For E-Publication This Fall
Editors Emeriti
2020 Editors’ Note
Dedication — Honoring Dr. John P. Albright
2020-2021 Schedule of Lectureships and Conferences
Department of Orthopedics & Rehabilitation Staff
Department of Orthopedics Group Photo
2020 Graduating Orthopedic Residents
2020 Graduating Fellows
2020 New Orthopedic Faculty

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Ann Van Heest, MD, Anna E. Nakamura
Radiation Exposure and Case Characteristics in National Sample of Female Orthopaedic Trauma and Arthroplasty Surgeons
Cara H. Lai, BS, Andrea Finlay, PhD, Lisa K. Cannada, MD, Antonia F. Chen, MD, MBA, Loretta B. Chou, MD
Women in Orthopedics and their Fellowship Choice: What Influenced their Specialty Choice?
Kathryn M. Jurenovich, DO, Lisa K. Cannada, MD, FAOS, FAOA

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Louis C. Grandizio, DO, Lisa Follett, BS, Lauren Skudalski, BA, C. Liam Dwyer, MD, Joel C. Klena, MD

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Alexander CM. Chong, MS, MSME, Lisa N. MacFadden, PhD, Bruce E. Piatt, MD, Benjamin C. Noonan, MD
Utilization of Short-Term Outcomes of Computer Navigation in Unicompartmental Knee Arthroplasty
Christopher N. Carender, MD, David E. DeMik, MD, Pharm D, Nicholas A. Bedard, MD, Alan G. Shamrock, MD, Qiang An, MPH, Timothy S. Brown, MD
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Susan T. Mahan, MD, MPH, Leslie A. Kalish, ScD, Apurva S. Shah, MD, MBA, Lanna Feldman, MS, Donald S. Bae, MD

The Iowa Orthopedic Journal
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Brendan A. Williams, MD, Noel E. Palumbo, MD, Sarah A. Phillips, MPH, Laurel C. Blakemore, MD

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Modified Outpatient Physical Therapy Improvement in Movement Assessment Log (mOPTIMAL): A Responsive and Reliable Tool for Patients with Non-Operative Shoulder Pain
Michael A. Shaffer, PT, OCS, ATC, Lisabeth L. Kestel, DPT, MBA, SCS, ATC, Brian R. Wolf, MD, MS,
Richard K. Shields, PT, PhD, FAPTA

SPINE
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Jocelyn Compton, MD, John Yanik, MD, Nathan Hendrickson, MD, Naina Bagrodia, MD, Peter Nau, MD, Andrew J. Pugley, MD

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Matthew Haleanski, MD, Pamela J. Long, MD

Haemophilus Parainfluenzae Septic Arthritis Following Primary All-Inside Meniscus Repair: A Case Report and Review of the Literature
Jacqueline E. Baron, MD, Alan G. Shamrock, MD, Alexander Volkman, MD, Robert W. Westermann, MD

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James R. Bailey, MD, Trent Christensen, MD, Benjamin L. Oshlag, MD, Kevin M. Dale MD, Christopher Kim, MD,
Barrett A. Little, MD, Kelby Brown, Kyle Beatty, Robert Zarzour MA, LAT, ATC, Jeffrey R. Bytomski, DO,
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Anterior Cruciate Ligament Reconstruction: A Comparative Clinical Study Between Adjustable and Fixed Length Suspension Devices
Bastian Uribe-Echevarria, MD, Justin A. Magnuson, BA, Annunziato Amendola, MD, Matthew J. Bollier, MD
Brian R. Wolf, MD, MS, Carolyn M. Hettrich, MD, MPH

Rapidly Progressive Arthritis in Femoroacetabular Impingement: Patient Characteristics and Risk Factors for Total Hip Arthroplasty by the Age of Forty
Kevin A. Schafer, MD, John C. Clohisy, MD, Jeffrey J. Nepple, MD

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Jacqueline E. Baron, MD, Robert W. Westermann, MD, Nicholas A. Bedard, MD, Michael C. Willey, MD,
T.S. Lynch, MD, Kyle R. Duchman, MD

Return to Collegiate Athletics After Distal Femoral Osteotomy: A Report of Three Cases and Review of the Literature
Jacqueline E. Baron, MD, Molly A. Day, MD, ATC, David E. DEmik, MD, PharmD,
Robert W. Westermann, MD, Brian R. Wolf, MD, MS

TRAUMA
Improving Efficiency of Hip Fracture Care by Simplifying Wound Management and Eliminating Unnecessary Clinical Follow-Up
Liana Meffert, John Davison, MPH, Natalie Glass, PhD, Michael Willey, MD

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Wyatt Vander Voort, MD, John Davison, MPH, Nathan Hendrickson, MD, Joseph Buckwalter V, MD, PhD,
Brian Guetschow, MD, Natalie Glass, PhD, MHCDs, Michael Willey, MD

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Gerard Chang, MD, Tyler Henry, BS, Keenan Sobol, BS, James Kriegl, MD

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Ronit Shah, MD, Daniel Miller, MD, Mahmoud A. Mahmoud, MD, Alexandre Arkader MD

SYSTEMS AND PRACTICE
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Dawn M. LaPorte, MD, Aviram M. Giladi, MD, MS

Obtaining Imaging Cost and Quality Information in Femoroacetabular Impingement: The Patient Experience
Chris A. Anthony, MD, Edward O. Rojas, BS, Natalie Glass, PhD, MHCDs, Robert W. Westermann, MD,
John C. Clohisy, MD, Stuart L. Weinstein, MD

Masks for the Reduction of Methyl Methacrylate Vapor Inhalation
Jocelyn Compton, MSc, MD, Jayson Clinger, MS, Ericka Lawler, MD, Jesse Otero, PhD, MD, Patrick O'Shaughnessy, PhD

Volume 40 Issue 1
INSTRUCTIONS FOR AUTHORS, 2020 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

2020 • Volume 40 • Issue 2

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

HAND
Thumb Reconstruction Utilizing Radial Forearm Pedicle Flap Following Childhood Burn Injury
Mitchell Hallman, BA; Elizabeth Duckworth, BA; Daniel Gittings, MD; Christine McAndrew, PA-C; David Bozentka, MD, L. Scott Levin, MD, FACS

PEDIATRICS
Ponseti Method After Walking Age – A Multi-Centric Study of 429 Feet: Results, Possible Treatment Modifications and Outcomes According to Age Groups
Davi de Podesta Haje, MD, MSc, PhD; Daniel Augusto Maranhão, MD, MSc, PhD; Gabriel Ferraz Ferreira, MD, MSc; Adolfo Cuauhtemoc Rocha Geded, MD; Alaric Aroojis, MD, MBBS, MS, DNB; Ana Claudia Queiroz, MD; Anisuddin Bhatti, MD, MSc, PhD; Antonio Luiz Gonçalves Brandão, MD, MSc; Edwin Giovanny Valencia Lucero, MD; Erika Ilana Arana Hernández, MD; Guillermo Oscar Hernández Tierro, MD, MSc, PhD; Juan Carlos Ocampo, MD; Jung Ho KIM, MD, MSc, Leopoldina Milanez da Silva Lette, MD, MSc, PhD

Buckling Down on Torus Fractures - Assessing Treatment Preferences and Perceived Management Barriers at a Single Institution
Brendan A. Williams, MD; Sarah A. Phillips, MPH; Robert C. Matthias, MD; Laurel C. Blakemore, MD

SHOULDER
The Cost-Effectiveness of Reverse Total Shoulder Arthroplasty vs. Open Reduction Internal Fixation for Proximal Humerus Fractures in the Elderly
Daniel C. Austin, MD, MS; Michael T. Torchia, MD, MS; Anna N. A. Tosteson, ScD; I. Leah Gitajn, MD; Stephanie J. Tapp, PhD; John-Erik Bell, MD, MS

SPORTS
Sex Difference in Contusion of the Medial Femoral Condyle Rim Associated with MRI Occult Meniscal Tears of the Knee: Assessment of MRI Occult Meniscal Tears in the ACL Deficient Knee
D. Lee Bennett, MA, MBA, MD, FACR

Risk Factors for Opioid Use after Patellofemoral Stabilization Surgery: A Population-Based Study of 1,316 Cases
Jacqueline E. Baron, BA; Zain M. Khazi, BS; Kyle R. Duchman, MD; Robert W. Westermann, MD

Combined Surgical Approach to Young Adults with Hip Dysplasia and Concomitant Intra-Articular Pathology using Intra-Abdominal Monitoring
Robert J. Wetzel, MD; Noah M. Joseph, MD, MS; Derrick M. Knapik, MD; Jonathan Copp, MD; Michael J. Salata, MD
IOWA ORTHOPEDIC JOURNAL
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We are pleased to present the 40th edition of the Iowa Orthopedic Journal (IOJ). As in previous years, we received submissions from institutions across the United States as well as internationally which reflects the breadth of our readership across the globe. Due to the continued increase in quality submissions to the IOJ, we will publish an electronic issue in the fall as was done in the 39th edition. With the continued growth of the journal, we anticipate the E journal becoming an exciting annual addition to the IOJ.

We would like to thank and recognize our graduating senior residents: Drs. Jocelyn Compton, Molly Day, Nathan Hendrickson, Jessell Owens, Christopher West, and Brandon Wilkinson. They have provided us with incredible leadership and teaching as well as camaraderie along the way. They will be missed here in Iowa City next year as they move on to fellowship. We wish them all the best as they complete their training and start their careers.

We would also like to thank several key individuals without whom the publication of the IOJ would not be possible. We would like to thank Phyllis Wood and Kelly Kauffman who were essential in the organization and preparation of this year’s IOJ. We thank John Yanik for obtaining corporate sponsors to make the publication of the IOJ financially possible. We also thank those sponsors for their generous support of the IOJ. We thank Dr. Jose Morcuende for his continued guidance as faculty advisor to the journal. Finally, we would like to recognize Alan Shamrock as Resident Reviewer of the Year for the exceptional quality and quantity of his reviews this year.

We are honored to serve as this year’s editors. The University of Iowa is a special place to train, and we feel privileged to be a part of its legacy. We are excited for the future of the department and hope that the readership enjoys this year’s publication of our journal.

Cameron Barton, MD
Christina J. Hajewski, MD
Co-Editors
Iowa Orthopedic Journal
University of Iowa Hospitals and Clinics
Department of Orthopedics and Rehabilitation
2020 DEDICATION OF THE IOWA ORTHOPEDIC JOURNAL

PROFESSOR JOHN P ALBRIGHT

Dedicated Hawkeye and Founder of University of Iowa Sports Medicine

We are pleased to dedicate the 2020 Iowa Orthopaedic Journal to Professor John P Albright. Affectionately known as JPA to generations of residents, he has served as a dedicated faculty member and as an enthusiastic supporter of the University of Iowa medical students, Orthopedic residents, athletic training students, sports medicine fellows, athletes and athletic programs for nearly 50 years.

John Albright was born in Aurora Illinois and attended East Aurora High School. His parents, Aaron and Francis, were both teachers and his father, Aaron, was also school administrator. In addition to teaching and serving as Dean of Students, Aaron Albright coached football and basketball. Given his father’s interest in sports it is not surprising that John was an enthusiastic athlete and lettered all four years in football, basketball and track and played American Legion Baseball. Given his father’s interest in sports it is not surprising that John was an enthusiastic athlete and lettered all four years in football, basketball and track and played American Legion Baseball. John’s high school record earned him acceptance to Yale. Fortunately for him he chose to attend the University of Illinois where he met Marcy, his wife to be, in 1961 when he was a junior and she was a sophomore.

John left Champaign-Urbana in 1963 for Chicago where he entered medical school at Loyola. Marcy graduated from the University of Illinois in 1964 and she and John married on June 14, 1964, in Chicago. In 1967 John and Marcy moved to New Haven Connecticut where John completed a General Surgery Internship followed by a research fellowship at the Mayo Clinic with the renowned bone biologist Jennifer Jowsey. He started his Orthopedic Residency in 1969 at Yale. The Yale Orthopedic Department had an outstanding faculty including John’s brother, Jim Albright, and enjoyed a reputation as one of the premier academic programs. John served as the Chief Resident in Orthopedic Surgery in 1970 and 1971, and then worked as an NIH Research Fellow in the Yale-New Haven Hospital investigating Osteogenesis Imperfecta, Osteoporosis and the skeletal effects of fluoride from 1971 until 1972.

Wayne Southwick, an iconic innovative American Orthopedic Surgeon, chaired the Yale Orthopedic Department from 1958 until 1979. Southwick played a critical role in the development of cervical spine surgery; among other contributions he advocated the anterior cervical spine approach, although a posterior cervical spine fixation technique is also named for him. In addition, Southwick is recognized for the Southwick osteotomy for the treatment of slipped capital femoral epiphysis. John Albright’s time with Wayne Southwick powerfully influenced his career and in particular his commitment to academic medicine.

In 1972 John and Marcy moved to Iowa City where John joined the University of Iowa Orthopedic faculty. The Yale Orthopedics Department had a tradition of expecting residents to conduct a substantive research project during their residency and present their work as a senior resident. After the resident presented his or her work a visiting professor critiqued the project and the presentation and questioned the resident. The presentations and critiques extended over several days named the “Days of Disputation.” Along with other Iowa faculty, Dr. Albright established the first Days of Disputation at Iowa. Over the years this program has evolved into the current Senior Residents’ Days which continues to have some characteristics of the original program. In addition to Days of Disputation, Dr. Albright brought with him Southwick’s approach to the treatment of cervical spine disorders and devoted part of his initial clinical practice to cervical spine surgery. For a number of years he continued to study bone metabolism and in particular the effects of life long exercise and load bearing on bone. This work was extended to the study of articular cartilage resulting in a paper entitled, “The Effects of Lifelong exercise on Canine Articular Cartilage.” This paper received the 1996 Cabaud Research Award from the American Orthopedic Society for Sports Medicine (AOSSM).

Within a few years of his joining the University of Iowa Orthopedics Department John found a passion for the then emerging and increasingly sophisticated field of sports medicine. In 1975 he accepted a six year appointment to the University of Iowa Board in Control of Athletics; his years on the Board in Control of Athletics gave him valuable insight into the operations of the University of Iowa Athletic Department including health care...
services for athletes. Shortly after starting his service on the Board in Control of Athletics, he started clinics for people with sports injuries, but soon saw a need for a comprehensive service for these patients. This led him to establish the University of Iowa Sports Medicine Services within the Department of Orthopedics in 1980. Traditionally, Student Health physicians had provided at least the initial care for University athletes and in some instances traveled with the athletic teams. Under Dr. Albright’s leadership, the Orthopedic Department assumed overall responsibility for the care of injured University Athletes and for designating team physicians; practices that continue today. The Sports Medicine Service also identified specialists in other departments within the University’s College of Medicine who would be available to provide care for athletes. Over the years the department’s Sports Medicine service grew to become the current UI Sports Medicine Center: a comprehensive multidisciplinary academic sports medicine center providing primary care sports medicine, orthopedic sports medicine, physical therapy, athletic training and radiology and musculoskeletal ultrasound services.

As the Sports Medicine service grew, John recognized that this service could provide high quality specialized education; and, in 1982, he established the University of Iowa Sports Medicine Fellowship. In the years that followed, multiple fellows received their fellowship education from John Albright; without exception they remember him fondly and feel that he made critical contributions to their careers. In 1984 John organized the first multidisciplinary University of Iowa Sports Medicine Symposium, an event that has been held annually.
through 2019. The symposium attendees and participants include physical therapists, athletic trainers, primary care physicians, orthopedic surgeons and fellowship trained primary care and orthopedic sports medicine specialists.

Perhaps more than any of his other professional activities, John enjoyed working directly with athletes. He spent endless hours in training rooms, attending athletic events and traveling with the University athletic teams.

Among his important accomplishments, Dr. Albright was instrumental in the creation of the University of Iowa athletic training student education program. He joined with athletic trainers to recruit outstanding students into the athletic training education program and gave them the opportunity to work with experienced athletic trainers and the Sports Medicine Service Orthopedic surgeons. The students participated in the evaluation and rehabilitation of injured athletes; inspired by these experiences many of them went on to distinguished careers in athletic training and some became head trainers for athletic departments and schools. Others pursued careers in physical therapy or medicine. Today the Masters in Athletic Training educational program and the athletic trainers that serve the university athletic teams are housed in the Orthopaedic department.

No one invested more of themselves in the care of University of Iowa athletes than John. Every hour of every day he was available to see injured athletes and work with the athletic trainers to promote the rehabilitation of those that had suffered injuries. Additionally, John and Marcy generously served as Town Hawks. They welcomed athletes into their home for holiday dinners; or breakfasts, lunches and dinners and at any other time. It was not unusual for them to have athletes or an athlete’s family members stay in their home. Michael Payne, David Browne, Greg Boyle, Franthea Price, BJ Armstrong, Roy Marble and many others enjoyed and benefited from John and Marcy’s kind hospitality and friendship. Not surprisingly many of the athletes consider John and Marcy to be their surrogate parents.

