents rod circumference.

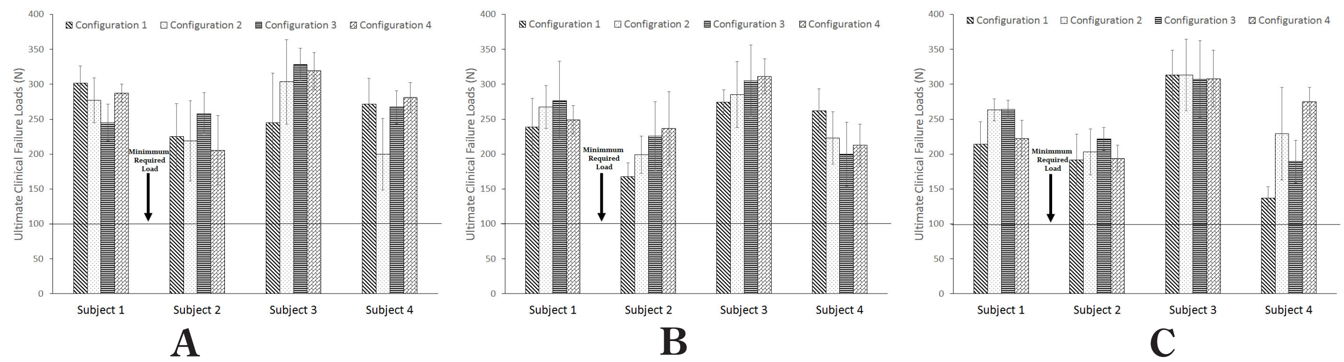

Figure 6. Mean ultimate clinical failure load (3 mm crosshead displacement) results of the four overhand/underhand stacked reversing half-hitches on alternating posts configurations with different base knot configurations. (a) Surgeon's Knot; (b) Weston Knot; (c) Tennessee Slider Knot

Statistical Analysis:

Data retrieved from the load-to-failure tests were analyzed for any differences among test subjects using one-way analysis of variance (ANOVA) with the least significant difference (LSD) multiple comparisons post hoc test method in SPSS software (Version 19.0; SPSS Inc, Chicago, IL) with $p<0.05$ denoted significant. The percentage of each failure mode group was calculated for each RHAP and base knot configuration. These values were used to determine the statistical relevance of the difference in arthroscopic loop and knot security for each configuration.

RESULTS

Figure 6 shows the mean ultimate clinical failure load (3 mm crosshead displacement) results of the three base knot configurations paired with four overhand/underhand stacking combinations of three RHAPs tied by each of the four subjects. Assessing knot tensile strength, all knots surpassed the estimated minimum required ultimate load per suture during a maximum muscle contraction (100 N).[10, 37, 38] There was, however, statistically large inter-subject variability for each base knot configuration. With the Surgeon's knot as the base knot, knot strength was found to vary the least between subjects with only thirteen (54%) significant differences noted out of twenty-four comparisons (Table 1). With the Weston knot as the base knot, knot strength was found to vary in a larger portion of samples with sixteen significant different between subjects noted out of twenty-four comparisons (67%), while with Tennessee base knot it was found to vary the most between subjects with twenty-one significant different noted out of twenty-four comparisons (Table 1). Assessing experience level, statistically significant differences were detected amongst base knot combinations with different overhand/underhand stacking combinations of three RHAPs (Table 1). When comparing different overhand/underhand stacking combinations of three RHAPs for each subject, some statistically significant differences were detected, except for two inexperienced subjects tying with the Tennessee Slider base knot (Table 2).

Mode of knot failure results indicated that the knot security was mostly influenced by the base knot configuration, and was not affected by the different overhand/underhand RHAP stacking combinations (Table 3). Knots tied with the Surgeon's base knot configuration had a higher incidence of suture material failure than the Tennessee Slider or Weston base knot configuration, across all the overhand/underhand stacking RHAP configurations. Knots tied with the Weston base knot had a higher incidence of failure in knot elongated but the loop and knot remained intact. Knot slippage failure mode, however, was higher compared to the other two configurations. Similar to the knots tied with Weston base knot, knots tied with Tennessee slider base knot experienced higher rates of elongated but intact failure modes (Table 3).

DISCUSSION

The most important finding of this study was that when constructing an arthroscopic knot, the base knot configuration has a higher influence on knot strength and security than the different overhand/underhand stacking combinations of three RHAPs. Few studies have been performed to objectively evaluate the ability of a surgeon to tie secure arthroscopic knots capable of resisting slippage when a load is applied.[2, 7, 25, 30, 32, 39-41] Arthroscopic knot tying requires significant practice and attention to detail. Past studies, however, have not clearly described how the RHAPs were created, leaving the reader unsure of how to interpret their findings. This uniquely designed study specified that stacking combinations of the three RHAPs are less likely to affect arthroscopic knot holding strength than selection of the base knot. Because using the overhand RHAPs stacking combination is secure enough to surpass the estimated maximum ultimate load per suture, residency-training programs can use this information to simplify the way they train the residents. This may reduce resident frustration and confusion for

Table 1. Statistical Analysis Results of Knot Tensile Strength Performance Comparing Different Overhand/Underhand Stacking RHAP Configurations on Each Base Knot Configuration and Between Test Subjects

Base Knot Configuration			Conf 1	Conf 2	Conf 3	Conf 4
Surgeon's	Subject 1	Subject 2	0.000	0.002	0.472	0.000
		Subject 3	0.002	0.144	0.000	0.081
		Subject 4	0.096	0.000	0.224	0.726
	Subject 2	Subject 3	0.267	0.000	0.000	0.000
		Subject 4	0.011	0.291	0.618	0.000
	Subject 3	Subject 4	0.145	0.000	0.001	0.037
Weston	Subject 1	Subject 2	0.000	0.000	0.004	0.483
		Subject 3	0.041	0.314	0.100	0.000
		Subject 4	0.182	0.011	0.000	0.038
	Subject 2	Subject 3	0.000	0.000	0.000	0.000
		Subject 4	0.000	0.175	0.133	0.167
	Subject 3	Subject 4	0.417	0.000	0.000	0.000
Tennessee Slider	Subject 1	Subject 2	0.155	0.000	0.008	0.069
		Subject 3	0.000	0.002	0.006	0.000
		Subject 4	0.000	0.030	0.000	0.001
	Subject 2	Subject 3	0.000	0.000	0.000	0.000
		Subject 4	0.001	0.097	0.042	0.000
	Subject 3	Subject 4	0.000	0.000	0.000	0.038

* Subject 1 had over 10 years of arthroscopic knot tying experience in a dry lab setting

Table 2. Statistical Analysis Results Comparing Knot Tensile Strength Performance for Each of the 4 Overhand/Underhand Stacking RHAP Configurations with Each Base Knot Created by Each Subject

Base Knot Configuration			Subject 1	Subject 2	Subject 3	Subject 4
Surgeon's	Conf 1	Conf 2	0.170	0.746	0.002	0.000
		Conf 3	0.002	0.069	0.000	0.806
		Conf 4	0.418	0.288	0.000	0.611
	Conf 2	Conf 3	0.080	0.033	0.173	0.000
		Conf 4	0.573	0.459	0.394	0.000
	Conf 3	Conf 4	0.021	0.004	0.608	0.451
Weston	Conf 1	Conf 2	0.098	0.070	0.543	0.025
		Conf 3	0.031	0.001	0.080	0.000
		Conf 4	0.562	0.000	0.033	0.005
	Conf 2	Conf 3	0.608	0.126	0.250	0.184
		Conf 4	0.281	0.032	0.127	0.560
	Conf 3	Conf 4	0.113	0.529	0.704	0.454
Tennessee Slider	Conf 1	Conf 2	0.002	0.474	0.996	0.000
		Conf 3	0.002	0.060	0.710	0.001
		Conf 4	0.610	0.914	0.744	0.000
	Conf 2	Conf 3	0.987	0.240	0.706	0.012
		Conf 4	0.009	0.543	0.740	0.004
	Conf 3	Conf 4	0.009	0.076	0.964	0.000

* Subject 1 had over 10 years of arthroscopic knot tying experience in a dry lab setting

tying the three RHAPs. Using a single-handed "overhand" throw technique is less likely to create unintentional tension applied to the suture limb which "flips" the seated half-hitch, and converts a series of RHAPs into a series of identical half-hitches on the same post. Half-hitches tied onto the same post are more likely to create insecure knots or suture loops with slippage as the most likely failure mechanism.

Previous studies had also noted variability among surgeons in knot and loop security.[2,7,25,30,32,39-41] These studies suspected this difference in ultimate failure loads and failure mode is caused by the tightness of the three RHAPs. The results of this study also showed vast inter-subject variability probably due to lack of basic competency in arthroscopic knot tying. The test subjects of this study were provided a brief instructional training period using a unique simulator device accompanied by an instructor verbally explaining how the knot is tied, how to eliminate twists and slack between throws, and provide guidance on proper tensioning of the suture limbs. The ability of each individual to appropriately learn and tie each arthroscopic knot greatly varies among each individual based upon learning styles. Basic instructional training appears to be sufficient for inexperienced individuals to learn easier base knot configurations, like the Surgeon's knot. A more challenging arthroscopic knot such as the Weston knot and the Tennessee Slider, however, requires training that is more intensive in order to obtain greater consistency in knot holding strength. This study discovered distinct learning curve variations for each base knot tied by each individual. This study agrees with previous studies[24,25] that a more comprehensive and intensive

Table 3. Knot Failure Mode Results

		RHAPs Sequence	Suture Material	Elongated But Intact	Knot Slippage
Surgeon's Knot	Subject 1	Conf 1	100%	0%	0%
		Conf 2	80%	20%	0%
		Conf 3	20%	80%	0%
		Conf 4	70%	30%	0%
	Subject 2	Conf 1	40%	50%	10%
		Conf 2	30%	60%	10%
		Conf 3	50%	50%	0%
		Conf 4	0%	80%	20%
	Subject 3	Conf 1	60%	30%	10%
		Conf 2	80%	20%	0%
		Conf 3	100%	0%	0%
		Conf 4	100%	0%	0%
	Subject 4	Conf 1	80%	20%	0%
		Conf 2	10%	90%	0%
		Conf 3	60%	40%	0%
		Conf 4	90%	10%	0%
Tennessee Slider Knot	Subject 1	Conf 1	0%	100%	0%
		Conf 2	0%	100%	0%
		Conf 3	10%	90%	0%
		Conf 4	0%	100%	0%
	Subject 2	Conf 1	0%	100%	0%
		Conf 2	10%	90%	0%
		Conf 3	0%	100%	0%
		Conf 4	0%	100%	0%
	Subject 3	Conf 1	90%	0%	10%
		Conf 2	80%	10%	10%
		Conf 3	60%	20%	20%
		Conf 4	80%	20%	0%
	Subject 4	Conf 1	0%	100%	0%
		Conf 2	10%	30%	60%
		Conf 3	0%	90%	10%
		Conf 4	20%	80%	0%
Weston Knot	Subject 1	Conf 1	10%	90%	0%
		Conf 2	10%	80%	10%
		Conf 3	0%	100%	0%
		Conf 4	10%	90%	0%
	Subject 2	Conf 1	0%	50%	50%
		Conf 2	0%	30%	70%
		Conf 3	0%	50%	50%
		Conf 4	10%	70%	20%
	Subject 3	Conf 1	40%	50%	10%
		Conf 2	50%	50%	0%
		Conf 3	70%	10%	20%
		Conf 4	80%	10%	10%
	Subject 4	Conf 1	0%	90%	10%
		Conf 2	0%	40%	60%
		Conf 3	0%	30%	70%
		Conf 4	0%	80%	20%

arthroscopic knot tying training program for orthopedic residents is needed. Gilmer et al.[17] and Chong et al.[25] suggest that a more structured, formal training program for inexperienced surgeons and residents may lead to higher consistency and improved biomechanical properties of arthroscopic knots. A brief training period does not appear to be adequate for mastery of skill, especially for the more complicated arthroscopic knot configurations. More structured training programs could address the learning curves for each base knot for each individual, as introducing each additional knot configuration adds an extra challenge to inexperienced residents or surgeons.

This study has certain limitations to recognize. First, this biomechanical investigation was performed in a dry laboratory environment at room temperature, whereas a fluid environment with varying temperature could potentially affect the results. Second, knots were tied on a standardized rigid post (30 mm in circumference) which differs from what is performed clinically, and therefore cannot account for the variability seen in clinical practice. The suture loop did not pass through any soft tissue, turn acute angles, risk abrasion on suture anchors, or rub over bony surfaces. Third, the data collected may not be generalizable to the fundamental aspects of training in arthroscopic surgery, such as difficulties with depth of vision on a 2-dimensional screen and hand-eye coordination, or on the long-term aspects of training. Fourth, only a single load-to-failure test was performed, however, a leading source of failure in orthopedic repairs has long been recognized by cyclic loading. Fifth, this study contained only three arthroscopic knot configurations with four overhand/underhand stacking combinations of three RHAPs that could limit the generalizability to other types of base knot configurations. Sixth, all knots were tied in one day and were tested as a batch, as opposed to immediately after knot construction. This short period of storage could have altered the properties of the knots. Despite these limitations, the outcomes of this study are valuable in revealing the possible impact of different overhand/underhand stacking combinations of three RHAPs involving different base knot configurations on arthroscopic knot security.

CONCLUSIONS

Arthroscopic base knot configurations paired with different overhand/underhand stacking combinations of RHAPs yielded an arthroscopic knot capable of secure tissue fixation. This study demonstrated that a short instructional training period appears to be sufficient for inexperienced individuals to learn easier base knot configurations, whereas more challenging and complicated base knots may require further training that is more gradual and intensive.

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A BIOMECHANICAL ANALYSIS OF TIBIAL FIXATION METHODS IN HAMSTRING-GRAFT ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

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ABSTRACT

Background: There are conflicting results on the biomechanical properties of tibial fixation devices in anterior cruciate ligament reconstruction. The objective of this study is to compare the initial biomechanical properties of tibial fixation in hamstring-graft ACL reconstruction with interference screw, suspension button, and Tape Locking Screw™ devices. We hypothesized there are no differences in the initial biomechanical properties of these three tibial fixation techniques.

Methods: Twenty-one fresh-frozen porcine tibiae were equally divided into three groups of seven tibiae to evaluate the fixation of human hamstring tendon grafts with interference screw, suspension button, or Tape Locking Screw fixation. Using a servohydraulic materials testing system, each graft was subjected to 500 cycles of loading followed by a monotonic failure test.

Results: Interference screw fixation demonstrated significantly lower cyclic displacement (1.28 ± 0.73 mm) than the other groups fixated with either a suspension button device (2.54 ± 0.27 mm, p = 0.003) or a Tape Locking Screw (2.32 ± 0.42 mm, p = .009), and a significantly greater cyclic stiffness (212.19 ± 40.30 N/mm) than the Tape Locking Screw (137.64 ± 26.17 N/mm, p = 0.002). The interference screw also demonstrated significantly higher pullout stiffness (166.83 ± 23.22 N/mm) than the suspension button (112.78 ± 24.14 N/mm, P = 0.002) and Tape Locking Screw (109.11 ± 12.91 N/mm, P = 0.0002).

Conclusions: Tibial fixation with an interference screw demonstrated superior biomechanical properties for cyclic testing compared to the suspension button and Tape Locking Screw. Load to failure did not differ between groups, and there were no significant biomechanical differences between the suspension button and Tape Locking Screw fixation devices.

Clinical Relevance: Despite the initial biomechanical differences, all three fixation devices exhibited mean loads to failure and cyclic displacements below clinically relevant thresholds of failure. These data suggest all three fixation methods are viable options for achieving a functional ACL reconstruction.

Level of Evidence: V

Keywords: tape locking screw, suspensory fixation, interference screw, biomechanics, ligament reconstruction

INTRODUCTION

Anterior cruciate ligament (ACL) reconstruction remains one of the most common orthopaedic procedures performed, with more than 100,000 ACL reconstructions performed annually in the United States.[1,2] The primary goals of ACL reconstruction are to restore knee stability and pre-injury level of function and prevent injury and degeneration to the knee joint. Surgeons utilize both autologous hamstring tendon and bone-patellar tendon-bone (BPTB) grafts in ACL reconstruction. While use of hamstring autograft has been shown to decrease knee flexion strength at high flexion angles,[3] many prefer this option due to reports of decreased incidence of anterior knee numbness,[4] kneeling pain,[5] and anterior knee pain.[6,7]

Stable graft fixation is necessary during biological incorporation to avoid graft elongation and failure.[8] This is especially true with the trend of early range of motion, weight-bearing and return to sport following ACL reconstruction.[9] While studies have demonstrated higher

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ultimate load to failure of hamstring graft compared to BPTB graft,[10,11] the fixation of hamstring graft to tibial bone is often the site of failure due to weaker tibial metaphyseal bone compared to that of the femur.[12]

The tibial fixation construct of choice is difficult to determine because clinical studies are limited by variability in outcomes reporting and various surgical techniques. Those that have compared various methods of tibial fixation have demonstrated no differences in clinical outcomes.[13,14,15,16] Many studies have compared the biomechanical properties of tibial fixation systems with varying results. Depending on the study, interference screws,[17] screw and washer fixation,[18,19] stirrup,[20] suspension button[8,21] or a combination of these[22] have been linked to superior results.

As the gold-standard tibial fixation device in hamstring-graft ACL reconstruction remains unclear, and a variety of devices are commonly implanted for this procedure, further research is warranted on the subject. This is especially true as the Tape Locking Screw (TLS,® FH Ortho, Chicago, USA), to our knowledge, has only been evaluated biomechanically twice previously,[23] one of which did not compare this device to other fixation methods.[24] The objective of this study is to compare the initial biomechanical properties of tibial fixation in hamstring-graft ACL reconstruction with three devices: Delta interference screw (Arthrex, Naples, USA), Tape Locking Screw, and TightRope RT (Arthrex, Naples, USA) suspension button. We hypothesized there are no differences in the initial biomechanical properties of these three techniques.

METHODS

Tibia Preparation:

A total of 21 skeletally mature (same age at slaughter, 11-12 months of age) fresh porcine tibiae were obtained from a local abattoir. The tibia was dissected of all soft tissue and stored in a freezer until the day of testing, at which time they were thawed for a minimum of 12 hours. The 21 porcine tibias were then divided into three groups based on ACL reconstruction and fixation technique. The first group of seven tibiae underwent ACL reconstruction with tibial fixation with a Delta interference screw. Seven tibiae underwent ACL reconstruction with the CoLS Classic System (FH Ortho, Chicago, USA), which utilizes a TLS. The remaining seven tibiae underwent reconstruction with the Graft Link All-Inside ACL (Arthrex, Naples, USA), utilizing TightRope RT suspension button fixation.

Tibial tunnels were prepared in accordance with the reconstruction method to which they were randomized. For the interference screw group, a tibial tunnel guide was set to 55° and the entry site placed midway between the tibial tubercle and posteromedial cortex. A tunnel matching the graft diameter was reamed in antegrade fashion with its intra-articular exit site located at the footprint of the native porcine ACL. The two remaining groups had identical landmarks to insert the guide pin so that it also exited at the footprint of the native porcine ACL. The sockets were created in a retrograde fashion to a depth and width as determined by their respective system.

Graft Preparation and Fixation:

Human hamstring tendon grafts were wrapped in saline-soaked gauze and stored frozen. On the day of testing, the grafts were thawed with normal saline and kept at room temperature for at least one hour. They were prepared depending on their respective product guides. For the interference screw technique, the original allograft was divided into two equal length segments and then each doubled over to create a four-strand graft with a total length of 60 mm—30 mm of tibial tunnel length and 30 mm outside the bone (extra-articular length). Number 5 Ethibond (Ethicon, Somerville, USA) sutures were utilized to whipstitch the free ends of the graft.

The GraftLink All-Inside ACL advocates a combined socket length (end of femoral socket to end of tibial socket) at least 10 mm longer than the graft to ensure that the graft does not bottom out in either socket. Thus, a single graft was quadruple-folded to a total length of 10 mm less than the pre-determined tibial socket length; an extra-articular length of 30 mm was established. Lastly, the CoLS Classic System determines total graft length by the patient's height. On the femoral side, the graft length is always 10 mm and the tibial side is always 15mm; the intraarticular length varies based on patient's height. Accordingly, for this testing model, a quadruple-folded graft with a total length of 45 mm was used: 15 mm of tibial tunnel length and 30 mm of extra-articular length.

Grafts for all reconstruction methods were sized to an 8 mm diameter determined by a sizing block. In addition, as is performed during surgery, the allografts underwent preconditioning prior to testing. The interference screw group was preconditioned at 67 N for 10 minutes on a pre-tensioning board while the TLS and suspension button groups were pre-tensioned according to their respective product manuals.

For Delta interference screw testing, all allografts were fixated using nine mm screws, one mm larger than the tunnel diameter. Using a guide wire, each screw was inserted co-linear to the tibial tunnels and inserted until the distal end of the screw abutted the cortical border of the tibia. A graft tensioner tensioned each strand of the graft to 15 N. For the remaining groups, grafts were fixated according to product manuals for the CoLS Classic System and GraftLink All-Inside ACL. The testing sequence was randomized to minimize potential surgical

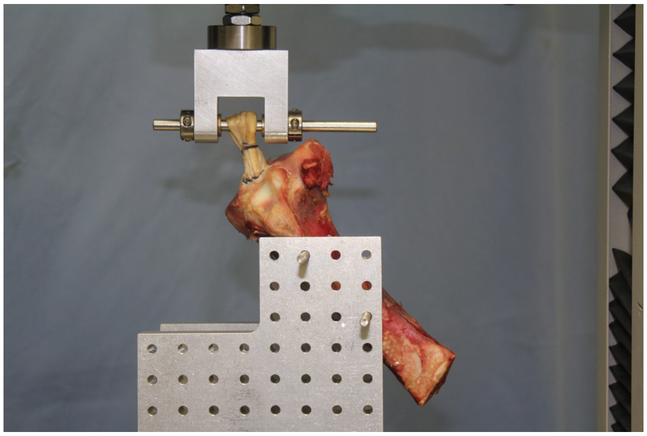

Figure 1. Mechanical testing of tibial fixation with human hamstring tendon in porcine tibia using a servohydraulic materials testing system.

bias. All surgical fixations were performed by the same orthopaedic surgeon [HF].

Biomechanical Testing:

Mechanical testing was performed using a servohydraulic materials testing system (Figure 1). Each tibia was secured in a custom-designed vise fixture, which allows unconstrained positioning of tibial specimens prior to testing. The base of the vise was mounted to the testing platform and the tibia positioned so the tunnel was parallel to the test actuator axis. This allowed for testing in a "worst-case" scenario with direct, in-line force on the graft. The proximal end of the graft was looped around the cross-pin of a "trapeze" fixture, which was connected directly to the load cell.

All tests were conducted at room temperature and the allografts regularly moistened with saline during testing. An initial preload of 5 N was applied to each graft before testing and the length of tendon outside of the tibial tunnel (approximately 30 mm) was reassessed for any displacement. Each specimen was then pre-conditioned at a displacement rate of 0.75 mm/sec between 10 and 50 N for 10 cycles. Next, cyclic tensile testing (havertriangle waveform) was performed at the same displacement rate using 500 cycles between 50 and 250 N. Finally, a load-to-failure test was conducted at 20 mm/min.

For each specimen, four parameters were computed for analysis. Cyclic displacement (net change in peak cyclic displacement over 500 cycles) and cyclic stiffness (the slope of the secant line joining minimum and maximum points of the loading phase of the load-deformation curve reported from the 500th cycle) were quantified from the cyclic protocol. Maximum failure load and pullout stiffness (the steepest slope of the load-deformation curve spanning 20% of the data points up to maximum load) were calculated from the load-to-failure test. To qualify for statistical analysis, the specimens must have completed the 500-cycle protocol and failed via the load-to-failure test. Any specimen that failed during cyclic loading was removed from statistical analysis. Student's t-tests were used to compare the three groups.

RESULTS

One specimen from the suspension button group failed during cyclic testing and was removed from statistical analysis. Of the remaining specimens that completed testing, the suspension button failed via tibial button loop rupture in five cases and button migration into the tunnel in one case. All constructs in the interference screw and TLS groups failed by graft pullout from the tunnel.

Interference screw fixation demonstrated significantly lower cyclic displacement (1.28 ± 0.73mm) than the other groups fixated with either a suspension button device (2.54 ± 0.27 mm, p = 0.003) or a TLS (2.32 ± 0.42 mm, p = 0.009), and significantly greater cyclic stiffness (212.19 ± 40.30 N/mm) than the TLS (137.64 ± 26.17 N/mm, p = .002) (Table 1). During load-to-failure testing, the interference screw trended toward a lower mean ultimate failure load (674.91 ± 183.85 N) than both the suspension button (880.05 ± 176.64 N) and TLS (843.93 ± 193.17 N), although there were no significant differences. The interference screw had significantly higher pullout stiffness (166.83 ± 23.22 N/mm) than the suspension button (112.78 ± 24.14 N/mm, p = 0.002) and TLS (109.11 ± 12.91 N/mm, p = 0.0002). There were no significant biomechanical differences between the suspension button and TLS.

DISCUSSION

Hamstring autograft is commonly used in ACL reconstruction due to decreased incidence of anterior knee numbness,[4] kneeling pain,[5] and anterior knee pain.[6,7] Stable graft fixation is necessary during biological incorporation to avoid graft elongation and failure,[8] and the fixation to tibial bone is often the site of failure due to weaker metaphyseal bone compared to that of the femur.[12] The ideal fixation technique of ACL reconstruction with hamstring graft remains controversial, and multiple studies have investigated the initial biomechanical properties of tibial fixation devices with differing results.[8,17-23] The objective of this study was to compare the initial biomechanical properties of tibial fixation with three devices: Delta interference screw, TLS, and TightRope RT suspension button. We hypothesized there are no differences in the initial biomechanical properties of these three techniques.