John’s influence on the field of sports medicine extended beyond the University of Iowa. He is one of the longest serving editorial board members of the American Journal of Sports Medicine and the Journal of Techniques in Knee Surgery. In addition to the 1996 Caboud Award, Dr. Albright’s research contributions have received multiple honors including the 1988 Excellence in Research award from the American Orthopedic Society for Sports Medicine (AOSSM) for his development of techniques and instruments for arthroscopic meniscal repair. In 1998, the AOSSM selected him as one of the first Sports Medicine Traveling Fellowship Godfathers; and, in 1999 he was elected to the Magellan Society an International Society that brings together the Traveling Fellows and the guiding Godparents who are selected by their parent Sports Medicine Societies of North America (AOSSM), Europe (ESSKA), the Pacific Region (APOA), and South America.
In 2001, he received the AOSSM George Revere Education award recognizing his contributions to education in the field of sports medicine, and in 2008 he was elected to the AOSSM Hall of Fame.

During their long tenure in Iowa City, John and Marcy Albright raised three accomplished sons. All three graduated from Iowa City West High School where they played Football and Basketball. Mark majored in Economics and Japanese at Northwestern University and spent his junior year in Japan. He is an attorney and Founding Partner of Perlman, Bajandas, Yevoli and Albright, P.L, a mid-sized law firm in South Florida. Mark and his wife Eve have three children Ryan, Jacob and Mia. Jeffrey majored in Finance and Asian Studies at Michigan State University and, like his older brother, spent his junior year in Japan. After graduating from Michigan State, he moved to Tokyo to work for an American company for three years during which time he did color commentary in Japanese for Big Ten Football games. He is President of YANMAR America a Japanese diesel engine and equipment manufacturer. Jeffery and his wife Angie have three children: Zachary, Paige and Chloe. Jay majored in Biology at the University of Michigan and is a graduate of the Iowa Orthopedic residency. He is now Assistant Professor of Orthopedics at the University of Colorado and Surgical Director of the Sports Medicine Center of the Colorado Children’s Hospital. Jay and his wife Stacy have two children: Jackson and Reese.

The list of experiences and professional contributions doesn’t capture Dr. Albright’s personality. He is affable, warm, caring and outgoing. He is a loyal steadfast friend. His patients quickly appreciate his concern for their welfare and willingness to spend time with them. It is hard to imagine how different the University of Iowa Department of Orthopedics would be, and in particular in University of Iowa Sports Medicine Services, the sports medicine fellowship and the athletic training education programs, without the sustained thoughtful and visionary contributions of John Albright.

~ Joseph Buckwalter IV, MD
DEPARTMENT OF ORTHOPEDICS AND REHABILITATION
SCHEDULE OF LECTURES AND CONFERENCES

Carroll B. Larson Shrine Memorial Lecture
May 29, 2020
Canceled Due to COVID-19
Larson Conference Room, 01090 JPP
University of Iowa Hospitals and Clinics
Department of Orthopedics and Rehabilitation

Intended speaker was:
Steve Frick, MD
Professor and Vice Chairman
Department of Orthopaedic Surgery
Stanford University School of Medicine

Chief, Pediatric Orthopaedic Surgery
Stanford University
Stanford, California

Spring 2021 to be arranged.
Contact Nancy Love: (319) 356-1872

36th Annual University of Iowa Sports Medicine Symposium
December 10-11, 2020
Marriott Hotel & Conference Center
300 East 9th Street, Coralville

Asheesh Bedi, MD
Chief, Sports Medicine and Shoulder Surgery
Harold W. and Helen L. Gehring Professor of Orthopaedic Surgery
Head Orthopaedic Team Physician, University of Michigan

Alison Brooks, MD MPH
Associate Professor
Team Physician, Sports Medicine
University of Wisconsin-Madison
Department of Orthopedics

2020 Senior Residents’ Day
June 5-6, 2020
Canceled Due to COVID-19

Intended speakers were:
John C. Clohisy, MD
Daniel C. and Betty B. Viehmann Distinguished Professor
Vice Chair, Department of Orthopaedic Surgery
Chief Adult Reconstruction Surgery
Director Adolescent and Young Adult Hip Service

Ann Van Heest, MD
Professor and Vice Chair of Education
Department of Orthopedic Surgery,
University of Minnesota

2021 Senior Residents’ Day
June 18-19, 2021
Discussants to be arranged.
Contact Jessica Dorsman: (319) 353-6747
DEPARTMENT OF ORTHOPEDICS AND REHABILITATION STAFF 2019-20

Dr. John Albright
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Dr. Eric Aschenbrenner
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DUE TO COVID-19 WE DID NOT TAKE A 2020 GROUP PHOTO.
IN LIEU OF THIS WE ARE USING LAST YEAR'S PHOTO.
PLEASE NOTE BELOW SOME PEOPLE PICTURED HAVE DEPARTED
OUR DEPARTMENT SINCE THIS PHOTO WAS TAKEN.

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 (departed)
30. Don Anderson, PhD
31. Jose Morcuende, MD
32. Tyler CarlLee, MD (departed)
33. Josef Tofte, MD (departed)
34. Chris Anthony, MD (departed)
35. Sean Sitton, MD (departed)
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
Dr. Jocelyn Compton, MD, MSc

Jocelyn T. Compton grew up the youngest of three in Hingham, Massachusetts. She was raised in a family of doctors and engineers and encouraged to “question everything” from an early age. After high school, she went on to Yale University where she earned a combined Bachelors of Science and Masters of Science in Molecular Biophysics and Biochemistry. It was here that she discovered an interest in basic science and original research at the bench.

After college, Jocelyn attended medical school at Columbia University. While in New York City, she spent as much time as possible attending musicals and exploring the vibrant food scene. She married Tom Compton during her third year, and together they acquired an adorable but stubborn beagle puppy named Stringer Bell. Given her upbringing, Jocelyn found orthopedic surgery was a natural choice to satisfy both her surgical and engineering inclinations. She moved her family to Iowa to pursue surgical training and cartilage research.

Throughout her education, Jocelyn has been drawn to the bench to perform basic science research. At Yale, under the (extremely) patient tutelage of Dr. Elizabeth Rhoades, she examined protein folding dynamics in the protein tau as a means to elucidate its role in Alzheimer’s Disease. In medical school, she again found herself in the lab with Dr. Jessica Kandel researching Tie2 regulation of bony metastatic disease in neuroblastoma. Jocelyn elected to take a year off from her studies to examine the mechanisms of fracture healing with Dr. Francis Lee, further solidifying her interest in orthopedics and basic science investigations.

Since starting residency, Jocelyn’s research interests have only expanded. She has delved into several clinical questions, from S. aureus nasal colonization and infection in trauma patients, to biases in patient-reported outcome measures, to dextrocardia and scoliosis. She has also spent time in the lab with Dr. Mitch Coleman and Dr. James Martin investigating the effect of sirtuins, a protein family implicated in mitochondrial biogenesis and regulation, on cartilage regeneration and chondrocyte progenitor cells. After graduation she looks forward to continuing her training at Washington University in Saint Louis where she will be doing a fellowship in hand surgery and continuing to perform research in an academic setting.

Jocelyn would like to thank her family, and especially Tom, for their ongoing support through the training process. Tom has been a stalwart source of love, humor, and sanity in the face of the trials of residency. She would also like to thank her co-residents, past and present, for tolerating her antics. Finally, she would like to thank the staff, both in the lab and the clinics, for their incredible dedication to education and patience.

Dr. Molly Day, MD, ATC

Molly grew up on her family’s 140-year-old homestead in Elderon, Wisconsin, a town of <180 people, with her parents, Lawrence and Mary Day, and one older sister, Erin. As a child, she was fascinated with the dynamic world around her and loved the outdoors. She could frequently be found playing sports, hunting and fishing, spending time in her father’s workshop or running in the woods (possibly from a bear).

She graduated from Wittenberg-Birnamwood High School in 2006, and went on to attend the University of Wisconsin-La Crosse, where she was on the women’s track and field team. She majored in athletic training and was recognized as the top scholar in the university’s graduating class in 2010, the first time this was awarded to an individual in her major. After graduation, she completed a post-graduate athletic training residency in Manchester, NH at the New Hampshire Musculoskeletal Institute from 2010-2011. She believes her decision to obtain a degree in athletic training provided her with unique experiences and perspectives which strongly impacted and shaped her future career path in orthopaedic surgery.

Molly returned to Wisconsin for medical school at the University of Wisconsin School of Medicine and Public Health. While obtaining her medical degree, she continued to work per diem as an athletic trainer to help fund her education, and on a Friday night was often with notebooks and flashcards on the sidelines of a high school football game.

After completing a sub-I rotation, Molly was thrilled to match at the University of Iowa for orthopedic surgery residency. Starting residency as a trauma team intern, she quickly became interested in clinical outcomes of the challenging trauma patient population, leading to her project, “3D Joint Space Width from Weightbearing CT Correlates with Outcomes after Intra-articular Calcaneal Fracture,” with Drs. Marsh and Anderson. Throughout residency, she has maintained wide research interests with a variety of faculty mentors. Molly has chosen to pursue a career in sports medicine, and after residency, is excited to head east to complete her fellowship at Hospital for Special Surgery in New York City.

Molly has many friends and family to thank for their endless support and encouragement. She credits her parents for instilling motivation, perseverance, and the importance of serving others. Their unwavering support and sacrifices are the reason she is here today. Her sister, brother-in-law, Derek, and nephew and niece, Colin and Isabelle, provide joy, laughter and fierce but friendly board game competition. Molly is fortunate to have incredible mentors in medical school and residency who have demonstrated endless possibilities, influencing her decision to pursue a fellowship in orthopaedic sports medicine. The energy and dedication of the faculty in the University of Iowa Department of Orthopedics have inspired a strong interest in research and a future career in academics. Lastly, Molly would like to thank her co-resident family for making this a fun and exhilarating journey throughout residency.
Dr. Nathan Hendrickson, MD, MS

Dr. Hendrickson, a title and surname which were previously thought to be incompatible, grew up in Prescott, WI. He is the youngest of four children born to Randall and Suzanne Hendrickson, and was the first member of his family to attend college. He graduated in 2004 from the University of Wisconsin-River Falls with a BS in Health and Human Performance Studies and minor in Biology. Following completion of his Bachelor’s degree, he joined his brother and close friends on an 18-month mobilization, including eleven months in Iraq. It has been rumored that his actions there were the basis for the Marvel character Captain America, although this has not yet been confirmed.

Nathan earned a Master of Science degree in Exercise Science at the St. Cloud State University (St. Cloud, MN). During this time, he was a Graduate Assistant in the Human Performance Lab under Dr. David Bacharach. Following graduate school he spent a blissful season as a Minor League Strength and Conditioning Coach with the Milwaukee Brewers. He then joined the Military Performance Division at the U.S. Army Research Institute of Environmental Medicine (USARIEM). While at USARIEM he worked with a number of remarkable basic and translational scientists who inspired Nathan to pursue an academic career in musculoskeletal medicine. During medical school at the University of Wisconsin, his aspiration to be an academic orthopedic surgeon was reinforced by the research mentorship of Dr. Paul Anderson.

Dr. Hendrickson was fortunate to join the University of Iowa Department of Orthopedics and Rehabilitation, where he counts many of the attending orthopedic surgeons as mentors and friends. Dr. Hendrickson has undertaken numerous research endeavors including multiple spine-related projects with his mentor, Dr. Andrew Pugely, as well as an ongoing prospective trial examining the effect of nutritional supplementation after operative fixation for acute musculoskeletal trauma with Dr. Michael Willey. He will go on to the University of Utah for a fellowship in spine surgery. He plans to pursue a career in academics in the Midwest.

He would like to recognize his parents, siblings, dear friends, and the mentors along the way that helped mark out the long and sometimes circuitous path he has traveled to arrive here today. Most importantly, he is grateful for the unwavering support, endless patience, and unconditional love of Anna and his children, Leif (7), Piper (5), and Nile (3).

Dr. Jessell Marie Owens, MD

Jessell was raised in Winnemucca, Nevada with her two older brothers (Ryan and Shawn) and her parents Mike and DeAnna Owens. She graduated, valedictorian, from Lowry High School in 2007. Jessell completed her undergraduate education at Pepperdine University in Malibu, California. Her undergraduate studies introduced her to international travel for which she quickly developed a passion. As a Division 1 swimmer, Jessell was named an NCAA All Academic Honoree and Female Scholar Athlete of the Year while earning summa cum laude honors upon graduation.

Jessell moved down the coast of California to continue studies at the University of California, San Diego Medical School. While serving as a senior anatomy teaching assistant her interest in orthopaedics began to develop. This interest grew as she was chosen as the recipient of the Ruth Jackson Steindler Award for Diversity in Orthopaedics. This opportunity lead her to residency at the University of Iowa after medical school graduation in 2015.

Jessell entered residency with an open mind with respect to subspecialty choices. Early on, she developed an interest in carpal tunnel pressure changes after distal radius fractures. This interest sparked the development of her project investigating changes in carpal tunnel pressures during volar plate fixation of distal radius fractures. As her interests evolved, she was also involved in several studies using large databases to evaluate pre-operative care of hip and knee arthritis and trends in hip and knee arthroplasty.

Following residency, Jessell will be moving to Denver, Colorado for fellowship at Colorado Joint Replacement. The potential for great mentorship and excellent training were important components in choosing this program.

Jessell is surrounded by amazing people that she would like to thank for the never ending support throughout residency. Her parents have been constant pillars of strength, encouragement and guidance throughout her life and she would certainly not be who or where she is without them. Her brothers have been the very best teammates, competitors and cheerleaders along the way. Iowa City also brought her Jim, who changed her life. Jessell will always be appreciative of his focus on growing through service to others. Finally, Jessell would like to thank her co-residents and faculty with whom she has shared the past 4 years. She is proud to have the opportunity to learn alongside some of the most incredible surgeons now and in the future.
Britt, who is his light through it all. The orthopedic track felt like a natural fit. It was during this time that Britt entered his life; his parents credit her as the catalyst to everything good in my life—it should be her picture to be my greatest and most cherished achievements.”

Dr. Christopher West, MD

Chris was born to Hugh and Julia West in Orange, California and grew up in Salt Lake City, Utah with 3 brothers and 2 sisters. Throughout childhood, he developed a strong love of nature as well as a keen interest in art and physics. After returning from a 2-year mission for the Church of Jesus Christ of Latter Day Saints in Samara, Russia, he attended college at Brigham Young University where he played lacrosse and obtained a degree in Mechanical Engineering. His interest in medicine and orthopedics was heavily influenced by his engineering inclinations and his observations of his father’s orthopedic practice throughout his childhood. In fact, several members of his family have been orthopedic surgeons including his great-grandfather, father, uncle and cousin. The orthopedic track felt like a natural fit. It was during this time that Britt entered his life; his parents credit her with saving him from his more ‘bohemian’ tendencies. It has been a wonderful journey ever since. They now have three darling kids, Samson, Evelyn, and Addison.

In his undergraduate studies, Chris was a member of the BYU Applied Biomechanical Engineering Laboratory where he led projects in ligament and tendon material property characterization. In medical school at UT Houston, he conducted fracture healing experiments on rat femurs in the setting of endocrine abnormalities. His experience on a sub-internship at Iowa on the pediatrics service sold him on Iowa and he was thrilled when he matched here for residency. During his time in residency he has continued his research interests in biomechanics, hip preservation, national registry data, boatbuilding, wood-fired hot tub manufacturing, skate-ramp production, meme-generation, Zamboni design, and igloo making. He has impressively succeeded in not containing his identity in the sea of Chris’s that have flooded the Iowa Orthopedics Department.

After graduation, Chris will continue his training in joint preservation and replacement at Washington University in St. Louis, MO with the goal of practicing with a comprehensive approach to the hip.

Chris would not have the wonderful opportunities he has had were it not for the unceasing support from countless mentors, family members and friends. Especially he would like to thank his parents for their constant willingness to listen and advise, faculty who have taken him under their wing, fellow residents who have taught him so much, his children for the joy and sanity they bring to life, and to Britt, who is his light through it all.

Dr. Brandon Wilkinson, MD

Born in Provo, Utah, Brandon was raised by his heroes Richard and Tami Wilkinson who placed a powerful emphasis on respect, integrity, faith, teamwork and work ethic. Their daily charge was “Each job is a self-portrait of the person who did it—autograph your work with excellence.” Little did Brandon know that success would not come from academia, but rather, adherence to the principles taught in his childhood home.

Inklings of a future in medicine first manifest in elementary school as Brandon was naturally drawn to those with physical disabilities. He was profoundly touched by Ksusha (a Russian immigrant with severe extremity deformities) and Zeek (who suffered from debilitating cerebral palsy)—both dealt with extraordinary physical limitations with grace and optimism. He could not have known then that those interactions would ultimately lead to a profession in orthopedic surgery.

Following high school, Brandon chose to postpone his university studies, instead choosing to serve a 2-year religious mission for the LDS Church in Sendai, Japan. Upon returning from Japan, he attended Brigham Young University graduating in Physiology and Developmental Biology with minors in Chemistry and Japanese. During this time, he married Erica Marie Wilkinson and ran a landscaping and construction service company. He then completed medical school at the University of Utah. His path to orthopedics took a short detour with a 1-year internship in general surgery at Vanderbilt University. This was a defining year for his family, providing priceless experience and grit.

Landing at UIHC was Brandon’s dream come true—now able to work in the shadows of the “pillars” in orthopedics. He took an early interest in research, culminating in opportunities to present research all across the country. He is particularly interested in comparative studies and medical stewardship in the era of cost containment. Brandon is humbled to work alongside the best co-residents in the country, noting that there is not a resident or faculty that has not touched his life for good. Specifically, he is deeply indebted to Dr. Weinstein, Dr. Callaghan, Dr. Marsh, Dr. Karam, Dr. Willey, and Dr. Hogue for tirelessly championing him to a fellowship in orthopedic trauma at R. Adams Cowley Shock Trauma Center in Baltimore, Maryland. Building on their mentorship, Brandon plans to give back to residents and academics while practicing at a level 1 trauma center.

Most importantly, Brandon states ‘everything I am or will ever become is a direct result of my beautiful wife Erica. She is my advisor and companion. She is the constant in our home and the catalyst to everything good in my life—it should be her picture here, not mine. Orthopedics is a team sport and my five children have been true teammates. The burden they have borne on this journey is far greater than mine. Tenley (9), Taylor (7), Nash (5), Blaire (3) and Wyatt (1). I am most proud of you—you will always be my greatest and most cherished achievements.’

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Brian Cohen, MD

Brian is the current Orthopedic Sports Medicine fellow at the University of Iowa. He received his undergraduate degree in Biochemistry and Cellular Molecular Biology at the University of Tennessee. He then went on to medical school at the University of Tennessee Health Science Center. He then moved to the northeast where he completed his Orthopedic residency and a Trauma fellowship at Brown University prior to coming to the University of Iowa. He is joined by his wife, Katie and son, Duke. He will be moving back to the northeast after fellowship to join a practice in Providence, Rhode Island.

Brian would like thank Drs. Wolf, Bollier, Westermann, and Duchman for their support, mentorship and training for the year. He enjoyed his once in a lifetime opportunity to take care of the Hawkeyes sports teams. He would also like to thank the whole Orthopedic department for welcoming him with open arms. The University of Iowa is a special place for orthopedics and the training is second to none.

Moses Lee, MD

Dr. Moses Lee grew up in Seoul, South Korea. He completed his medical training at the Yonsei University, graduating with his MD in 2006, and then finished his residency in Orthopaedic surgery at Severance Hospital in 2011. After serving three years of military duty as a Navy officer, he completed his Orthopedic Foot and Ankle Fellowship at the Severance Hospital in 2014. Then, he completed additional training under Dr. Lew Schon, Baltimore, in 2015. Upon starting his practice in 2016, he introduced a modern percutaneous foot and ankle technique for the first time in East Asia and South Korea.

He is currently finishing his Orthopedic Foot and Ankle Fellowship at the University of Iowa and is grateful for all the outstanding training he has received. He is thankful to extend his scope of foot and ankle to complex foot and ankle deformity after time in Iowa.

Lucas Seiler, MD

Lucas Seiler is the current hand surgery fellow. He received his undergraduate degree in Biology from the University of Nebraska Omaha and his medical degree from the University of Nebraska Medical Center. He then completed his orthopaedic surgery residency at UCSF Fresno prior to coming to Iowa. Lucas, his wife, and his two young boys plan to move back to Fresno, California this fall to join his prior mentors in practice. Lucas is incredibly thankful for all of the wonderful educators and mentors he has had throughout his many years of education and training, especially the fantastic hand faculty at the University of Iowa. Drs. Lawler, Fowler, Buckwalter, and Caldwell have all been incredibly generous with their time and knowledge, and they each bring something special to the Iowa Hand Fellowship to make it the great experience that it is.
NEW ORTHOPEDIC FACULTY

Adam Arendt, DPM
Dr. Adam Arendt is a Podiatrist who joined the Department of Orthopedics and Rehabilitation in 2019. He is a graduate of Des Moines University and completed residency training in Podiatric Medicine and Surgery at Saint Joseph Hospital in Chicago, IL. He is board certified by the American Board of Podiatric Medicine. After practicing in Chicago for 6 years, he made the decision to return to Iowa and join the University of Iowa Hospitals and Clinics - Foot and Ankle Team. His clinical and research interests include the diabetic foot and amputation prevention. In his free time he enjoys spending time with his son and he is happy to now call Iowa home.

Nicolas Bedard, MD
Dr. Nicholas Bedard grew up in Cedar Rapids, IA. He completed his undergraduate training at Creighton University in Omaha, NE, where he majored in Exercise Science. He then moved back home and completed both his medical school education and orthopedic residency training at the University of Iowa. Following residency, Dr. Bedard and his family moved to Rochester, MN to compete his fellowship in Adult Hip and Knee Reconstruction at Mayo Clinic. Upon completing fellowship, Dr. Bedard returned to the University of Iowa in the fall of 2019 to join the orthopedic faculty. He lives in Iowa City, IA with his wife Katie and his three daughters (Ruby - 8 years, Isabel - 6 years, Polly - 3 years). Dr. Bedard enjoys caring for patients with hip and knee arthritis and taking care of complex hip and knee arthroplasty problems. His research interest includes clinical outcomes of hip and knee arthroplasty surgery and interventions to minimize complications in high risk patients.

Jacob Elkins, MD, PhD
Dr. Jacob (Jake) Elkins completed his orthopaedic residency from the University of Iowa and fellowship at Colorado Joint Replacement. He is now an Assistant Professor in Orthopaedics specializing in adult joint reconstruction. He completed bachelor’s degrees in chemical engineering and physics as well as a master’s degree in chemical engineering at the University of Nevada Reno, and a PhD in biomedical engineering from the University of Iowa. His research interests are in computational modeling of orthopaedic implants and joint biomechanics.

Originally from Carlsbad, NM, he has lived in Iowa with his wife (Jaymie) for 15 years. They are both thrilled to be a part of the Iowa Ortho family, to which they have contributed with four of their own (Madelyn, Tessa, Matthias & Dorothy).
Dr. Cesar de Cesar Netto
MD, PhD

Dr. Cesar de Cesar Netto is an Orthopaedic Surgeon specialized in Foot and Ankle surgery. He serves as an Assistant Professor at the University of Iowa, Carver College of Medicine, in the Department of Orthopaedics and Rehabilitation. He had four Clinical Fellowships in Orthopedic Foot and Ankle Surgery: University of Sao Paulo, Sao Paulo-SP, Brazil (2010); University of Alabama at Birmingham - UAB, Birmingham-AL (2016-2017); Hospital for Special Surgery - HSS, New York-NY (2017-2018); and Medstar Union Memorial Hospital, Baltimore-MD (2018-2019). In his research, Dr. de Cesar Netto specializes in Foot and Ankle Surgery Disorders and Imaging of the Foot and Ankle, with focus on Flatfoot Deformity, Weightbearing Computed Tomography and Achilles Tendinopathy.

Sarah Polk, DPM

Dr. Sarah Polk is a Podiatrist who joined the Department of Orthopedics and Rehabilitation in the fall of 2019. A native of Kearney, Nebraska, Dr. Polk received her doctorate from Rosalind Franklin University in North Chicago, IL. She completed a 3 year podiatric surgery residency with the William S. Middleton VA in Madison, WI. She is board certified by the American Board of Podiatric Medicine. After 10 years in private practice in Sioux City, Iowa she made the decision to join the University.

Ryan C. Kruse, MD, CAQSM, RMSK

Dr. Ryan Kruse is a Clinical Assistant Professor in the Department of Orthopedics and Rehabilitation at the University of Iowa. He is also a team physician for US Soccer and USA Rugby. He completed his Physical Medicine and Rehabilitation residency at the Mayo Clinic followed by a Sports Medicine fellowship at the University of Iowa. He currently lives in Iowa City with his wife, Natalie. He has a special interest in diagnostic and interventional musculoskeletal ultrasound as well as the field of orthobiologics. In his free time, he enjoys woodworking and spending time outside with his wife and their dog.
ABSTRACT
Background: 15% of orthopedic surgery trainees in 2018-2019 in ACGME accredited programs are female, which lags behind all other specialties.
Methods: The bottleneck for achieving gender diversity in orthopedic surgery is that female medical students do not choose orthopedic surgery as a career. In 2018-2019, twelve ACGME accredited programs had no women trainees, highlighting the uneven distribution of female trainees across residency programs. Social science has outlined that 30% representation within a population is the diversity goal. Conclusion: A goal of having females comprise 30% of orthopedic surgeons trainees can be achieved with: pipeline programs such as the Perry Initiative and Nth Dimensions; increased orthopedic surgery rotation clinical experience during medical school; and mentorship that promotes and encourages gender diversity. Additionally, recognizing implicit bias as well as explicit discrimination, harassment, and bullying, creates a workplace environment that is inclusive and safe for employees, trainees and physicians, as well as the patients that we serve.
Level of Evidence: V
Keywords: gender, diversity, orthopedic, residency, surgery

INTRODUCTION
Defining the Problem
The pipeline for training orthopedic surgeons is filled with women. 57% of undergraduate students in the United States are female; 51% of medical students are women. Nevertheless, only 15% of orthopedic residents are women.

As shown in Table 1, at 15.4% in 2018-2019, orthopedic surgery has the smallest percentage of female residents of the top 10 specialties by size of residency.1
In examining the composition of residents training in surgical subspecialties, orthopedic surgery is training the lowest percentage of women, falling behind neurosurgery, urology, plastic surgery, general surgery, and colorectal surgery.1

As a profession, we cannot state that we recruit and accept the best and brightest medical students to the practice of orthopedic surgery as a career, if we continue to fail to attract and accept more women into our ranks. Adding diversity to an organization provides more diverse perspectives for effective decision-making, greater innovation and creativity for organizations, as well as greater understanding of the population that we treat.2 Diversity expands the talent pool and can strengthen our profession.

The goal of this paper is to outline steps that need to be taken in order to improve gender diversity within orthopedic surgery.

METHODS
Obstacles to Achieving Gender Diversity in Orthopedic Surgery
The bottleneck for achieving gender diversity in orthopedic surgery is that female medical students do not choose orthopedic surgery as a career. In fact, women medical students choose orthopedic surgery as a significantly lower rate than any other medical or surgical career, as demonstrated in Tables 1 and 2. Significant research has been done examining the question: why do female medical students not choose orthopedic surgery for residency training?

The most common reason medical students choose a specialty is experiences during medical school.3 In many medical schools, musculoskeletal medicine is poorly represented in the curriculum and is not a required clinical rotation. Studies have proven that a required third-year rotation exposes more medical students to orthopedics and increases the diversity of matching students.4 Female medical students have also indicated that they more commonly are influenced by clinical rotations (85%) and faculty mentors (55%) than are male medical students (56%, 37% respectively).3

Musculoskeletal curriculum in medical schools generally is poorly represented. Additionally, the presence of enthusiastic orthopedic surgery role models in medical school are significantly more important for

1University of Minnesota, Department of Orthopedic Surgery, Vice Chair of Education, Residency Program Director, Minneapolis, MN
Corresponding Author: Ann Van Heest, MD; Phone: (612) 279-9400; Fax: (612) 273-7959; Email: vanhe003@umn.edu
Disclosures: The authors report no potential conflicts of interest.
Sources of Funding: No sources of funding declared.
female medical students. Because female medical students rely heavily on faculty role models, the importance of enthusiastic and encouraging role models in orthopedic surgery cannot be overstated.5

A non-inclusive work environment in orthopedic surgery is another reason that female medical students may not choose orthopedic surgery. In a recent survey of members of the AAOS, 81% of females who responded to the survey had experienced discrimination, bullying, sexual harassment, or harassment with definitions as shown in Table 3.6

This AAOS workplace culture survey found that 66% of respondents have experience such behaviors including all age groups, racial groups, and genders. In a hierarchical surgical social structure, significant power differential exists between individuals, which can be abused to create a negative work culture. Similar to these AAOS Survey findings, the Royal Australasian College of Surgeons found that 49% of its responding members had experienced discrimination, bullying, sexual harassment, and harassment behaviors in the workplace.7 The most common individuals displaying harasing behaviors were attending surgeons, but also fellow trainees, non-surgical attending’s, nursing staff and administrators. It would be reasonable to extrapolate that negative workplace behaviors in a culture that supports these behaviors are barriers to entry into the field of orthopedic surgery particularly for women. Changing the workplace culture to be inclusive and equitable with a safe work environment for all of the orthopedic surgeons, both in training and in practice, is an important goal for our profession.

**Importance of Workplace Culture**

An inclusive workplace culture values people. Diversity in leadership styles with a caring safe and respectful culture embraces and inclusive workplace and provides a more effective and innovative organization for all. Diversity within the organization is also important because organizations include not only physicians but also the ancillary personnel, residents, medical students, employees, as well as patients that we serve. The workplace culture embraces all aspects of the physician patient encounter and improves patient care by valuing diversity inclusion and equity for all.

Unconscious bias also affects patient care. For example, a Canadian study with a standardized male and female patients with moderate knee osteoarthritis reported that the odds of a family practice physician recommending a total knee arthroplasty to a male patient was twice that of a female patient. They also reported that the odds of an orthopedic surgeon recommending total knee arthroplasty to a male patient was 22 times that of a female patient.8 Diversifying our workforce helps reflect the population that we serve and the care that we deliver, to help address healthcare discrepancies.

**30% Rule As Diversity Goal**

In a culture where a woman is the only female surgeon in a sea of male sugeons is a culture where the female is placed in a position of being the token. As a token female, her point-of-view can be construed to represent

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**Table 1. Top Ten Specialties By Size**

<table>
<thead>
<tr>
<th>Specialty</th>
<th>Number of Residency Positions</th>
<th>Percentage of All Residency Positions</th>
<th>Number of Female Residents</th>
<th>Percentage of Residents Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal Medicine</td>
<td>27,179</td>
<td>20%</td>
<td>11,474</td>
<td>42%</td>
</tr>
<tr>
<td>Family Medicine</td>
<td>12,441</td>
<td>9%</td>
<td>6,670</td>
<td>54%</td>
</tr>
<tr>
<td>Surgery, General</td>
<td>9,303</td>
<td>7%</td>
<td>3,839</td>
<td>41%</td>
</tr>
<tr>
<td>Pediatrics</td>
<td>8,950</td>
<td>7%</td>
<td>6,449</td>
<td>72%</td>
</tr>
<tr>
<td>Emergency Medicine</td>
<td>7,681</td>
<td>6%</td>
<td>2,722</td>
<td>35%</td>
</tr>
<tr>
<td>Anesthesiology</td>
<td>6,141</td>
<td>5%</td>
<td>2,065</td>
<td>34%</td>
</tr>
<tr>
<td>Psychiatry</td>
<td>6,014</td>
<td>4%</td>
<td>2,999</td>
<td>50%</td>
</tr>
<tr>
<td>Obstetrics / Gyn</td>
<td>5,453</td>
<td>4%</td>
<td>4,550</td>
<td>83%</td>
</tr>
<tr>
<td>Radiology</td>
<td>4,362</td>
<td>3%</td>
<td>1,171</td>
<td>27%</td>
</tr>
<tr>
<td>Orthopedic Surgery</td>
<td>4,021</td>
<td>3%</td>
<td>619</td>
<td>15%</td>
</tr>
</tbody>
</table>

**Table 2. Surgical Subspecialty Female Resident Representation**

<table>
<thead>
<tr>
<th>Surgical Specialty</th>
<th>Percentage of Female Trainees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colorectal Surgery</td>
<td>42.7%</td>
</tr>
<tr>
<td>General Surgery</td>
<td>41.3%</td>
</tr>
<tr>
<td>Plastic Surgery</td>
<td>30.5%</td>
</tr>
<tr>
<td>Urology</td>
<td>25.8%</td>
</tr>
<tr>
<td>Neurosurgery</td>
<td>17.5%</td>
</tr>
<tr>
<td>Orthopedic Surgery</td>
<td>15.4%</td>
</tr>
</tbody>
</table>
Lack of Gender Diversity in Orthopedic Surgery

“the women’s” point-of-view, and her performance can be construed to represent the performance of all women. In that way, the introduction of females into the orthopedic workplace has required resilience, grit, and toughness for the pioneering women. As a token woman, “Whatever women do, they must do twice as well as men to be thought half as good” (Mayor Charlotte Whitten 1951).

Overtime, the next step in the evolution of gender diversity is to “tick the box” by having two women representatives. “On board of directors, many have worked hard to recruit two women, then efforts appear to have declined presumably because they hit a level of diversity they seen satisfactory” (Washington post November 3, 2018)

Social science has outlined that 30% representation within a population is the diversity goal. At 30% of the population, the critical mass has been reached so that the under-represented population becomes incorporated and represented in the institutional culture. One example of this phenomenon was seen in the following setting. In an insurance company with eight separate offices, a diversity initiative was launched, with one female hired into each group. Within one year, nearly all females had quit. This diversity initiative was re-examined. Rather than putting one female in each insurance unit, four females were hired into select units. With the structure of 30 to 50% females in each of the select units, an inclusive culture was created, and the female insurance hires succeeded. Changes to the institutional culture to be accepting of a diverse population is key to incorporating that underrepresented population. This defines the goal of 30% critical mass.

Distribution of Females in Residency Programs

According to the social science data presented above, an analysis of the distribution of female residents within training programs in the United States can help shed light on some of the challenges that exist.