An interference screw is considered a type of aperture fixation, which compresses the graft against the cortical or cancellous bone in the wall of the tunnel. Robert et al.'s study also used porcine tibiae and their Delta interference screw fixation exhibited cyclic displacement 3.81 ± 11.25

Table 1. Biomechanical Results of Tape Locking Screw, Suspension Button, and Interference Screw Tibial Fixation Devices

Fixation Device	Cyclic Displacement (mm)	Cyclic Stiffness (N/mm)	Load to Failure (N)	Pullout Stiffness (N/mm)
	(mean ± SD)	(mean ± SD)	(mean ± SD)	(mean ± SD)
TLS	2.32 ± 0.42	137.64 ± 26.17	843.93 ± 193.17	109.11 ± 12.91
SB	2.54 ± 0.27	171.75 ± 32.16	880.05 ± 176.64	112.78 ± 24.14
IS	1.28 ± 0.73[a,b]	212.19 ± 40.30[c]	674.91 ± 183.85	166.83 ± 23.22[d,e]

[a]Significantly different from TLS (p = 0.009).
[b]Significantly different from SB (p = 0.003).
[c]Significantly different from TLS (p = 0.002).
[d]Significantly different from TLS (p = 0.0002).
[e]Significantly different from SB (p = 0.002).
TLS = Tape Locking Screws, SB = Suspension Button, IS = Interference Screw

mm, cyclic stiffness 309.7 ± 75 N/mm, load to failure 844 ± 394 N, and pullout stiffness 195.7 ± 59 N/mm.[23] Suspension button devices utilize proprietary loop configurations to seat the tensioned graft in the tunnel and fix the button against cortical bone. Potential advantages of this method include the necessity of only one tendon graft, implant fixation on cortical instead of weaker cancellous bone, and a larger area of graft to cancellous bone surface area for healing.[21]

The TLS achieves fixation via an interference screw with a polyethylene terephthalate strip, which attaches to the tendon graft loop. Potential advantages of this technique include the need to only harvest a single tendon, better interference fit between the strip and screw compared to the graft,[25] and a shorter working length of the suspension construct resulting in a lower likelihood of tunnel widening often seen with suspension button fixation.[24] To our knowledge, the initial biomechanical results of TLS fixation has only been studied twice previously. Ayzenberg et al. found load to failure of 523 ± 269 N, but they did not conduct cyclic tensile testing.[24] Only one study compared it to other modes of tibial fixation: Robert et al.'s TLS analysis exhibited cyclic displacement 1.23 ± 0.36 mm, cyclic stiffness 295.9 ± 78 N/mm, load to failure 1015 ± 129, and pullout stiffness 138.2 ± 35 N/mm.[23]

Many studies have compared the biomechanical properties of tibial fixation systems with varying results. Interference screws have been studied extensively and compared to multiple other devices. Kousa et al. compared a titanium interference screw, a bioabsorbable interference screw, a sheathed interference screw, and washer and screw fixation, and demonstrated the sheathed interference screw had the lowest residual displacement and was the strongest in load-to-failure.[17] Chivot et al. compared an interference screw, a sheathed interference screw, an absorbable cross pin, and a nonabsorbable cross pin, and determined the interference screw exhibited higher load to failure and less slippage[26] Giurea et al. compared a stirrup, a clawed washer with cancellous bone screw, a soft titanium interference screw, and a rounded-head interference screw, demonstrating significantly higher load to failure with the stirrup.[20]

Specific to the devices used in this study, Mayr et al. compared the TightRope RT suspension button and the BioComposite (Arthrex, Naples, USA) biodegradable interference screw, demonstrating that grafts with interference screw fixation showed less cyclic displacement, higher pull-out stiffness, and a lower ultimate failure load compared to suspension button fixation.[8] In contrast, the TightRope ABS (Arthrex, Naples, USA) suspension button has also been compared to BioComposite interference screw fixation, demonstrating a higher load to failure but comparable cyclic displacement.[21] In our study, the Delta interference screw demonstrated lower cyclic displacement, no difference in load to failure, and higher pullout stiffness compared to the TightRope RT.

To our knowledge, the TLS's biomechanical properties have only been investigated in one other comparative study: Robert et al. compared the TightRope RT, WasherLoc (Zimmer Biomet, Warsaw, USA) screw and washer fixation, Delta interference screw, and TLS using porcine bone and human tendons.[23] In their study, TLS demonstrated lower cyclic displacement compared to the other three devices. This contrasts with our study, in which the interference screw group had lower cyclic displacement than the other groups. The difference may be attributed to the fact that Robert et al. included trials with lacerated tendons, which they say accounted for high cyclic displacement in the interference screw group, whereas tendons that could not complete cyclic testing were excluded from our study. Robert et al.'s study demonstrated no difference between groups for cyclic stiffness, but our study showed higher cyclic stiffness for the interference screw than the TLS.

For load-to-failure in Robert et al.'s study, both the TLS and Delta interference screw had the higher yield load compared to the two remaining systems; the TLS and interference screw yield loads were not significantly

Table 2. Fixation Superiority for Initial Biomechanical Results

	Cyclic Displacement	Cyclic Stiffness	Load to Failure	Pullout Stiffness
Robert et al.	TLS > IS TLS > SB TLS > W	-	TLS > W TLS > SB	IS > TLS IS > SB IS > W
Current Study	IS > TLS IS > SB	IS > TLS	-	IS > TLS IS > SB

IS = interference screw, TLS = Tape Locking Screw, SB = suspension button, W = screw/washer

different. During load-to-failure testing in our study, the interference screw group trended toward a lower mean ultimate failure load than the other groups, although there were no significant differences. The interference screw group also exhibited higher pullout stiffness than the other groups in both studies. There were no significant biomechanical differences between the suspension button and TLS fixation devices in our study. The comparison of these two studies is summarized in Table 2.

This study has a few limitations. First, it describes the initial biomechanical properties of hamstring-graft ACL reconstruction tibial fixation, but it does not evaluate the femoral fixation, the properties of both constructs in tandem, nor the change in biomechanics of these constructs over time. Also, porcine bone was used instead of human bone and direct extrapolation to tibial fixation in human ACL reconstruction cannot be made. However, young human cadaveric bone is difficult to obtain, and a previous study has demonstrated the average density of porcine bone is similar to young human bone and significantly higher than elderly human cadaveric bone.[27] Further, there is low variability in porcine tibiae bone mineral density.[28] For these reasons, combined with the fact that porcine bone has been used for similar studies in the past,[17,18,23] we believe it is an acceptable substitute.

In sum, Delta interference screw fixation demonstrated less cyclic displacement and greater pullout stiffness than the TLS and Arthrex TightRope RT suspension button and greater cyclic stiffness than the TLS. Load to failure did not differ between groups, and there were no significant biomechanical differences between the suspension button and TLS fixation devices.

Adequate tibial fixation in ACL reconstruction is necessary to allow early rehabilitation and a stable environment for ligamentization and tendon-bone integration. A 500 N load is the estimated tension of an ACL graft during intensive rehabilitation.[18] The post-operative stability of the knee after ACL reconstruction can also be measured using a KT-1000 arthrometer, with a side-to-side difference greater than three mm considered reconstruction failure.[8] While cyclic displacement is not synonymous with change in anterior laxity, it has been used as an approximation for the purpose of clinical correlation in previous studies.[8,23] Therefore, despite the initial biomechanical differences, all three fixation devices exhibited mean loads to failure and cyclic displacements below these clinically relevant thresholds of failure. These data suggest all fixation methods investigated in this study are viable options for achieving a functional ACL reconstruction.

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ARTHROSCOPIC HIP JOINT ASSESSMENT CAN IMPACT THE INDICATIONS FOR PAO SURGERY

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ABSTRACT

Background: The purpose of this study was to analyze clinical, radiographic and intraoperative disease characteristics of patients with symptomatic acetabular dysplasia in which periacetabular osteotomy (PAO) was contraindicated due to advanced intraarticular findings at the time of disease staging hip arthroscopy (HA).

Methods: A prospective cohort was used to identify all patients who were scheduled for a PAO and concomitant hip arthroscopy for the treatment of symptomatic acetabular dysplasia. From a total of 286 patients (286 hips), 11 patients (11 hips) were identified in whom the PAO was contraindicated due to the intraarticular findings of a disease-staging hip arthroscopy. Clinical characteristics, radiographic and intraoperative findings were analyzed and compared to those patients in whom the joint was judged to be appropriate for PAO surgery.

Results: 11 patients (11/286 or 4%), in whom a PAO was contraindicated after joint assessment with HA, were identified and included in this study. There were nine females and two males. All patients were potential candidates for PAO surgery. The PAO was contraindicated in these cases due to severe articular cartilage damage on both the femoral head and acetabulum. The patients when compared to those in which the PAO was performed, were significantly older (42.3 years (IQR, 38.1-46.8) vs. 24 years (IQR, 19-34)) ($p<0.001$) and had more severe dysplasia with a lower median lateral center-edge angle (LCEA, 12.9° vs. 17.7°, $p=0.001$) and lower anterior center-edge angle (ACE, 14.4° vs. 20.3°, $p=0.021$).

Conclusions: Patients in which the PAO was contraindicated, compared to those in which PAO was performed, were older and had significant more severe dysplasia. The main cause of intraoperative disqualification for PAO was advanced articular cartilage disease.

Level of Evidence: IV

Keywords: acetabular dysplasia, PAO, hip arthroscopy, developmental dysplasia

INTRODUCTION

The Bernese periacetabular osteotomy (PAO) is a well-established technique for the treatment of symptomatic acetabular dysplasia.[1] With only a few prospective, long-term studies of PAO outcomes, proper patient selection remains challenging.[2, 3] PAO is indicated for those patients who are symptomatic, yet have relatively preserved articular cartilage. A combination of clinical history and physical examination, along with plain radiography, computed tomography and magnetic resonance imaging (MRI) are normally utilized to establish a predictable indication.[1, 4-6]

The use of imaging studies aids in the qualification process, but imaging may not completely define the severity of the articular cartilage and labral lesions.[7, 8] Severe cartilage damage as determined by radiographic joint space narrowing is a significant predictor of failure and relative contraindication for PAO.[9-12] Since cartilage damage is common in patients with symptomatic DDH,[13, 14] MRI has been established as part of preoperative imaging modality for patient selection. However, the diagnosis of cartilage damage through noninvasive imaging modalities can have limitations relative to determining the exact size and thickness of a given articular cartilage lesion in the hip.[8, 15, 16]

In patients with equivocal clinical presentation and imaging studies relative to indicating PAO surgery, hip arthroscopy (HA) provides an excellent tool to directly visualize and determine articular cartilage integrity.[17] Additionally, in patients with symptomatic acetabular dysplasia and associated intra-articular abnormalities (labral tears, ligamentum teres tears, and chondral lesions) concurrent hip arthroscopy can provide improved access, visualization and technical precision in the central compartment compared to an open anterior arthrotomy.[18]

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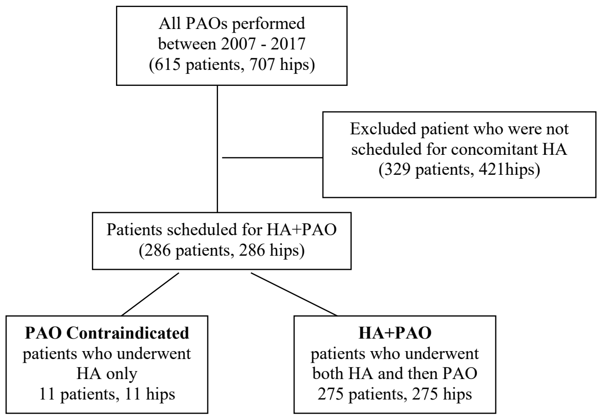

Figure 1. Flowchart shows final cohort and reason for exclusion. PAO = periacetabular osteotomy, HA = hip arthroscopy

Over the past several years, hip arthroscopy has been used in combination with the PAO (HA+PAO) to stage articular cartilage degeneration and diagnose and treat associated intraarticular abnormalities.[13, 19-21] However, the superiority of hip arthroscopy concomitantly with the PAO has not been established.

Uncommonly, despite the use of strict clinical parameters and advanced imaging for patient selection, the indication for PAO may not be completely clear due to uncertainty regarding the health of the femoral head and acetabular articular cartilage. Since intra-articular lesions and more advanced articular cartilage disease have been described as a risk factor for poor outcomes and osteoarthritis progression following PAO,[9-12] it is important to determine joint health prior to indication for PAO treatment. In cases with equivocal health of the articular cartilage, a staging hip arthroscopy can provide important information regarding joint health and appropriateness of PAO surgery. The purpose of this study was to analyze the clinical and radiographic characteristics of patients with symptomatic acetabular dysplasia in whom PAO surgery was contraindicated due to the findings of advanced articular cartilage disease at the time of a disease-staging hip arthroscopy.

MATERIALS AND METHODS

Selection criteria

This study was performed under an institutional review board–approved protocol. An institutional prospectively longitudinal database of PAOs was reviewed and 286 consecutive patients (286 hips) who were scheduled for HA+PAO by the senior surgeon (JCC) from April 2007 to April 2017, were identified. Throughout the study period, the indications for the HA+PAO were (1) symptomatic acetabular dysplasia[22] as diagnosed by the senior author (center-edge angle of Wiberg of less than 25° and skeletal maturity) (2) failed nonsurgical treatment

Table 1. Demographic and History Data for the 286 Patients

Parameter	PAO Contraindicated (n=11)	HA + PAO (n=275)	Significance level
Age (years)	42.3 (38.1 - 46.8)	24 (19 - 34)	p<0.001
Sex (M: F ratio)	2: 9	30: 245	p=0.453
BMI (kg/m2)	23.5 (21.8 - 25.1)	22.7 (20.6-25.2)	p=0.32
Previous hip surgery (Y: N ratio)	1: 10	39: 236	p=0.633
Pain chronicity			p=0.637
< 6 months	1	14	
6 months - 1 year	1	56	
1 - 3 years	5	120	
3 - 5 years	1	44	
> 5 years	3	39	

BMI - body mass index; M - male; F - female; Y - yes; N - no
The Data are Median (IQR) for Age and BMI and Ratios for Sex and Previous Hip Surgery.

(minimum three months, including physical therapy, activity modification, NSAIDs and variable intra-articular corticosteroid injection), (3) mechanical hip symptoms, (4) MRA diagnosed labral detachment and/or (5) concern regarding the integrity of the femoral head and acetabular articular cartilage. The contraindications for PAO were (1) osteoarthritis (Tönnis Grade 2 and higher), (2) poor hip congruence on plain radiographs, (3) BMI greater than 35 and/or (4) limited hip range of motion (flexion less than 90°, abduction less than 20°). After all patients scheduled for HA+PAO were identified, all of their operative notes were searched manually to identify those, who were intraoperatively disqualified from continuing with the PAO. This left 11 patients (11 hips) in the study group (contraindicated for the PAO) and 275 in a comparison group (HA+PAO). The process is presented in Fig. 1.

Outcomes

Demographic and clinical data regarding age, sex, height, weight and previous surgeries (Table 1) were obtained. Additionally, the preoperative clinical scores including modified Harris Hip Score (mHHS),[23] HOOS[23] and UCLA score[24] were recorded.

Radiographic analysis

One author (MKW), who was not aware of the status of the hip, assessed all conventional radiographs (Table 2). All patients had preoperative radiographs, which included an antero-posterior pelvis (AP), frog-lateral, false profile,

Table 2. Patient-Reported Outcomes for Both Groups at Baseline

Parameter	PAO Contraindicated (n=11)	HA+PAO (n=275)	Significance level
UCLA	4 (3 - 6)	6 (4 - 10)	p=0.080
HOOS Symptoms	60 (50 - 75)	50 (35 - 65)	p=0.165
HOOS Pain	57.5 (50 - 70)	47.5 (35 - 65)	p=0.141
HOOS ADL	69.9 (57.4 - 82.4)	63.2 (47.1 - 80.9)	p=0.422
HOOS S&R	53.1 (25 - 75)	37.5 (18.8 - 56.3)	p=0.133
HOOS QoL	34.4 (18.8 - 37.5)	25 (12.5 - 43.8)	p=0.617
WOMAC	68.8 (57.3 - 79.2)	61.5 (45.8 - 76)	p=0.324

and 45° Dunn lateral view.[4, 25-27]

The following radiographic parameters were measured: the center-edge angle of Wiberg,[28] acetabular index angle[29] and minimal joint space width.[30] The minimal joint space width was measured as the smallest distance between the acetabular sclerotic zone and the femoral head. The degree of osteoarthritis was graded preoperatively according to the Tönnis classification (Grades 0–3).[29] All of the measurements above were performed using the OrthoStudio plug-in (Boston Children's Hospital, Boston, MA) for the OsiriX Lite DICOM viewer (Pixmeo Sarl, Bernex, Switzerland). The congruence of the hip was evaluated by identifying the center of the femoral head using the best-fitted circle; then another best-fitted circle of the acetabulum was drawn with a digital software (BJC Clinical Desktop, BJC Healthcare, St. Louis, MO). We considered the hip congruent if the centers of the femoral head and the acetabulum were concentric within one millimeter.

All patients had preoperative MRI with a 1.5-T magnetic resonance system (Avanto; Siemens, Erlangen, Germany) with T1, T2 and PD fat sat sequences. The following parameters were used: slice thickness 0.82 mm, Repetition time (TR) 15.96 ms, Echo time (TE) 6.2 ms, Field of view (FOV) 400 mm at the hip joint, 512 512 matrix. MRI images were read by a fellowship-trained musculoskeletal radiologists and their reports were abstracted and findings analyzed.

Operative findings

The operative data was collected prospectively from a standardized data worksheet that was filled out by the operating surgeon (JCC) at the completion of the surgery. It described the status of the labrum and the articular surfaces (both acetabulum and femoral head). Labral tears were classified by involvement of anterior, superolateral and posterior regions of the acetabulum.[31] For the

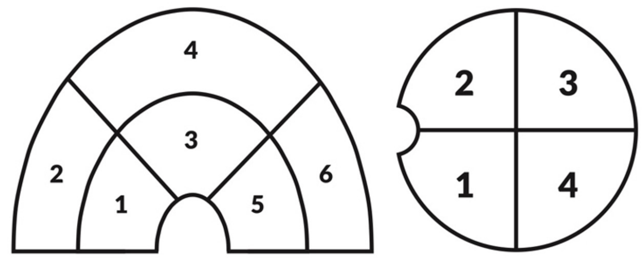

Figure 2. For each zone, the surgeon was requested to describe the worst chondromalacia for each section involved. Six anatomic locations were defined in the acetabulum: anterior central (1) anterior peripheral (2), superolateral central (3), superolateral peripheral (4), posterior central (5) and posterior peripheral (6). For the femoral head 4 quadrants were established as 1: posterolateral, 2: anterolateral, 3: anteromedial and 4: posteromedial.

chondromalacia, Beck scoring was used.[32] Acetabular chondromalacia was identified in each one of the sextants of the acetabulum: anterior central, anterior peripheral, superolateral central, superolateral peripheral, posterior central and posterior peripheral. Femoral chondromalacia was graded in each one of the quadrants of the femoral head: anterolateral, anteromedial, posterolateral and posteromedial (Fig. 2). The results are analyzed as either the presence of chondromalacia or not. Then the grading according to Beck (ref) was clustered in two subgroups for every region and grades 2-3 vs. 4-5 were compared.

Statistical analysis

Data are presented as means with 95% CIs when normally distributed and as medians with interquartile ranges (IQRs) when not normally distributed. Shapiro-Wilk test was used for normality testing. For comparing medians, t-test and for medians, U Mann-Whitney test was used. Occurrences were compared with a chi-square test with appropriate corrections, when necessary. The p value of < 0.05 was considered statistically significant. All calculations were performed in Statistica 13.1 software package (StatSoft Inc., Tulsa, OK).

RESULTS

Demographics and history

From a total of 286, 11 patients (11 hips, 4%) were disqualified from the PAO due to the findings of hip arthroscopy. These included advanced articular cartilage lesions in all cases. There were nine females and two males with median age of 42.3 years (IQR, 38.1-46.8). The HA +PAO comparison group was comprised of 245 females and 30 males with a median age of 24 years (IQR 19-34). Further demographic data and data from patients' history, including BMI, previous hip surgery and pain chronicity,

Table 3. Radiographic Data for the 286 Patients

Parameter	PAO Contraindicated (n=11)	HA+PAO (n=275)	Significance level
AP min. JSW	4.2 (3.2 - 4.9)	4 (3.6 - 4.5)	p=0.674
LCEA	12.9 (5.6 - 14.7)	17.7 (14.7-20.4)	p=0.001
AI	18.6 (9.1 - 22.8)	13.6 (10.9 - 16.2)	p=0.070
ACE	14.4 (8.5 - 21.4)	20.3 (14.5 - 25.6)	p=0.021
Tönnis grade			p=0.087
0	5	192	
1	6	83	

AP min. JSW – minimal joint space width on the AP radiographic view; LCEA – lateral center-edge angle; AI – acetabular index; ACE – anterior center-edge angle

are provided in Table 1. Patients in the study group (PAO contraindicated) were significant older than patients in the HA+PAO group (U Mann Whitney test, $p<0.001$).

Patient reported outcomes

No significant difference was observed in pre-operative clinical scores. Mean preoperative mHHS for the HA group was 61.1 (95% CI, 55.2-67) vs 57.5 (95% CI, 13.2-100) for HA+PAO (p=0.44). Other baseline patient-reported outcomes also did not differ statistically (Table 2).

Radiological characteristics

The study group had significantly more severe acetabular deformity than the comparison. Additionally the study group had a lower median lateral center-edge angle of 12.9° (IQR 5.6° - 14.7°), compared to the median 17.7° (IQR 14.7° - 20.4°) in the comparison group (p=0.001). When comparing IQRs, only 25% of the study patients and the majority (75%) of the comparison group patients had LCEA larger than 12.9°. Significantly less anterior coverage (median ACE 14.4°; IQR 8.5° - 21.4°) was observed in the study group, compared to the comparison group (median ACE of 20.3°, IQR 14.5° - 25.6°; p=0.021). Other radiographic parameters did not differ significantly and are provided in Table 3.

Magnetic resonance imaging

The prevalence of labral tears, paralabral cysts and chondrosis in the MRI did not differ between two groups. Details are provided in Table 4 and 5.

Intraoperative findings

All of the acetabula in the study group showed chondromalacia, which was also present in 92% of the hips in the comparison group (p=0.329). The study group cases had more advanced cartilage disease (grades 4 and 5, representing cleavage and defects) compared to milder lesions (grades 2 and 3, representing malacia and debonding), in anterior central, anterior peripheral and superolateral peripheral regions of the acetabulum. Seven (64%) out of 11 patients in the study group had femoral head chondromalacia, compared to 52 (17%) of the comparison group patients ($p<0.001$). Detailed comparisons are given in Table 6.

Labral tear was diagnosed intraoperatively in all study group patients and in 99% (271/275) of the comparison group patients (p=0.854). Labrum morphology was normal in only two disqualified PAO patients and 140 HA+PAO patients, in the remaining it was either hypertrophic or ossified (p=0.033).

DISCUSSION

The most significant finding of this study was that findings at hip arthroscopy rarely provide a contraindication to PAO surgery. Only 4% of patients scheduled for combined HA/PAO were disqualified. These patients were significantly older and had radiographically more severe dysplasia. Disqualification was secondary to severe articular cartilage damage on both femoral and acetabular side.

Advanced age[33] and severity of dysplasia[34, 35] have previously been proposed as a risk factor for advanced cartilage disease and failure following PAO.[11, 36, 37] Still, in our cohort there were older patients that were not disqualified from PAO. Therefore, qualification for PAO cannot be based on the age alone. Additionally, Millis et al. showed that PAO would give satisfactory functional and pain scores in patients over age 40 having dysplastic hips with mild or no arthrosis.[2] During mean follow-up of five years, they had to convert 12% of patients with preoperative Tönnis grade 1 and 27% of patients with preoperative Tönnis grade 2. Different from our study, none of their patients had preoperative MRI and none were treated with a concomitant HA. Therefore, it is possible that some of those failures were attributable to the articular cartilage damage already present at the time of PAO. Thus, in patients over 40, Garbuz et al. recommended direct articular cartilage assessment for older patients.[38] Based on the results of our study, this recommendation seems well-founded.

Clinical results of PAO for the treatment of severe dysplasia have been promising, although in populations younger than in our study group.[39] Unfortunately, neither hip arthroscopy, nor MRI results were available for analysis in those patients. Despite the fact that most of the patients in the study group displayed significant acetabular undercoverage, it is difficult to attribute disqualification

Table 4. Magnetic Resonance Imaging Findings

parameter		PAO Contraindicated (n=11)	HA+PAO (n=275)	significance level
labral tear				p=0.295
	present	6	191	
	absent	5	84	
paralabral cysts				p=0.519
	present	0	10	
	absent	11	265	
chondrosis in any location				p=0.265
	present	3	22	
	absent	8	253	
chondrosis of the femoral head				p=0.640
	present	2	14	
	absent	9	261	
chondrosis of the acetabulum				p=0.232
	present	2	22	
	absent	9	253	

to the increased severity of acetabular dysplasia. Additionally, patients in both groups had satisfactory congruence and joint space width, making them suitable candidates for PAO.[1, 11] Lastly, neither hip arthroscopy, nor MRI were performed before PAO in that study.

When considering both age and degree of acetabular dysplasia, no distinct pattern of those two risk factors could be eluded from the present study. Neither age, nor lateral undercoverage, nor combination of those two factors could predict the arthroscopic findings.

Most of the patients who were disqualified displayed femoral head chondromalacia. This might be an important threshold for aborting PAO. The subchondral bone exposure on the femoral head has been previously identified as a risk factor for progression of osteoarthritis after pelvic osteotomy.[9] Horisberger et al. showed that if subchondral bone exposure is found in addition to the acetabular lesions, failure of hip arthroscopy ensues quickly.[40] Streich et al. found chondral defects to be prognostic of failure in arthroscopic labral repair.[41] Unfortunately, many of the studies available do not give any information about the cartilage damage at the femoral head.[40]

Success of PAO depends on the amount of preoperative osteoarthritis (OA), even though there is little evidence to guide the choice of cut-off point.[10] In general, patients with no to little radiographic evidence of OA are considered

Table 5. Acetabular Cartilage Disease in 286 Patients

location / compartment		PAO Contraindicated (n=11)	HA+PAO (n=275)	significance level
acetabular cartilage				
in any region:				p=0.329
	chondromalacia present	11	253	
	chondromalacia absent	0	22	
anterior central				**p=0.022**
	2-3	0	24	
	4-5	3	6	
anterior peripheral				**p=0.013**
	2-3	2	133	
	4-5	4	39	
superolateral central				p=0.347
	2-3	1	13	
	4-5	2	3	
superolateral peripheral				**p=0.041**
	2-3	5	187	
	4-5	5	53	
posterior central				N/A
	2-3	0	4	
	4-5	0	1	
posterior peripheral				p=0.783
	2-3	3	28	
	4-5	1	2	

For Each Location, the Number of Patients with Grades 1-3 and Grades 4-5 are Provided. Occurrences were Compared with Chi-Square Test, and Chi-Square Test with Yates Correction for Continuity when any of the Expected Counts was Smaller than 5

the best candidate for PAO.[3, 42] There are currently three imaging modalities available for staging intraarticular damage prior to PAO. These include plain radiography, conventional MRI, and compositional MRI techniques.

Radiographs assess cartilage loss indirectly by measuring apparent joint space loss or morphologic changes caused by arthritis. Thus, they cannot detect early cartilage injuries. In this study, all preoperative radiographs of aborted cases were judged to be Tönnis grade 0 or 1. Therefore, plain radiography underestimated the extent of cartilage damage in the aborted cases.[43]

Conventional MRI allows visualization of the cartilage

Table 6. Femoral Cartilage Disease in 286 Patients

location / compartment		PAO Contraindicated (n=11)	HA+PAO (n=275)	significance level
femoral head cartilage				
in any region:				**p<0.001**
	chondromalacia present	7	52	
	chondromalacia absent	4	223	
posterolateral				p=0.283
	2-3	1	10	
	4-5	5	15	
anterolateral				p=0.684
	2-3	1	15	
	4-5	3	15	
anteromedial				p=0.769
	2-3	1	9	
	4-5	4	14	
posteromedial				p=0.467
	2-3	1	7	
	4-5	5	15	

morphology. Even though it remains a good tool to identify labral damage, MRI has known limitations in detecting cartilage lesions.[16] Importantly, a negative MRI study does not exclude important intra-articular pathology that can be identified and treated arthroscopically.[43] This was also the case in this study, as the MRI results did not discern disqualified patients from the rest of the cohort.

Compositional MRI techniques analyze the content of hyaline cartilage and may one day become biomarkers that would influence patient selection. In the last decade, multiple studies using delayed gadolinium-enhanced MRI of cartilage (dGEMRIC) suggest this type of MRI may be a better diagnostic tool to assess early OA in the dysplastic hip.[45-46] Coronal dGEMRIC index[44] and then anterior index calculated based on anterior part of selected saggital cuts[45] were proposed as a predictors of failure. These results can be considered preliminary at best, as they both come from the same population. There is a need for rigorous, multicenter prospective studies to establish the usefulness of compositional MRI techniques in prediction of failure and/or patient selection for conservative or surgical treatment.[46]

Since the preoperative imaging is not fully reliable for patient selection, some surgeons perform PAO with hip arthrotomy to address intraarticular lesions and femoral head-neck deformities.[47] Other surgeons consider performing diagnostic arthroscopy before PAO to address intraarticular damage.[3, 48] Good results have also been reported with hip arthroscopy, followed immediately by PAO during the same procedure.[19, 49] A concomitant arthroscopy at the time of a PAO allows more complete visualization of the intraarticular hip structures plus improved ability to address intraarticular pathology.[9, 14, 50] However, it is not clear whether the added surgical time and risks result in improved outcomes,[51] although short-term studies show no adverse outcomes and equivalent or improved results.[49, 52] Disadvantages of combined HA+PAO include increased operative time (by adding HA, but also by making PAO more difficult), possibility for fluid extravasation, and increased risk of capsular adhesions from intra-articular work.[19, 49, 53, 54]

Our study has limitations. One is that the decision to abort the PAO was made at the discretion of the operating surgeon. Secondly, we could not provide exact cut-off values for the factors predicting intraoperative disqualification. We believe, though, that the recorded differences in patients' characteristics have the potential to improve selection of patients who will benefit from PAO and help in the future identify patients who might otherwise be subjected to unnecessary hip-preserving surgery, instead of being offered a primary total hip replacement.