<table>
<thead>
<tr>
<th>Discrimination</th>
<th>Treating a person with an identified attribute or personal characteristic less favorably than a person who does not have that attribute or characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bullying</td>
<td>A behavior or pattern of behaviors that a reasonable person would expect might victimize, humiliate, undermine or threaten a person to whom the behavior is directed</td>
</tr>
<tr>
<td>Sexual Harassment</td>
<td>Unwelcome sexual advances, request for sexual favors and other unwelcome conduct of a sexual nature by which a reasonable person would be offended, humiliated or intimidated</td>
</tr>
<tr>
<td>Harassment</td>
<td>An unwanted, or unwelcome or uninvited behavior that makes a person feel humiliated, intimidated or offended</td>
</tr>
</tbody>
</table>

GME track is a national database that records the demographics of all residents training in ACGME accredited programs. The 2018-19 GME track data (Figure 1) shows that of the 179 orthopedic surgery residency programs, 12 programs had no women residents. Additionally, 33/179 (18%) have only one woman. For medical students that are rotating at programs with zero or one woman, difficulties of an inclusive and accepting workplace may arise.

The number of females training in orthopedic surgery is increasing over time. For the academic year of 2004-2005, the percent of females in ACGME accredited residency programs was 7.8%; for 2018-2019, this has now improved to 15.4%. In 2004-2005, the number of programs with greater than 20% women was 47/145 (32%), which in 2018-2019, is now improved to 102/179 programs (57%).

DISCUSSION

If our goal is to have females comprise 30% of orthopedic surgeon trainees, at the present rate of “improvement”, this will be achieved in 2072. How could we achieve this goal more quickly? Research has shown that pipeline programs such as the Perry Initiative and Nth Dimensions are effective in recruiting female medical students into the profession of orthopedic surgery. Additionally, the importance of the orthopedic rotation clinical experience and requiring a musculoskeletal experience is necessary. Providing mentorship that promotes and encourages gender diversity can increase medical student interest in orthopedic surgery. Most importantly, recognizing implicit bias as well as explicit discrimination, harassment, and bullying, can create a workplace environment that is inclusive and safe for employees, trainees and physicians, as well as the patients that we serve.

CONCLUSION

In conclusion, gender diversity is needed to increase in orthopedic surgery. Female surgeons help provide culturally competent care and can help address healthcare disparities. Gender diversity can be achieved. If each medical school in the United States attracts one additional
female medical student to choose orthopedic surgery, this 
would provide 30% female representation in orthopedic 
surgery residency programs within two years. After 
30% is achieved, gender diversity can be self-sustaining. 
If programs that help increase the medical student 
interest, such as Perry Initiative and Nth Dimensions, 
were available at every United States medical school, 
we could achieve this diversity goal. Additionally, an 
improved workplace culture that grounds its selection and 
promotion on competency based data, rather than outdated 
“old boys club” values, will create a safe environment that 
values inclusion and equity.

REFERENCES
1. Brotherton & Etzel, Graduate Medical Education, 
2. Herring C. Does diversity pay?: Race, gender, and the 
ABSTRACT

Background: The risks of radiation exposure in orthopaedic surgery have become a topic of increasing interest in the setting of widespread fluoroscopy use and concern for an increased prevalence of breast cancer among female orthopaedic surgeons. The aim of this national study of 31 female orthopaedic surgeons was to achieve a deeper understanding of fluoroscopic use in the OR and its associated exposure to radiation, by comparing female orthopaedic trauma and arthroplasty surgeons.

Methods: A total of 31 surgeons wore dosimeters for 10 operating days each to track cumulative radiation exposure. Surgeons were not asked to modify their practice in any way, with no requirement that the operating days had to be chosen with the knowledge that fluoroscopy would be used. Participants were also asked to fill out a form at the end of each day, detailing the number of cases that day, the number of hours spent in the OR, and the total amount of time using fluoroscopy.

Results: Trauma surgeons received significantly higher radiation doses in the OR (p=0.01) and reported longer use of fluoroscopy (p<0.001). Trauma surgeons also spent more time per day in the OR and had more cases per day compared to arthroplasty surgeons, but this difference was not significant. Radiation dose penetrating through protective equipment remained minimal.

Conclusion: Although the female trauma surgeons in the study operated longer and performed more procedures per day, the higher radiation exposure was best explained by the amount of time fluoroscopy is used in the OR. The fluoroscopic times in this study therefore may be a useful self-assessment tool for attending trauma and arthroplasty surgeons. Awareness of these differences will hopefully increase an individual surgeon’s mindfulness toward the length of fluoroscopy use in each case, regardless of orthopaedic subspecialty.

Level of Evidence: IV

Keywords: radiation exposure, female orthopaedic surgeons, dosimetry

INTRODUCTION

The widespread adoption of fluoroscopy in orthopaedic procedures has led to increasing interest in evaluating the risks of occupational radiation exposure to the surgeon. Although evidence directly linking cancer prevalence to radiation exposure among orthopaedic surgeons is minimal, it is well known that a dose-dependent relationship exists between radiation exposure and malignancy. 1-3 Female orthopaedic surgeons, in particular, have a 2.9 fold higher prevalence of breast cancer compared to the general US population, as well as an increased prevalence relative to surgeons in other surgical specialties. 4-5 Similarly, a 3-fold higher risk of breast cancer has been reported in female radiographic technologists with exposure to long-term, low-dose radiation. 6

Practice guidelines have been developed to mitigate this exposure, with maximum acceptable radiation limits set by the National Council on Radiation Protection and the United States Nuclear Regulatory Commission (USNRC). Methods of reducing radiation risk include wearing protective equipment such as lead aprons and thyroid shields, using optimal intra-op fluoroscopic positioning, using smaller fluoroscopy machines, and standing a safe distance from the source. Many institutions require surgeons to wear dosimeters clipped above lead aprons to track intra-operative radiation exposure, although the recorded doses are not a true reflection of the actual radiation that is received underneath the lead. Indeed, a recent study that used several standard lead apron sizes
on an anthropomorphic model demonstrated substantial scatter radiation to the breast region. Several studies track radiation exposure secondary to specific procedures or fluoroscopic techniques, but differences between practices and individual surgeons also limits the generalizability of these studies. Gausden et al. tracked cumulative radiation dose in one year among various orthopaedic subspecialties and across several training levels at a single institution, demonstrating that trauma surgeons were exposed to the highest amounts of radiation and arthroplasty surgeons the least. The relationship between operating room (OR) data such as total fluoroscopy time, number of procedures performed per day by a surgeon, and radiation exposure, was explored in one previous study but focused on hand radiation exposure and was limited to one institution. Given the increased prevalence of breast cancer in female orthopaedic surgeons relative to the general US population and even other surgical specialties, radiation exposure in the context of operating room characteristics has significant implications for limiting occupational risk in this population. Therefore, further research is needed to gain a deeper understanding in why radiation exposure varies among female orthopaedic surgeons in different specialties, specifically how OR data translate into fluoroscopy use.

Thus, the purpose of this study was to achieve a deeper understanding of fluoroscopic use in the OR and its associated exposure to radiation comparing female orthopaedic trauma and arthroplasty surgeons. The hypothesis was that female trauma surgeons would spend more time in the OR with surgical procedures, and have increased fluoroscopy exposure leading to overall higher radiation exposure compared to arthroplasty surgeons. The primary outcome measure was the radiation dose measured by dosimeters, as well as the practice parameters of the surgeons involved in the study.

**METHODS**

**Data Collection**

After obtaining Institutional Review Board (IRB) approval, 40 female orthopaedic trauma and arthroplasty surgeons in various practice settings across the United States were recruited using personal contacts and word-of-mouth recommendations from colleagues in the field. A few participants also reached out directly to ask to be enrolled. A total of 31 surgeons competed the study (Figure 1).

All participants were mailed two dosimeters provided by Stanford University’s Environmental Health and Safety Department. The dosimeters were from Mirion Technologies (Model: Genesis Ultra TLD) and were the same type worn by surgeons at Stanford University Hospital, who use fluoroscopy in their practice, to track cumulative radiation exposure. Participants were asked to wear one dosimeter on the outside of their lead apron, and one dosimeter on the inside of the lead apron clipped to the pocket of the scrub top. These dosimeters were worn for a total of 10 operating days. With the exception of wearing the dosimeters, surgeons were not asked to modify their practice in any way. There was no requirement that the operating days had to be chosen with the knowledge that fluoroscopy would be used.

Participants were also asked to fill out a paper form at the end of each day, detailing the number of cases that day, the number of hours spent in the OR, and the total amount of time using fluoroscopy. To gather the most accurate data, the fluoroscopy time was recorded directly from the device used for fluoroscopy in each case. Demographic information on the type of institution (academic versus private) and use of personal protective equipment (PPE), i.e. axillary protection wings, was also collected. At the end of data collection, participants mailed back both dosimeters and paper forms.

**Statistical Analysis**

Frequency and percentage or means and standard deviation were calculated for each measure, separately by surgeon type (trauma versus arthroplasty). Differences between surgeon type were tested using Fisher’s exact test for personal protective equipment and Student’s t-tests for cases/day, operating time/day, fluoroscopy use/day, and outside dosimeter reading. Correlation tests were used to examine if operating time correlated with fluoroscopy use and if fluoroscopy use correlated with outside dosimeter reading. Correlations were calculated separately for each surgeon type and a Fisher’s (1925) z test was used to examine if the correlation coefficients were significantly different between the two groups. Exploratory univariate and multivariate linear regression tests were used to examine surgeon characteristics of...
surgeon type, practice setting, axillary protection wing use, number of procedures, and operating time/day associated with fluoroscopy use and outside dosimeter reading. Fluoroscopy use was also included as an independent variable in the model examining outside dosimeter. R version 3.6.1 and Rstudio version 1.2.1335 and R packages psych and lme4 were utilized, and p<0.05 denoted statistical significance.

RESULTS

Patient Population
A total of 20 female orthopaedic trauma surgeons and 20 female orthopaedic arthroplasty surgeons were recruited, representing 8% and 20% of all U.S. female orthopaedic surgeons in trauma and arthroplasty, respectively. Out of these, 15 trauma surgeons and 16 arthroplasty surgeons completed the study by wearing the dosimeters for 10 days in the OR and returning both dosimeters and paper forms. Nine surgeons were excluded, as the remaining participants lost their dosimeters (two), returned the dosimeters but not the paper forms (two), or were lost to follow-up (five). All surgeons were attendings at their respective institutions, with the exception of one surgeon who at the time of data collection was a trauma fellow.

Descriptive statistics for participating surgeons are reported in Table 1. Surgeons were located all across the United States, representing a total of 30 institutions in 18 states (Figure 1). In our study population, trauma surgeons practiced mostly in an academic setting, while arthroplasty surgeons practiced mostly in a private setting. All participants reported using a lead apron in every case in which they used either fluoroscopy. Only two participants in each group reported using axillary protection wings attached to their lead apron.

Across the 31 participants with 10 OR days per participant, a total of 759 cases were reported (n=381 for arthroplasty, n=378 for trauma). Surgeons used fluoroscopy on a total of 199 days (n=51 for arthroplasty, n=148 for trauma). The average length of fluoroscopy time in cases utilizing fluoroscopy was 66.80 seconds. Description of procedures was not elicited.

Radiation Exposure
Trauma surgeons used fluoroscopy 213.54 seconds per day ± 142.40 (mean ± standard deviation [SD]), which was significantly more than arthroplasty surgeons (25.21 seconds ± 48.64, p < 0.001, Figure 2A). Outside dosimeter readings were significantly higher for trauma surgeons (76.60 millirems ± 96.35) than arthroplasty surgeons (5.00 millirems ± 7.97, p = 0.01, Figure 2B). Inside dosimeter readings were all zero millirem, except for two surgeons (one trauma, one arthroplasty) who had a reading of two mrem and one surgeon (trauma) who had a reading of nine mrem. Given the very low radiation dose penetrating through the lead apron, no further analysis was performed on the inner dosimeter. Years of experience as an attending surgeon were not elicited, but of note, the dosimeter from the trauma fellow in the study had the highest reading at 273 millirems.

TABLE 1. Descriptive Statistics of Sample of 31 Female Orthopaedic Surgeons

<table>
<thead>
<tr>
<th>Variables</th>
<th>Trauma Surgeons (n=15)</th>
<th>Arthroplasty Surgeons (n=16)</th>
<th>T-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Practice Setting</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Academic</td>
<td>12 (80%)</td>
<td>4 (25%)</td>
<td></td>
</tr>
<tr>
<td>Private</td>
<td>3 (20%)</td>
<td>12 (75%)</td>
<td></td>
</tr>
<tr>
<td>Personal Protective Equipment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lead Apron</td>
<td>13 (87%)</td>
<td>14 (88%)</td>
<td></td>
</tr>
<tr>
<td>Axillary Wing</td>
<td>2 (13%)</td>
<td>2 (12%)</td>
<td></td>
</tr>
<tr>
<td>Cases/Day</td>
<td>2.55 (0.83)</td>
<td>2.40 (0.70)</td>
<td>.59</td>
</tr>
<tr>
<td>Operating Time (hours)/Day</td>
<td>4.51 (1.69)</td>
<td>3.80 (1.55)</td>
<td>.23</td>
</tr>
<tr>
<td>Fluoroscopy Use (seconds)/Day</td>
<td>213.54 (142.40)</td>
<td>25.21 (48.64)</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Outside Dosimeter Reading (mrem)</td>
<td>76.60 (96.35)</td>
<td>5.00 (7.97)</td>
<td>0.01*</td>
</tr>
</tbody>
</table>

SD = standard deviation, * = statistically significant
In univariate linear regression models testing the association between surgeon factors and fluoroscopy use, being a trauma surgeon ($b = 188.83$, standard error [SE] = 37.72, $p < 0.001$) and having longer operating time/day ($b = 34.12$, SE = 14.66, $p = 0.03$) had significantly more fluoroscopy use (Table 2). A multivariate linear regression model found the same results and indicated that being a trauma surgeon ($b = 176.98$, standard error [SE] = 44.72, $p < 0.001$) and having longer operating times ($b = 31.91$, SE = 14.62, $p = 0.04$) were independently associated with more fluoroscopy use after adjusting for other factors (Table 3). Univariate linear regression models testing the association between surgeon factors and outside dosimeter reading found that being a trauma surgeon ($b = 71.60$, SE = 24.15, $p = 0.006$) and having longer fluoroscopy use/day ($b = 0.37$, SE = 0.07, $p < 0.001$) had significantly higher outside dosimeter readings. A multivariate linear regression model indicated that longer fluoroscopy use ($b = 0.42$, SE = 0.12, $p = 0.001$) was independently associated with higher outside dosimeter reading, but the type of surgeon was no longer significant.

**DISCUSSION**

This study found that trauma surgeons had significantly higher radiation exposure levels based on the dosimeter placed outside the lead apron compared to arthroplasty surgeons. Very little to no radiation penetrated through the lead apron in either the trauma or arthroplasty groups, regardless of operating time or fluoroscopy use. Trauma surgeons used fluoroscopy significantly more than arthroplasty surgeons, with the type of surgeon also having a large effect size on fluoroscopy use.

**Dosimeter Readings**

The finding that trauma surgeons have significantly higher radiation exposure levels according to the dosimeter outside the lead apron aligns with our hypothesis, and previous findings describing higher radiation exposure levels among trauma surgeons. Given the large effect size and population coverage of our sample (6% and 16% of female trauma surgeons and arthroplasty surgeons, respectively), this result helps confirm on a national level that the differences

<table>
<thead>
<tr>
<th>Table 2. Univariate Linear Regression Models Examining Surgeon Characteristics Associated with Fluoroscopy Use and Outside Dosimeter Reading</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Fluoroscopy Use</strong></td>
</tr>
<tr>
<td>Surgeon Type</td>
</tr>
<tr>
<td>Practice Setting</td>
</tr>
<tr>
<td>Axillary Wing</td>
</tr>
<tr>
<td>Number of Procedures</td>
</tr>
<tr>
<td>Operating Time/Day</td>
</tr>
<tr>
<td>Fluoroscopy Use/Day</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Outside Dosimeter Reading</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Surgeon Type</td>
</tr>
<tr>
<td>Practice Setting</td>
</tr>
<tr>
<td>Axillary Wing</td>
</tr>
<tr>
<td>Number of Procedures</td>
</tr>
<tr>
<td>Operating Time/Day</td>
</tr>
<tr>
<td>Fluoroscopy Use/Day</td>
</tr>
</tbody>
</table>

*Fluoroscopy use was the dependent variable in the first linear regression model and an independent variable in the second linear regression model. SE = standard error, * = statistically significant
in radiation exposure between these two specialties are reproducible. Radiation exposure increases cancer risk, and does accumulated over the course in career could be a concern for contributing to the increased prevalence of breast cancer among female orthopaedic surgeons. The proportion of women in orthopaedic surgery training programs has also increased over the past few decades, and female orthopaedic surgeons under the age of 40 represent a higher proportion of all orthopaedic surgeons compared to older age groups (15.9% in age<40, 8.1% in age 40-49, 6.7% in age 50-59). As the proportion of female orthopaedic surgeons increases and trainees choose among various subspecialties for post-residency fellowships, detailed investigation into radiation-associated occupational risk is warranted.

Our study reported radiation doses as 10-day cumulative totals, to control for variation in OR days per week. Therefore, there is not a perfect comparison for the dose levels reported in our study compared to other studies on radiation exposure, which are usually grouped by exposure per month or per case. Nevertheless, the dose levels grouped by specialty are still in a similar range, with one study reporting an average of 52.7 mrem/month among trauma surgeons and 4.0 mrem/month among arthroplasty surgeons.

According to the dose readings from the dosimeters placed under the lead apron on the chest, almost no radiation penetrated through the lead aprons. Considering every surgeon in this study reported wearing a lead apron when fluoroscopy was used, the overall risk of radiation penetration to the surgeon’s chest in the area detected by the dosimeter is reassuring. Several studies have shown that orthopaedic surgeons are exposed to radiation levels lower than the recommended yearly limit given proper use of protective equipment. As with these previous studies, the authors recommend the use of a lead apron any time there is the possibility of fluoroscopy use during the surgical procedure.

### Surgeon Factors
Fluoroscopy use was significantly higher in trauma surgeons compared to arthroplasty surgeons, aligning with the study’s hypothesis. Interestingly, while trauma surgeons on average also spent more time per day in the OR and had more cases per day compared to arthroplasty surgeons, the difference was not significant. When including other variables in a multivariable regression, and after adjusting for operating time and number of procedures, fluoroscopy use was still significantly associated with higher outside dosimeter readings. Therefore, regardless of surgeon type, fluoroscopy use was still the most important explanation of higher dosimeter readings. Average fluoroscopy use per case was overall lower than existing reports describing a range of 1.5-6.3 minutes/case in common orthopaedic trauma procedures, although our study did not elicit specific procedure descriptions. Efforts to decrease radiation exposure should thus be focused in ways to decrease the amount of fluoroscopy use, rather than limiting OR time or the number of procedures that surgeons perform per day. This strategy can be seen in the introduction of various technologies aimed toward decreasing fluoroscopy time such as computer-aided intra-op visualization technology. In one such study on computer-aided surgical navigation in an orthopaedic trauma OR, the use of fluoroscopic time per procedure was lowered to 30 seconds per case. However, computer navigation equipment has overall not been widely adopted and at present is not a part of routine practice at most institutions.

Several outside dosimeter readings had a reading of 0 millirems despite the surgeon reporting using fluoroscopy for every case, which did not align with the finding overall that fluoroscopy use was the most important factor in radiation dose. The importance of a well-maintained lead apron that is new, well cared for, and is without cracks cannot be overstated. It is likely that the high quality of the protective equipment used

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**Table 3. Multivariate Linear Regression Models Examining Surgeon Characteristics Associated with Fluoroscopy Use and Outside Dosimeter Reading**

<table>
<thead>
<tr>
<th>Surgeon Factors</th>
<th>Fluoroscopy Use</th>
<th>Outside Dosimeter Reading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surgeon Type</td>
<td>b    SE  t  p-value</td>
<td>b    SE  t  p-value</td>
</tr>
<tr>
<td>Practice Setting</td>
<td>176.98 44.72 3.96 &lt;0.001*</td>
<td>16.03 32.79 0.49 0.63</td>
</tr>
<tr>
<td>Axillary Wing</td>
<td>20.42 49.40 0.41 0.68</td>
<td>31.25 28.50 1.10 0.28</td>
</tr>
<tr>
<td>Number of Procedures</td>
<td>-6.06 29.80 -0.20 0.84</td>
<td>0.32 17.15 0.02 0.99</td>
</tr>
<tr>
<td>Operating Time/Day</td>
<td>31.91 14.62 2.18 0.04*</td>
<td>-8.77 9.17 -0.96 0.35</td>
</tr>
<tr>
<td>Fluoroscopy Use/Day*</td>
<td></td>
<td>0.42 0.12 3.65 0.001*</td>
</tr>
</tbody>
</table>

*Fluoroscopy use was the dependent variable in the first linear regression model and an independent variable in the second linear regression model. SE = standard error, * = statistically significant
by these surgeons is partially responsible for the results. Additionally, research into scatter radiation shows that doses exponentially decrease with even short distances standing away from the source of the fluoroscopy.\textsuperscript{20,21} It is possible that surgeons may have stood away from the radiation field, given the association between radiation exposure and breast cancer in women, although this was not assessed. It is also possible that surgeons may have used other protective equipment, such as lead shields. Therefore, while the results of this study suggest that duration of fluoroscopy use is the most important factor explaining radiation exposure, there may be other surgeon factors that affect dosage read on the dosimeter.

Lastly, all surgeons in this study were practicing orthopaedic surgeons at their respective institutions with the exception of one trauma fellow. Although this study did not elicit years of experience, previous studies at the resident level have shown that fluoroscopy use decreases as residents advance in their training.\textsuperscript{12,22} It has been proposed that fluoroscopy use times could be a useful assessment tool for resident proficiency at certain procedures. In this study, the outside dosimeter reading from the trauma fellow was the highest in the study in both the trauma and arthroplasty group. However, this should be interpreted not necessarily as being a reflection of the level of training, given that trauma fellows tend to operate more than the average practicing orthopaedic surgeon. Overall, taking into account variations in practices and case load, as well as case variety, the fluoroscopic times in this study therefore may be a useful self-assessment tool for attending trauma and arthroplasty surgeons.

**Strengths and Limitations**

The strengths of this study lie primarily in its breadth of 31 surgeons across 30 institutions in the US who completed 759 cases. To the authors' knowledge, this is the largest multi-institutional study completed analyzing radiation exposure and OR characteristics in female orthopaedic surgeons and aligns with existing studies utilizing dosimeters both above and below the lead apron to observe penetrance of radiation through protective equipment. This study builds off existing literature describing both increased radiation exposure among orthopaedic trauma surgeons as a whole, as well as previous studies showing increased prevalence of breast cancer among female orthopaedic surgeons.\textsuperscript{4,5,12} Therefore, these results can contribute to advancing knowledge of radiation risk factors and also present an opportunity for surgeons to evaluate their own fluoroscopy use in the context of this study's data. The finding that fluoroscopy use is the single most important factor for radiation exposure can guide female surgeons in decreasing radiation exposure. It may be prudent to consider using fluoroscopy more selectively each case, comparing one's own fluoroscopy times per day to the results in this study as a self-assessment tool, or incorporating the use of technologies aimed at decreasing the need for fluoroscopy such as computer aided navigation systems.

Although this is the largest study of its kind, the regressions should still be considered exploratory given the small sample size relative to the total number of orthopaedic surgeons in the US. Factors that affect radiation exposure on an individual surgeon's level such as distance from fluoroscopy source, angle relative to fluoroscopy source, and type of procedures were not captured. Also, it is theoretically possible that the dosimeters did not function properly and that surgeons may have deviated from the protocol. All dosimeters were acquired from the same source to minimize this risk. Other limitations include the selection of the participant population and operating days, which may be comprised of surgeons particularly interested in radiation exposure and thus already more likely to take additional safety precautions, as well as the fact that we did not ask for information regarding the surgeon's role in each case. Additionally, there are far fewer female arthroplasty surgeons in the US compared to female trauma surgeons, thus this study captured a greater fraction of all female trauma surgeons compared to arthroplasty surgeons.

Lastly, the dosimeter placed under the lead in this study's protocol may not have captured radiation to the axillary region, and very few surgeons in this study noted wearing axillary protection wings. Previous publications have described the axilla as being most susceptible to scatter radiation exposure,\textsuperscript{23} therefore it is recommended that axillary protection wings be included in a surgeon's set of standard radiation protection equipment.

**ACKNOWLEDGMENTS**

We would like to thank Drs Muyibat Adelani, Ayesha Abdeen, Elke Ahlmann, Sharon Babcock, Daphne Beingessner, Ereny Bishara, Michelle Bramer, Tiffany Castillo, Cara Cipriano, Jennifer Cook, Carmen Crofoot, Catherine Cunagin, Elizabeth Dailey, Candice Dubose, Jennifer Hagen, Holly Haight, Robyn Hakanson, Sanaz Hariri, Kathleen Hogan, Rinelda Horton, Tamara Huff, Catherine Humphrey, Mitra Javadel, Laura Ko, Megan Manthe, Jessica McBeth, Anna Miller, Danielle Ponzio, Christine Pui, Mara Schenker, Gillian Soles, Carla Smith, Emily Squyer, Kelly Stets, Audrey Tsao, and Karen Wu for their time and generous contribution to this study.
REFERENCES
ABSTRACT

Background: Female orthopedic surgeons have different life choices, experiences, and influences that may alter their decisions when choosing a fellowship. There is no data that describes why women choose their specialty and if it is related to their mentorship, athletic background, family, family planning, physical attributes needed, location, practice setting, or discrimination. After a five year orthopedic residency, what influences their specialty choice to work in a specific field?

Questions/purposes: To understand why women in orthopedics chose a certain fellowship and if they are influenced by any specific factor.

Methods: A 28 question survey created through SurveyMonkey was emailed to all members of the Ruth Jackson Orthopedic Society (RJOS) in July 2019. After six weeks the survey was closed and data was analyzed through SurveyMonkey.

Results: 252 members of RJOS completed the 28 question survey. 94% of the women who responded did a fellowship after their orthopedic residency. 62% chose their fellowship specialty based on pure enjoyment. 79% were not influenced by a female role model, 92% were not influenced by a significant other, 85% were not influenced by wanting children or a family, and 96% were not influenced by being pregnant or planning on being pregnant. 64% were not influenced by physical attributes or perception of strength needed for the specialty.

Conclusions: 94% of the women who responded did a fellowship after their orthopedic residency and 62% chose their fellowship specialty based on pure enjoyment. It was not found that female mentorship, family, pregnancy, significant other, or physical attributes contributed to their fellowship choice.

Level of Evidence: V

Keywords: orthopedics, women, fellowship, residency, ruth jackson orthopedic society, specialty

INTRODUCTION

The majority of orthopedic residents pursue fellowship training. The percentage of female residents has been consistent over the years at 14%. Details regarding females in orthopedic fellowships are sparse. Cannada et al. found using the latest match data that the percentage of female applicants that matched were 8%-12% from 2010-2014. This was the most recent article to publish match data due to the difficulties of distinguishing genders on the SF match and ASES match applications. Both applications do not list gender, therefore first names and letters of recommendation were used. In their study, the women matched at a higher rate than men.

Why women choose a certain fellowship specialty has not been reported. It is important to understand why women choose certain fellowships over others. It has been discussed women may not apply to orthopedic residencies due to work/life balance or physical strength perception. How does this relate to women already in an orthopedic residency and now are deciding on a certain fellowship for a specialty they will focus on for another year? Cannada et al. found pediatrics had the highest proportion of female applicants (25%) and spine had the lowest (3%). There is no study at this time that demonstrates the reasoning behind these statistics. A 28 question survey was sent to members of the Ruth Jackson Society (RJOS) to discover a better understanding as to why women choose a certain fellowship over another.

METHODS

A 28 question survey was created through SurveyMonkey (Figure 1).

Questions included: Was there an influence from being in the military or a college athlete? Were they brought up in a family that consisted of a surgeon? Were there mentorships from a female role model along the way? Did their desire to have a family influence their choice of which fellowship they decided on? Did pregnancy...
Figure 1. Women in orthopedics survey.

1. What is your age?
   a. 30–34
   b. 35–39
   c. 40–44
   d. 45+
2. What is your ethnicity?
   a. White or Caucasian
   b. Black or African American
   c. Hispanic or Latino
   d. Asian or Asian American
   e. American Indian or Alaska Native
   f. Native Hawaiian or other Pacific Islander
   g. Another race
3. What is your marital status?
   a. Single (never married)
   b. Married
   c. Domestic partnership
   d. Divorced
   e. Widowed
4. Have you ever served in the military?
   a. Yes  b. No
5. Were you a college athlete?
   a. Yes  b. No
6. Do you have any family members that were surgeons?
   a. Yes  b. No
7. How many publications do you have?
   a. 0
   b. 1–5
   c. 5–10
   d. 10+
8. Did you do a fellowship?
   a. Yes  b. No
9. What fellowship did you go into?
   a. Adult Reconstruction  f. Spine
   b. Foot and Ankle  g. Sports
   c. Hand  h. Trauma
   d. Oncology  i. Shoulder
   e. Pediatrics  j. Elbow
10. Did you pursue a second fellowship?
    a. Yes  b. No
11. What was your second fellowship?
    a. Adult Reconstruction
    b. Foot and Ankle
    c. Hand
    d. Oncology
    e. Pediatrics
    f. Spine
    g. Sports
    h. Trauma
    i. Shoulder and Elbow
    j. I did not do a second fellowship
12. Why did you pursue a fellowship?
    a. Enjoy the subspecialty
    b. Felt like you needed additional training in this field and did not receive adequate training in your residency
    c. Desirable to do a fellowship for job market
    d. It was suggested by others (fellow residents, mentor, program director, attending, etc)
    e. Other
13. Were you influenced by a female role model when you made your fellowship choice?
    a. Yes
    b. No
14. Who was this female role model?
    a. Program Director
    b. Attending
    c. Educator
    d. Family Member
    e. I did not have a female role model
    f. Other
15. What type of job did you go into?
    a. Medical School
    b. PGY 1/2
    c. PGY 3/4
    d. Other
16. Did a significant other/partner influence your fellowship choice?
    a. Yes
    b. No
17. Did your desire to have children/family influence your fellowship choice?
    a. Yes
    b. No
18. Did pregnancy (pregnant at time of fellowship or planning to be) influence your fellowship choice?
    a. Yes
    b. No
19. Did any of these physical aspects contribute to your fellowship choice?
    a. Standing for majority of cases
    b. Sitting for majority of cases
    c. Case duration
    d. Perception of strength needed
    e. None of these contributed to my choice
    f. Other
20. Did your desired practice setting (full time/part time) influence your fellowship choice?
    a. Yes
    b. No
21. Are you full time or part time?
    a. Full time
    b. Part Time
    c. Other
22. What type of job did you go into?
    a. Private practice
    b. Hospital Employee
    c. Hybrid
    d. Academic
    e. Other
23. Did geographic location influence your choice?
    a. Yes
    b. No
24. If location did influence your choice, why?
    a. Close to family/friends
    b. Familiar with location
    c. Based choice off of climate
    d. Other
25. Did you ever feel discriminated against (bullied, harassed, sexually harassed) when pursuing/interviewing for fellowship?
    a. Yes
    b. No
26. If yes, what was the context?
    a. Bullied
    b. Harassed
    c. Sexually Harassed
    d. Other
27. Did you ever feel sexually harassed, bullied, or discriminated against (bullied, harassed, sexually harassed) when pursuing/interviewing for fellowship?
    a. Yes
    b. No
28. If yes, what was it pertaining towards?
    a. Significant other/partner
    b. Marital status
    c. Pregnancy plans
    d. Maternity leave
    e. Other
influence their choice, either at the time or in the future? Did they have a significant other that influenced their choice? Did physical aspect of a specialty influence their choice, for example standing for cases, sitting for cases, case duration, and perception of strength? Did lifestyle or desired practice setting influence their choice, for example full time, part time, private practice, hospital employed, academic. Did their location influence their choice, for example close to family/friends, familiarity, or climate. Or did the process of fellowship influence their choice? Were they ever discriminated against when pursing a fellowship or interviewing for a fellowship, for example bullied, harassed, or sexually harassed.

The survey was emailed to RJOS members in July 2019. Members of RJOS were given the opportunity to complete the survey up to 6 weeks. The data was then collected through SurveyMonkey analysis.

**RESULTS**

The survey was completed by 252 members of RJOS between July-September 2019. Of the 252 responses, 94% did a fellowship and 19% of those individuals did a second fellowship (Figure 2).

For the demographics, 20% were between 30-34 years old, 31% 35-39 years old, 15% 40-44 years old, and 34% were 45+. 84% of the respondents were Caucasian, 7% Asian or Asian American, 4% Hispanic/Latino, 2% African American, and 3% chose “another race”.

70% of the respondents were married, 17% single (never married), 8% divorced, 4% in a domestic partnership, and 1% widowed. 7% of the women served in the military at some point in time.

88% of the respondents are working full time. 22% are working private practice, 16% are hospital employed and 42% are in an academic practice.

Overall 62% chose their fellowship based on their enjoyment of the sub specialty, with 67% of the women making their decision as a PGY 3/4 during residency. 17% felt it was desirable for the job market and 12% felt they needed additional training in their chosen fellowship. The most popular choice of fellowship was hand 23% and pediatrics 22%, and the least was spine 2% (Figure 3).

The 19% of females that chose to do a second fellowship completed a shoulder and elbow (40%) or oncology (36%) fellowship initially. 20% of the shoulder and elbow trained completed a second fellowship in hand and 15% of those completing an oncology fellowship did a second fellowship in adult reconstruction or pediatrics.

Only 21% were influenced by a female role model, 15% of which were a female attending. Therefore 79% were not influenced by a female role model at any stage during their training. When making their fellowship choice, 92% were not influenced by a significant other, 85% were not influenced by wanting children or a family, and 96% were not influenced by being pregnant or planning on being pregnant.

Overall 81% were not influenced by their desired practice setting or type. 67% were not influenced by geographic location.

We asked if physical attributes of the specialty contributed to their choice. Overall 2% chose standing for the majority of the case, 9% chose sitting, 16% chose case duration, and 9% chose perception of strength, 64% selected “other” in which the comments the majority of women wrote “no”. Of women who did hand fellowships 29% answered sitting for the majority of the case and 12% perception of strength.
47% were a college athlete (Figure 4). Of the college athletes, 96% did a fellowship and 25% did a sports fellowship. 16% had a family member that was a surgeon (Figure 5). Of the women who had a family member that was a surgeon, 61% were college athletes, 100% did a fellowship with 20% completing a hand fellowship.