To conclude, our data indicates that intraoperative disqualification from PAO is rare, with only 4% of the whole cohort disqualified. Patients that have been disqualified from the PAO were significantly older and presented radiographically higher grades of dysplasia. In cases with strong suspicion of substantial intra-articular damage or questionable indications, HA performed before PAO helps identify hips in which advanced articular cartilage disease may diminish the predictability of the PAO.

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AN ELEVATED METRORAIL AS A SOURCE OF ORTHOPEDIC INJURIES AND DEATH AT A LEVEL-I TRAUMA CENTER

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ABSTRACT

Background: Elevated Metrorail systems differ from conventional trains by their slower speeds and collisions with pedestrians predominantly occurring at accessible stations or platforms. Here, the orthopedic implications of pedestrians struck by a Metrorail are evaluated, as were the correlations of substance abuse and psychiatric history on injury and death.

Methods: Retrospective cohort study at a single Level-1 trauma center of patients requiring admission with orthopedic injuries following Metrorail impact from 1/2004-2/2017. Demographics, substance abuse, psychiatric history, intentionality, LOS, follow-up, fracture characteristics, and management were studied.

Results: 33 patients sustained 104 total orthopedic injuries requiring admission; nine sustained 15 traumatic amputations. There were at least 37 open fractures, with some incomplete data in deceased (5) and amputation (9) patients. Suicide attempts were completed at 35.7% and were associated with a documented psychiatric illness and prior psychiatric evaluation. Spine injuries were associated with increased traumatic brain injuries, rib fractures, and open pelvic ring injuries, yet fewer humerus fractures. Open fractures were significantly predictive of death. 14 patients (42.4%) required ICU admission, and 26 (78.8%) patients required orthopaedic surgery (mean 1.3 ± 1.4 operations).

Conclusions: Metrorail systems are unique sources of orthopaedic injuries requiring high rates of critical care and surgical intervention. Patients sustain multiple injuries, many with amputations. With this mechanism, there is a high rate of open fractures and suicide. Trauma centers should emphasize an extensive evaluation of orthopaedic injuries in this patient setting.

Level of Evidence: II

Keywords: train-pedestrian fatalities, railway suicide, orthopedics, polytrauma, metrorail, spine trauma, accident prevention, urban injuries

INTRODUCTION

There are currently 108 rail transport systems operating across the United States, and of these, 29 are classified as Metrorail commuter rail systems.[1] In 2016, over 8,000 injuries occurred in American railway systems, resulting in 786 deaths.[2] In the city of our study, there are 25 miles of elevated railway used by approximately 33,000 people per month.[3] This system differs from traditional train systems in that a Metrorail typically maintains slower speeds, avoids motor vehicle interaction, and only interacts with pedestrians at stations/platforms. While much literature has been published regarding the dangers of vehicles or cyclists being struck by conventional trains,[4,5] there is almost no literature regarding the orthopaedic ramifications of pedestrians struck by an elevated Metrorail system.

This study is the largest single-center review of Metrorail injuries to date and is the first attempt at risk factor correlation with analysis of age, gender, substance abuse and psychiatric illness. Due to its central location in a major city, our Level-I trauma center was well-equipped to study Metrorail injuries. Riding a Metrorail is low-cost, easily accessible, and a frequently utilized mode of travel; however, Metrorail stations have minimal, if any, safety barriers in place. Pedestrians often fail to adhere to critical safety guidelines requiring safe distances from the Metrorail tracks. Substance abuse, psychiatric comorbidities, and suicidal ideation increase the risk of intentional and unintentional injury at such locations.[6]

Currently there is limited data demonstrating frequency of suicide in regards to elevated Metrorails[7] as well as concomitant factors associated with being struck. The primary objective was to describe patient characteristics, detail intentionality, and analyze the anatomic

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distribution of injury with a focus on orthopedic fractures. Secondary objectives include risk factor identification and patient outcomes. Such information may allow for possible safety measures and management strategies to prevent or mitigate consequences from these injuries.

MATERIALS AND METHODS

Study Design

After receiving Institutional Review Board (IRB) approval, a retrospective cohort study was performed at a single Level-I trauma center of patients requiring inpatient admission for significant orthopedic injuries after being struck by a Metrorail from 1/2004-2/2017.

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. For this type of study formal consent is not required.

Participants

"Orthopedic injuries" were defined as joint capsule violations, joint dislocations, tendon lacerations, and all fractures except those of the face/skull and ribs. Patients who presented to the emergency room but were then discharged without requiring admission were excluded. Patients who expired prior to arrival or shortly thereafter were included, albeit with missing data due to incomplete fracture workup and medical history.

Charts were reviewed for age, gender, psychiatric illness, substance abuse, hospital length of stay (LOS), intensive care unit (ICU) duration, follow-up time, orthopedic injuries, traumatic brain injuries (TBI), rib fractures, hospital course, and outcomes. Orthopedic injury information was based on radiologist reports, clinical notes, operative notes and discharge summaries. We also documented prior formal psychiatric evaluations at our institution based on chart review. Drug abuse was defined as a documented history of using illicit drugs, and alcohol use defined as those who reported daily intake.

Management

Per institutional protocol, all patients with open fractures received a 3-day course of intravenous (IV) antibiotics (2g ceftriaxone, daily) initiated immediately upon presentation. Usually a patient with this mechanism of injury (MOI) received a full body computed tomography (CT) scan if hemodynamically stable at presentation. If unstable, management varied depending on the degree of instability, with some patients receiving bedside radiographs before urgent surgical management with general trauma surgery. Open fractures were irrigated with 2-4 liters of normal saline in the trauma bay and then immobilized, and large wounds loosely approximated with nylon sutures prior to formal operative debridement.

Data analysis

Statistical analysis was performed using SAS University Edition. Correlations were determined using either analysis-of-variance (ANOVA) or Chi-square/Fisher's Exact Test, for parametric and non-parametric data, respectively. Means and frequencies were analyzed and p-values of <0.05 were considered significant.

RESULTS

Orthopedic injuries

A total of 33 patients with 104 total orthopedic injuries met our inclusion criteria. The cohort included 25 males (75.8%) and 8 females (24.2%) with a mean age of 37.7 ± 13.8 years (range 19-79 years) (Table 1). Nine patients (4 male, 5 female) did not survive their hospital stay (mean LOS of 8.7 ± 8.6 days, median 1 day). Of these, one acutely expired on arrival and the orthopedic injuries were not accounted for; this patient was excluded from further statistical analysis. Of the 24 surviving patients, the mean hospital LOS was 24.7 ± 25.0 days (median 14 days). The entire cohort had a mean of 1.2 ± 1.3 trips to the operating room for orthopedic issues, and 4 (12.1%) patients had operations performed for spinal injuries.

There were 37 (35.2%) upper extremity (9 radius, 5 scapula, 4 clavicle, 2 hand, 6 ulna, and 9 humerus), 33 (31.4%) lower extremity (9 femur, 9 tibia, 11 fibula, and 3 foot), 15 (14.3%) vertebral, 6 (5.7%) pelvic ring, and 5 (4.8%) acetabular injuries (Figure 1). Of the 33 patients, 20 (60.6%) patients sustained open fractures, with 9 (27.3%) patients sustaining more than one (Table 2). There were 37 open fractures in total (11 (29.7%) upper extremity, 22 (59.5%) lower extremity, and 4 (10.8%) pelvic ring). 9 (27.3%) patients sustained a total of 15 traumatic amputations (7 below knees, 2 above knees, 5 humeral, and 1 hand).

Spine injuries

In reviewing each patient's injury profile, of particular interest was the distribution of spinal injuries and their association with other orthopaedic injuries. Four surviving patients were taken to the operating room for spinal injuries ($p=0.038$). Patients sustaining spinal injuries had a significantly higher incidence of comorbid TBI ($p=0.024$), >1 rib fracture ($p=0.015$), and open pelvic ring fractures ($p=0.042$), as well as a significantly lower incidence of humerus fractures ($p=0.011$) than those patients who did not. Furthermore, there was no significant association between spinal injury and gender or intentionality.

Table 1. Patient Demographics & Hospital Course Stratified by Surviving & Death (At Arrival / While In-Patient)

Demographics	Total[a]	Alive[b]	Dead[c]	p-value
Total (with completed Hx)	33	24 (72.7%)	9 (27.3%)	-
Mean age ± SD	37.7 ± 13.8	38.1 ± 13.9	37.3 ± 14.3	0.894
Males	25 (75.8%)	**21 (87.5%)**	4 (44.4%)	**0.009**
Females	8 (24.2%)	3 (12.5%)	**5 (55.6%)**	**0.009**
White	18 (54.5%)	**16 (66.7%)**	2 (22.2%)	**0.022**
Black	11 (33.3%)	6 (25.0%)	5 (55.6%)	0.103
Hispanic	4 (12.1%)	2 (8.3%)	2 (22.2%)	0.291
Psychiatric History	17 (51.5%)	14 (58.3%)	3 (42.9%)	0.512
Drug/EtOH abuse	19 (57.6%)	17 (70.8%)	2 (28.6%)	0.072
Intentional Injury	14 (42.4%)	9 (37.5%)	5 (55.6%)	0.141
Hospital Course				
Mean open fractures ± SD	1.2 ± 1.3	**0.75 ± 0.99**	2.4 ± 1.5	**0.019**
Mean LOS ± SD	19.5 ± 23.3	**24.7 ± 25.0**	8.7 ± 8.9	**0.010**
Mean Ortho OR trips ± SD	1.2 ± 1.3	1.3 ± 1.4	0.9 ± 1.1	0.339
Spine OR trips	4 (12.1%)	**4 (36.4%)**	0 (0.0%)	**0.038**
Mean follow-up days ± SD	-	538.5 ± 1129.1	-	-
Mean days to death ± SD	-	5.4 ± 8.7	-	-

[a]Percentages listed refer to percent of total n=33.
[b]Percentages listed refer to percent of surviving patient n=24.
[c]Percentages listed refer to percent of non-surviving patient n=9.
*2 deceased patients were excluded from statistical analysis of psychiatric and drug/EtOH abuse due to incomplete history, as were 2 surviving patients and 1 dead patient being excluded from statistical analysis of open fractures due to incomplete assessment. All significant findings are listed in bold. (Hx) history; (Ortho) Orthopedic Surgery (LOS) Length of Stay; (EtOH) Alcohol; (OR) Operating Room; (SD) Standard Deviation

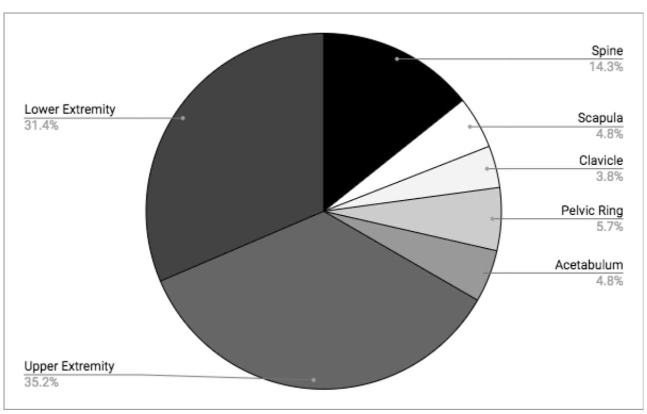

Figure 1. Anatomic distribution of the 104 orthopedic injuries sustained from being struck by a Metrorail.

Survivors vs Deceased

Comparing the 24 (72.7%) surviving patients to the 9 (27.3%) who died either at presentation or as an inpatient, surviving patients had a mean age of 38.1 ± 13.9 years (range of 22-79 years), compared to non-surviving patients with a mean age of 37.3 ± 14.3 years (range 19-64 years; p=0.894) (Table 1). Gender was a predictor of survival with 21/25 (84.0%) males surviving, compared to just 3/8 (37.5%) females (p=0.009). Surviving patients had a mean hospital stay of 24.7 ± 25.0 days, and those who died in-hospital had a mean hospital stay of 8.7 ± 8.6 (p=0.010), with an average of 5.4 ± 8.7 days to death. While surviving patients sustained an average of 0.75 ± 0.99 open fractures, compared to the mean of 2.4 ± 1.5 open fractures in deceased patients (p=0.019), a full evaluation of deceased patients may have been limited at presentation.

Intent, psychiatric illness, and substance abuse

A secondary parameter of interest was the intent behind injury (intentional vs accidental) and any associations with patient psychiatric history, comorbid

Table 2. Association of Spine Injury (Bone or Ligamentous) with Other Orthopedic Injuries

Injury	Total	Spine Injury	No Spine Injury	p-value
n (patients)	32*	15	17	
TBI (patients)	19	**12 (80.0%)**	7 (41.2%)	**0.024**
Rib fracture (patients)	12	**9 (60.0%)**	3 (17.7%)	**0.015**
Open fractures	37	13 (35.1%)	24 (64.9%)	0.237
Upper Extremity (Injuries)				
Scapula	5	3 (20.0%)	2 (11.8%)	0.544
Clavicle	4	1 (6.7%)	3 (17.7%)	0.354
Humerus	9	1 (6.7%)	**8 (47.1%)**	**0.011**
Bilateral humerus	1	0 (0.0%)	1 (5.9%)	0.332
Open humerus	6	0 (0.0%)	**6 (35.3%)**	**0.010**
Open elbow joint	2	1 (6.7%)	1 (5.9%)	0.930
Radius	9	4 (26.7%)	5 (29.4%)	0.868
Open radius	2	1 (6.7%)	1 (5.9%)	0.930
Ulna	6	3 (20.0%)	3 (17.7%)	0.871
Open ulna	3	2 (13.3%)	1 (5.9%)	0.498
Hand	2	0 (0.0%)	2 (11.8%)	0.163
Pelvis (Injuries)				
Pelvic ring	6	5 (33.3%)	1 (5.9%)	0.063
Open pelvic ring	4	**4 (26.7%)**	0 (0.0%)	**0.042**
Acetabulum	5	4 (26.7%)	1 (5.9%)	0.131
Lower Extremity (Injuries)				
Femur	9	3 (20.0%)	6 (35.3%)	0.260
Bilateral femur	1	0 (0.0%)	1 (5.9%)	0.332
Patella	0	0 (0.0%)	0 (0.0%)	-
Open knee joint	1	0 (0.0%)	1 (5.9%)	0.332
Tibia	9	2 (13.3%)	7 (41.2%)	0.119
Bilateral tibia	4	1 (6.7%)	3 (17.7%)	0.354
Open tibia	11	3 (20.0%)	8 (47.1%)	0.273
Fibula	11	4 (26.7%)	7 (41.2%)	0.167
Bilateral fibula	3	0 (0.0%)	3 (17.7%)	0.083
Open fibula	10	2 (13.3%)	8 (47.1%)	0.130
Foot	4	4 (26.7%)	0 (0.0%)	0.104
Bilateral foot	2	2 (13.3%)	0 (0.0%)	0.334
Open foot	1	1 (6.7%)	0 (0.0%)	0.334

*1 patient was excluded from statistical analysis due to unknown presence or absence of spine injury. All significant findings are listed in bold; (TBI) Traumatic Brain Injury

Table 3. Intention Behind Injury Versus History of Psychiatric Disorder, Psychiatric Evaluation, Substance Abuse, and Death

	Total	Intentional	Accidental	p-value
n	31*	14*	17*	-
Documented psychiatric Hx	17 (54.8%)	**11 (78.6%)**	6 (35.3%)	**0.014**
Prior documented psychiatric evaluation	13 (41.9%)	11 (78.6%)	2 (11.8%)	**<0.001**
Days from last psychiatric evaluation to injury (mean ± SD)	-	**730.2 ± 902.5**	**19.0 ± 15.6**	**0.026**
Drugs/EtOH Abuse Hx	18 (58.1%)	10 (71.4%)	8 (47.1%)	0.098
Alive	24 (77.4%)	9 (64.2%)	15 (88.2%)	0.138
Dead	7 (22.6%)	5 (35.7%)	2 (11.8%)	0.141

*2 patients were excluded from statistical analysis due to unknown intention behind injury; All significant findings are listed in bold; (EtOH) Alcohol; (Hx) History (SD) Standard Deviation; 730.2 days is approximately 24 months.

substance abuse, and mortality (Table 3). Nineteen of the 33 patients (57.6%) had a history of substance abuse and 17/19 (89.5%; p=0.072) patients survived. No significant associations were found between intent and substance abuse or mortality. Furthermore, 17/33 (51.5%) had a known history of psychiatric illness and 14/17 (82.3%; p=0.512) patients survived. Out of the 14 patients sustaining intentional injuries, 11 (78.6%) also had a history of psychiatric disorder (p=0.014), and 11/14 (78.6%) had a prior psychiatric evaluation at our institution (p<0.001). Interestingly, those suffering intentional injuries with a prior psychiatric evaluation were injured an average of 24 months (range 1 day-7.8 years) from their last evaluation. Of the 31 patients with known intentionality, injuries were believed to be intentional in 14 (45.2%) patients, with 5/14 (35.7%; p=0.141) achieving suicide.

DISCUSSION

The available literature regarding train-related injury has focused on traditional railways. Our study specifically evaluated an elevated Metrorail system, allowing us to uniquely exclude any incidences involving motor vehicles. Train-related trauma results in extremely high hospitalization costs. Documented case series have shown a monetary rate averaging $18,698 in one study and $61,159 in another,[8,9] with some hospitalizations approaching $165,000 per patient.[8] In 1998 Goldberg et al.[9] documented significant deficits in reimbursement compared to cost of hospitalization in train trauma, with an estimated cost to society of $300 million annually.

The majority of the patients involved were male—a fact correlating with multiple studies describing male gender as a possible risk factor in traditional traumatic train injuries.[8,10-13] While males were the primary victims; they were also significantly more likely to survive than females. This study demonstrated a need for orthopedic intervention in 78.8% of cases, especially given that 60.6% of patients sustained ≥1 open fracture, highlighting the unique, high-energy mechanism of injury. Open fractures were significantly associated with death, and the presence of ≥1 open fracture correlated with an increased risk of fatal injuries. Traumatic amputations occurred in 27.3% of cases, with 15 amputations in 9 patients, reflecting their prevalence in train-pedestrian accidents[9,13] Moore[14] described a series of accidents in which there were 10 traumatic amputations in 8 victims. Blazar et al.[8] described a series of 17 train-child accidents in which there were 20 traumatic amputations in 17 victims.

Our investigation demonstrated an approximately equal distribution of upper (35.2%) and lower (31.4%) extremity fractures. Prior studies document a higher incidence of lower extremity injuries. Singer reported 19 lower and 2 upper extremity amputations, with the foot being the most commonly injured body segment, with 52% of patients sustaining direct fractures and/or amputations.[15] Agalar also documented a high rate of lower extremity amputation in traditional train-pedestrian trauma.[13] In contrast to traditional, ground-level train tracks, Metrorail stations and tracks are usually elevated, with minimal access to track level, aside from intentionally or unintentionally falling onto them. Traditional tracks provide easier means of access, which may explain the higher incidence of lower extremity injuries, as both train and pedestrian are at ground level. Overall, the amputation rate is extremely high (38% to 61%),[8,15,16] causing high morbidity in survivors.

In this series, 19% of patients sustained spine injuries. Those with spine injuries were significantly more likely to sustain TBI, rib fractures and open pelvic fractures, suggesting that these patients sustain higher-energy injury, more direct body-centered impact loads, and a poorer prognosis compared to those without. Interestingly, in a 10-year review of pediatric train-related injuries, no intentional injuries were recorded and no spinal injuries documented,[8] suggesting that spine trauma in train-pedestrian accidents may be related to suicide attempts, intentionality, and mature musculoskeletal systems.

While many prior studies well document pediatric injuries while playing or walking on train tracks, ours included no children. Singer published a series of 211 patients where 8% of the patients were children. Children injured in that population were mainly toddlers who wandered onto train tracks in rural areas. The 10-year review by Blazar et al. focused specifically on pediatric train trauma, detailing 17 cases where children were injured while boarding moving trains, walking on tracks, and running alongside moving trains.[8] It is likely that pediatric injuries are much less common in our Metrorail-related trauma due to the fact that the tracks are not at ground level and inaccessible to the public. The location of the tracks precludes many mechanisms of accidental trauma described in the pediatric population, providing a mode of protection from such injury.

Both psychiatric disorders and substance abuse are risk factors for Metrorail injuries. The rate of suicide attempts in the current study was 45%, much higher than that in published train-pedestrian studies, with rates ranging from 17-22%.[13,17] Due to the lack of information and relatively small population in each of these studies, it is unclear whether suicide rates are truly higher in Metrorail versus train accidents, warranting more study. Of note, in our study intentionality itself was not predictive of death, since several of our deceased patients had no intentionality documented.

Alcohol intoxication has previously been studied as a possible risk factor for train-pedestrian accidents. Nixon et al. demonstrated alcohol as one of the highest risk factors for injury, second only to being a railway employee.[17] Our study demonstrated alcohol influence in a staggering 58.1% of cases; although this number relies on appropriate documentation and patient disclosure of such information, this number is similar to those in previous studies. In a study of tram-pedestrian injury by Hedelin et al., 60% of cases involved alcohol intoxication.[10] Similarly, in his study of railroad-related deaths, Pelletier found that 78% of cases occurred while under the influence of alcohol.[12] Metrorail-related injury is thus similar to train and tram-related injury, where alcohol is an independent variable associated with a higher risk of injury. Our study did not demonstrate any significant relation between alcohol and intentionality. Out of the 18 cases with documented alcohol use, 10 cases were intentional and 8 were unintentional ($p=0.098$).

Psychiatric history was evaluated, to our knowledge, for the first time with respect to railway-related accidents. 55% of our cases had a documented psychiatric history. The presence of a known psychiatric condition correlated with a higher risk of intentionality ($p=0.014$), and those with a previous inpatient psychiatric evaluation demonstrated an even more significant correlation ($p<0.001$). Thus, when involved in a Metrorail-pedestrian accident, psychiatric patients are more likely to have acted intentionally. Interestingly, we observed that the time since a patient's previous psychiatric follow-up appointment had a significant impact on intentionality. Of those with a documented history of psychiatric treatment at our facilities, the amount of time from the last known evaluation to the injury was 730.2 days (2 years) in the intentional group compared to just 19 days in the unintentional group ($p<0.001$). This difference may suggest the importance of follow-up in patients with psychiatric disease, as loss to follow-up and noncompliance may increase the likelihood of suicide.

One of the weaknesses of our study is its retrospective nature, and we relied on documentation available to understand the patient's injury and circumstances surrounding the event. We also lacked a complete evaluation on total fracture numbers with regards to amputated limbs, and no radiographs were obtained on patients who died shortly after presentation. When investigating the time since last psychiatric evaluation, we were only able to view those occurring at our institution, and any evaluation at an outside practice was unknown to our team, possibly skewing the time to injury. We also frequently relied on the patient's disclosure regarding sensitive information such as psychiatric illness, intentionality, and substance abuse. Furthermore, our study focused only on admitted patients, yet theoretically some patients with Metrorail injuries may not require orthopedic surgery consultation. Finally, we did not analyze the outcome of wounds treated as outpatients.

In conclusion, this study of train-pedestrian accidents demonstrates an extensive injury profile and associations with mental illness and substance abuse. Unfortunately, both accidental and intentional patients sustain a high rate of open fractures, traumatic amputations and subsequent orthopedic surgery. Open fractures were significantly associated with death. With the increases in Metrorail prevalence, manufacturers, policymakers, and healthcare employees should work towards improving technologies and usage rules to protect bystanders and reduce the burden of pedestrian injuries on healthcare systems.

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TREATMENT OF DISTAL FIBULAR MALUNION WITH CORRECTIVE OSTEOTOMY: YABLON REVISITED

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ABSTRACT

Yablon originally described that late posttraumatic degenerative ankle arthritis was due to ongoing tibio-talar joint incongruity, and more importantly that anatomic reduction of the lateral malleolus was key to anatomic reduction of the ankle joint, as the talus "faithfully followed that of the lateral malleolus." Ankle fractures involving the lateral malleolus, left unreduced, can lead to malunion and posttraumatic degenerative arthritis. Treatment of this often includes a fibular osteotomy to restore length and rotation. We revisit Yablon's original principles and present a review of the literature pertaining to techniques and outcomes of lateral malleolus malunions treated with distal fibular osteotomies as well as a case report highlighting the challenges and considerations when facing this problem.

Keywords: case report, ankle fracture, malunion, corrective osteotomy

INTRODUCTION

Ankle fractures are common injuries, with an incidence of 187 fractures per 100,000 person years.[1] They are the fourth most common fracture type, accounting for approximately 7% of all fractures.[2] These injuries can lead to posttraumatic ankle arthritis, which is the leading cause of ankle arthritis. Rotational ankle injuries, most of which involve a significant injury to the lateral malleolus, are the most common subgroup of ankle fractures and the most common subgroup to lead to posttraumatic arthritis.[3,4] Yablon originally described that late posttraumatic degenerative ankle arthritis was due to ongoing tibio-talar joint incongruity, and more importantly that anatomic reduction of the lateral malleolus was key to anatomic reduction of the ankle joint, as the talus "faithfully followed that of the lateral malleolus".[5] The importance of an anatomic tibio-talar joint reduction was further elucidated by Ramsey, who showed that even 1mm of residual tibio-talar misalignment increased contact pressure by 42%.[6] Thus, the goal of treating ankle fractures is to restore an anatomic tibio-talar reduction to prevent future ankle arthritis.

We present a review of the literature and a case of a non-operatively treated, displaced ankle fracture with lateral malleolus malunion, ankle subluxation, and residual pain. Treatment included a distal fibular osteotomy to correct fibular length and rotation, as was first described by Yablon. This serves as a reminder of the principles of treatment which he first described, and which universally dictate care.

The authors have obtained the patient's informed written consent for print and electronic publication of the case report.

CASE REPORT

Clinical Scenario

We present the case of a 45 year-old female, with a history of intellectual disability, who initially presented to an urgent care facility with right ankle pain following a twist and fall injury while getting out of bed. Her past medical history was significant for intellectual disability, anxiety, depression, type-1 diabetes, hypertension, and hyperlipidemia. Before the fall, she ambulated independently without assistive devices and performed full activities of daily living herself. A non-displaced lateral malleolus fracture was diagnosed on x-ray and she was treated with a short leg splint, crutches, and was made non-weight bearing (Figure 1). Several days later she was evaluated in the outpatient setting by an orthopaedic physician, who continued non-operative treatment. She was placed in a fiberglass cast and was directed to be non-weight bearing on her right lower extremity.

At her one-month visit she was changed to a CAM boot and was made weight bearing as tolerated. At her two-month visit she was cleared of the boot. Radiographs were obtained at each of these visits and were interpreted by the treating physician as a non-displaced lateral malleolus fracture demonstrating proper fracture healing.