Overall, 39% of the respondents had 10+ publications at the time they answered the survey, with 86% of those being women who did an oncology fellowship.

During the fellowship process or interviewing, 18% felt discriminated (bullied, harassed, or sexually harassed). Of the 18%, 83% were women pursuing spine fellowships and stated 50% of their discrimination was from harassment. 39% overall had negative questions asked (marital status or maternity leave) during the interview process, again 83% were women pursuing a spine fellowship, with 33% of the questions asking about a significant other or marital status, 17% asking about pregnancy.

**DISCUSSION**

Why women choose a certain fellowship has not been reported previously. The influences throughout the life of a female orthopedic surgeon differs from the male with the choices they have to make with work/life balance, pregnancy, and family. This has been a hypothesis why women do not apply to orthopedic residencies to begin with. However, our results found these life choices of family, pregnancy, and significant other did not influence their choice of their fellowship specialty. This could be due to the fact a fellowship involves only one year of training.

With 47% of the women being college athletes, it is apparent this is an influence on choosing orthopedics and demonstrates a relationship with a fellowship choice. With 25% of those who responded “yes” to a college athlete did a sports fellowship.

Mentorship from a female was listed as not influential in choosing a fellowship by 79%. It has been widely reported having a female role model is important in choosing a career in orthopedics. Many programs are developed to encourage exposure to females as role models for a career in orthopedics. Yet for fellowship choice, the respondents indicated having a female mentor was not a significant influence in their decision.

It was interesting to see 16% of these women had a family member that was a surgeon. It was not asked what gender the family member was or what specialty they were in, but 100% of these women that had a family member that was a surgeon did a fellowship.

Our survey also brings light to the negative aspect of the fellowship application process for women. 18% felt they were being discriminated against and 39% were asked negative questions related to marital status, pregnancy, or maternity leave. The most common negative questions a study done by Bohl from 1971-2015 were associated with pregnancy (29.7%), raising children (37.9%), and marital status (32.4%) during residency.

Overall, 61.7% of participants were asked an inappropriate question during an interview and only 1.4% were reported the incident to authorities. In a study by Mulchaey, 59.5% reported they experienced bias from co-residents about women having children during residency and 49.5% reported bias from their attendings.

We did not ask if these negative questions/discriminations altered or changed their fellowship choice specialty. With the majority of these women who felt discriminated against or were asked negative questions, they were women who did a spine fellowship (Figure 6). With 2% of women in spine fellowships further research needs to be pursued if this is a causal relationship as to why more women do not pursue spine.

With 94% of these women doing a fellowship and 62% selecting their choice base on pure enjoyment of the subspecialty this may correlate with the findings from Kavolus that intellectual stimulation was one of the major reasons behind selecting a fellowship.
Limitations

Our survey did not break up the responders by age/date they went through their fellowships, therefore fellowship choice could have been altered by when they were pursuing their fellowship. We also only sent the survey to women in RJOS and had 253 responses. Therefore, this may not include all of the female members of RJOS or represent the entirety of all female orthopedic surgeons.

ACKNOWLEDGMENT

Lisa Cannada, MD and members of RJOS, SurveyMonkey Inc.

REFERENCES


9. SurveyMonkey Inc. San Mateo, California, USA www.surveymonkey.com
ABSTRACT

Background: Subspecialty training is a common part of orthopedic surgical training. The factors which influence resident subspecialty choice have important residency design and workforce implications. Our objective was to present survey data gathered from orthopedic residents regarding their fellowship plans and relative importance of factors which influence those plans.

Methods: An anonymous online survey tool was developed and distributed to orthopedic residents through their program directors at academic institutions across the country with orthopedic surgery residency programs.

Results: 227 residents completed the survey. 97% planned to pursue fellowship training after residency. The most common presumptive subspecialties were sports (29.7%), joints (17.3%) and shoulder/elbow (12.8%). The majority of senior residents (57%) reported that their subspecialty choice had changed during residency. When making their choice of subspecialty, residents were most influenced by their experiences working on the subspecialty service in question, their experiences working with a mentor, and intellectual interest. The factors influencing their choice were affected by gender, residency year and presumptive subspecialty.

Conclusions: The most critical factors influencing subspecialty choice of orthopedic residents included experiences in rotations as a resident, intellectual interest and mentors in certain subspecialties. Factors influencing subspecialty choice changes over the course of residency and differ between male and female residents. This information may be useful for residency design, mentorship structuring, career counseling and for addressing subspecialty surpluses or shortages which arise in the future.

Level of Evidence: IV

Keywords: education, subspecialty, fellowship, residency, orthopaedic surgery

INTRODUCTION

Fellowship is an important and common part of modern orthopedic surgical training. In recent decades there has been a sharp increase in the proportion of orthopedic residents pursuing postgraduate subspecialty training; as it stands, over 90% of orthopedic residents plan to complete at least one year of fellowship.1-4

Because fellowship training is so prevalent in orthopedics and so influential on the future practice of orthopedic trainees, it is important to understand the factors which influence residents when choosing a subspecialty. This information has implications for residency curriculum design, mentorship structuring and career counseling. On a broader scale, understanding the factors which influence residents while making their choice of fellowship training is the first step in addressing potential shortages of surgeons in particular subspecialties.

Here we present survey data gathered from orthopedic residents regarding their fellowship plans and the relative importance of the factors which influence those plans. We analyze this data as a whole, based on year in training, and based on likely subspecialty of choice.

METHODS

Survey

A survey was designed and built using SurveyMonkey software (SurveyMonkey, San Mateo, CA). The survey gathered basic demographic information including gender, year in residency, and information regarding plans for fellowship. Additionally, the survey included fourteen factors which could potentially influence choice of subspecialty (Figure 1). Respondents were asked to rate the importance of each factor in their decision-making on a five point Likert scale, with one point representing “Not At All Important” and five points representing “Very Important”.

1McGaw Medical Center of Northwestern University Department of Orthopedic Surgery, Chicago, IL 60661
Corresponding Author: Bennet A. Butler; Phone: (267) 337-3179; Email: bennet-butler@northwestern.edu
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Sources of Funding: No sources of funding declared.
Distribution of Survey

The survey was distributed to 196 orthopedic residency programs directors through the American Orthopaedic Association with instructions to distribute the survey to their residents. Participation in the survey was completely voluntary, with no reward for participation offered.

Statistics

Continuous variables are reported as mean ± standard deviation. Categorical variables are reported as counts and percentage of whole. Continuous variables were compared with a student t-test. Categorical variables were compared with Pearson chi-square tests. Multiple continuous variables are compared with an analysis of variance and a post hoc Tukey Honest Significant Difference test. Alpha level was set at p<0.05. All data and statistical analyses were performed using JMP Pro (version 13.0, SAS, Cary, NC).

RESULTS

Demographics

227 orthopedic residents representing all postgraduate years (PGY1-5) responded to the survey and were included in final analysis. 19% of respondents were female. 97% responded yes, 3% responded unsure, and <1% responded no when asked whether they planned to pursue fellowship training. 5.8% of respondents planned on pursuing multiple fellowships (Table 1).

Subspecialty Choice and Confidence Level

Overall, the most common fellowship choice was Sports (29.7%), followed by Joints (17.3%) then Shoulder/Elbow (12.8%) (Table 2). When asked how sure they were that they would eventually apply into the subspecialty they listed on the survey, the plurality of PGY1s responded “25-50% sure”, the plurality of PGY2s responded “50-75% sure”, the plurality of PGY3s responded “>75% sure” and the vast majority of PGY4s and PGY5s were fully set on their subspecialty choice. 57% of senior residents (PGY4s and PGY5s) responded that their presumptive subspecialty of choice had changed during residency (Table 1).

Factors Influencing Choice of Subspecialty

Overall, the most important factors to respondents when choosing a subspecialty were “experiences as a resident on the subspecialty in question”, followed by “intellectual interest” then “experiences with a mentor working in that subspecialty”. The least important factors were “desire to work in an academic setting following fellowship”, “influence of family or significant other” and “experiences as a medical student on the subspecialty in question”. (Table 3)

With regard to gender, males placed significantly more importance on “earning potential/salary” (p = 0.01), while

Table 1. Post-Residency Plans by PGY Level

<table>
<thead>
<tr>
<th>Factor</th>
<th>PGY1 (N= 62)</th>
<th>PGY2 (N = 36)</th>
<th>PGY3 (38)</th>
<th>PGY4 (55)</th>
<th>PGY5 (36)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Male</td>
<td>80%</td>
<td>81%</td>
<td>84%</td>
<td>82%</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>20%</td>
<td>19%</td>
<td>16%</td>
<td>18%</td>
</tr>
<tr>
<td>Are you planning on pursuing fellowship</td>
<td>Yes</td>
<td>90%</td>
<td>97%</td>
<td>97%</td>
<td>100%</td>
</tr>
<tr>
<td>training after residency?</td>
<td>No</td>
<td>2%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>Unsure</td>
<td>8%</td>
<td>3%</td>
<td>3%</td>
<td>0%</td>
</tr>
<tr>
<td>Are you planning on completing multiple</td>
<td>Yes</td>
<td>5%</td>
<td>14%</td>
<td>8%</td>
<td>2%</td>
</tr>
<tr>
<td>fellowships after residency?</td>
<td>No</td>
<td>58%</td>
<td>56%</td>
<td>71%</td>
<td>82%</td>
</tr>
<tr>
<td></td>
<td>Unsure</td>
<td>37%</td>
<td>30%</td>
<td>21%</td>
<td>16%</td>
</tr>
<tr>
<td>If you are currently unsure of which fellow-</td>
<td>&lt;25%</td>
<td>9%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>ship you will pursue, what is the likeli-</td>
<td>25-50%</td>
<td>35%</td>
<td>26%</td>
<td>6%</td>
<td>0%</td>
</tr>
<tr>
<td>hood that you will eventually apply for the</td>
<td>60%</td>
<td>40%</td>
<td>23%</td>
<td>2%</td>
<td>0%</td>
</tr>
<tr>
<td>fellowship you listed?</td>
<td>&gt;75%</td>
<td>27%</td>
<td>20%</td>
<td>46%</td>
<td>9%</td>
</tr>
<tr>
<td></td>
<td>100%</td>
<td>13%</td>
<td>6%</td>
<td>23%</td>
<td>89%</td>
</tr>
<tr>
<td>Has your fellowship of choice changed since</td>
<td>Yes</td>
<td>18%</td>
<td>39%</td>
<td>47%</td>
<td>60%</td>
</tr>
<tr>
<td>your residency training began?</td>
<td>No</td>
<td>82%</td>
<td>61%</td>
<td>53%</td>
<td>40%</td>
</tr>
</tbody>
</table>
females placed significantly more importance on "desire to work in an academic setting following fellowship" (p = 0.01), "intellectual interest" (p = 0.01) and "patient interactions on subspecialty service in question" (p < 0.01).

With regard to subspecialty choice, a number of interesting differences were observed. For one, respondents interested in Spine and Joints placed significantly more importance on "earning potential/salary" than respondents interested in Hand and Pediatrics (p < 0.01). Additionally, respondents interested in Sports, Hand, Shoulder/Elbow and Joints placed significantly more importance on "lifestyle" than respondents interested in Trauma, Pediatrics and Spine (p < 0.01). Finally, respondents interested in Sports placed significantly more importance on "life experience outside of medicine" than residents interested in other fields (p < 0.01) (Table 4).

With regard to PGY level, seniors residents placed significantly more importance on "technical challenge/difficulty of subspecialty" (p = 0.03) and "experiences as a resident in the subspecialty in question" (p < 0.01) than junior residents. Junior residents placed significantly more importance on "experiences as a medical student on the subspecialty in question" (p = 0.03) than senior residents (Table 5).

**CONCLUSION**

In recent decades, the prevalence of fellowship training in orthopedics has increased substantially. A study by Emery et al. in 2012 found that over 90% of orthopedic residents pursued additional subspecialty training after residency compared to approximately 60% of residents in the 1990s. This finding was confirmed in additional studies by Horst et al. and Cannada et al. in 2013 and 2015, respectively. Daniels et al. found that as of 2011 there were more available fellowship positions than graduating fellows, suggesting that subspecialty choice is influenced more by resident priorities than by workforce needs. This has important implications for the future of the field as a whole; Salzberg et al. noted that "the problem may not be that we have a shortage of orthopedic surgeons, but rather... an oversupply of surgeons in some subspecialties and an undersupply in others."6

Currently, the factors which influence resident subspecialty choice are poorly understood. There are numerous studies which have looked at the factors which influence medical students when choosing a residency.7 9 Other studies have analyzed the factors which influence orthopedic residents when differentiating fellowship programs within their chosen subspecialty.10,12 Fewer studies have attempted to assess the factors which influence orthopedic residents when choosing a subspecialty. Kavolus et al. noted that intellectual stimulation and variety of cases were important when choosing a subspecialty, while research potential and residency tradition were not.13 A follow up study by the same group found that senior residents tended to place greater importance on intellectual stimulation and variety of cases than junior residents, who were more concerned with geographic considerations, on call duties and financial compensation.14 Hariri et al. also found that intellectual factors were the most important deciding factor for residents choosing a subspecialty.4

Our study supports and expands on these previous studies. As in those studies, respondents to our survey listed "intellectual interest" as the most important factor overall when choosing a subspecialty. Our data also supports the critical role that resident rotations ("experiences as a resident in the subspecialty in question") and mentorship ("experience with a mentor working in that subspecialty") play in the decision-making process.

<table>
<thead>
<tr>
<th>Table 2. Presumptive Fellowship Choice</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>N</strong></td>
</tr>
<tr>
<td>Sports</td>
</tr>
<tr>
<td>Joints</td>
</tr>
<tr>
<td>Shoulder/Elbow</td>
</tr>
<tr>
<td>Hand</td>
</tr>
<tr>
<td>Spine</td>
</tr>
<tr>
<td>Trauma</td>
</tr>
<tr>
<td>Pediatrics</td>
</tr>
<tr>
<td>Foot &amp; Ankle</td>
</tr>
<tr>
<td>Oncology</td>
</tr>
</tbody>
</table>

**note**- one respondent did not plan on attending fellowship

**Table 3. Overall Importance of Factors**

<table>
<thead>
<tr>
<th><strong>Factors</strong></th>
<th><strong>Average</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Earning potential/salary</td>
<td>3.15</td>
</tr>
<tr>
<td>Lifestyle</td>
<td>3.96</td>
</tr>
<tr>
<td>Ease of finding a job</td>
<td>3.42</td>
</tr>
<tr>
<td>Desire to work in an academic setting following fellowship</td>
<td>2.37</td>
</tr>
<tr>
<td>Desire to work in a private practice setting following fellowship</td>
<td>2.80</td>
</tr>
<tr>
<td>Intellectual interest</td>
<td>4.00</td>
</tr>
<tr>
<td>Technical challenge/difficulty of subspecialty</td>
<td>3.66</td>
</tr>
<tr>
<td>Patient interactions on subspecialty service in question</td>
<td>3.89</td>
</tr>
<tr>
<td>Experiences as a medical student on the subspecialty service in question</td>
<td>2.67</td>
</tr>
<tr>
<td>Experiences as a resident on the subspecialty in question</td>
<td>4.03</td>
</tr>
<tr>
<td>Experience with a mentor working in that subspecialty</td>
<td>3.98</td>
</tr>
<tr>
<td>Extent of exposure to subspecialty in medical school/residency</td>
<td>3.55</td>
</tr>
<tr>
<td>Life experience outside of medicine</td>
<td>3.33</td>
</tr>
<tr>
<td>Influence of family or significant other</td>
<td>2.43</td>
</tr>
</tbody>
</table>

**Scoring Guide**

1- Not at All Important, 3- Somewhat Important, 5- Very Important
From a residency design perspective, this suggests that program directors should aim to expose their junior residents to a wide range of subspecialties and potential mentors before they’ve made their subspecialty choice. Furthermore, our data shows that the subspecialty decision remains malleable even in the 3rd year of residency, and that the relative importance of the factors influencing this decision changes over the course of residency. As such, program directors should continue to provide career counseling to residents regarding their subspecialty options until at least their PGY4 year, with a focus on how new experiences and changing priorities may have changed their presumptive fellowship choice.

Finally, this data provides a foundation for influencing the fellowship decisions of residents as a whole to address any surpluses or shortages of surgeons in specific subspecialties. This could be accomplished primarily by dispelling misconceptions which may exist about particular subspecialties. For example, respondents to our survey interested in Sports, Shoulder/Elbow, Hand and Joints placed significantly more importance on “lifestyle” than respondents interested in Trauma, Pediatrics or Spine. In our opinion, “lifestyle” is more dependent on practice structure and individual surgeon rather than...
any individual subspecialty. Ensuring that residents understand this could potentially address a source of disparities in fellowship application numbers.

Our study has a number of limitations. For one, our data was collected through a voluntary survey, creating the potential for both sampling and response bias. Additionally, analyzing any decision making process is difficult due to their inherent complexity. While we attempted to comprehensively list the factors involved in the subspecialty decision, we almost certainly missed factors which were important to some or many respondents. The factors we did include were left somewhat broad for the sake of comprehensiveness, but this possibly created room for misinterpretation of their meaning on the part of respondents. This is an important topic, which we feel warrants further study. In particular, as fellowship applications become more competitive, it would be interesting to see if residents are making, and potentially feeling locked into, their subspecialty decision at an earlier time point in their training.