At 3 months post injury, the patient presented for a second opinion with continued right ankle pain. She was ambulating independently, but with continued right ankle

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Figure 1. AP and lateral ankle post injury radiographs demonstrating a minimally displaced lateral malleolus fracture.

Figure 2. Mortise and lateral ankle radiographs at presentation to our clinic that show a lateral malleolus fracture malunion that healed in a short and externally rotated position with valgus alignment of her talus.

pain and a limp. A focused clinical exam revealed lateral ankle fullness but no focal swelling, no tenderness to palpation, intact sensation to light touch, and intact skin. She had pain and a significant limp with ambulation.

Diagnostic assessment

AP, lateral, and mortise views of the right ankle were reviewed and showed a right lateral malleolus fracture malunion. It was short and externally rotated. She also had valgus alignment of her talus with a lateral shift (Figure 2). No significant ankle arthritis was seen.

Treatment

Due to the symptomatic lateral malleolus malunion with tibio-talar incongruity, we recommended a right lateral malleolar corrective osteotomy in order to improve her function and minimize the risk of degenerative joint disease.

A posterolateral approach was made to the distal fibula. The obliquity of the fracture plane was identified fluoroscopically and marked with a Kirschner wire (Figure 3). An oscillating saw was used to create an oblique osteotomy through the previous fracture site (Figure 4). Callus was removed and morselized with a rongeur and saved for autogenous bone graft. Next, an anteromedial approach was made to the ankle over the anterior aspect of the medial malleolus. The incision was carried through skin and subcutaneous tissue and the capsule was incised. A significant amount of scar tissue was encountered in the medial gutter, and was removed with a rongeur.

Next, we turned our attention back to the lateral side. A precontoured lateral fibular plate was affixed to the distal segment of the fibula with 3.5mm locking screws (Zimmer, Warsaw, IN) (Figure 5). A screw was then placed proximal to the plate in the fibular shaft. A lamina spreader was used to obtain fibular length. Rotation was corrected through the osteotomy by manipulating the plate, and the tibiotalar joint reduction was confirmed on fluoroscopy (Figure 6). The plate was affixed to the shaft with a 3.5mm cortical screw. This construct was further reinforced with cortical screws in the proximal fibula, and locking screws in the distal fibular segment. A lag screw was placed across the oblique osteotomy and engaged the tibia for better fixation. The autogenous bone graft was placed anterior and posterior to the osteotomy site. Postoperative radiographs showed anatomic ankle joint reduction and symmetrical clear space (Figure 7). Finally, the wounds were closed with 3-0 nylon, and the patient was placed in a short leg plaster splint.

Figure 3. Intra-operative fluoroscopy demonstrating the obliquity of the malunion with a Kirschner wire.

Figure 4. Intraoperative fluoroscopy showing an oscillating saw that was used to create an oblique osteotomy through the previous fracture site.

Follow-up and outcomes

Postoperatively the patient was made non-weight bearing for two months. At her eight-week visit, her splint was removed and a lace up ankle orthotic was prescribed. We allowed her to begin weight bearing as tolerated on her operative leg. She was encouraged to increase her activity and continue outpatient physical therapy. The patient was seen five months from her surgery and was pain free in her ankle. Radiographs at five months showed maintenance of ankle joint reduction and a healed distal fibular osteotomy. She was doing all activities she wanted to and was using a lace-up ankle brace as needed.

DISCUSSION

Unstable ankle injuries can lead to abnormal talar motion under physiologic load, resulting in dynamic tibio-talar incongruity.[7] Many studies have looked at the relationship between ankle injury patterns and instability. Multiple authors have shown that isolated lateral malleolus fractures are stable, do not progress to posttraumatic arthritis, and can be treated non-operatively.[8-10] Therefore ankle instability requires an additional injury on the medial side of the ankle, either by fracture or disruption of the deltoid ligament. Yablon first described this in 1977, when he showed that unstable bimalleolar ankle injuries led to late degenerative arthritis and that incomplete anatomic reduction of the lateral malleolus was the most common fault in treatment.[5] Several studies have subsequently confirmed this and have shown superior results with anatomic ankle joint reduction via open reduction internal fixation compared to non-operative treatment of unstable injuries.[11,12]

When bimalleolar injuries are treated non-operatively, malunion of the lateral malleolus can occur. A fibular malunion highlights the continued malreduction of the tibiotalar joint, and degenerative ankle arthritis is likely to follow. This was the case in our patient, whose unstable bimalleolar injury was not appreciated and she progressed to a lateral malleolus malunion.

Management of ankle malunions remains somewhat controversial. Not all distal fibular malunions are symptomatic. A study following 17 bimalleolar injuries with fair to poor reductions showed mixed results with 10 having good objective and subjective results.[13] However, it is well known that a poor reduction will eventually lead to degenerative arthritis.[14] Corrective osteotomy of distal fibular malunions is a reasonable treatment option with several studies showing good to excellent clinical outcomes ranging from 67-92% at short to intermediate follow up.[15-18] In the long-term, according to some authors, corrective osteotomy of fibular malunions reduces the

Figure 5: Intraoperative fluoroscopy showing fixation of the plate to the distal fragment.

Figure 6: Intraoperative fluoroscopy showing use of a lamina spreader to gain length and reduce tibio-talar joint.

progression of post traumatic ankle arthritis.[15,19–21] Weber et al. followed 23 patients, who had distal fibula malunions treated with corrective osteotomies, for an average of 11.2 years and found 17 of 23 to have good to excellent clinical results. The remaining six patients were graded fair to poor with radiographs confirming progression of degenerative arthritis. Only one patient was symptomatic enough to require ankle fusion.[19] Surgical treatment of distal fibular malunions has shown encouraging results, however the decision to operate should be made in concert with the patient and should be influenced by factors such as age, condition of cartilage, time since injury, functional level, and comorbidities.

Technical consideration

Several distal fibular osteotomy techniques have been described in the treatment of fibular malunions. In the largest series published, patients received a transverse osteotomy at the level of the fracture site with autologous tibial bone graft for lengthening. In this series, they report zero nonunions and showed 20 of 26 patients resumed preinjury level of function, three improved but had slow gradual deterioration of the ankle, and three showed no improvement.[20] Other techniques have been described that do not require bone graft for lengthening including the sliding Z-osteotomy and oblique osteotomy.[16,18] Chao et al. described the long oblique osteotomy in the sagittal plane that recreates the original fracture pattern. Elongation of 4-5mm can be achieved while still maintaining adequate cortical apposition so that bone graft is not necessary to achieve union. In their series, the non-union rate was zero and 11 of 12 patients had good to excellent results.[16]

In this case, we describe the technique for a long oblique distal fibular osteotomy. A pre-contoured plate was first fixed to the distal fibular segment with locking screws allowing control of the lateral malleolus in length and rotation. Four millimeters of lengthening was easily achieved through a screw outside the plate and a plate distractor. Fibular length was assessed using the “dime sign” and the talocrural angle on fluoroscopy. Fibular rotation was corrected by rotating the plate internally prior to fixation to the proximal fibular segment and this was confirmed with fluoroscopy. Although adequate bony contact was achieved using this technique, bone graft, removed from the healing callus, was placed to assist in bony union.

In order to assess the quality of the reduction, intraoperative fluoroscopy should be used to inspect lateral talar subluxation, medial clear space widening, and talar tilt. If medial space widening persists, it is important to

Figure 7: Final mortise and lateral ankle radiographs showing anatomic ankle joint reduction and symmetrical clear space.

consider evaluating the medial gutter. In most cases a medial sided procedure, whether arthroscopic or open, is indicated to address medial intra-articular fibrosis that blocks anatomic reduction, as was the case in this patient.[22]

Postoperative treatment

Postoperatively, the goal should be to promote healing of the osteotomy and ankle ligaments. We recommend that patients be made non-weight bearing in an ankle immobilizer for at least 8 weeks, depending on patient related factors such as age, smoking, and comorbidities. Follow up radiographs should be obtained at two-month intervals to evaluate for osteotomy site healing.

Conclusion

Unstable bimalleolar ankle injuries need to be accurately diagnosed and properly treated with anatomic reduction of the fracture and tibio-talar joint. In cases, where the ankle is poorly reduced, that go on to develop distal fibular malunion and tibio-talar incongruity, correction with distal fibular osteotomy and medial gutter debridement is a reasonable and sometimes necessary treatment option to minimize posttraumatic arthritis.

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OPERATIVE VERSUS NONOPERATIVE MANAGEMENT OF TRAUMATIC ARTHROTOMIES FROM CIVILIAN GUNSHOT WOUNDS

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ABSTRACT

Background: Although the rate of non-fatal gunshot wounds (GSW) has increased, few studies have compared the effectiveness of operative and nonoperative treatment with specific focus on infection. We compared the risk of septic arthritis in patients with traumatic arthrotomies caused by GSW treated operatively with irrigation and debridement versus nonoperatively with antibiotics and wound care.

Methods: From 2009 to 2016, 46 patients at our institution sustained traumatic arthrotomies from low-velocity GSW with at least 90-day follow-up. Medical records were reviewed for demographic information, imaging, type and duration of antibiotics, details of operative and nonoperative interventions, and evidence of infection at follow-up visits. We measured the rate of septic arthritis using a 2-tailed *t* test.

Results: The knee was the most commonly affected joint (34 patients; 73.9%). Eight patients (17.4%) were treated nonoperatively and 38 (82.6%) were treated operatively. In the nonoperative group, one patient (12.5%) developed a superficial wound infection that resolved with oral antibiotics. In the operative group, one patient (2.6%) developed a superficial wound infection requiring operative irrigation and debridement. There was no statistically significant difference in risk of infection between the two groups (P = 0.32). No patient developed septic arthritis.

Conclusions: In select patients, nonoperative treatment with wound care and antibiotics may be sufficient for preventing infection after GSW-related traumatic arthrotomies. Findings of randomized studies and treatment algorithms are needed to further evaluate this relatively common injury.

Level of Evidence: IV

Keywords: septic arthritis, gunshot, arthrotomy, antibiotics

INTRODUCTION

The clinical importance of infections from ballistic injuries is as relevant today as it was in 1881 for United States President James Garfield, who died of sepsis 79 days after a gunshot wound to his right shoulder and back.[1] Firearm-related injuries in the United States are common and accounted for an average of 67,197 emergency department visits between 2010 and 2012.[2] Although the rate of fatal firearm injuries has remained grossly unchanged, the rate of non-fatal firearm injuries has continued to rise in the past decade.[3] About 49% to 67% of these injuries occur in the extremities.[2] Management of firearm injuries has been well described, particularly regarding fracture care.[4–13] Fractures caused by gunshot wounds (GSW) are generally defined as open injuries, although they constitute a unique problem owing to infection risk, soft tissue injury, and fracture stabilization.[14]

Ballistic injuries have been classified as low velocity (< 609.6 m/sec) and high velocity (> 609.6 m/sec). However, physical characteristics of the projectile, kinetic energy, entrance profile, and biologic characteristics of the soft tissue all play considerable roles in the extent of injury.[14,15] Studies have shown that low-velocity bullets should be considered nonsterile;[16,17] but use of antibiotic prophylaxis has not significantly altered infection rates in patients undergoing nonoperative treatment of low-velocity gunshot-induced fractures.[6] Furthermore, controversy remains as to the extent of superficial versus deep extensive debridement in low-velocity GSW with stable fracture patterns.[5]

Some studies have proposed algorithms for treating intraarticular GSW,[7,10] yet few data exist comparing operative and nonoperative treatments of these injuries. The aim of this study was to compare the risk for developing septic arthritis between operative treatment with irrigation and debridement (I&D) and nonoperative treatment with antibiotics and wound care of patients with traumatic arthrotomies caused by GSW.

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Table 1. Characteristics of 46 Patients with Gunshot Wounds

Variable	No. Patients (%)*
Mean age, y +/-SD	32.6+/-15.9
Sex	
Male	37 (80.4)
Female	9 (19.6)
Insurance	
Uninsured	13 (27.7)
Government	27 (57.4)
Private	7 (14.9)
Joints affected	
Knee	34 (73.9)
Elbow	4 (8.7)
Wrist	2 (4.3)
Hip	2 (4.3)
Shoulder	4 (8.7)

*Values in the column reflect number of patients (and percentage) unless noted in the variable.

METHODS

Institutional review board approval was obtained for this study. The authors reviewed consult logs of all patients seen by the orthopaedic service at a level I trauma center from August 2009 to August 2016. A total of 109 patients with GSW were identified. Inclusion criteria were a positive saline load test or GSW near the shoulder, elbow, wrist, hip, knee or ankle. Patients were considered to have traumatic arthrotomies on the basis of a positive saline load test[18] or presence of gas within the joint on computed tomography scans.[19] Exclusion criteria were no follow-up within 90 days of injury, high-velocity GSW, or shotgun-related injuries.

A total of 46 patients with 46 traumatic GSW-related arthrotomies met inclusion criteria (Table 1). The average age was 32.6+/-15.9 years. Thirty-seven patients (80.4%) were men and 9 (19.6%) were women. Thirteen patients (27.7%) were uninsured, 27 (57.4%) had some form of government-assisted insurance, and 7 (14.9%) had private insurance. Thirty-four patients (73.9%) had an associated fracture with their arthrotomy. Most injuries were to the knee joint (34 patients, 73.9%).

The medical records of each patient (n=46) were reviewed for demographic information, imaging, type and duration of antibiotics, details of any operative and nonoperative interventions, and evidence of infection at follow-up visits. Superficial infection, deep infection, and joint infection were defined according to the 2008 Centers for Disease Control and Prevention's National Healthcare Safety Network criteria.[20] Data were evaluated with 2-tailed *t* test. Statistical significance was set at alpha = 0.05.

RESULTS

All 46 patients underwent bedside wound care. Forty-five were treated with prophylactic antibiotics. One patient left against medical advice before receiving antibiotics. Cefazolin was the most commonly used antibiotic. Details of antibiotic administration are shown in Table 2.

Owing to wound appearance, associated injuries, and surgeon preference, eight patients (17.4%) were treated nonoperatively and 38 patients (82.6%) were treated operatively within 48 hours. Table 3 shows treatment methods of patients treated nonoperatively and operatively. Two of the 8 patients treated nonoperatively and 1 of the 38 patients treated with I&D underwent arthroscopic removal of bullet fragments at 6 weeks after the injury.

Outcomes

No patient developed septic arthritis. Patients in the nonoperative group received an average 2.4 doses of cefazolin at 8-hour intervals, followed by a 5-day course of cephalexin. Two patients developed superficial infections. In the nonoperatively treated group, one patient (12.5%) presented with an erythematous wound at 4 weeks after injury, which resolved after completing an extended oral course of cephalexin. In the operatively treated group, one patient (2.6%) presented with an associated metadiaphyseal femur fracture treated with I&D and retrograde

Table 2. Antibiotics Administered to 46 Patients with Gunshot Wounds Treated Operatively (n=38) and Nonoperatively (n=8)

Antibiotics	Operative Group No. Patients (%)	Nonoperative Group No. Patients (%)	Total
None	0	1 (12.5)	1
Cefazolin	32 (84.2)	2 (25)	34
Cephalexin	0	1 (12.5)	1
Cefazolin + other	5 (13.1)	4 (50)	9
Clindamycin + doxycycline	1 (2.6)	0	1

Table 3. Treatment Methods of Patients with Gunshot Wounds Treated Operatively (n=38) and Nonoperatively (n=8)

Treatment	Operative Group No. Patients (%)	Nonoperative Group No. Patients (%)
Cefazolin with home antibiotics	--	7 (87.5%)**
No antibiotics	--	1 (12.5%)
I&D without arthrotomy	7 (18.4%)	--
I&D with fracture fixation	2 (5.3%)	--
I&D with open arthrotomy	12 (31.6%)	--
I&D with arthroscopy	5 (13.1%)	--
I&D with arthrotomy and fracture fixation	12 (31.6%)*	--

Abbreviations: --, not applicable; I&D, irrigation and debridement.
*Of the 12 patients, one developed a wound infection.
**Of the 7 patients, one developed a wound infection.

femoral nail fixation. He returned to clinic at 12 days after injury with purulent drainage from his wound and underwent superficial I&D. The patient had no intraoperative evidence of deep-space infection in the joint. Intraoperative cultures revealed methicillin sensitive *staphylococcus aureus*. This patient was administered a 48-hour course of cefazolin followed by 2 weeks of cephalexin. His fracture and wounds went on to heal uneventfully.

DISCUSSION

The aim of our study was to evaluate the occurrence of septic arthritis in patients with intraarticular, low-velocity GSW treated operatively versus nonoperatively. Notably, we found a low rate of infection regardless of the type of treatment. This suggests a low risk for infection after appropriate treatment of intraarticular GSW and success with nonoperative treatment.

In general, the strict indications for operative treatment with I&D of GSW include fractures requiring internal fixation, large intraarticular loose osteoarticular fragments, or large bullet fragments remaining in the joint.[21] Multiple studies[22,23] have shown a risk of lead absorption from intraarticular bullet fragments, and this remains an indication for I&D and bullet removal. However, I&D can result in anesthetic and postoperative risks to patients and substantial healthcare costs.[24] Patients undergoing I&D typically spend at least one night in the hospital, whereas those treated nonoperatively could potentially be discharged from the emergency department. To justify the risks and expense of operative treatment, demonstrable improvement in outcomes are needed. The current study findings indicate that equal outcomes (ie, prevention of infection) can be achieved nonoperatively. Thus, the goal of preventing infection may not single-handedly justify operative treatment with I&D of intraarticular GSW.

In patients with minimal soft tissue injury and minimal wound contamination, I&D may only result in further damage to surrounding tissues. Regarding small clean traumatic arthrotomies from a low-velocity GSW, extending the arthrotomy for formal I&D may not always be necessary and can contribute to morbidity such as stiffness. In the current study, eight patients treated without formal I&D in the operating room developed no deep infections or septic arthritis. Our results are similar to that of Nguyen et al.[7] in which 24 patients with intraarticular GSW were treated nonoperatively and did not develop deep infections. Low-velocity GSW violating a joint without considerable soft tissue injury or contamination may be treated safely nonoperatively with prophylactic antibiotics and bedside I&D. Although some studies have found a high incidence of intraarticular meniscal and ligamentous injuries after GSW,[4,25,26] proceeding to the operating room should be undertaken based on intraarticular pathological features (foreign body removal) or fracture patterns rather than the basis alone that a traumatic arthrotomy occurred.

There were limitations to this study. This was a retrospective review subject to inherit selection bias. Furthermore, numerous patients were treated operatively for indications other than infection control such as fracture fixation. Additionally, the decision for operative or nonoperative treatment was made at the discretion of several different treating surgeons, with no pre-defined criteria. The study was also limited by fewer number of patients and infections. A post-hoc analysis revealed that 110 patients in each group would be necessary to reach 80% power. The study is underpowered to clearly prove an acceptable infection rate with nonoperative treatment. The results of the 8 patients treated nonoperatively with no joint infections suggests this treatment may be effective and worth investigating in a larger randomized study.

The current study found low rates of infection in intraarticular, low-velocity GSW treated with or without operative intervention. Indications for operative treatment of intraarticular GSW include the need for fracture fixation or removal of intraarticular osteochondral fragments and bullet fragments. If selected appropriately, patients with intraarticular GSW may be safely treated nonoperatively without an increased risk of infection compared to those treated operatively.

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USE OF CT VS. MRI FOR DIAGNOSIS OF HIP OR PELVIC FRACTURES IN ELDERLY PATIENTS AFTER LOW ENERGY TRAUMA

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ABSTRACT

Background: Elderly patients who fall account for more than two million emergency department visits each year. In 4-10 % of these patients, initial plain radiographs do not identify a hip or pelvis fracture later diagnosed with advanced imaging. No consensus exists about what type of imaging, CT or MRI, should be obtained in elderly patients with hip or pelvic pain after a low energy trauma. The purpose of this study was to determine whether CT or MRI is more likely to result in a definitive fracture diagnosis in elderly patients with hip or pelvic pain after low energy trauma.

Methods: A retrospective chart review was conducted of all patients who presented to the ED at a single level one trauma center over a 4.5 year period. Inclusion criteria were age greater than fifty years old, presentation with hip and/or pelvis pain due to a low energy trauma, and radiographic imaging including both plain radiographs and at least one pelvis MRI or CT.

Results: Of the 218 patients who met inclusion criteria and had negative initial plain radiographs, CT or MRI later diagnosed a fracture in 69 patients (32%). Seventy eight patients underwent MRI (24 fractures, 32%), 132 underwent CT imaging (41 fractures, 31%), and eight had both CT and MRI (5 fractures, 63%). Patients who underwent CT spent less time in the ED on average (430 minutes) than those who underwent MRI, or MRI and CT (502 minutes and 620 minutes respectively). Patients who underwent CT were just as likely to be diagnosed with a fracture as those who underwent MRI ($p= 0.002$). We encountered no cases where CT imaging did not identify a fracture that was later identified on MRI. Fifty six patients (26%) had at least one contraindication to MRI.

Conclusion: Our study suggests CT may be adequate to rule out hip and pelvic fractures in this patient population. CT may be preferable to MRI based on decreased time spent in the ED and the large percentage of elderly patients with contraindications to MRI.

Level of Evidence: III

Keywords: hip fracture, computed tomography, mri, diagnostic imaging, elderly fracture

INTRODUCTION

Hip and pelvic pain after low energy trauma is a common cause for emergency room visits. A hip or pelvic fracture can often be diagnosed with plain radiographs alone, but in 2-10% of patients, fractures cannot be identified on plain radiographs.[1] Physicians may further evaluate patients with advanced imaging such as CT or MRI, but disagreement persists about which imaging modality may be the best choice. In several small series of patients, MRI appears to be better than CT for detection of hip and pelvic fractures in elderly patients with low energy trauma. In a study of 13 patients, Lubovsky et al. reported that MRI more often correctly identified the location of pelvic and hip fractures when compared to pelvic CT.[2] Cabarrus et al. evaluated 64 patients with suspected hip fractures with both CT and MRI.[3] MRI detected fractures in 99% of patients, while CT identified fractures in 53% of patients.[3] Likewise, Haubro et al. reported greater sensitivity for detecting proximal femur fractures with MRI (100% vs 87% for CT), although this was not statistically significant.[4] Verbeeten et al. found MRI specificity and sensitivity was near 100% for hip and pelvic fractures.[5] MRI also offers the ability to identify other soft tissue problems that may be the source of pain, such as tumors, muscle tears, and hematoma.

Although pelvic MRI may be more sensitive than CT for fracture detection, MRI is also more expensive, more time consuming, and may not be available at all times at all institutions. Many elderly patients also have implants or medical devices that preclude MR imaging. In addition, the fractures identified by MRI may not result in changes in treatment. Of 69 fractures identified by MRI in one study, only 23 (33%) required operative intervention.[6] Improvements in CT technology may also result in

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Table 1: Baseline Characteristics by Use of Imaging Technology

	MRI only (n=76)	CT Only (n=131)	MRI + CT (n=8)	P-value
Age (mean (std dev))*	76 (12)	79 (12)	68 (10)	0.031
Male	22 (29%)	39 (30%)	1 (13%)	0.71
History of Osteoporosis	25 (33%)	52 (40%)	1 (13%)	0.22
Ambulatory Before	75 (100%)	120 (92%)	8 (100%)	0.019
Ambulatory Now	30 (42%)	56 (46%)	4 (50%)	0.76
History of Dementia	17 (23%)	53 (40%)	2 (25%)	0.026
History of Insufficiency Fx	9 (12%)	14 (11%)	1 (13%)	0.93
Living Situation:				0.33
Assisted Living	17 (22%)	29 (22%)	3 (38%)	
Home	49 (64%)	70 (54%)	5 (63%)	
Nursing Home	10 (13%)	28 (22%)	0 (0%)	
Other	0 (0%)	3 (2%)	0 (0%)	
Weight Bearing	34 (49%)	60 (52%)	4 (50%)	0.93

increased sensitivity compared to older studies.[3]

The primary goal of this study is to determine which secondary study (CT or MRI) is most likely to result in a fracture diagnosis in elderly patients presenting with hip or pelvic pain. Our secondary goal was to determine the ED length of stay based on type of study performed. The ultimate goal is to determine the most efficient manner to evaluate elderly patients with a potential hip or pelvic fracture but negative plain radiographs.

MATERIALS AND METHODS

Under IRB approval we retrospectively reviewed the charts of all patients over age 50 years who presented to the Emergency Department at our Level 1 trauma center with hip pain after a low energy fall between 2009 and 2013. We identified these patients by searching order codes for radiographic studies performed. We included all patients who had negative plain radiographs (AP pelvis and AP and lateral hip) and a subsequent pelvic MRI or CT. We defined "negative plain radiographs" as the official radiology reading not reporting any fracture. In an effort to identify all patients who may have been diagnosed with a fracture at some point after their ED visit, we included any patient who had negative plain radiographs in the ED and pelvic MRI or CT within 30 days of their initial visit. We excluded any patients who suffered a high energy trauma (anything greater than fall from a standing height). We obtained demographic data such as patient age, sex, mechanism of injury, and premorbid living condition (home, assisted living, nursing home). When available in the records, we recorded if the patient was able to ambulate. We reviewed the radiology reports for any fracture diagnosed on CT or MRI. We also recorded the time spent in the ED for each patient and if the patient had a contradiction to MRI such as an implanted defibrillator.

We divided patients into 3 groups: those who underwent CT, those who underwent MRI, and those who had both studies. We compared the demographic and medical history information between the CT and MRI groups using t-test for all variables except age, which was compared using ANOVA. We calculated the percentage of patients in each group who were diagnosed with fractures, and compared the likelihood of diagnosing a fracture between the different groups. We used ANOVA to compare time spent ER between the three groups (CT, MRI, and CT and MRI).

We performed a second analysis comparing demographic and medical history between those patients with fractures and those without fractures using ANOVA for age and t-test for the remaining medical history variables.

RESULTS

We identified 218 patients over age 50 who presented to the Emergency Department with hip pain after low energy trauma with negative plain radiographs and a subsequent hip or pelvis CT or MRI. Seventy-eight patients underwent MRI only, 132 patients underwent CT only, and eight patients had both MRI and CT. Nine patients had more than one visit for the same problem and underwent advanced imaging at the subsequent visit. These patients were excluded from the ED length of stay calculations, but included in all other analyses.

The CT only group was slightly older than the MRI

Table 2: Fractures Identified on Advanced Imaging

Type of fracture	CT only	MRI only	CT and MRI
Pelvic ring	9	4	0
Femoral neck	8	5	1
Greater trochanter	3	3	0
Sacral	9	0	1
Intertrochanteric	1	2	0
Pubic rami	5	4	1
Other proximal femur	2	4	0
Acetabular	2	1	2
Other	2	1	0

only group (mean age 79 vs 76 years) (Table 1). No significant difference existed between the two groups with regard to the other demographic and clinical variables.

We found no significant difference in the likelihood of fracture diagnosis between the CT only and MRI only groups. The CT identified a fracture in 41 of 132 patients (31%) and MRI identified a fracture in 24 of 78 patients (32%). Of the eight patients who underwent both MRI and CT, five patients had a fracture (63%). No patient who had a negative CT later had a fracture diagnosed on MRI. Rather, in those five cases, surgeons requested a CT after the fracture diagnosis was made on MRI to better characterize the fracture pattern. Fractures identified included femoral neck fractures, intertrochanteric fractures, sacral fractures, greater trochanter fractures, isolated pubic rami fractures, acetabular fractures, and pelvic ring patterns (e.g. sacrum and pubic rami) (Table 2).

Of those patients who made multiple visits for the same problem within 30 days of the index visit, seven underwent CT only (3 fractures) and one underwent MRI only (no fracture). One patient had a negative CT and MRI at the index visit, but a sacral fracture was identified on a second CT exam obtained 15 days later after a second fall.

Patients who went underwent MR imaging spent significantly more time in the ED than those who underwent CT only (502 minutes vs 430 minutes, $p=<0.0001$). Patients who underwent both tests spent an average of 630 minutes in the ED. Fifty-six patients (26%) had at least one contraindication to MRI.

We found no significant difference between patients with and without fracture with regard to age, sex, medical history, and premorbid living situation (Table 3). Ability to ambulate after the fall was not predictive of a fracture diagnosis. Patients who could bear weight were less likely to have a fracture ($p=0.035$), but ability to bear weight did not exclude a fracture diagnosis.

Table 3: Baseline Characteristics for Patients With and Without Diagnosed Fractures

	No Fracture (n=147)	Fracture (n=70)	P-value
Age (mean (std dev))	77 (13)	78 (11)	0.46
Male	43 (29%)	19 (27%)	0.87
History of Osteoporosis	48 (33%)	31 (45%)	0.10
Ambulatory Before	138 (95%)	67 (96%)	1.00
Ambulatory Now	64 (47%)	26 (39%)	0.30
History of Dementia	50 (34%)	23 (33%)	0.89
History of Insufficiency Fx	16 (11%)	8 (11%)	1.00
Living Situation:			0.81
Assisted Living	34 (23%)	14 (21%)	
Home	83 (57%)	43 (61%)	
Nursing Home	26 (18%)	12 (17%)	
Other	3 (2%)	0 (0%)	
Weight Bearing	72 (56%)	26 (39%)	0.035

DISCUSSION

Most previous studies examining these modalities reported MRI to be superior to CT for diagnosis of fracture. In contrast, our research suggests that CT and MRI are equally likely to diagnosis fractures in this patient population. Demonstrating which study (CT or MRI) is most likely to provide a diagnosis can increase the likelihood of providing a timely diagnosis and decrease unnecessary imaging studies.

Although previous studies found MRI to be more sensitive, most of these studies included a small number of patients and utilized older CT scanners.[2-6] Advances in CT scanner technology may improve the ability of modern CT to detect more subtle fractures. For example, Mallee et al. found comparable sensitivity, specificity, and accuracy when comparing MRI with 64 slice multidetector CT (MDCT).[7] Heikal et al. reviewed 65 patients evaluated by MDCT for occult femoral neck fractures, and found no instances where a patient with a negative CT was later found to have a fracture.[8]

Of studies using current CT technology, our results nearly match those of Gill et al., who reported occult fracture rates of 36% (CT) and 38% (MRI) among 92 patients drawn from a similar patient population.[9] As in our study, patients underwent either CT or MRI based on the ordering physician, and they could not directly compare sensitivities of the two studies. Our study includes a larger patient group and more clearly defines the patient population of interest (over age 50 years, low energy mechanism) which allows more direct application of this information to other clinical practices.

In a smaller study of 24 patients, Hakkarinen reported 4 cases where MRI detected fractures that were missed on CT.[10] In contrast, our study found no instance where MRI identified a fracture missed on CT. One explanation for this discrepancy could be variation in radiologist experience and variability in what constitutes a fracture diagnosis on MRI or CT. Collin et al. reported variation in the number of hip MRI/CT images read as "equivocal" for fracture based on the experience and specialty of the radiologist.[11] Likewise, Haubro et al. found differences in ability to detect fracture by surgeons and radiologists with varying levels of experience.[4] Several studies describe intertrochanteric fractures identified on MRI that were interpreted as isolated greater trochanter fractures on CT or plain films.[4,9,12] The clinical significance of this injury pattern is not clear. For example, two of four patients in the Haubro study with greater trochanter fracture on CT and intertrochanteric extension on MRI, underwent surgical fixation while two other patients with identical fractures were managed nonoperatively. The authors could not identify the reason for variation in treatment. Our radiologists may have been less likely to interpret this pattern as a true fracture.

We also analyzed all radiographic studies obtained within 30 days of the index ED visit to ensure that we did not overlook fractures identified on later exam. We found nine patients with multiple visits during that time span, but none of the patients with a negative CT were later diagnosed with a fracture.

In an effort to describe patient factors that may increase the likelihood of occult fracture, we recorded demographic data, medical history, and ability to walk when available in the chart. We were unable to identify any specific patient characteristic that was associated with fracture. Like other studies, we found that patients were less likely to have a fracture if they could bear weight, but neither ability to walk nor ability to bear weight could exclude a fracture diagnosis.

Our study also provides new information on length of stay in the ED based on imaging choice. Our findings confirmed our anecdotal impression that patients who went underwent MRI imaging spent significantly more time in the ED than those who underwent CT (502 minutes vs 430 minutes) at our Level 1 trauma center. The length of stay differences would likely be exaggerated in smaller facilities where MRI is not readily available.

Limitations of our study include retrospective data collection with some information (such as ability to bear weight) being absent from some patient records. Because most patients had only CT or MRI, we can not declare with certainty that MRI would not have detected additional fractures in patients who underwent CT with a negative result. However, given that the two patient populations - those who underwent CT and those who underwent MRI- were demographically very similar, we would expect that the incidence of fracture would also be similar between the two groups. If MRI was truly significantly more sensitive to diagnose a fracture, we would expect to find a higher incidence of fracture diagnosis in the MRI only group, or multiple patients returning with displaced fractures after negative CT. Instead, the incidence of fractures was nearly identical.

CONCLUSION

Although previous studies suggest MRI has a superior sensitivity for fractures, our study found CT to be adequate to rule out hip and pelvic fractures in this patient population. CT may also be preferable to MRI based on decreased time spent in the ED and the large percentage of elderly patients with contraindications to MRI. Further prospective study is necessary to definitively determine the best and most efficient diagnostic tool in this patient population.

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RADIOGRAPHIC ENCHONDROMA SURVEILLANCE: ASSESSING CLINICAL OUTCOMES AND COSTS EFFECTIVENESS

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ABSTRACT

Background: Enchondromas are a common long bone benign tumor often discovered incidentally on imaging for adjacent pathology. These benign cartilaginous tumors can be difficult to differentiate from low-grade chondrosarcomas on imaging and histology. Multiple advanced imaging studies and clinic visits are required to confirm stability. Surveillance for these lesions can lead to significant patient costs without a clear oncologic or functional benefit. There is a lack of evidence-based consensus guidelines for the surveillance of enchondromas. The purposes of our study are: 1) to determine the number and proportion of low-grade cartilaginous tumors that demonstrate growth or require treatment and 2) to optimize the efficacy and cost-effectiveness of surveillance strategies for detecting biologically active lesions.

Methods: A retrospective single-institution study was performed on 55 subjects, 18 years or older, with long bone enchondromas without concerning radiographic characteristics that were referred to our institution's orthopaedic oncology clinic from July 1, 2009 to November 30, 2016. All subjects had at least 12 months of radiographic follow-up. We performed a chart and imaging review to assess for growth of the lesion over time. The number of pre-referral imaging and the number of follow-up imaging studies were recorded. The costs of plain radiographs and advanced imaging were estimated using our institution's global charge list in 2016.

Results: For stable enchondromas, 35 out of 52 lesions (67.3%) presented in the lower extremities compared to three out of three (100%) growing cartilaginous tumors. Three out of 55 (5.45%) long bone cartilaginous lesions exhibited growth at a median of 23 (range 21-25 months) follow-up. There was no apparent difference in median presenting age for stable versus growing lesions (58.5 versus 55.0 years old, p =0.5673) or median lesion size at presentation (4.1 cm versus 3.6 cm, p = 0.2923). None of these lesions presented with pain attributable to the lesion. One out of seven biopsied cartilaginous lesions (four stable and three growing) had a histology diagnosis of grade 1 chondrosarcoma. There was no significant difference in the median number of total clinical visits for stable (four) and growing (five) enchondromas (p = 0.0807). The median pre-referral costs per patient were: plain radiographs ($383.00), CT scans ($0.00), and MRI imaging ($3,969.00). The median post-referral costs for plain radiographs and MRI per patient were $1,326.00 and $4,668.00, respectively. The annual median costs for plain radiographs and MRI were $609.23 and $2,240.64, respectively.

Discussion: In conclusion, enchondroma growth was a rare event and typically occurred at two years follow-up in our series. Given the low risk for malignant transformation, we propose surveillance with plain radiographic follow-up for stable enchondromas every 3-6 months for the first year and then annually for at least three years of total follow-up. The most significant costs savings can be made by limiting MRI imaging in the absence of clinical or radiographic concern. Additional studies are needed to determine the long-term risk of growth or declaration of chondrosarcoma.

Level of Evidence: IV

Keywords: enchondroma, cartilaginous tumor, surveillance, cost analysis

INTRODUCTION

Enchondromas are a common subset of benign cartilaginous lesions found in long bones with an estimated incidence of 2.1-2.8%.[1,2] The aggressiveness of benign

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tumors is described by Enneking by three stages (1=latent, 2=active, 3=aggressive).[3] Enchondromas are often discovered incidentally from imaging for adjacent painful pathology, leading to orthopaedic referral.[4,5] Up to 85% of patients undergo unnecessary MRI imaging prior to presenting to the orthopaedic surgeon.[4,6] Biopsies are rarely needed in the setting of a stable enchondroma lesion.[7-9] Given that enchondromas are difficult to differentiate from low-grade chondrosarcomas,[10-12] imaging surveillance is needed to rule out progression. Although clinical and radiographic follow-up are justified,[4] multiple advanced imaging and clinic visits can lead to a significant cost for patients[13] without a clear benefit in survival or function.[6] Advanced imaging is not without risks and can increase patient exposure to radiation, although in this scenario it is likely negligible.[14,15] Although there have been national recommendations published for long-term surveillance of malignant bone tumors by the National Comprehensive Cancer Network (NCCN) and European Sarcoma Network Working Group (ESMO),[16,17] there is a lack of evidence-based consensus guidelines for the surveillance of benign bone tumors. The purposes of our study are: 1) to determine the number and proportion of low-grade cartilage tumors that demonstrate growth or require treatment and 2) to optimize the efficacy and cost-effectiveness of surveillance strategies for detecting biologically active lesions.

METHODS

A retrospective single-institution study was performed at our institution to identify the surveillance of enchondromas. Using ICD-9 codes (213.4, 213.7, 213.9) and ICD-10 codes (D16.0, D16.20, D16.21, D16.22, D16.9) we identified 498 subjects with benign bone tumors that were referred to our institution's orthopaedic oncology clinic from July 1, 2009 to November 30, 2016. Institutional Review Board approval was obtained prior to data collection.

Our radiographic inclusion criteria included subjects older than 18 years old with a long bone enchondroma without worrisome features. Our goal was to select "textbook" cases that were consistent with benign enchondromas without concerning findings for malignancy. Radiographically, we selected cases with well-defined tumor margins (e.g. a geographic border), the presence of stippled calcification without surrounding radiolucency, no extra-osseous soft tissue mass, no bone deformity or cortical remodeling, less than 66% endosteal scalloping, no cortical disruption, and no evidence of periosteal reaction. Exclusion criteria included patients with syndromic associations (ie Ollier's disease, Maffucci disease), axial lesions, radiographic findings (periosteal reaction, cortical breakage, soft tissue mass) suggestive of malignancy, recurrent tumors, immature patients, and patients with less than 12 months of radiographic follow-up. All radiograph reports of the low-grade cartilaginous tumors were initially made by members of musculoskeletal radiology department. The plain radiographs were reviewed by fellowship-trained musculoskeletal oncologist (B.J.M.), blinded to the clinical history of the subjects, to confirm inclusion.

Our primary outcome of this study was stability over time for long bone enchondromas. Radiographic size of the enchondroma was defined as the largest dimension on the AP or lateral plain radiograph view of the affected extremity in centimeters (cm). Subjects were followed radiographically for a minimum of one year (median 25 months, range 12 to 88 months). Changes in radiographic appearance of the enchondroma including growth, scalloping, demineralization, and fracture were recorded. Additionally, surgical intervention such as time to intralesional biopsy, curettage, and fixation was recorded.

The secondary outcome of this study was to compare the cost of tumor surveillance. For our cost analysis, we utilized our institution's global charge list in 2016. These charges include both physician and facility fees associated with both clinic fees and imaging fees. New office visit charges were: CPT 99202 ($370.00), CPT 99203 ($525.00), CPT 99204 ($671.00), and CPT 99205 ($770.00). Established patient clinic charges included: CPT 99211 ($235.00), CPT 99212 ($301.00), CPT 99213 ($376.00), CPT 99214 ($636.00), and CPT 99215 ($750.00). Plain radiograph charges included: shoulder ($451.00), humerus ($383.00). elbow ($343.00), femur ($440.00), forearm ($358.00), bilateral hip ($600.00), knee ($412.00), and tibia/fibula ($383.00). MRI imaging with contrast charges included: upper extremity joint ($3,942.00), upper extremity other than joint ($3,886.00), lower extremity joint ($3,969.00), and lower extremity other than joint ($4,038.00). The charge for a full body CT scan was $2397.00. Non-contrast CT imaging charges included: upper extremity ($2,144.00) and lower extremity ($2,147.00). We recorded the number of pre-referral images prior to presentation at our institution. We differentiated between pre-referral and post-referral imaging (plain radiographs, CT scan, MRI, and body scans). We compared costs of plain radiograph versus advanced imaging surveillance at final follow-up.

Independent variables collected included age, laterality, location of the enchondroma, incidental finding, radiographic size of the tumor, and interval growth. Statistical analysis was performed for descriptive statistics. Wilcoxon rank sum test and Fisher exact test were used to make group comparisons in continuous variables, and categorical variables, respectively. These statistical analyses were conducted using SAS version 9.4 (SAS Institute, Cary, NC) and statistical significance was set

Table 1. Demographics

	Stable	Growing	p-value
n	52	3	
Median age (years)	58.5	49.0	0.5673
Gender (female)	(69.23%)	0 (0%)	0.0369
Laterality (left)	18 (34.62%)	3 (100%)	0.0507
Pain at presentation	44 (84.62%)	2 (66.67)	0.4214
Incidental finding	52 (100%)	3 (100%)	1.0000
Number of pre-referral images [mean, median (range)]	[2.02, 2 (1-5)]	[3, 2 (1-6)]	0.7070
Median size @ px (cm)	5.01	3.6	0.2923
Fracture at presentation	0 (0%)	0 (0%)	1.0000

at a p-value <0.05.

RESULTS

A total of 55 out of 80 subjects (68.8%) with at least 12 months follow-up were included in our study (Table 1). The overall median age of our cohort was 58.0 years old. There were 19 males (36.5%, median age 58.0) and 36 females (69.2%, median age 57.5), (p =0.7480). Fifty-two of the lesions were stable and three demonstrated growth over time. There was no statistical difference in the median presenting age for stable versus growing lesions, respectively (58.65 versus 55.0 years old, p =0.5673), median lesion size at presentation (4.1 cm versus 3.6 cm, p = 0.2923), or median final follow-up (25 versus 26 months, p = 0.6802). Overall, the most common enchondroma locations were the proximal humerus (15/55=27.3%) and distal femur (16/55=29.1%), femoral shaft (9/55=16.4%), proximal tibia (4/55=7.3%), and fibula (4/55=7.3%) (Figure 1). For stable enchondromas, 35 out of 52 lesions (67.31%) presented in the lower extremities compared to 3 out of 3 (100%) growing cartilaginous tumors. All stable and growing cartilaginous lesions were found incidentally on imaging. Stable enchondromas presented with pain from adjacent pathology 44 out of 52 (84.6%) of cases while 2 out of 3 (66.6%) of growing cartilaginous lesions presented with pain from adjacent pathology (p = 0.4214). No patient presented with a fracture related to the tumor.

Three out of 55 (5.45%) of long bone enchondromas exhibited growth at a median of 23 (range 21 to 25) months follow-up. The first growing lesion was discovered incidentally in a 48 year-old healthy male and was located in his distal femur. At 23 months follow-up, the lesion grew from 3.6 cm to 4 cm and subsequently underwent an open biopsy which was most consistent with the diagnosis of an enchondroma. The second case of an enlarging cartilaginous lesion occurred in a 49 year-old male with a painful femoral shaft lesion (Figure 2). At 25 months follow-up, the lesion size grew from 7 cm to 7.43 cm and showed endosteal scalloping with cortical erosion. The patient underwent open curettage and bone grafting and biopsy results confirmed an enchondroma. The growing cartilaginous lesion was found incidentally in the femoral shaft of a 68 year-old male during screening for prostate cancer. At 21 months follow-up, the lesion grew from 3.2 cm to 10 cm and exhibited radiographic demineralization and endosteal scalloping. This subject underwent open biopsy and internal fixation of their lesion, and histol-

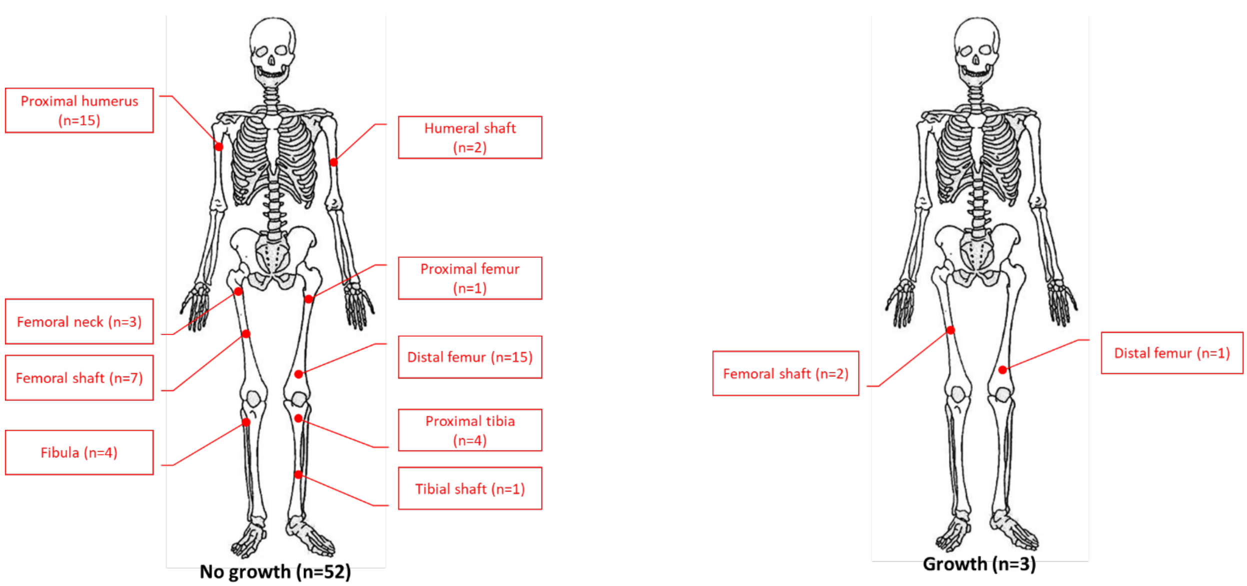
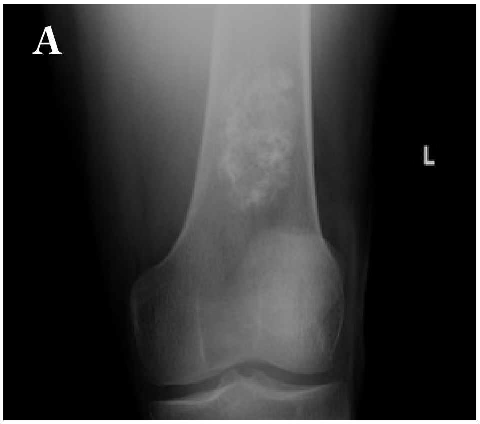


Figure 1. Location of enchondroma for stable (A) and growing (B) lesions.



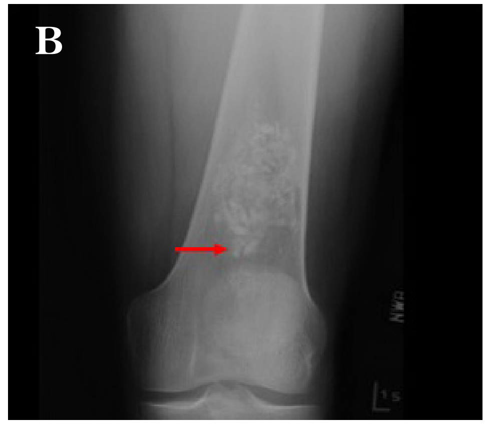


Figure 2. Growing enchondroma. Plain radiographs of the left femur of a 49 year-old male with a painful distal femoral shaft lesion. At 25 months follow-up, the lesion size grew from 7 cm (A) to 7.43 cm (B) inferiorly and showed endosteal scalloping with cortical erosion.

ogy revealed grade 1 chondrosarcoma. Incremental size increase at presentation for lower extremity [OR 1.282 CI (0.880-1.869)], metaphyseal [0.768 (0.208-2.835)], and diaphyseal [1.304 (0.724-2.3470] enchondromas lesions were not predictive of growth at final follow-up.

A total of seven open biopsies were performed on 4 out of 52 stable enchondromas and 3 out of 3 enlarging cartilaginous lesions at a median of 0.9 months (range 0.55 to 23) follow-up (Table 2). For the stable lesions undergoing biopsy, no patients had pain related to the lesion, one patient had endosteal scalloping without growth, and the remaining two had cystic regions within the cartilaginous matrix. All the stable lesions had a biopsy diagnosis of enchondroma while 1 out of 3 (33.3%) of the growing cartilaginous lesions ended up with a histologic diagnosis of grade 1 chondrosarcoma.

There was a total of 55 (45.1%) pre-referral plain radiographs, 5 (4.1%) CT scans, and 52 (42.6%) MRIs of the involved extremity (Table 3). There were also nine (7.4%) pre-referral full body bone scans. The median pre-referral costs per patient were plain radiographs ($383.00), CT scans ($0.00), and MRI imaging ($3,969.00) (Table 4A). The median follow-up time for stable and growing enchondromas was 25 and 26 months ($p = 0.6802$). The total median cost for post-referral follow-up was $8,982.00. The median post-referral costs for clinic fees, plain radiographs and MRI per patient were $1,799.00, $1,326.00, and $4,668.00, respectively. (Table 4B). The annual median costs for plain radiographs and MRI were $609.23 and $2,240.64, respectively.

DISCUSSION

There is much debate on the appropriate follow-up of long bone enchondromas without features of malignancy at presentation. Radiographically, it is often difficult to differentiate between enchondroma and low-grade chondrosarcomas.[10,11] Our exclusion criteria was similar to other studies that differentiated low and high-grade cartilaginous tumors.[12,18-20] In regards to radiographic diagnosis, Murphey et al. found that pain related to the cartilaginous lesion, endosteal scalloping greater than two-thirds the cortical thickness, periosteal reaction, and marked radionuclide uptake.[19] Geirnaerdt et al. did not find clinical pain to be associated with chondrosarcoma.[12] However, they found that radiographic size greater than 5 cm, axial skeleton location, and ill-defined margins were indicative of low-grade chondrosarcomas. The Skeletal Lesions Interobserver Correlation among Expert Diagnosticians (SLICED) study group reviewed 46 patients (mean age 47.7 years old) with low and high-grade cartilaginous tumors.[10] Despite analysis by nine expert bone tumor pathologists and eight expert bone tumor radiologists, there was low interobserver reliability for accurately differentiating between low and high-grade lesions on histology and radiographs. Clinically, our entire cohort presented incidentally on imaging for adjacent painful pathology such as mechanical knee pain or subacromial impingement. Levy et al. similarly found that 86% of enchondromas presented with pain from adjacent pathology.[21] Given the difficulty of differentiating enchondromas from low-grade chondrosarcomas at initial presentation, radiographic and clinical follow-up of cartilaginous lesions is warranted.

Our study is the first to our knowledge to assess the clinical follow-up and growth of isolated long bone enchondromas. Our overall median enchondroma size at presentation was 4.1 cm (mean 5.11 cm), and 3 out of 55 (5.45%) of long bone enchondromas exhibited growth at a median time of 23 months. Pain at presentation, location, and age did not appear to predict growth. The mean enchondroma size for Wilson's study was 4 cm.[6] Kumar et al. performed a retrospective study on 46 subjects (median lesion size 2.3 cm) with long bone cartilage lesions with a minimum of three years of MRI or CT follow-up.[22] They found that 11 out of 46 (23.9%) cartilaginous lesions ex-

Table 2. Open Biopsy Cohort

Stable	Age	Female	Laterality	Location	Size (cm)	Presentation	Radiographic features	Months to biopsy	Treatment	Final diagnosis
	53	M	R	proximal humerus	4.23	incidental	endosteal scalloping	2.5	open biopsy, curettage, grafting	enchondroma
	85	F	R	femoral neck	3.62	incidental, central hip arthritis	cystic cartilaginous lesion	0.57	open curettage, grafting, DHS	enchondroma
	48	F	R	distal femur	5.8	incidental, arthritis	central lucency	0.55	open biopsy, curettage, grafting	enchondroma
	68	F	L	distal femur	4.1	incidental	chondroid matrix	0.5	open biopsy and curettage	enchondroma
Growing										
	48	m	L	distal femur	3.6	incidental, knee osteoarthritis	cartilaginous matrix	1.16	open biopsy and curettage	enchondroma
	49	M	L	femoral shaft	7	pain from tumor	endosteal scalloping, cortical erosion	23	open biopsy, curettage, grafting	enchondroma
	68	M	L	femoral shaft	3.2	incidental, f/u prostate CA	scalloping, inferior area of demineralization	0.9	open biopsy, curettage, internal fixation	grade 1 chondrosar-coma

hibited at least 6 mm of growth at three years follow-up. One patient (2.2%) in Kumar's series exhibited 11 mm of growth at one year follow-up and was confirmed to have an atypical enchondroma at the time of surgery. Unlike our study, Kumar et al. did not exclude chondrosarcomas or atypical radiographic features in their cohort as 10% of their cohort had endosteal scalloping on plain radiographs at the time of presentation. They also found that growing cartilaginous lesions had greater than 50% demineralization compared to stable lesions. One of the subjects in our study exhibited significant growth from 3.2 to 10 mm and demineralization at 21 months follow-up. Upon open biopsy, this subject had grade 1 chondrosarcoma. This case confirms that growth of seemingly benign cartilaginous lesions warrants longer follow-up and surgical biopsy for a definitive diagnosis.

Most clinicians utilize radiographic findings to differentiate enchondromas from low-grade chondrosarcomas. However, atypical radiographic features or subsequent growth may require biopsy to confirm the diagnosis and surgical intervention. One growing cartilaginous lesion had a biopsy-confirmed diagnosis of a grade 1 chondrosarcoma at 21 months follow-up. Surgical intervention for low-grade cartilaginous lesions includes intralesional versus wide resection. Given the low occurrence of recurrence and metastasis for low-grade cartilaginous tumors, the treatment of choice is open biopsy and curettage.[23-25] Intralesional curettage allows for the preservation of the affected limb without significant morbidity. Leerapun et al. retrospectively compared 70 patients with grade 1 long bone chondrosarcomas that underwent wide resection or intralesional curratage.[26] At a mean of 8.5 years follow-up, one patient in each group had local recurrence and metastasis without any difference in overall outcomes. At 5.1 years follow-up, Hanna et al. reported a 5% recurrence rate in their retrospective cohort of low-grade long bone chondrosarcomas treated with intralesional curettage and cementation.[23] Verdegaal et al. retrospectively studied 85 patients that underwent intralesional curettage with phenol and ethanol adjuvant treatment.[24] At an average follow-up of 6.8 years, biopsy-confirmed recurrence occurred in 5.9% of cases, all of which were grade 1 chondrosarcomas. Dierselhuis et al. retrospectively reported on 108 patients with grade 1 chondrosarcomas treated with intralesional curettage, adjuvant phenol, and defect filling (polymethylmethacrylate, bone graft, or bone substitute).[25] Complications included residual tumor (4.6%), recurrence (0%), and fracture (10.2%) at a mean follow-up of 4.1 years. They recommended that intralesional curettage is safe for tumors less than 100 cm^2. One previous retrospective study by Schwab et al. of 164 patients with surgically treated grade 1 chondrosarcomas did show a high rate of local recurrence (13%), metastasis (4.3%), and death (3.7%).[27] More importantly, decreased survival was not seen until five years after surgical treatment. The occurrence of one biopsy-confirmed grade 1 chondrosarcoma in our cohort highlights the importance of follow-up longer than six months.