REFERENCES

ABSTRACT

Background: Many orthopedic surgeries involve the challenging integration of fluoroscopic image interpretation with skillful tool manipulation to enable procedures to be performed through less invasive approaches. Simulation has proved beneficial for teaching and improving these skills for residents, but similar benefits have not yet been realized for practicing orthopedic surgeons. A vision is presented to elevate community orthopedic practice and improve patient safety by advancing the use of simulators for training and assessing surgical skills.

Methods: Key elements of this vision that are established include 1) methods for the objective and rigorous assessment of the performance of practicing surgeons now exist, 2) simulators are sufficiently mature and sophisticated that practicing surgeons will use them, and 3) practicing surgeons can improve their performance with appropriate feedback and coaching.

Results: Data presented indicate that surgical performance can be adequately and comparably measured using structured observations made by experts or non-expert crowds, with the crowdsourcing approach being more expedient and less expensive. Rigorous measures of the surgical result and intermediate objectives obtained semi-automatically from intra-operative fluoroscopic image sequences can distinguish performances of experts from novices. Experience suggests that practicing orthopedic surgeons are open to and can be constructively engaged by a family of mature simulators as a means to evaluate and improve their surgical skills.

Conclusions: The results presented support our contention that new objective assessment measures are sufficient for evaluating the performance of working surgeons. The novel class of orthopedic surgical simulators available were tested and approved by practicing physicians. There exists a clear opportunity to combine purpose-designed simulator exercises with virtual coaching to help practicing physicians retain, retrain, and improve their technical skills. This will ultimately reduce cost, increase the quality of care, and decrease complication rates.

Clinical Relevance: This vision articulates a means to boost the confidence of practitioners and ease their anxiety so that they perform impactful procedures more often in community hospitals, which promises to improve treatment and reduce the cost of care while keeping patients closer to their homes and families.

Keywords: surgical skills training, performance assessment

INTRODUCTION

The manner in which orthopedic surgical skills are trained and assessed is rapidly changing. New training methods, higher quality simulators, public health concerns, and a mandate from certifying bodies have together catalyzed the structured teaching of surgical skills outside of the operating room (OR) across surgical specialties. Unfortunately, the ubiquitous Halstedian model of training is stymied by limited resources for the evaluation of technical competency. Worse, existing evaluation methods may be flawed; suffering from bias, impractical for high-volume use, and of unverified accuracy. Programs routinely credential surgeons for procedures they have never done. Self-reported caseloads are inconsistent across institutions, and caseload or academic rank provide imperfect measures of true technical skill.
Compared to residency training, the adoption of simulation in the larger community of practicing surgeons has lagged behind. This is an important missed opportunity. Surgeons with lower technical skills demonstrate a 5x higher mortality rate, 3x higher complication rate, and 29% longer operative time compared to top-quartile technical skills performers. Indeed, with over 135,000 surgeons performing 51,000,000 procedures in the U.S. each year, identifying surgeons at high risk for poor patient outcomes and providing them with targeted coaching is an acute, high-priority need.

Community practitioners could benefit from targeted training. In orthopedics, common fracture surgeries, such as the operative reduction of articular fractures and pinning of pediatric elbow fractures, are too often referred from community practitioners to tertiary care centers or treated using out-of-date techniques. In fact, the skill required to pin a pediatric elbow fracture is among those with the lowest self-reported competence among orthopedic surgeons, despite elbow fractures accounting for approximately 8% of all pediatric fractures. This presents an opportunity for simulation and coaching to improve the community practice of orthopedic trauma surgery. At the nexus of this opportunity is the skillful use of fluoroscopy, which enables surgical procedures to be performed through less invasive approaches. Less invasive approaches reduce the risk of wound complications, lead to quicker recovery times, and improve patient comfort, all while ensuring comparable results, at least for experts.

Unfortunately, not all orthopedic surgeons are adept with the skills that enable these less invasive approaches, and others lack the confidence to utilize them. Two target surgeries are emblematic: articular fractures of the distal tibia and pediatric supracondylar humerus fractures. Complex articular fractures require precise reduction to achieve optimal outcomes. These surgeries have historically been done through extensile open approaches that risk further trauma to compromised soft tissues. More limited approaches are associated with fewer complications, but they rely heavily on fluoroscopic guidance and skillful reduction maneuvers. Similarly, when treating a pediatric supracondylar humerus fracture, a surgeon aims to restore pre-injury position and alignment. Then K-wires are placed across the fracture site to help maintain alignment until the fracture heals, while protecting the growth plate in these young children. Supracondylar humerus fractures are the most common pediatric fracture treated surgically worldwide. Their treatment requires skill that takes time and concerted effort to master. Many community surgeons do not feel competent to perform this surgery. This leads to referrals that delay care, and it also costs more to be treated at a tertiary care facility than at a community hospital.

We propose that the coupling of simulation with virtual coaching provides a unique opportunity to facilitate retaining, retraining, and improving the technical skills of practicing surgeons, which can reduce the cost of care, increase its quality, and decrease complications. In the following we present the rationale and arguments for the potential of this approach and a path forward. This vision to improve the community practice of orthopedic trauma surgery builds upon three recent fundamental advancements. First, unique and rigorous analysis approaches for modeling and assessing surgical skill based upon fluoroscopic sequences and/or video collected in the OR have been developed. Second, simulators that incorporate technologies mixing physical realism with synthetic fluoroscopy images have been shown to be effective, and they capture exciting and attractive technical targets for practicing surgeons. Finally, the simulators and assessment procedures facilitate virtual coaching that leverages scientifically-supported formative and summative feedback approaches imbedded with a deep understanding of successful surgical behaviors.

METHODS
Assessment Techniques are Ready to Measure the Skill Level of Practicing Surgeons

Most technical skills assessment methods employ video-based evaluation by expert surgeons utilizing survey instruments based on the Objective Structured Assessment of Technical Skills (OSATS). In bariatric surgery, OSATS scores have been shown to correlate with patient outcomes, but this correlation has not been well studied in orthopedics. Structured survey instruments such as OSATS are subject to confirmation bias in expert ratings, and OSATS scores fail to correlate with surgical results measured in a laboratory setting.

A key challenge to establishing simulator skill transfer to the OR is finding a way to objectively measure OR performance. We have pioneered a technique analyzing surgical behavior from fluoroscopic image sequences. Our experience has shown that important insights can be extracted from a surgical fluoroscopic image sequence, including details of surgical strategy, surgical skill, and the quantitative assessment of the final implant placement. One challenge in obtaining these insights involves collecting detailed measurements from as many as 150 images in a sequence for a long or complex surgery.

To address this challenge, we developed a semi-autonomous process involving artificial intelligence and customized image analysis software. The software speeds
Using Simulation and Virtual Coaching to Improve the Community Practice of Orthopedic Trauma Surgery

the sequence analysis so that dozens of surgical images can be analyzed by a non-surgeon in minutes, rather than days. The original implementation was tailored toward analyzing fluoroscopic sequences of a guide wire being placed during intertrochanteric hip fracture reduction and fixation. The analysis provides the wire entry-point, the actual wire trajectory versus that desired, the duration of the surgical step, the number of images collected, and the tip-apex distance (TAD). A large TAD is a strong predictor of later implant failure. For this reason, a central surgical objective is to minimize the TAD, but it can come at the cost of substantial fluoroscopic radiation and additional operative time when skills are poorly developed. The details extracted from these OR images has proven useful in distinguishing expert from novice performance.

A more recent adaptation of the software analyzes the pinning of pediatric supracondylar humerus fractures (Figure 1). We are extending the software to analyze the reduction and fixation of distal tibia fractures, as well. This semi-automated analysis approach has yielded powerful quantitative, repeatable insight into surgeon behavior that allows us to assess skill in new ways. The technique is also uniquely suited to compare performance in simulation and in the OR. Finally, the technique provides insights that lead directly to timely formative feedback, because analysis at the decision-making level captures each step of a surgical procedure.

Another problem with OSATS video evaluation methods is that they are impractical for widespread use, largely due to the excessive time burden demanded of experts or faculty raters. This motivated the pioneering use of “crowds” of non-expert raters to provide inexpensive evaluations that proved statistically concordant with expert ratings, obtaining thousands of ratings at unprecedented speeds. This method has come to be called crowd-sourced assessment of technical skill (CSATS). Unlike expert raters, ratings aggregated from non-expert crowds are fast (available within hours of video upload), scale to practically unlimited numbers of ratings, and are available for repeated ratings around the clock at near-minimum wage. Further, CSATS ratings prove statistically favorable compared to typical panels of experts or faculty and correlate well to patient outcomes.

Simulator Technologies Are Ready for Practicing Surgeons

The key to developing an effective simulator is understanding and defining specific educational objectives and the manner in which performance is measured. Properly used, simulators can be more effective than traditional training approaches. They are also useful for identifying skill performance issues. Thus, simulation makes an attractive target for assessing, training, and retraining the skills of practicing surgeons.

Our group has developed and tested simulators for navigating surgical wires using fluoroscopic guidance and for reducing fractures through limited open incisions, two common and difficult skills in orthopedic surgery. These simulators feature replaceable, plastic foam bones and
These experiences with practicing surgeons suggest that a comparative performance assessment or training goal. We initially developed this platform to simulate the navigation of a wire in the treatment of intertrochanteric hip fractures. After several years of development and testing, this hip fracture wire navigation simulator\cite{19} is currently under study by the American Board of Orthopaedic Surgery (ABOS) and is used twice annually as part of resident fracture courses offered by the Orthopaedic Trauma Association (OTA). Seeking to get more data from advanced users, we tested at the OTA Trauma Fellows course in 2019, observing the performance of 30 fellows near the pinnacle of their surgical training in orthopedic trauma. We have demonstrated that the platform is extensible to other relevant orthopedic applications,\cite{20} including the pinning of a pediatric supracondylar humerus fracture (Figure 3).\cite{26}

Our team has also recently developed an articular fracture reduction simulator to help train more limited surgical approaches that are associated with faster recovery and fewer complications (Figure 4).\cite{21,22} This is accomplished through an electromagnetic system that provides real-time tracking of surgical tools and artificial fracture fragments buried in a soft tissue model. The system provides quantitative feedback on 17 different performance metrics including novel features, such as a summative snapshot of fracture displacement over time.

Although each of these simulators was initially developed for training residents, we have begun to use them to assess experienced surgeons, typically to provide a comparative performance assessment or training goal. These experiences with practicing surgeons suggest that the simulators are capable of distinguishing skill levels among practicing surgeons and that surgeons find the experience challenging and enjoyable, as described in the results section.

**Simulator Training is Likely to Improve Performance**

Constructive feedback strategies are essential for effective skill training and performance improvement,\cite{28,29} but different types of feedback are more or less effective at different stages in skill mastery. Formative feedback is information provided to the learner during an educational exercise to modify behavior and improve learning.\cite{30} In general, timely detailed formative feedback is most effective for early training stages, and delayed, summative feedback is more effective for later retaining, retraining, and improving performance. Experienced surgeons may find immediate, detailed, formative feedback frustrating. For instance, the formative feedback currently provided with the wire navigation simulator includes recommendations such as “drop your hand” or “shift the wire angle 5° distally.” This level of detail, effective for novice residents, projects a presumed procedural approach for which an experienced surgeon may have developed their own effective and appropriate alternative strategies.

Summative feedback, often more effective for advanced learners, provides information about the results of an entire procedure that is generally intended to provide the basis of comparison with peers or an external standard.\cite{31} Our articular fracture reduction simulator currently emphasizes summative feedback on the duration and the precision of the fracture reduction, for example. Summative feedback is typically provided upon completion of the procedure, but intermediate extrapolation can be used to project some elements of performance, like reduction quality. This type of feedback can be useful for someone who is fine-tuning details of their approach as they integrate the tradeoffs between different steps of a procedure. However, if the learner is unclear on appropriate strategies to achieve particular intermediate goals, summative feedback can be less effective than formative feedback.
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There are many ways to provide feedback and not all are equally helpful. For example, providing an explanation for why an answer was wrong is 50% more effective than providing the right answer and 10 times more effective than saying that a given answer was incorrect. The Interactive Tutor Model is one approach to understanding the diversity of factors that affect feedback design in order to produce effective feedback. This model depends on a close match between the learner and the instructors’ understanding of the objectives and intermediate goals. With a loosely defined surgical task, different surgeons may approach the task with different strategies, all equally acceptable. If the feedback presumes one goal when the surgeon is appropriately choosing another, it may decrease the surgeon’s trust in the automated feedback, weakening its effectiveness.

RESULTS

The following sections summarize data from various experiments that we have conducted over the past decade supporting the three foundational arguments that underlie the vision of expanding simulation training to practicing surgeons.

Assessment Techniques Can Measure Transfer of Training

The predominant assessment techniques have important flaws. Surgical assessment approaches have assumed that faculty ratings are the most reliable measure of performance and identity-blind video ratings are the “gold-standard” for assessment. But mounting evidence suggests that both approaches are flawed. Experts appear to reward speed over technical accuracy. Preliminary results suggest that expert raters’ expectations of a surgeon’s technical skill based on expertise/reputation do not agree with their own scores assigned based upon anonymized video. When two faculty coders reviewed 56 anonymized videos of benchtop laparoscopic exam tasks, they identified 30 as below average competency or non-competent. They were not told that these were videos of surgeons whom they had just nominated as “experts” by reputation or academic rank. The crow-sourcing approach provided an inexpensive and expeditious method for analyzing surgical performance both with simulators and in the OR. Another objective assessment method links performance to specific surgical behaviors.

We evaluated the transfer of training on the wire...
navigation simulator in both a mock OR and in the actual OR (Figure 6). This allowed us to begin to differentiate performance improvements caused by simulator training from those that accrue with experience. We define consistent measures that are common to both the simulator and the actual OR. For example, residents were assessed in the mock OR based on their use of fluoroscopy, total time, and TAD. Residents that trained on the simulator had a lower TAD than those who did not (p = 0.001), and their performance on the simulator (i.e., TAD, image use, and overall time) was correlated with performance in the mock OR. This assessment approach was clearly sufficient to measure the performance gain achieved by residents with some focused training, but as the next section will demonstrate, it was also sufficient to distinguish different cohorts of experts.

Simulators are Ready for Practicing Surgeons

In addition to the numerous tests with first- and second-year residents, in November 2019 we attended the Hennepin Orthopaedic and Trauma Seminar in Minneapolis to gather data on the performance of community orthopedic surgeons. After orientation to the simulator, 17 community surgeons completed three assessments with the hip fracture wire navigation. We compared the practicing surgeons’ performance with that of a cohort of residents we previously studied. Figure 7 illustrates normalized composite scores on the wire navigation. In this admittedly limited sample of community surgeons, we found their performance to be on average better than the residents, but there was a broad distribution of performance amongst both residents and community surgeons. Subjective rating questionnaires and informal interviews with the practicing surgeons confirmed that they felt the simulation was interesting, sufficiently realistic and challenging for practicing surgeons.

Results with the fracture reduction simulation promise even greater interest among practicing surgeons. Figure 8 presents performance results comparing an expert and a novice reducing a distal tibia fracture on the fracture reduction simulation. Although both surgeons achieved an acceptable final reduction (<2mm), the unique in-the-moment summative feedback provided by the simulator (Figure 8a) clearly demonstrates how the novice struggled in achieving their result, unnecessarily manipulating the fragment by moving it cumulatively 158 mm more than the expert. This line of inquiry also indicates that experienced surgeons utilize tools more efficiently during fracture reduction (Figure 8b). The novice surgeon lacked an understanding of proper tool placement to assist in the reduction, instead relying on an iterative method where they continuously attempted to replace their tool in equally ineffective locations, in all contacting the bone over a 517% larger area than the expert. As experts have attested when using the simulator, the unique, performance-specific feedback from the simulator is particularly helpful, because it provides viewpoints and measures that cannot be replicated in the OR environment. This provides practicing surgeons with the opportunity to reflect on their performance with a new perspective, offering new insights.

Training is Likely to Improve the Skills of Practicing Surgeons

In the course of our work defining performance assessment metrics, we found limitations in the use of simple “final result” measures (e.g., the TAD) that do not account for in-the-moment decision-making that is a hallmark of performance. We came to recognize that it is precisely during these moments of what we have come to call micro-decisions, that there is a unique opportunity to teach. In response, we surveyed performance as reflected by the series of fluoroscopic images, and defined a short list of five errors we routinely observed, such as when a
novice adjusts the wire in the wrong direction, or over compensates for an alignment error, or switches from the antero-posterior to the lateral view inappropriately. These clearly indicate errors in judgment that can be readily detected, and each error has an unambiguous corrective behavior that can be taught.

For the application in the hip, we have defined a composite score that includes the TAD metric, the number of decision errors made, and the average angle of the wire movement errors. Each metric was first normalized based on the overall population. A higher composite score indicates better performance. A score that is equal to zero would indicate that it matches perfectly with the average performance across all subjects. Our studies with residents have supported the idea that relevant surgical experience correlates with performance on the simulator. This shows the value of considering the behavior at the micro-decision level and also strengthens our ability to distinguish expert from novice performance.