Table 3. Clinical Follow-up

	Stable (n=52)					Growing (N=3)					
	Min	Max	Median	Mean	SD	Min	Max	Median	Mean	SD	p-value
Age	34	85	58.5	58.65	12.65	48	68	49	55.00	11.27	0.5673
Presenting size	1.2	18.6	4.105	5.01	3.09	3.6	10	7	6.87	3.20	0.2923
Follow-up months	12	88	25	30.23	14.84	6	36	26	22.67	15.28	0.6802
Number of visits	2	11	4	4.37	1.79	5	10	5	6.67	2.89	0.0807
# Pre Clinical Imaging	0	5	2	2.02	1.02	1	6	2	3.00	2.65	0.7070
# Pre Clinical X-ray	0	2	1	0.90	0.57	1	5	1	2.33	2.31	0.1402
# Pre Clinical CT	0	1	0	0.10	0.30	0	0	0	0.00	0.00	1.0000
# Pre Clinical MRI	0	2	1	0.88	0.58	0	1	1	0.67	0.58	0.6208
# Final X-ray	0	9	3	3.33	2.06	2	9	3	4.67	3.79	0.6975

Using Wilcoxon Rank-sum test

Our study also aimed to determine the appropriate time and costs of clinical and radiographic follow-up for isolated, non-syndromic long bone enchondromas. The median follow-up for stable and growing enchondroma in our cohort was 25 and 26 months, respectively. Enchondromas rarely undergo malignant transformation into chondrosarcomas, except in the setting of Ollier disease (25% occurrence) or Maffucci syndrome (100% occurrence).[28] Additionally, when malignant transformation occurs, it is often low-grade chondrosarcoma and metastasis is rare.[29] Clinical surveillance for low grade bone sarcomas have been previously published.[16,17] Both the National Comprehensive Cancer Network (NCCN)[17] and the European Sarcoma Network Working Group (ESMO)[16] recommend follow-up imaging for low-grade bone sarcomas every six months for two years, and then annually. For cartilaginous lesions, Kumar et al. concluded in their retrospective study that MRI surveillance should be performed at one year and then at three year follow-up. They also suggested that surgical intervention should be performed if growth greater than 6 mm is seen.[22] Most recently, the Musculoskeletal Tumor Society (MSTS) published new guidelines for surveillance of newly identified bone lesions.[30] For asymptomatic stable lesions, they recommended serial radiographs and review by a fellowship-trained musculoskeletal radiologist every three to six months for two years. Observed growth or aggressive radiographic findings warrants immediate referral to an orthopaedic oncologist. Given the time to growth seen in our study, our proposed surveillance would include radiographic follow-up every 6 months for the first year, and then annually for a total of at least three years.

Our goal with this investigation was to investigate if there was a means to identify a low-grade cartilaginous lesion with no potential for growth after short-term radiographic surveillance. While we did find the majority of lesions remained stable and painless, the identification of a grade 1 chondrosarcoma in an asymptomatic patient at nearly 2 years of radiographic follow-up is concerning and gives pause to a global recommendation of limiting follow-up to 6 months in stable "textbook" lesions.

One way to view this issue is that the vast majority of patients (48 out of 55 in our cohort) in retrospect did not require any intervention. Even for the biopsied lesions that exhibited growth (n=3) or atypical features (n=4), only one lesion was diagnosed as a grade 1 chondrosarcoma and no lesions were limb-threatening. One should remember that the goal of radiographic surveillance is not to identify growing enchondromas, but to accurately diagnose chondrosarcomas. In addition, the patient with a grade 1 chondrosarcoma was referred to us after identification of growth in a radiograph performed nearly two years after the initial presentation without intervening surveillance, so it is not clear whether this progression would have been recognized earlier. Given the substantial growth between studies, it is likely that the progression would have been apparent at shorter surveillance. These observations would suggest that shorter follow-up is likely sufficient to identify a potential malignancy.

Alternatively, none of the patients with growth over time, in particular the patient with chondrosarcoma, exhibited pain. This is concerning as often clinicians will advise individuals with apparently non-aggressive pathology to return if symptoms arise. Because we cannot depend on discomfort to prompt return evaluation, radiographic surveillance is the only option to determine tumor biology over time. In addition, growth was not clear until two years after the initial study in our cases, arising concern that perhaps more lesions will demonstrate growth with a longer period of follow-up.

Table 4. Cost Analysis for Pre-Referral (A) and Post-Referral (B) Costs

A.

Pre-referral imaging	X-ray	MRI	CT	Full body scan	Total pre-referral imaging	Total pre-referral Cost
Mean costs	$405.47	$3,456.53	$233.69	$305.07	2.07	$4,406.51
Median costs	$383.00	$3,969.00	$0	$0.00	2	$4,411.00
Range	$0 to $880.00	$0 to $8076.00	$0 to $2850.00	$0 to $2397.00	0 to 4	$383.00 to $11,300.00
Standard deviation	$335.92	$2,301.03	$749.03	$806.23	1.14	$2,712.25

B.

Post-referral Costs	Clinic	X-ray	MRI	Total	Annual X-ray	Annual MRI	Annual X-ray + MRI
Mean	$1,914.93	$1,506.98	$6,501.95	$10,344.11	$700.96	$2,584.20	$3,285.16
Median	$1,799.00	$1,326.00	$4,668.00	$8,982.00	$609.23	$2,240.64	$2,628.68
Range	$ 901.00 to $4656.00	$0 to $4059.00	$0 to $29,220.00	$2117.00 to $37,284.00	$0 to $2,250.75	$0 to $9,740.00	$338.25 to $10,876.00
Standard deviation	$787.98	$943.63	$7,771.81	$8,029.40	$469.57	$2,921.96	$2,764.99

We suggest a common-sense approach that minimizes cost, maximizes efficiency, and accurately identifies clearly biologically active cartilage tumors. An initial period of close follow-up every 3-6 months as recommended by the MSTS, is reasonable to identify growing lesions in the short- or medium-term.[30] If there is no growth for one year, lengthening the period of time to annual surveillance is acceptable. Unless there is a clinical concern, such as pain that cannot be attributed to another source or growth on plain radiographs, advanced imaging is unnecessary. Because we saw growth at an average of two years, we would recommend a full three years of follow-up, and would suggest future studies investigate if a longer period of surveillance is beneficial. Additional cost-saving measures could include local surveillance with repeat specialty referral only if there is radiographic growth or unexplained pain, remote appointments with telemedicine, or surveillance performed by specialized advanced practice providers.

Our results indicate that there is a significant cost associated with pre-referral imaging, with 42% of costs coming from MRI. Wilson et al. retrospectively reviewed 121 patients (105 enchondromas and 19 chondrosarcomas) and utilized decision analysis to determine the number of unnecessary images.[6] They found that 85% of enchondromas had at least one unnecessary advanced image and 58% had two unnecessary images. They also found that the average unnecessary cost per enchondroma was $1346.18. Donthineni et al. also found that 85% of patients presented with MRI imaging and 15% of patients with pre-referral MRI imaging did not have plain radiographs.[4] Our study similarly found that 54.8% of pre-referral and 29.2% of post-referral imaging were advanced images. In clinical practice, it is common for orthopaedic surgeons to practice defensive medicine by obtaining excessive imaging to prevent litigation.[31] Pre-referral costs can be reduced by properly educating non-oncology physicians when to obtain advanced imaging. Intraarticular lesions and lesions with evidence of aggressive features warrants advanced imaging. If the benefits of advanced imaging are in question, then the patient should be referred to an oncology center for proper management. Once referred to an oncology physician, extended follow-up and appropriate imaging may reduce the risk of missing a malignant tumor. A proposed cost-savings protocol would include plain radiograph imaging for three years for stable lesions. This would amount to an annual savings per patient of $2,240.64 per year.

There are several limitations of this study. This was a retrospective study with a significant amount of the cohort lacking adequate imaging follow-up. These excluded patients may have altered the results obtained. Although we intentionally excluded patients without long bone enchondromas, our study may have been underpowered as a result and thus not able to detect a statistical significance for size of the lesion and growth. We followed tumor growth with plain radiographs, which may not be as accurate at following growth as advanced imaging modalities. Additionally, we did not follow-up patients after biopsy and surgical intervention to determine the rate of recurrence and metastasis. Given our limited follow-up after surgical treatment, future studies should address continued long-term surveillance of low-grade cartilaginous lesions and risk for subsequent malignant identification.

In conclusion, enchondroma growth was a rare event and typically occurred at two years follow-up in our series. We propose plain radiographic follow-up for stable enchondromas every six months for the first year and then annually for at least three years of total follow-up. Significant costs savings can be made by limiting MRI imaging for stable lesions. Additional studies are needed to determine the risk of recurrence and malignant transformation for lesions exhibiting growth.

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EVIDENCE OF SELECTION BIAS AND NON-RESPONSE BIAS IN PATIENT SATISFACTION SURVEYS

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ABSTRACT

Background: Patient satisfaction surveys are increasingly utilized to measure the patient experience and as a tool to assess the quality of care delivered by medical providers. Press Ganey (PG) is the largest provider of tools for patient satisfaction measurement and analysis. The purpose of this study was to determine if patient satisfaction surveys were subject to selection and/or non-response bias.

Methods: Patients seen in an outpatient academic orthopedic clinic were included in this retrospective cohort study. Demographic data included age, race, gender, marital status, primary payer, and native language. All surveys were administered by PG Associates per internal protocols adhering to exclusion criteria within the institutional contract with PG Associates.

Results: 3.5% of outpatient encounters generated PG survey data, which were generated by 9.1% of all patients evaluated. The population of patients who were administered as well as patients who responded to the patient satisfaction survey represented a unique population with regards to age, race, gender, marital status, insurance status, and native language.

Conclusions: Demographically, patients who were administered and patients who responded to PG surveys differed from the overall population of patients seen in an outpatient orthopedic setting, evidencing both selection and non-response bias. Because of these differences, and considering the small number of survey returned, caution should be exercised when interpreting and applying these data.

Level of Evidence: III

Keywords: survey science, non-response bias, selection bias, patient satisfaction

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INTRODUCTION

Recent legislation requires evaluation of the quality of care provided by healthcare professionals, and patient-reported outcome measures (PROMs) are one metric used to measure quality.[1,2] Patient satisfaction surveys are a widely recognized PROM. Press Ganey Associates is the largest provider of tools for patient satisfaction measurement, and provides the only survey approved by the Centers for Medicare and Medicaid Services (CMS). Data generated from Press Ganey (PG) surveys are being used to grade, rank, and reimburse hospitals and physicians.[2,3,4] Despite widespread use, the application of PG data is controversial since PG survey scores have not been shown to correlate with other outcome metrics.[5] Moreover, patient reported outcome scores have been shown to correlate with patient-specific characteristics such as age, sex, race, insurance, employment, psychological distress, and distance traveled to the healthcare delivery site.[6,7,8]

While PG survey results (i.e. PG scores) receive considerable attention, the methodology employed to generate patient survey data has not been broadly discussed. Survey-derived data is subject to multiple sources of bias that potentially threaten its validity. Because each institution contracting with PG may customize exclusion criteria, selection bias may inadvertently and significantly alter the surveyed population. Furthermore, non-response bias occurs when survey analysis is limited to data from respondents who differ from non-respondents.[9,10] Since survey validity is undermined when the survey data is derived from a sample not representative of the whole, a thorough understanding of the surveyed and respondent population is essential to meaningfully interpret survey data.[11]

PG scores are regularly discussed at orthopaedic professional meetings, faculty meetings, and amongst administrators. While potential methodological shortcomings are often implied, they are typically not quantified or analyzed in depth. The purpose of this study was to analyze the methodology applied by our institution in collecting PG data, specifically 1) the response rate of the survey, 2) the exclusion criteria applied by the institution and its potential effect on survey response, and 3) the demographic characteristics of respondents, non-respondents, and the overall population.

Table 1. Comparison of Respondents to all Other Patients Seen as Outpatients During an 18-Month Time Period

	Respondents (N=3,363)	All Other Patients (N=33,231)	p-value
Age (years)	52.9 (+/-21.8)	40.2 (+/- 22.5)	<0.0001
Gender (F)	56.11%	51.68%	<0.0001
English as Native Language	98.99%	97.48%	<0.0001
Race			
White	95.43%	87.79%	<0.0001
Non-white	4.57%	12.21%	<0.0001
Marital status			
Married	55.19%	39.86%	<0.0001
Divorced	6.43%	6.17%	0.5808
Separated	0.63%	1.06%	0.0273
Single	31.33%	49.36%	<0.0001
Widowed	6.02%	3.32%	<0.0001
Life Partner	0.38%	0.24%	0.1612
Insurance status			
Medicare	34.14%	17.93%	<0.0001
Medicaid	8.18%	17.79%	<0.0001
Veteran's Affairs	0.65%	0.48%	0.1663
Tricare	0.68%	0.53%	0.2463
Commercial	11.63%	13.57%	0.0016
Workman's Compensation	6.39%	7.19%	0.0882
Blue Cross Blue Shield	38.15%	41.61%	0.0001
Self-Pay	0.12%	0.81%	<0.0001

MATERIALS AND METHODS

After approval from the Institutional Review Board, all outpatient encounters from the Department of Orthopedics and Rehabilitation at our academic institution from 1/1/2015 to 6/30/2016 were identified. Demographic data were extracted from patient medical records that included age, gender, race, native language, marital status, and primary payer. All patients and those who responded to the PG survey within this population were identified and compared.

At our institution, in accordance with institutional policy, the following patients were excluded from receiving a PG survey: 1) a patient surveyed within 90 days by the orthopedics outpatient clinical service, 2) deceased patient, 3) newborn patient, 4) patient admitted or referred to another service which also surveys patients, 5) patient declined publicity (for example, patients who do not wish to be contacted for survey data), 6) patient with a primary psychiatric diagnosis, 7) prisoner or patient otherwise in custody, 8) involvement of child protective services, and 9) patient restricted due to state regulations. Beyond 90 days, PG does not retain a record of patients who were administered surveys or how many surveys were sent. Therefore, the response rate (number of surveys returned/number of surveys administered) for this 18 month patient cohort could not be calculated retrospectively. Consequently, we prospectively collected the number and demographics of patients sent a survey from a 90 day period outside the prior 18 month study period, from 11/13/2017 to 2/16/2018.

All surveys were administered by PG according to internal protocols. Patients received survey by United States Post Service (USPS) mail or by electronic mail. Survey responses were recorded for up to 1 month for electronic mail and up to 1 year for USPS mail.

The demographic data provided for these patient populations were compared using the t-test for continuous variables and the chi-square of exact test, as appropriate, for categorical variables. A p-value of $p<0.05$ considered statistically significant. An analysis of maximum likelihood estimates was performed for significant variables. Analyses were completed using SAS statistical software version 9.4 (SAS Institute, Inc., Carey, NC).

RESULTS

Comparison of respondents to all other outpatients from 18 month cohort

In this retrospective cohort study, 107,656 patient encounters were generated by 36,918 unique patients from 1/1/2015 to 6/30/2016. 3720 PG surveys were generated by 3363 of these patients. The average age of patients seen in our outpatient clinics during this time period was 40.2 ±22.5 years (standard deviation 22.5 years); 51.7% identified as female, 97.5% spoke English as a native language, 87.8% identified as white by race, 39.9% were married, 49.4% were single, 3.3% were widowed, and 1.1% were separated. By contrast, patients who returned at least one survey were on average 52.9 ±21.0 years old, 56.1% identified as female ($p<0.0001$), 99.0% spoke English as a native language ($p<0.0001$), 95.4% were white ($p<0.0001$), 55.2% were married ($P<0.0001$), 31.3% were single ($p<0.0001$), 3.3% were widowed ($p<0.0001$), 0.6% were separated ($p<0.0001$). Each of these categories were statistically significant between patients who had returned a PG survey and patients for whom survey data was not available (all other patients) for the encounter (Table 1).

Multivariate analysis was performed using the Wald

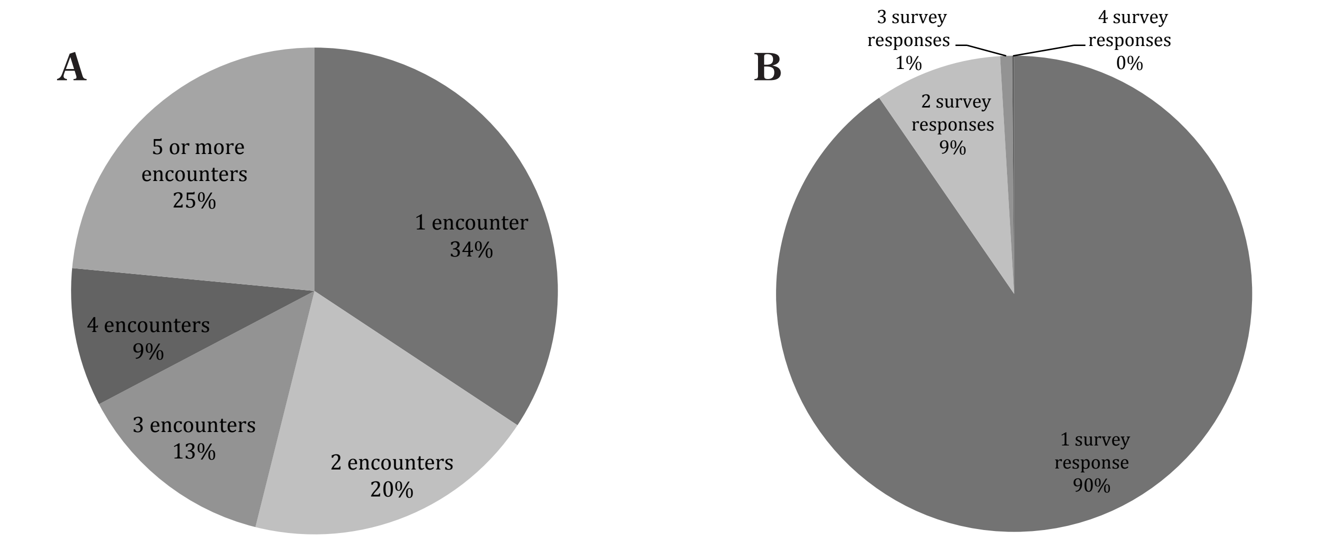

Figure 1. A) Number of encounters per patient over 18 month period. Over one third of patients generated one encounter, however 25% of patients generate more than five encounters. B) Number of Surveys Returned Per Patient over 18 Month Period. The majority of patients (90%) return only one survey, independent of number of outpatient visits the patient attended.

chi-square test. Age, gender, race, marital status, and payor status were found to be independent variables (p<0.01).

Several parameters regarding the returned surveys were also analyzed. Over the course of the study period, 34.3% of patients generated one encounter in the outpatient clinic, 19.6% generated two encounters, 46.1% generated three or more encounters (range: 1 encounter to 40 encounters). 3041 patients, regardless of number of encounters (1-38) returned only 1 survey (90.4% of surveys); however, 2217 patients (72.9%) generated more than a single encounter (Figure 1A and 1B).

In the 18 month cohort, 3.5% of outpatient encounters generated PG survey data. Because patients frequently attend multiple visits, these data represent 9.1% of all patients receiving medical care in the outpatient setting. Per specialty, arthroplasty and spine patients were more likely to respond to a survey, whereas pediatric patients were less likely to generate survey data (Figure 2). Across specialties, respondents were statistically different with regards to age, in that respondents were about 10 years older than the overall population. Respondents generally differed with regard to payor status, with Medicaid tending to be under-represented and Medicare tending to the over-represented. On the other hand, Worker's Compensation respondents were statistically similar to non-respondents in gender, race, language, or marital status (Table 2).

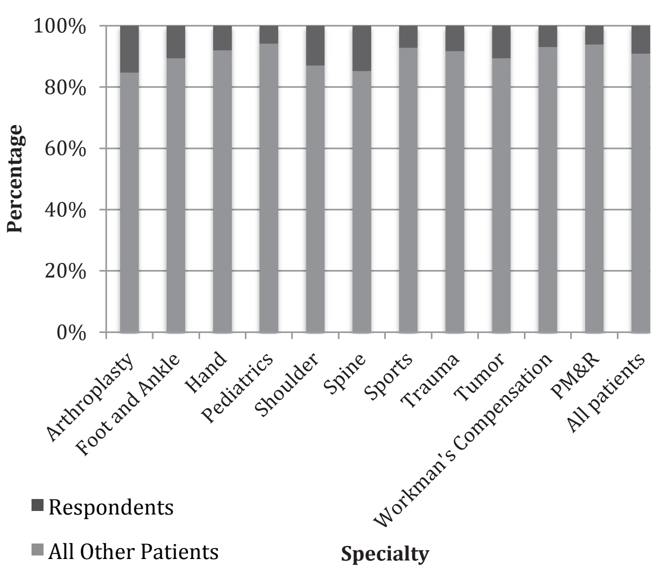

Figure 2. Percentage of patients who responded to survey by specialty.

Analysis of patients administered a survey from 90 day cohort

In order to evaluate patients included for survey administration, data was prospectively collected over a 90-day period. During 11/13/2017 to 2/16/2018, 10,421 patients generated 14,544 encounters. Due to exclusion criteria, 7,741 patients were not eligible to receive a survey (11,850 encounters). Thus, 81.5% of patient encounters were excluded from sampling, representing 74.3% of the patient population. Patients were excluded due to address error (2100 patients, 27.1%), duplicate visit within 90 days (5629 patients, 72.7%) or other exclusion criteria met (12 patients, 0.1%). There were no changes in the exclusion criteria during either time period studied.

To evaluate for selection bias, the demographics of all clinic patients were compared to the demographics of patients sent a survey. Patients significantly differed by

Table 2. Comparison of Respondents to all Other Patients by Specialty During an 18-Month Time Period

	Age		Gender		Medicare		Medicaid		Race (white)		Primary Language (English)		Marital status (Married)	
	All Other Patients	Respondents	All Other Patients	Respondents	All Other Patients	Respondents	All Other Patients	Respondents	All Other Patients	Respondents	All Other Patients	Respondents	All Other Patients	Respondents
PMR	48.4	53.2 (p=0.01)	56.70%	61.6% (p=0.4)	23.60%	31.5% (p=0.12)	27.00%	17.8% (p=0.08)	88.10%	91.8% (p=0.02)	96.20%	100% (p=0.11)	49.70%	56.1% (p=0.32)
Tumor	44.6	55.5 (p<0.01)	48.80%	51.6% (p=0.52)	24.90%	42.8% (p<0.01)	15.00%	6.92% (P=0.01)	89.60%	96.7% (p<0.01)	97.40%	99.4% (p=0.17)	46.50%	56.2% (p=0.04)
Foot and Ankle	50.7	58.0 (p<0.01)	58.70%	58.5% (p=0.97)	24.10%	32.5% (p<0.01)	16.30%	8.9% (p<0.01)	87.50%	95.5% (p<0.01)	98.10%	99.2% (p=0.31)	51.80%	61.0% (p=0.01)
Trauma	40.8	53.8 (p<0.01)	46.20%	51.8% (p=0.09)	22.20%	34.0% (p<0.01)	23.10%	11.1% (p<0.01)	85.20%	94.1% (p<0.01)	96.80%	98.0% (p=0.29)	33.30%	48.2% (p<0.01)
Shoulder	59.2	65.5 (p<0.01)	43.70%	48.2% (p=0.39)	42.40%	56.5% (p=0.01)	11.10%	2.8% (P<0.01)	92.70%	98.2% (p=0.03)	98.60%	100.0% (p=0.38)	55.60%	64% (p=0.11)
Pediatrics	11.6	19.6 (p<0.01)	56.10%	55.8% (p=0.93)	1.70%	2.9% (p=0.15)	30.10%	18.3% (p<0.01)	84.30%	91.6% (p<0.01)	97.20%	99.3% (p=0.04)	2.50%	4.4% (p=0.09)
Sports	36.1	45.0 (p<0.01)	50.60%	58.7% (p<0.01)	8.50%	18.2% (p<0.01)	14.10%	7.7% (<0.01)	84.90%	94.0% (p<0.01)	97.90%	99.2% (p=0.01)	38.50%	54.5% (p<0.01)
Spine	53.9	64.8 (p<0.01)	49.20%	51.6% (p=0.42)	35.70%	56.7% (p<0.01)	16.70%	4.9% (p<0.01)	92.30%	96.0% (p=0.03)	98.40%	98.6% (p=0.83)	55.50%	63.4% (p=0.01)
Hand	40.4	52.1 (p<0.01)	49.20%	61.3% (p<0.01)	15.40%	25.3% (p<0.01)	21.90%	9.8% (p<0.01)	84.10%	94.6% (p<0.01)	96.90%	98.8% (p=0.05)	40.50%	55.6% (p<0.01)
Arthroplasty	55.8	58.5 (p<0.01)	55.80%	58.5% (p=0.18)	45.30%	58.8% (p<0.01)	12.60%	5.8% (p<0.01)	90.60%	95.9% (p<0.01)	98.10%	99.3% (p=0.03)	57.50%	67.4% (p<0.01)
Worker's Compensation	47.3	51.1 (p<0.01)	40.90%	40.5 (p=0.92)	**	**	**	**	82.20%	84.7% (p=0.5)	95.70%	96.9% (p=0.50)	28.70%	32.8% (p=0.31)

Table 3A-C. Demographic Characteristics of Patients Administered and Respondents During a 90-Day Period. A) Comparison of Patients who were Administered a Survey Versus Patients who were not Administered a Survey. B) Comparison of Respondents Versus Non-Respondents of the Administered Survey. C) Comparison of Respondents to all Other Patients.

A	No survey administered	Survey administered	p-value
Age (years)	44.6 (± 22.7)	41.9 (±23.1)	<0.0001
Gender (% female)	52.3%	49.7%	0.023
Payor			
Medicare	24.0%	20.9%	0.0006
Medicaid	16.9%	18.4%	0.0608
Worker's Compensation	7.9%	8.7%	0.124
Marital status (married)	38.8%	37.8%	0.6445
English native speaker	98.0%	98.1%	0.6757
White race	87.4%	87.4%	0.1228

B	Respondents	Non-respondents	p-value
Age (years)	53.0 (± 22.2)	39.8 (± 22.7)	<0.0001
Gender (% female)	56.0%	48.5%	0.0046
Payor			
Medicare	33.3%	18.5%	<0.0001
Medicaid	10.9%	19.9%	0.0003
Worker's Compensation	5.7%	9.4%	0.0143
Marital status (married)	57.1%	35.5%	<0.0001
English native speaker	99.8%	97.7%	0.0044
White race	95.5%	87.7%	<0.0001

C	Respondents	All Other Patients	p-value
Age (years)	53.0 (± 22.2)	44 (± 22.8)	<0.0001
Gender (% female)	56.0%	52.0%	0.1042
Payor			
Medicare	33.3%	23.7%	<0.0001
Medicaid	10.9%	17.7%	0.0003
Worker's Compensation	5.7%	6.7%	0.3998
Marital status (married)	57.1%	44.7%	<0.0001
English native speaker	99.8%	97.8%	0.006
White race	95.5%	88.6%	<0.0001

age and gender. Those sent a survey were significantly younger and less likely to identify as female. They also were less likely to have Medicare. Patient demographics did not significantly differ with regards to race, marital status, or primary language (Table 3A). Furthermore, the rate of survey administration varied by department, ranging from 12.1% in trauma patients (99/820 patients) to 34.5% of hand patients (464/1347 patients).

To evaluate for non-response bias, the demographics of patients who responded to the survey and those who did not respond were similarly compared. Respondents were significantly older, more likely to identify as female, more likely to have Medicare, less likely to have Medicaid, more likely to be married, speak English as a native language and identify as White (Table 3B).

Similar to the 18-month cohort, patients in the 90 day cohort who responded to the survey versus patients for whom survey data was not available (all other patients) were significantly different with regards to multiple demographic characteristics queried. (Table 3C).

Determination of response rate

In the prospective 90 day cohort from 11/13/17 to 2/16/18, 2693 surveys were sent out of 10,426 patients (14,544 encounters), thus 25.8% of patients (18.5% of patient encounters) were surveyed. 425 surveys were returned, yielding a response rate of approximately 15.8%.

DISCUSSION

The purpose of this study was to describe the methodology used by our institution to obtain patient satisfaction scores in the outpatient setting. This investigation was part of a quality improvement effort to identify ways to improve reporting rates as well as provide contextual information for patient satisfaction surveys. Our objective was to quantify, characterize, and compare the overall outpatient population, patients who were surveyed, and patient respondents to the survey.

From the 18 month cohort, we determined that the PG survey data at our institution were based on responses from 9.1% of the total patients seen on an outpatient basis. Since some patients had multiple visits, the survey data represented 3.5% of total clinical encounters during the study interval. The demographics of the responding population differed significantly from the population as a whole with regards to age, gender, payor status (Medicare and Medicaid), marital status, race, and native language. These differences were observed across all orthopaedic subspecialties. We had expected that some orthopedic specialties, such as joint arthroplasty, would be more resistant to demographic differences between the entire population and survey responders due to a relative homogeneity of the specialty population. However, we observed statistical differences in the demographics of respondents within each orthopedic specialty as well as when compared with the overall orthopedic population. Of all the orthopaedic patient populations, only Worker's Compensation patients showed no statistical differences in demographics between survey respondents and the whole population with the exception of age. This may be due to Worker's Compensation populations being more homogenous demographically, or perhaps due to a higher response rate (32.0% response rate).

Interestingly, PG does not retain a record of patients administered beyond 90 days. Thus, the total number of surveys administered during the 18 month study period was unknown. To determine the response rate, we prospectively collected data, including who was sent a survey, from a separate 90 day cohort of patients. The response rate (number of surveys returned/number of surveys administered) was 15.8%.

Given this response rate and the demographic differences between the respondent and non-respondent population, the possibility of nonresponse bias undermining survey validity is concerning. Although in survey based research there is no minimum acceptable response rate, the effects of survey non-response bias can be mitigated by increasing the response rate.[6,12] Reasons why patients respond or do not respond to satisfaction surveys are speculative and likely multifactorial.[6,9,13,14] The Journal of the American Medical Association editorial policy suggests that survey studies need a response rate of at least 60% to be considered for publication, and references the metrics proposed by the American Association for Public Opinion Research.[15] The Office of Management and Budget, who reviews most survey protocols funded by the federal government, asks surveys being reviewed to "submit a plan for a non-response bias analysis if the expected unit response rate is below 80%."[16]

In planning the survey with PG, institutions may customize their exclusion criteria. An individual may be categorically excluded from participating in the survey (for example, an institution may choose to exclude Worker's compensation patients). Within our department, a patient sent a survey is excluded from being sent another survey for 90 days. In many clinical scenarios, frequent clinic visits are required and/or a single patient requires multidisciplinary care. In the current study, 3041 patients, regardless of number of encounters (1-38) returned only 1 questionnaire (90.4%); however, 2217 patients (72.9%) had more than a single encounter. In our practice, a patient was most likely to be excluded due to duplication (they had attended another clinical visit within 90 days). Duplicates represented 54.0% of excluded patients in the time period. While the impact this has on PG scores for an individual provider is speculative, this practice likely influences survey data by altering the representation of high- versus low-health care utilization patients. Complex orthopedic patients requiring frequent evaluation and resource utilization may have the same survey representation as the patient seen once with a condition not warranting additional orthopaedic intervention.

Previously, non-modifiable patient characteristics such as distance traveled to facility, age and gender have demonstrated correlation with satisfaction ratings.[17,18,19] Analysis of our excluded patients suggests that the population of patients selected for administration of a survey is different from the population on the whole with regards to age and gender, as well as proportion of Medicare patients. Selecting for a population that is significantly different from the overall population likely introduces bias into survey results. Furthermore, the effect of non-response bias discussed previously in the literature is likely underestimated because respondents are compared with the entire patient population instead of the patients administered a survey.[20]

In a similar study of PG respondents at an academic orthopedic university affiliated system, Tyser et al. found a response rate of 16.5% to the Press Ganey survey,[21] although it is unclear if the 16.5% is of the total population, total number of patient encounters, or the population administered a survey. These authors raised the issue of non-response bias given this low response rate. In a study from the same institution, Abtahi et al. identified age, sex, insurance type, and orthopaedic subspecialty as variables that affected the odds of responding to the survey.[8] Neither study addressed the potential of selection bias due to exclusion criteria applied to the population of patients generating an encounter; in this study, we found almost 75% of patients are not eligible to receive a survey. During our investigation of PG survey methodology, we found that the exclusion criteria amongst institutions are variable and customizable. Thus, respondent data cannot be generalized between institutions without a high level of transparency and understanding of each institutional contract.

In conclusion, our investigation revealed a low response rate to the PG survey with significant demographic differences between the outpatient orthopedic patient population, patients who were administered a survey and patients who responded. Although there was evidence of selection bias, non-response bias was more consistently evident across a variety of patient characteristics. This suggests non-representative sampling which may be the product of methodological shortcomings, and may explain the lack of correlation the PG score has with other outcome metrics. Although surveys administered to patients by PG are not required to meet the strict standards of survey science, the data generated are being used to compare physician and hospital performance by both consumers and third-party payors. It is also used within institutions to direct quality improvement measures. Moreover, given the customizable features of PG survey methodology, results cannot necessarily be generalized across institutions, nor can survey data be used for comparison against patient outcomes. Administers of healthcare, healthcare providers, and patients must exercise caution when interpreting and applying these data.

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GENDER PREFERENCES OF PATIENTS WHEN SELECTING ORTHOPAEDIC PROVIDERS

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ABSTRACT

Background: Orthopaedic surgery is a male-dominated specialty associated with many stereotypes, despite the increased representation of females compared to 30 years ago. Numerous studies have examined medical student and resident perceptions regarding females in orthopaedic surgery to explain the disparity, but there are few studies that analyze whether patients have a gender preference in their orthopaedic surgeon. Our study sought to determine whether patients have a preference for the gender of their orthopaedic surgeon, and what traits in orthopaedic surgeons are important to their patients.

Methods: A total of 191 new patients seen in the emergency department and orthopaedic urgent care clinic were administered a 22-question survey regarding preferences in their orthopaedic provider. Patients were asked questions regarding preferred gender of their provider, as well as preferences in characteristics exhibited.

Results: The majority of patients did not have a preference for the gender of their orthopaedist (83.9%); however, 14.5% of patients preferred a female surgeon and 1.6% of patients preferred a male surgeon. Female patients had a preference for the same gender compared to male patients and preferred females (p=0.04). Of the patients that had a preference, 90% preferred a female provider. There were trends towards preference for gender that varied depending on subspecialty. There was a statistically insignificant trend towards preference for male providers in total joint replacements and spine surgery, and conversely a preference for female providers in hand surgery and pediatric orthopaedics. 48.6% of patients cited the single most important trait to be board certification, followed by years in practice (27.1%), then reputation or prestige (16.7%). Over one-third of patients found physical appearance, gender, racial background and age to be important traits.

Conclusion: The majority of patients did not have a preference for the gender of their orthopaedic surgeon. 16.1% of patients had a preference, and the majority of these patients preferred female surgeons. Preferences for a specific gender were seen that varied based on the subspecialty. Efforts at increasing gender diversity in orthopaedics should continue to be a major goal.

Level of Evidence: III

Keywords: gender, patient preferences, female orthopaedic surgeons, women in surgery

INTRODUCTION

Orthopaedic surgery is a male-dominated specialty, despite the increasing number of females entering medical school. In 2010, the total number of female medical students was 47.8%.[1] Despite this, the percentage of full time women faculty in orthopaedics in that same year was 15%.[1] Blakemore in 2003 found that 0.6% of all female residents chose orthopaedics as a specialty, a percentage that has not changed in the past two decades despite the increase in female representation that is seen in other fields of medicine and surgical subspecialties.[2] In 2003, orthopaedics had the lowest percentage of female representation compared to all other surgical specialties except thoracic surgery.[2] Recent data from the 2017-2018 National GME Census report that orthopaedics has the lowest number of women with only 15.4% female residents, compared to all other surgical subspecialties.[3] General surgery residencies are comprised of 40% women, while other traditionally male-dominated specialties such as otolaryngology, urology, thoracic surgery, and neurosurgery have higher female representation than seen in orthopaedics (35.9%, 25.6%, 24.3%, 17.8%, respectively).[3] Van Heest found that from 2004-2009 there was only a 1% increase in the number of female medical students going into orthopaedics.[4] Numerous studies have examined medical student and resident perceptions regarding females in orthopaedic surgery as an explanation for the decreased female representation.[2,5-7] Rohde et al. questioned female orthopaedic residents and members of

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Preferences for your Provider

Select which scenario you would prefer for each question (*please check only ONE of each pair):*

Would you rather have your orthopaedic provider:

10. ☐ Spend more time interacting with me in clinic and getting to know me as a person
OR
☐ Ask concise questions that are efficient and to the point

11. ☐ Have more technical competence and mechanical skill (works well with tools)
OR
☐ Be friendly, warm and focus on my needs

12. ☐ Spend more time encouraging me to make the right decisions for my health
OR
☐ Direct me to the decision he or she thinks is best

13. ☐ Possess superior physical strength
OR
☐ Sympathize with me and be able to relate to my problems

14. ☐ Understand and play sports and be able to relate to athletes
OR
☐ Ask me about my feelings and emotions

15. Please rank the following characteristics in the order of importance to you to have in your orthopaedic provider (1 (most important) to 9 (least important):

1 ☐ Age
2 ☐ Gender
3 ☐ Racial Background
4 ☐ Physical Appearance
5 ☐ Years in Practice
6 ☐ Amount of Published Research
7 ☐ Reputation or Prestige
8 ☐ Hospital he/she works at
9 ☐ Board Certification

16. Have you ever been treated by a female provider, and if so what kind? (*Check all that apply)*

1 ☐ Primary Care Doctor
2 ☐ Orthopaedist
3 ☐ Other

The following are hypothetical questions about your preferences. Please answer the following questions to the best of your ability.

17. If you were to undergo a knee or hip replacement, would you prefer a Male or Female Surgeon?

1 ☐ Female
2 ☐ Male
3 ☐ No Preference

18. If you were to undergo surgery on your hand, would you prefer a Male or Female Surgeon?

1 ☐ Female
2 ☐ Male
3 ☐ No Preference

19. If your child required an orthopaedic surgery, would you prefer a Male or Female Surgeon?

1 ☐ Female
2 ☐ Male
3 ☐ No Preference

20. If you were to undergo surgery on your neck or back, would you prefer a Male or Female Surgeon?

1 ☐ Female
2 ☐ Male
3 ☐ No Preference

21. If you were to undergo surgery on your feet, would you prefer a Male or Female Surgeon?

1 ☐ Female
2 ☐ Male
3 ☐ No Preference

22. If you were to undergo a surgery to help you get back to playing sports, would you prefer a Male or Female Surgeon?

1 ☐ Female
2 ☐ Male
3 ☐ No Preference

Figure 1. Survey questions regarding preferences for trait of provider.

the Ruth Jackson Orthopaedic Society who cited factors such as physical strength and perceived lack of work-life balance as deterrents for females entering the field.[8] Hill et al. further investigated barriers to females entering orthopaedics and cited acceptance by senior faculty as a barrier.[1] Despite these findings, there are few studies that analyze whether acceptance by patients play a role in the lack of female representation and whether patients have a gender preference in their orthopaedic surgeon.

Current literature demonstrates that female physicians add important elements to the doctor- patient relationships. Bertakis et al. found that female physicians displayed different approaches to medicine; for example, taking a greater interest in learning about patients' feelings and arriving to mutual decision-making.[9] These practice styles have been described as "female traits."[9] Additionally, female primary care physicians have been identified to have more empathy, spend more time with patients and display more sensitivity than their male counterparts.[10,11] Patients have been shown to often have a specific gender preference for their primary healthcare or obstetrics providers.[11-13] However, little research exists regarding patient gender preference in their orthopaedist or the traits displayed by a female orthopaedic surgeon. The purpose of this study is to determine whether patients have a preference for the gender of their orthopaedic surgeon, and what traits are important to patients in their orthopaedic surgeon. We hypothesized that patients would not have a preference of the gender of their orthopaedic surgeon, but would prefer a surgeon who displays traits commonly associated with female providers.

METHODS

At a single university healthcare system, 191 new pa-

Table 1. Demographics of Patient Population

	n (%)	Missing data points
Gender		2
Male	72 (38.7)	
Female	114 (61.3)	
Age	52.7 years (mean)	37
	18-90 years range	
Ethnicity		7
White or Caucasian	139 (75.5)	
Black or African American	28 (15.2)	
Hispanic or Latino	11 (6.0)	
Asian, Native Hawaiian or Pacific Islander	4 (2.2)	
American Indian or Native American or Alaska Native	1 (0.5)	
Other	3 (1.6)	
Education		5
8th grade or less	4 (2.2)	
Some high school, but did not graduate	14 (7.5)	
High school graduate or GED	26 (14)	
Some college or 2-year degree	34 (18.3)	
4-year college graduate	38 (20.4)	
More than 4-year college degree	70 (37.6)	
Emotional health		5
Excellent	77 (41.4)	
Very good	67 (36.0)	
Good	26 (14.0)	
Fair	14 (7.5)	
Poor	2 (1.1)	
Marital status		7
Single	43 (23.4)	
Partner/married	109 (59.2)	
Separated/divorced	21 (11.4)	
Widowed	11 (6.0)	
Other	0	

tients seen consecutively in the Emergency Department and orthopaedic urgent care for outpatient orthopaedic complaints over a course of six months were administered a 22-question survey regarding their preferences for follow-up with an orthopaedic provider. This was an institutional review board approved study.

New patients were defined as patients who presented to the Emergency Department and orthopaedic urgent care for care provided by a resident or a midlevel provider, as this represented a population of patients who were not a current patient of an orthopaedic surgeon. Patients were excluded if they were under the age of 18 years old, non-English speaking, or an established orthopaedic patient to minimize bias from an ongoing relationship with an orthopaedic provider. Only patients who were to be discharged from the Emergency Department that day were administered the survey. Questions were asked regarding the preferred gender of their provider, as well as preferences in traits exhibited by their provider (Figure 1). Surveys were administered by both a male and female trained administer.

Surveys were anonymously given and returned to the provider in a sealed envelope to minimize social desirability bias. There was a 100% response rate; however, of the 191 surveys completed, 49.2% were incomplete, in that a minimum single question or demographic inquiry was left unanswered. Incomplete questions were denoted as "no answer given" and included for analysis of remaining answered questions. Questions were asked regarding nine traits in an orthopaedic surgeon and respondents were asked to rank them in order of importance from "most important" to "least important." We designated traits with the number "1" assigned to them to receive a ranking of "most important;" "2" received a ranking of "second most important;" "3" received a ranking of "very important;" "4" received a ranking of "important;" "5" received a ranking of "somewhat important;" "6" received a ranking of "less important;" "7" was designated "not very important;" "8" was designated "not important;" and "9" received a ranking of "least important."

Overall, 191 patients responded to the survey. 61.3% were female and 38.7% were male. Mean age of the patient was 52.7 years [range 18-90 years of age, SD 16.97]. Ethnicities identified included 75.5% Caucasian, 15.2% Black or African American, 6% Hispanic or Latino, 2.2% Asian, Native Hawaiian or Pacific Islander, 0.5% American Indian, Native American or Alaska Native, and 1.6% identified as "Other." 37.6% of patients reported more than a 4-year college degree (Table 1). Emotional health was represented with 41.4% of patients reporting "excellent," 36% of patients reporting "very good" (Table 1). 59.2% of patients were married or had a partner (Table 1).

A two-way contingency table was used to explore the

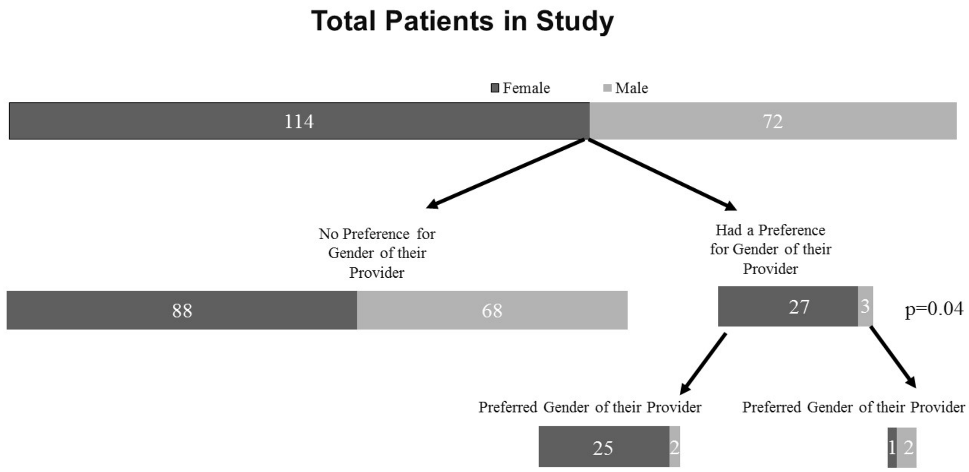

Figure 2. Patient preferences for gender of orthopaedic provider. Flowchart illustrating patient gender preferences of questionnaire respondents. A majority of respondents had no gender preference for their orthopaedic provider; however, when respondents preferred a provider of a specific gender, the respondents were more likely to be female and more likely to prefer a female provider.

association between participants' preference on various survey questions and their demographic backgrounds (gender, education level, ethnicity, marital status, and emotional status). The significance of association was determined by Pearson's chi-squared test and Fisher's t-test. For the analysis of association between participant's age and their preference, the linear regression model was used, where age was regressed on their preference on individual survey questions. The t-test was carried out to test whether such associations are significant. Data analyses were conducted by R (version 3.3.0). Significance was set at $p<0.05$.

RESULTS

When directly asked whether patients preferred a male or female surgeon, 83.9% of patients had no preference. However, 14.5% of patients preferred a female surgeon and 1.6% of patients preferred a male surgeon. Female patients had a preference for a similar gender compared to male patients ($p=0.04$). Of the patients that preferred a female surgeon, 89.2% of respondents were female (Figure 2). Additional analysis was performed to stratify for age, ethnicity, emotional health, and education, and there was not a statistically significant difference seen in regard to preference.

Overall, 33.5% of patients reported that they had been treated by a female orthopaedic provider in the past. There was no statistically significant difference in patients who had been treated by a female orthopaedic provider in regards to their preference for a specific gender of their orthopaedist. 88% of patients had no preference in the gender of their orthopaedist after being treated by a female provider. However, 10.2% of patients preferred a female orthopaedist after being treated by a female orthopaedist, compared to 1.7% of these patients who preferred a male orthopaedist ($p=0.32$).

Patients were asked questions regarding their preferred gender of their orthopaedist depending on the type of subspecialty care they required. Overall, females tended to have more of a preference for the gender of their subspecialty orthopaedist compared to males. The majority of patients reported that they did not have a preference for their provider, but there were trends towards a preference for male or female provider depending on the subspecialty (Table 2). For example, when asked about the preference for the gender of their joint replacement surgeon, of the patients that did have a preference, twice as many preferred a male surgeon (6.6% vs 2.8%, respectively; $p=0.24$). Of the patients that had a preference, 94% were female. Conversely, when asked about the preferred gender of their hand surgeon, the majority of patients had no preference. However, of the patients that did have a preference, patients preferred female surgeons at a rate almost three times that of male surgeons, although this difference approached statistical significance (6.2% versus 2.2%, respectively, $p=0.08$). 86.7% of patients who had a preference were female.

Questions were asked regarding preferences for specific traits in their orthopaedic surgeon. When asked whether patients prefer an orthopaedic surgeon who is more athletic versus an orthopaedic surgeon who expressed interest in patients' feeling and emotions, female patients valued emotional insight more than athleticism ($p=0.007$). Male patients valued the ability to relate to athletes ($p=0.007$). While male patients desired the ability to understand and relate to sports, physical strength of the orthopaedist was not found to be an important factor for either gender. Male and female patients preferred a physician who displays sympathy and is able to relate to patients' problems versus a physician who demonstrates

Table 2. Gender Preferences Based on Subspecialty

Subspecialty	% no preference	% with a preference		p-value
Joints	90.3	9.7	6.8 ♂	0.24
			2.8 ♀	
Spine	89.9	10.1	6.2 ♂	0.64
			3.9 ♀	
Hand	91.6	8.4	2.2 ♂	0.08
			6.2 ♀	
Pediatrics	90.5	9.0	2.8 ♂	0.15
			6.2 ♀	
Foot and Ankle	91.1	9.0	4.5 ♂	1.00
			4.5 ♀	
Sports	92.7	7.26	4.5 ♂	0.79
			2.8 ♀	

physical strength, although this preference was not statistically significant (p=0.24). There was no significant difference seen between males and females in their desire for an orthopaedist who directs patients to the decision that he or she thinks is best versus an orthopaedist who supports patient-centered decision making (p=0.73).

Questions were asked regarding the importance of specific traits desired in an orthopaedic surgeon. When asked the single most important trait, 48.6% of patients cited board certification, followed by years in practice (27.1%), followed by reputation or prestige (16.7%). Over 90 percent of patients reported that the hospital the provider worked at, board certification, reputation of provider, as well as amount of published research were all considered "important" traits (Figure 3). 44.4% of patients ranked physical appearance to be important. 34.3% of patients found gender to be important, while racial background and age were found by 33.3% and 30.9% of patients, respectively, to be important traits (Figure 3).

DISCUSSION

There is compelling evidence for the need to increase diversity in medicine, as communication, patient satisfaction and access to care for the underserved can be improved by gender and ethnic diversity.[14-16] Bertakis found that patients of female primary care physicians are more satisfied than those treated by a male physician, even after accounting for patient characteristics and physician practice style.[9] Furthermore, gender concordance has been shown to have an effect on communication style. Relationships between female patients and female providers have been shown to have a longer encounter length as well as a perceived more equal contribution to conversation.[10,11] Encounters with male-male dyads tend to be the shortest, with more domination of dialogue by the male physician.[10,11] Additionally, female concordant visits have been shown to have more positive statements and emotional exchange.[10,11] Female physicians have been suggested to participate in more patient-centered communication and have demonstrated to spend more time counseling and teaching preventive behaviors when compared to their male counterparts.[9-11] Thus, female orthopaedic surgeons may have different attributes to contribute to each patient encounter, and the lack of female representation in orthopaedics is a cause for concern.

Our results show that the majority of patients do not have preferences for the gender of their orthopaedic provider, as 83.6% of patients when asked directly reported that they had "no preference." This data suggests that patient preference is unlikely to contribute to the gender disparity in orthopaedics. However, when patients did cite a preference, females were requested more frequently than males, and more commonly by female patients (p=0.04). These results are in accordance with the literature that demonstrates females tend to have more of a preference for the gender of their physician compared to male patients.[17,18] Huis In't Veld et al. studied female patients seeking a plastic surgeon and found that the majority did not have a preference for the gender of their surgeon.[19] However, similar to our study, of the patients that did have a preference, females were preferred over males.[19] There is evidence that suggests that patients are more comfortable with providers of their same gender. Plunkett et al. found that in obstetrics and gynecology, female physicians were preferred 52.8% of the time compared to 9.6% who preferred male physicians.[20] This finding is echoed across fields where intimate interactions are routine.[17] When asked reasons for desiring a female physician, patients who had preferences found it easier to talk with female physicians versus male. Likewise, patients who preferred male physicians found it more comfortable to speak with male physicians.[17]

Interestingly, despite the overall lack of preference for gender of an orthopaedic surgeon, differences in gender preferences according to subspecialty were observed. For total joint replacements and spine surgery, male orthopaedists were preferred over females at double the rate. This preference was displayed by females; however, it was not statistically significant. Abhighari et al. investigated patient gender preferences and found a trend towards preference of male orthopaedists compared to females, although this was found to be statistically insignificant and was not evaluated by subspecialty.[21] Questions arise whether this preference is from the current lack of female representation in these specialties, or from perceived stereotypes that may exist regarding need for physical

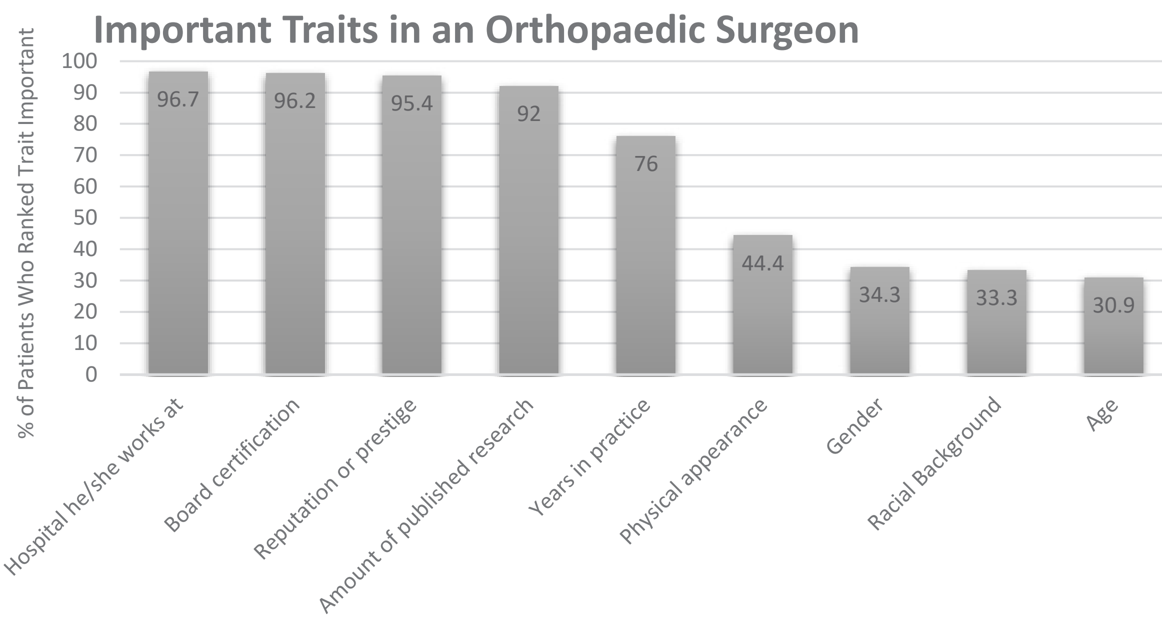

Figure 3. Important Traits in an Orthopaedic Surgeon. This chart illustrates the percentage of patients that rated the listed traits as "important" ("most important," "second most important," "very important," "important," or "somewhat important"). The majority of respondents rated modifiable traits such as hospital affiliation, board certification, reputation, and published research as "important." While non-modifiable traits like gender, racial background, and age were rated "important" less often, they were still rated "important" by about one-third of respondents.

strength and stature. Cannada recently reviewed the number of female fellowship applicants for hip, knee and tumor fellowships and found only 6% of these fellowship applicants are female. Likewise, only 3% of spine applicants are female.[22] This lack of gender representation begs the question of whether there is female disinterest in the particular specialty or other factors such as lack of female mentors in these fields that may prevent increasing female representation. Conversely, of patients that had a gender preference, female physicians were preferred in hand surgery and pediatric orthopaedic surgery, although these trends were not statistically significant (p=0.08, p=0.15, respectively). Hand surgery and pediatric orthopaedics have a larger female representation, which may explain the preference seen. Cannada found that the highest number of female fellowship applicants was seen in pediatrics, at 25 percent.[22] Bae cited the number of female hand surgeon trainees at 20 percent, although this is comprised of plastic and general surgery applicants in addition to orthopaedic surgery.[14] Thus, the higher female representation in pediatrics and hand surgery may suggest increased level of exposure and comfort experienced by patients, as well as female mentors available for trainees.

Our study additionally sought to answer questions of whether patients have preferences for certain traits other than gender. There was no significant difference seen between males and females in their desire for an orthopaedist who employs more patient-centered decision making strategies compared to an orthopaedist who favors surgeon-centered decision making (p=1.00). We aimed to determine whether stereotypes that may exist about orthopaedics, including physical strength and athleticism, were important to patients. Traits more readily desired by both male and female patients included the ability of the orthopaedist to sympathize and provide empathy to the patients' problems as opposed to possessing physical strength, although this difference was not significant (p=0.24). However, there was a statistically significant difference seen in female patients' preference for an orthopaedic surgeon who inquires about patient feelings and emotions versus athleticism and ability to relate to athletes (p=0.007). This suggests that there are preferences for various traits exhibited by the orthopaedist that may vary according to patient gender. Additionally, questions were asked regarding traits considered to be of importance to patients (Figure 3). Traits related to experience such as years in practice, reputation or prestige, hospital affiliation, and board certification were widely considered to be important factors. However, personal, non-modifiable factors unrelated to competency or experience such as racial background, physical appearance, gender, and age were listed as an important trait in over a third of patients. This preference argues for the ongoing need for recruitment of orthopaedic trainees of not only diverse gender, but racial background and age, as well. Orthopaedics has been found to lag behind in racial diversity from medical school to orthopaedic residency, when compared to general surgery and other nonsurgical specialties.[23] Day et al. found that Asians, Hispanic and

Latinos, and African-Americans submit fewer applications for orthopaedic surgery residency compared to Whites, which is troubling due to the trajectory of fewer minorities entering orthopaedics.[23] This lack of representation of minorities may impact patient preference from lack of exposure to a diverse group of orthopaedists as well as desire of minority groups for orthopaedists of similar ethnic background and physical appearance. Thus, diversity in gender, age and racial background in orthopaedics can help to address these needs of different patient populations. Improving cultural competency in orthopaedists can be a starting point to achieve this goal. Further studies on racial diversity in orthopaedics may be helpful to further delineate successful strategies for recruitment of orthopaedists of diverse genders as well as racial backgrounds.

Limitations of our study include our sample population, as it was comprised largely of female, Caucasian patients with a greater than 4-year-college education level who sought care in an urgent care or Emergency Department setting. There may be differences in preferences seen in patients of different demographic characteristics. This study demographic is similar to an academic outpatient orthopaedic clinic.[24] However, we believe that there would still be preferences seen in our study that are reflective of the gender and ethnic status of the patient, as there is a positive association between physician-patient gender and ethnic/racial concordance.[10,16,17] Additionally, our surveys were conducted regardless of patient diagnosis and actual need for surgery. There may be differences in patient preferences in patients who presented with a surgical vs nonsurgical problem that we were unable to detect. However, we believe that patients who sought care in an urgent care or Emergency Department setting were more likely to perceive a need for surgery or acute care than patients who presented for elective outpatient evaluation. Additionally, a formal power analysis was not performed, which could suggest that our nonsignificant findings may have been underpowered. Lastly, our surveys were anonymous, yet 49% of our surveys were incomplete, which may be due to patients' fear of having their answers revealed. We believe that this may suggest that the preferences seen in our study are an underestimation, as patients may have displayed a Hawthorne effect and chose a more socially acceptable answer that may not be in accordance with their true preferences.

CONCLUSIONS

Orthopaedic surgery continues to lag behind other surgical subspecialties in female representation. Our results demonstrate that the majority of patients do not have a preference for the gender of their provider; thus, patient acceptance of female orthopaedic surgeons should not be a factor in this disparity. Bucknall et al. attempted to discover medical student attitudes towards orthopaedics and found that only 24% of female medical students would consider orthopaedic surgery careers.[6] Reasons cited included disinterest and male domination.[6] Furthermore, medical students who go into orthopaedics tend to report their medical school experiences as the primary influences of their career decision.[25] Thus, exposure to orthopaedics early in medical school, with female resident and faculty role models, may help to correct this gender disparity. Lastly, our study shows that there may still be an element of bias in patient perceptions towards orthopaedic surgeons seen in certain subspecialties. Thus, efforts at increasing the number of female orthopaedists should be a major goal that starts at the recruitment level of qualified female medical students, as well as the fostering of female role models.

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MIDLEVEL PROVIDERS IN ORTHOPAEDIC SURGERY: THE PATIENT'S PERSPECTIVE

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ABSTRACT

Background: Midlevel providers (i.e. physician assistants [PAs] and nurse practitioners [NPs]) are being integrated into systems of care due to the exponentially increasing demand for orthopaedic care. There is a lack of studies which investigate orthopaedic patients' perspectives regarding midlevel providers.

Methods: An anonymous questionnaire was administered to 538 first-time patients of four orthopaedic surgeons before their new patient visit. Content included patient perspectives regarding: optimal scope of practice, midlevel provider importance in physician selection, and reimbursement equity with physicians.

Results: Of 538 consecutive patients, 415 (77%) responded. 57% were female with an average age of 63.9 ± 11.4 years. Most patients (68%) considered the training background of the surgeon's midlevel provider when initially choosing an orthopaedic surgeon. 34% of all patients perceived PAs to be more highly trained than NPs while 17% perceived the opposite. Patients had specific preferences regarding which services should be surgeon-provided: follow-up for abnormal tests (82%), initial postoperative appointment (81%), new patient visits (81%), and determining the need for advanced diagnostic studies (e.g. MRI) (76%). Patients had specific preferences regarding which services could be midlevel-provided: preoperative teaching (73%), minor in-office procedures (65%), long term postoperative appointments (61%), and prescriptions (61%). Patients lacked a consensus on reimbursement equity for midlevel providers and orthopaedic surgeons, despite most patients (78%) reporting the surgeon provides a higher-quality consultation.

Conclusions: As health care becomes increasingly consumer-centric and value-driven, a data-based utilization of midlevel staff will allow orthopaedic physicians to optimize efficiency and patient satisfaction. Surgeons may consider our results in division of clinical duties among midlevel staff since patients had specific preferences regarding which services should be physician-provided or midlevel-provided. Orthopaedic surgeons may also consider including the midlevel provider in marketing efforts, as most patients considered the midlevel provider's training background when initially choosing a surgeon and perceived PAs to be more highly trained than NPs. Patients lacked a consensus towards reimbursement equity for orthopaedic surgeons and midlevels, despite reporting that the surgeon provides a higher quality consultation. These findings are important as the midlevel workforce grows in response to the rising demand for orthopaedic care.

Level of Evidence: IV

Keywords: physician assistant, nurse practitioner, orthopaedic surgery, midlevel providers

INTRODUCTION

As health care delivery paradigms evolve, midlevel providers (i.e. physician assistants [PAs] and nurse practitioners [NPs]) have become an important consideration in patient care and medical workforce planning. PAs and NPs are being increasingly integrated into orthopaedic systems of care due to the exponentially increasing service demand by the aging population.[1] Hence, the midlevel workforce continues to increase in size. From 2003 to 2014, the number of graduating NP students in the United States increased from 6,611 to nearly 18,500 annually.[2] The physician assistant workforce also experienced similar increases in size during this period.[2]

As the midlevel workforce continues to grow, so does the debate surrounding their scope of practice. This controversy centers on whether midlevel providers have adequate experience and training to administer high-quality patient care with minimal or no supervision by a physician.[3] Orthopaedic NPs and PAs are also important as health care payment and delivery systems become increasingly consumer-focused and value-driven. In this

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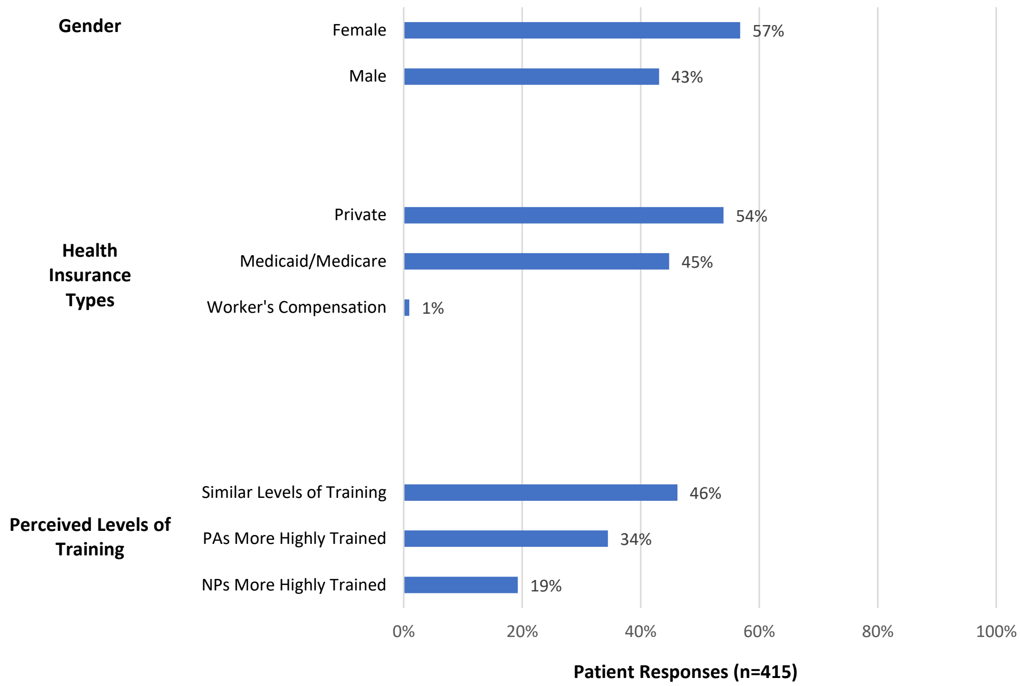

Figure 1. Respondent demographics and perceptions of training differences between nurse practitioners (NPs) and physician assistants (PAs).

context, orthopaedic surgeons must consider midlevel providers' ideal role in optimizing patient satisfaction and clinical outcomes while maintaining efficiency and quality. This debate is ongoing amongst numerous medical specialties in the United States of America.[4] Regardless of outcome, it will have significant implications for health care payors, providers, and patients.

Although previous studies have examined physician and nurse perspectives on midlevel providers,[5-7] there is a lack of studies on patient perspectives, especially regarding orthopaedic surgery. The objectives of the present study are to identify orthopaedic patient perspectives regarding midlevel provider: 1) optimal scope of clinical practice, 2) impact on care quality, and 3) importance in patients' initial selection of their orthopaedic surgeon

MATERIALS AND METHODS

Following Institutional Board Review approval (ORA# 16121907), an anonymous survey was administered to 538 consecutive patients prior to their first clinic appointment with four orthopaedic surgeons. In order to minimize patient bias from evaluation or treatment, all patients who agreed to participation completed the questionnaire prior to their initial clinic visit.

The first section of the survey regarded demographic information (age, gender, health insurance type) and patient perceptions of any differences in training level between NPs and PAs. The second section focused on the optimal scope of clinical practice for orthopaedic midlevel providers. Respondents were presented a clinical service (e.g. "initial postoperative appointment", "minor in-office procedures", "long-term postoperative appointments", etc) with answer options of "Should be provided by orthopaedic physician only" or "Can be provided by either orthopaedic midlevel provider or physician". The third section examined patient perspectives of midlevel provider: supervision during procedures, reimbursement equity with physicians for the same services, and importance when initially selecting their physician. The final section assessed patient perspectives towards how orthopaedic care quality may be affected by the growing midlevel workforce. Survey contents were generated based on the authors' experiences and previous similar studies.[5,7] Patient responses were calculated for each item.

RESULTS

Of 538 consecutive patients given the questionnaire, 415 (77%) completed the survey. For participating patients, response rates for each item ranged from 98% to 100%.

Figure 1 contains demographic data of respondents. There was a majority of female participants (57% female versus 43% male). Most patients had private health insurance (54%) and a mean age of 63.9 ± 11.4 years (mean ± standard deviation). Over half of the patients (53%) perceived a difference in PA and NP training levels, with 34% of total patients perceiving PAs as more highly trained and 19% of total patients perceiving NPs to be

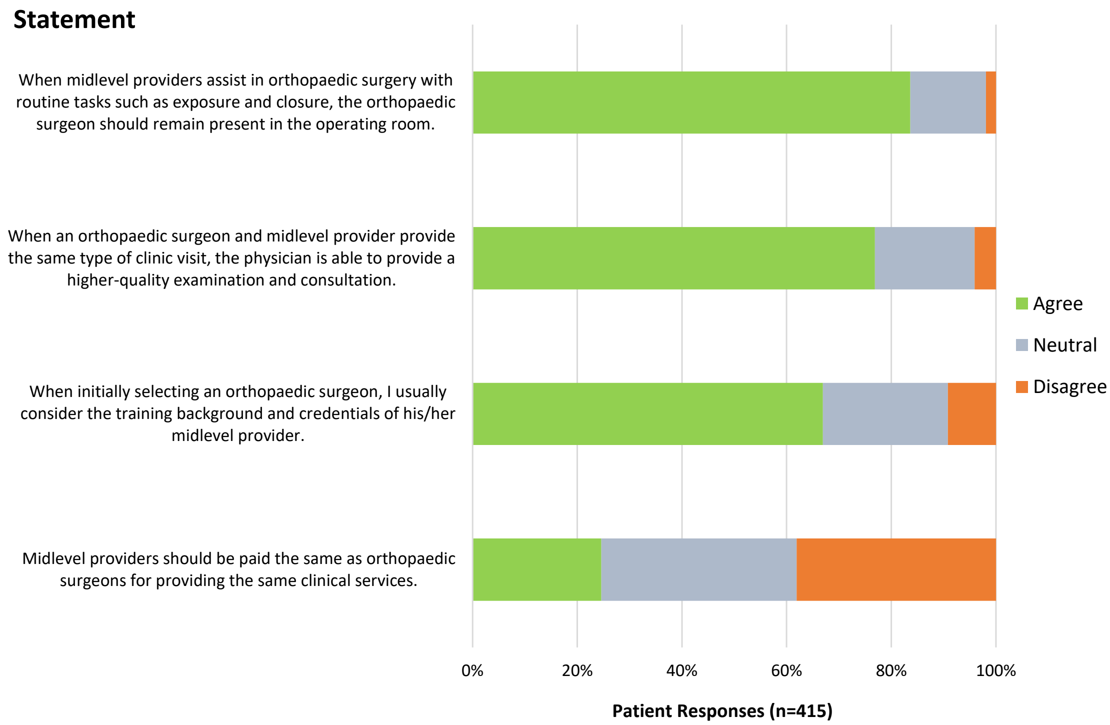

Figure 2. Orthopaedic patient perspectives regarding midlevel providers. Participants were surveyed regarding their level of agreement or disagreement with each statement, with the choices being "strongly agree", "somewhat agree", "neutral", "somewhat disagree", or "strongly disagree". Responses were then combined under the "Agree", "Neutral", or "Disagree" categories, respectively.

more highly trained.

Figure 2 lists patients' general views towards midlevel providers. Most patients responded that the surgeon's midlevel provider is an important consideration when: 1) initially choosing an orthopaedic surgeon (67%), and 2) referring their orthopaedic surgeon to family or friends (71%). 77% of respondents perceived that the orthopaedic surgeon offers a higher-quality consultation and exam than a midlevel for the same clinic visit type. Most patients (84%) reported that the orthopaedic surgeon should remain in the operating room while the midlevel provider assists with operative exposure and closure. Patient responses varied regarding whether orthopaedic surgeons and midlevel providers should receive equal reimbursement for providing the same type of clinical service.

Figure 3 refers to midlevel providers' scope of practice, with specific consideration on whether patients prefer certain clinical services be provided by the orthopaedic physician only or either the orthopaedic physician or midlevel provider. Patients preferred that some services be provided by the orthopaedic physician only, including: follow-up regarding abnormal test results or imaging (82% of patients), the first follow-up appointment after surgery (81%), and the initial clinic appointment (new patient visit) (81%). Patients also reported that certain services could be provided by either the orthopaedic physician or midlevel provider, such as: preoperative teaching (73%), minor in-office procedures (65%), long term postoperative appointments (61%), and prescriptions (61%).

Figure 4 pertains to the potential impact of midlevel providers on orthopaedic care quality. Most patients reported that utilization of midlevel providers can improve timeliness of care (66% of patients), efficiency and cost-effectiveness (61%), and health care costs (60%). Patient perceptions varied regarding midlevel providers' impact on patient outcomes and effectiveness.

DISCUSSION

An understanding of orthopaedic patient perspectives towards midlevel providers is growing in importance. Our findings are relevant as the midlevel workforce grows in response to the rising demand for orthopaedic care. First, midlevel provider training backgrounds and credentials are important considerations to patients when initially selecting an orthopaedic surgeon, as is their experience with the midlevel when recommending their orthopaedic surgeon to family and friends (Figure 2). However, responses varied regarding perceived training levels and expertise of NPs versus PAs (Figure 1). Second, patients had distinct preferences regarding clinical services that should be physician-provided and those that could be provided by either the orthopaedic physician or midlevel

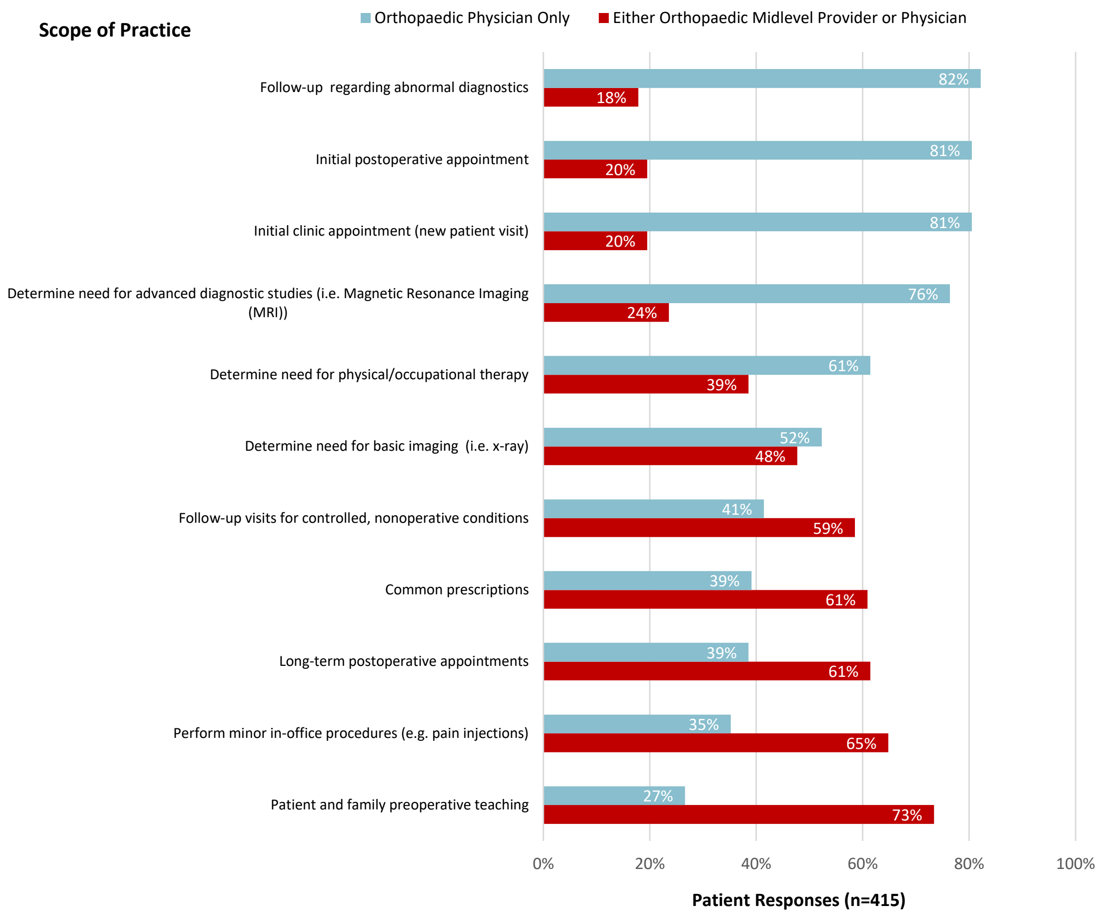

Figure 3: Midlevel providers' scope of practice in orthopaedic surgery. Survey participants were asked "In an orthopaedic clinic, who should provide...?" with each respective clinical service subsequently listed. Response options were "Should be provided by orthopaedic physician only" or "Can be provided by either orthopaedic midlevel provider or orthopaedic physician."

provider (Figure 3). Third, patients reported that the orthopaedic physician could provide a higher quality consultation and exam than the midlevel provider. However, there was no consensus regarding reimbursement equity for physicians and midlevel providers performing the same services (Figure 2). These results are useful as orthopaedic surgeons seek to balance quality, efficiency, and patient satisfaction in the setting of an increasingly consumer-focused and value-driven healthcare system.

Previous studies have investigated factors considered by patients when selecting a new orthopaedic physician.[8-10] Although all studies found the physician's credentials and training background to be among patients' most important criteria, none examined the training background of the midlevel provider as a selection criterion. Our patients considered the midlevel provider when initially selecting their orthopaedic surgeon (Figure 2), but perspectives were varied regarding perceived training differences between PAs and NPs (Figure 1). Over half of patients (54%) perceived one to be more highly trained, with 34% of all patients perceiving PAs to be more highly trained and 19% of all patients perceiving NPs to be more highly trained. The training of PAs and NPs differs in duration and extent, as does their process for credentialing and licensure. Both usually require a prerequisite bachelor's degree. PA-C (physician assistant-certified) licensure by the National Commission on Certification of Physician Assistants (NCCPA) requires completion of an accredited PA-C master's program, which are usually 3 years in duration. CNP (certified nurse practitioner) licensure by the American Academy of Nurse Practitioners (AANP) typically requires clinical experience as a registered nurse (RN) and subsequent completion of a doctoral or master's nursing program. Several program types exist (e.g. Adult Nurse Practitioner [ANP-BC], Master's of Science in Nursing [MSN], etc), and all are considered an Advanced Practice Nurse (APRN). These programs are 2 years or more in duration. Maintenance of PA-C certification includes a mandatory recertification examination every 10 years, while maintenance of NP certification occurs in 5-year cycles but does not necessarily require a recertification examination. Guidelines regarding midlevel providers' scope of clinical practice and physician supervision are established by each state's medical board.[11, 12]

Patients were notably neutral (37%) regarding reimbursement equity for orthopaedic physician and midlevel provision of the same clinical services (Figure 2). Interestingly, the percentage of patients (38%) opposing reimbursement equity (presumably favoring higher reimbursement for orthopaedic physicians than midlevel providers for a given clinical service) is inconsistent with the percentage (77%) who reported that the orthopaedic physician provides a higher quality consultation and exam (Figure 2). Our findings also suggest patients do not believe that increasing the orthopaedic midlevel workforce will have an effect on patient safety or outcomes, but may improve cost-efficiency and timeliness of care (Figure 4). Previous studies on primary care patients demonstrated lower diagnosis and management expenditures for NP patients compared to patients assigned to a primary care physician (PCP), with similar satisfaction scores.[13, 14] Studies have also considered whether increasing the midlevel workforce size while offering equal reimbursement as physicians would negate the current savings from their current disproportionately lower reimbursement.[7] Additional studies regarding the economics and division of the workforce between physicians and midlevel providers are necessary as society seeks potential cost savings by expanding midlevel providers' scope of clinical practice.

Patient preferences were notable regarding which services should be provided by an orthopaedic physician only and which could be provided by either the midlevel provider or orthopaedic physician (Figure 3). Patients strongly preferred physician-only provision of: follow-up regarding abnormal test results or images (82%), the first postoperative appointment (81%), the initial clinic visit (81%), and ordering advanced diagnostic studies (e.g. MRI) (76%). Conversely, patients were most amenable to midlevel providers offering: preoperative teaching (73%), minor in-office procedures (e.g. pain injections) (65%), long-term postoperative appointments (months/years) (61%), and prescriptions (61%). Most patients (84%) responded that the orthopaedic surgeon should remain in the operating room while the midlevel provider assists with operative exposure and closure (Figure 2). Additional studies are needed regarding patient preferences on disclosure regarding each team member's role in the operating room, especially which operative steps are performed without the surgeon present. We are unaware of other studies regarding orthopaedic patient preferences towards clinical service provision by the orthopaedic surgeon or midlevel provider. A study of primary care patients found appointment availability to be most important in patients' willingness to receive care from a midlevel provider.[15] Another 2012 review of midlevel provider independent procedure billing of Medicare found that NPs and PAs independently billed for over 4 million procedures, with radiographs and joint injections being among the most common.[16] Although our results suggest patients are amenable to receiving these clinical services from a midlevel provider, other authors have expressed concerns regarding these independent billings for diagnostic radiographs in the context of the inherent liability and difficulty in their interpretation.[16] Patients also strongly preferred to see the surgeon at the first postoperative visit (81%), which is often provided by a midlevel provider since it is within the "global period" for billing purposes. Further studies regarding patient perspectives towards the global billing period and provision of clinical services may also be useful.

Midlevel providers' scope of clinical practice is also interesting in the context of orthopaedic care, as medical groups and hospitals often advertise orthopaedic clinics which may be primarily staffed by orthopaedic "providers" with variable training backgrounds (orthopaedic surgeon, family practice physician, doctorate of nursing practice, orthopaedic nurse practitioner, etc). While our patients sought care from orthopaedic surgeons, the general public may be unaware of differences in provider qualifications. One 2008 study from the American Medical Association found 40% percent of the general public incorrectly believed a doctor of nursing was a medical doctor.[17] Legislation which mandates all provider types clarify their qualifications and degree may be beneficial to orthopaedic patients in considering their provider's recommendations. Regardless, our results highlight those services which patients are most amenable to receiving from the midlevel, thereby allowing the orthopaedic surgeon to focus on clinical services that patients prefer to receive from the physician only.

Our study had potential limitations. First, survey patients were from one private practice in an urban setting. Therefore, the study findings may not represent all orthopaedic practice types and geographic regions. Second, although study participants were patients of four orthopaedic surgeons, all responses were obtained prior to the initial clinical visit in order to minimize bias from assessment, treatment, or the clinic visit. Third, obtaining additional demographic data with which to stratify our results may have allowed determination of patient characteristics which drive preferences regarding physician and midlevel involvement in their orthopaedic care. However, this is outside the scope of our investigation, which was to assess patients' perspectives of midlevel providers in their orthopaedic care. Future studies could acquire data from academic and private orthopaedic practices in various locations for greater generalizability.

CONCLUSION

As health care becomes consumer-centric and value-driven, understanding patient perspectives on midlevel providers will allow orthopaedic surgeons to optimize quality, patient satisfaction, and efficiency. Our study suggests that the midlevel provider influences patients' selection of an orthopaedic surgeon and referrals of family and friends. Patients preferred that certain clinical services be provided by the orthopaedic surgeon only, but were amenable to others being provided by either the orthopaedic physician or midlevel provider. Patients lacked a consensus towards reimbursement equity for physicians and midlevels providing the same clinical service. These findings are important as the midlevel workforce grows in response to the rising demand for orthopaedic care.

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