The advantage of this micro-decision analysis framework, as well as the other objective performance measures, is that they provide benchmarks against which a specific performance can be assessed. This benchmarking strategy allows us to provide specific, timely feedback to surgeons as they work or immediately afterwards. Subjective ratings by experts and crowdsourced assessments do not always provide such direct feedback. When timely, specific feedback is provided, it naturally results in improved performance.

### DISCUSSION

The results presented support our contention that the current assessment methods are sufficient for measuring the performance of working surgeons. We demonstrated the advantages of two approaches: wire position analysis and crowd sourcing. Figure 7 demonstrates that the simulator assessment approach can distinguish skill levels between a cohort of residents and practicing surgeons. It is important to remember that reliably measuring the performance of a single individual is more difficult, however, than measuring group characteristics. We did not yet demonstrate how much testing is required to quantify an individual as having sufficient skill. Measuring performance with repeated exercises will enable such an assessment. Providing a variety of exercises will make the activity more enjoyable and the measurement more robust. Overcoming the vagaries of bias and the challenge of noisy measurements was an essential obstacle for objectively measuring performance level and performance gains, which are both essential for training practicing surgeons.

The novel class of orthopedic surgical simulators we have developed were tested and approved by practicing physicians. The successful adaptation of the hip wire navigation simulator to pediatric elbow and iliosacral screws indicates that the simulators can be adapted as needed to create training environments that are clinically relevant and intellectually demanding for practicing physicians. Novel summative performance assessment provided by the fracture reduction simulator promises to open new opportunities for training and assessment that is not possible in the OR nor with typical cadaver exercises. The informal feedback and enthusiasm of practicing physicians who work with the simulators suggests that the simulator technology is ready for the next step.

Finally, the micro-decision analysis and quantitative analysis approaches to feedback generation make excellent input for a virtual coach. The micro-decision analysis can provide important observations of specific moments that a practicing surgeon could use to further refine his or her performance. The analytic analysis of the whole performance provides an opportunity for practicing surgeons to gain insights into their performance that go beyond the more rigidly defined decision analysis. The feedback is ready for practicing surgeons.

Our research approach leverages existing relationships with a regional consortium of residency programs, the ABOS, and the OTA. We have begun to expand our reach to include statewide Orthopedic Societies in Iowa and Minnesota, as well as an annual orthopedic and trauma seminar run in Minneapolis. This will allow us to extend our experience with recruiting and training hundreds of residents to the relatively new challenge of working with

Figure 8. (a) Fracture reduction accuracy (step-off) over time (seconds). Vertical red lines indicate the reduction period of a mock surgery. Compared to an expert (left), the novice (right) showed a large amount of fragment manipulation. Note the time scaling is compressed in the novice performance to fit. (b) Heat maps of tool and fragment interaction points. Blue = no interaction, yellow = an interaction lasting longer than 1.5 seconds. The tool-fragment interaction of the expert (left) differed notably from that of a novice (right).
community practitioners. The work promises to extend our insight into how expertise is manifested and can be measured in the OR, how that can be compared with behaviors observed during simulated surgeries, what type of feedback is effective in simulation, and how this knowledge can be integrated into a virtual coach to make surgery more effective.

Efforts are already underway to refine our existing simulators so that they effectively allow working surgeons to practice their skills in a manner that will enable them to retain, retrain, or improve their performance. More generally, the simulators will improve skill in the broader area of navigating surgical wires with fluoroscopic guidance. The work will permit surgeons to rehearse these technical skills before further exercising them on live patients in the high-stakes atmosphere of the OR. The methods derived will boost the confidence of practitioners and ease their anxiety with performing these procedures in community hospitals, which will improve treatment and reduce the cost of care while keeping patients closer to their homes and families. We expect to demonstrate the clinical benefits of the surgical simulator and virtual coaching by increasing the number of procedures done by practitioners in their community hospital settings.

REFERENCES


ABSTRACT
Background: Early detection of diabetic foot ulcers can improve outcomes. However, patients do not always monitor their feet or seek medical attention when ulcers worsen. New approaches for diabetic-foot surveillance are needed. The goal of this study was to determine if patients would be willing and able to regularly photograph their feet; evaluate different foot-imaging approaches; and determine clinical adequacy of the resulting pictures.

Methods: We recruited adults with diabetes and assigned them to Self Photo (SP), Assistive Device (AD), or Other Party (OP) groups. The SP group photographed their own feet, while the AD group used a selfie stick; the OP group required another adult to photograph the patient’s foot. For 8 weeks, we texted all patients requesting that they text us a photo of each foot. The collected images were evaluated for clinical adequacy. Numbers of (i) submitted and (ii) clinically useful images were compared among groups using generalized linear models and generalized linear mixed models.

Results: A total of 96 patients consented and 88 participated. There were 30 patients in SP, 29 in AD, and 29 in OP. The completion rate was 77%, with no significant differences among groups. However, 74.1% of photographs in SC, 83.7% in AD, 92.6% in OP were determined to be clinically adequate, and these differed statistically significantly.

Conclusions: Patients with diabetes are willing and able to take photographs of their feet, but using selfie sticks or having another adult take the photographs increases the clinical adequacy of the photographs.

Level of Evidence: II
Keywords: photograph, foot ulcer, m-health, texting, SMS, remote monitoring

INTRODUCTION
In the United States, approximately 29 million people have diabetes, and the prevalence of the disease is expected to increase. People with diabetes suffer from many different complications of the disease, but diabetic foot ulcers are a major case of morbidity. In the United States the majority of atraumatic lower extremity amputations are attributable to diabetes, and most are preceded by a diabetic foot ulcer. Diabetic foot ulcers also contribute to substantial excess healthcare costs: one third of the direct healthcare costs generated by diabetes are associated with the treatment of diabetic foot ulcers.

Patients with diabetes have an estimated life-time risk up to 25% of developing a diabetic foot ulcer, and the risk may now be higher. Among people who develop a diabetic foot ulcer, 40% will have a recurrence within a year of the initial ulcer healing. Yet diabetic foot ulcers are largely preventable. Furthermore, early detection of diabetic foot ulcers can help lead to more effective and conservative treatment including debridement and casting. Unfortunately, patients do not always engage in effective foot monitoring and self-care or seek medical attention when ulcers progress. Accordingly, there is a critical need for developing new, more effective approaches to routine foot surveillance, tracking ulcer progression, and detecting pre-ulcerous lesions.

To detect diabetic ulcers sooner, investigators have proposed various home or telehealth assessment approaches to identify foot lesions from photographs. Prior work has validated the diagnosis of various soft-tissue wounds using photographs and proposed software algorithms that allow for the identification of wounds.
However, for remote, photo-based, diabetic-foot-ulcer surveillance approaches to work, patients with diabetes need to be willing and able to take clinically useful photographs of their feet in the home environment.

The purpose of this study was to: (1) determine if patients with diabetes would be willing and able to photograph (using a mobile phone) their feet on a weekly basis; (2) evaluate different approaches for patients to take photographs of their feet; (3) determine the potential clinical utility of foot photographs taken at home; and (4) investigate patient satisfaction with mobile phone-assisted diabetic-foot monitoring.

METHODS

This study was a randomized observational trial approved by our Institutional Review Board. We recruited adults over 21 years of age diagnosed with Type 1 or Type 2 diabetes from our institution's internal medicine clinic. Participants were required to (i) have a mobile phone capable of both taking and texting front-facing “selfie” photographs, and (ii) have another adult living with them who could help take photographs. Patients were excluded if they had (i) a cognitive impairment documented in the medical record, (ii) lack of fluency in speaking or understanding English, or (iii) were pregnant.

To inform how patients should take photographs of their feet, patients were randomly assigned to one of three groups: Self Photo (SP), Assistive Device (AD), or Other Party (OP). The SP group required patients to capture an image of their own feet, while the AD group was instructed to use a selfie stick that we provided to facilitate the process; the OP group required another adult to photograph the patient’s foot (hence the qualifying criteria of living with another adult). A set of 100 random 3-digit numbers were generated without replacement. Each new participant was given the next number on the list. If the number was divisible by three, they were placed in the SP group. If there was a remainder of one when the number had a remainder of two when divided by three, they were placed in the OP group. If the number had a remainder of two when divided by three, they would were placed in the AD group. If there was a remainder of one when the number was divided by three, they would were placed in the AD group, and if the number had a remainder of two when divided by three, they were placed in the OP group. Patients were recruited, consented, enrolled and trained by research assistants.

Patient and Public Involvement

Patients and the public were first involved in this study at recruitment. The research questions and outcome measures were developed by the research team, which consists of experts in orthopedics, infectious diseases, and epidemiology, all of whom have extensive experience working with patients with diabetic foot ulcers. Patients and the public were not involved in the design or conduct of the study, and they were not involved in the dissemination of study results. However, they were asked about the burden of the research. Patients were asked if the process was difficult and if they would be willing to continue to send photos if required.

Procedures

All patients were told to rest their legs on a surface that was no higher than hip height. Patients in the SP group were told to take a picture of the bottom of their foot with a front facing camera such that the heel aligned with the bottom of the captured image (Figure 1A). Patients in the AD group were told to place their phone in the provided selfie stick such that the front-facing camera/screen of phone was perpendicular to the stick and pointing in the direction of the patient’s foot. The patient was told to align their foot and camera in order to capture the entire bottom of the foot in the image with the heel at the bottom of the image (Figure 1B). Patients in the OP group were told to have the patient dorsiflex their foot so that the toes point up towards the ceiling. The other party should then take a picture with their rear facing camera such that the heel aligns with bottom of image (Figure 1C). All patients practiced taking pictures of their feet, and they were told to check their photographs for clarity and to make sure that they captured their whole foot in the photo. Patients were also told that the photos would not be used for any clinical decisions or care.

Once a week for eight weeks, we prompted patients with an SMS (short message service) text message to send a photograph (via return MMS, the multimedia extension of SMS) of their left foot and a photograph of their right foot. We did not send reminders to patients who did not respond. Thus, patients should have submitted 16 photographs (eight right, eight left). After eight weeks, subjects received a text message thanking them for their participation in the study. We then conducted exit interviews for each participant via telephone.

Our software application is implemented in Python using the Django web framework. Text messages are sent by the server via a commercial web-to-SMS gateway.
Diabetic Foot Surveillance Using Mobile Phones

Statistical Analysis

Response rates and photograph accuracy were compared across the three study populations. We used a generalized linear model (GLM) to estimate the likelihood that a participant would comply or send an “adequate” photograph each week based on the study method. Specifically, we modeled each week as a binary outcome (e.g., comply or not, adequate photograph or not) as a function of the study group. We used a binomial distribution and logit link. For the model of photograph accuracy, we also controlled for the corresponding foot side for the photo. Because of the longitudinal nature of our study, we also considered a generalized linear mixed model (GLMM) with a subject-specific-random intercept and a subject-specific-random slope for foot side (to control for within-subject clustering and possible subject handedness).

To analyze the factors associated with satisfactory photographs, we first performed an inter-rater reliability analysis. For each of the seven dimensions for which photographs were reviewed, we compared the degree of agreement between our two reviewers using Cohen’s kappa. Second, we used a regression analysis to determine the photograph dimensions most predictive of an adequate photo. Specifically, we estimated the overall photograph score, across reviewers, as a function of the other six individual scoring items. Variable importance was assessed using the absolute value of the coefficient test statistic, and values are scaled relative to the coefficient with the greatest t-statistic.

Finally, we analyzed subject satisfaction by comparing responses to the post-study questionnaire among study groups. First, we compared the perceived difficulty in capturing and submitting photos among the groups (difficulty scores were assigned on a 5-point scale, with 1=easy; 5=hard). We compared difficulty scores between groups using a one-way ANOVA analysis. Second, we compared subjects’ reported preferences for frequency of photograph submission. Submission frequency was binned into daily, three or more times per week, twice per week, once per week, or other. We used a chi-squared goodness of fit test to compare differences in preferred frequency across study groups. Preferred frequency was also segmented based on whether patients had a foot ulcer.

RESULTS

A total of 96 patients were consented to participate in the study; seven participants subsequently elected not to participate, yielding a final study population of 88 subjects. The first patient was enrolled on October 4, 2016. The last patient was enrolled on January 20, 2017. The last text message was sent on March 21, 2017, and the last exit survey was conducted on March 26, 2017. The number

Table 1. Exit Survey Questionnaire

<table>
<thead>
<tr>
<th>On a scale from 1 to 5, with 1 being the easiest:</th>
</tr>
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<tbody>
<tr>
<td>How difficult was it for you to take photographs of your feet?</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>How difficult was it for you to send photographs by text message?</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>Did the texts help to remind you to take pictures of your feet?</td>
</tr>
<tr>
<td>YES</td>
</tr>
</tbody>
</table>

[www.twilio.com] responses (and photographs) are routed back to the server the same way. Patient responses are time-stamped upon receipt and automatically inserted into a database. Patients indicated a desired time to receive their weekly SMS text prompts. At the designated time, the system would send the patient a message reminding them to photograph their foot. If a patient responded with a photograph, our software application would subsequently extract the photograph, insert it into a secure database, and send the participant a follow-up message requesting a photograph of the contralateral foot.

The response rate was defined as the percent of the 16 total potential photographs each patient provided. Photographs were individually assessed by two separate reviewers (CAA, PMP) in blinded fashion across a number of categories that were determined by a previous consensus meeting including capture of the forefoot & midfoot, capture of toes, capture of heel, picture angle, image focus, and appropriate lighting. Additionally, a photograph was deemed “adequate” if it was felt in the opinion of the reviewer that the photograph could be used for clinical decision making. For those photographs that exhibited disagreement between raters in terms of overall adequacy, a “tie-breaker” was performed by an independent rater. The percentage of photographs that were deemed adequate were compared across our three groups. We also evaluated patient satisfaction with the software through a post-study questionnaire (see Table 1) administered by phone after completion of the study.
Table 2. Participant Characteristics Based on Group (n = 88)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Overall (n = 88)</th>
<th>Self Photo (n = 30)</th>
<th>Assistive Device (n = 29)</th>
<th>Other Party (n = 29)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>Mean (SD) (Min, Max)</td>
<td>Mean (SD) (Min, Max)</td>
<td>Mean (SD) (Min, Max)</td>
<td>Mean (SD) (Min, Max)</td>
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<tr>
<td></td>
<td>45.2 (15.3) (19.0, 76.0)</td>
<td>44.8 (15.2) (19.0, 69.0)</td>
<td>46.3 (14.3) (23.0, 75.0)</td>
<td>44.4 (16.7) (21.0, 76.0)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>172.9 (10.4) (149.9, 190.5)</td>
<td>170.6 (10.4) (149.9, 186.7)</td>
<td>176.4 (9.3) (153.7, 188.0)</td>
<td>171.6 (10.8) (157.0, 190.5)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>95.3 (23.4) (55.6, 180.6)</td>
<td>87.1 (16.9) (61.6, 125.3)</td>
<td>106.3 (29.3) (60.6, 180.6)</td>
<td>92.7 (19.0) (55.6, 137.8)</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>44 (50.0%)</td>
<td>13 (44.8%)</td>
<td>18 (61.3%)</td>
<td>16 (55.2%)</td>
</tr>
<tr>
<td>Female</td>
<td>44 (50.0%)</td>
<td>17 (63.3%)</td>
<td>11 (38.7%)</td>
<td>16 (44.8%)</td>
</tr>
<tr>
<td>Race</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Caucasian</td>
<td>82 (93.2%)</td>
<td>30 (100.0%)</td>
<td>26 (89.7%)</td>
<td>26 (89.7%)</td>
</tr>
<tr>
<td>Other</td>
<td>6 (6.8%)</td>
<td>0 (0.0%)</td>
<td>3 (10.3%)</td>
<td>3 (10.3%)</td>
</tr>
<tr>
<td>Marital Status</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Divorced</td>
<td>2 (2.3%)</td>
<td>0 (0.0%)</td>
<td>1 (3.4%)</td>
<td>1 (3.4%)</td>
</tr>
<tr>
<td>Married</td>
<td>54 (63.1%)</td>
<td>19 (63.3%)</td>
<td>19 (65.5%)</td>
<td>16 (55.2%)</td>
</tr>
<tr>
<td>Single</td>
<td>22 (25.0%)</td>
<td>5 (16.7%)</td>
<td>8 (27.6%)</td>
<td>9 (31.0%)</td>
</tr>
<tr>
<td>Widowed</td>
<td>2 (2.3%)</td>
<td>2 (6.7%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
</tr>
<tr>
<td>No Info</td>
<td>8 (9.1%)</td>
<td>4 (13.3%)</td>
<td>1 (3.4%)</td>
<td>3 (10.3%)</td>
</tr>
<tr>
<td>Foot Ulcer</td>
<td>3 (3.4%)</td>
<td>1 (3.4%)</td>
<td>0 (0.0%)</td>
<td>2 (6.9%)</td>
</tr>
</tbody>
</table>

Table 3: Summary Statistics for Photograph Compliance and Photograph Accuracy Across Individuals in Each Study Group:
Self Photo (SP), Selfie Stick (AD) and Other Party (OP)

<table>
<thead>
<tr>
<th></th>
<th>SP</th>
<th>AD</th>
<th>OP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compliance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total photos sent</td>
<td>13.4 (4.10)</td>
<td>11.9 (4.09)</td>
<td>12 (4.59)</td>
</tr>
<tr>
<td>Percent of possible photos sent</td>
<td>83.5 (25.6)</td>
<td>74.4 (25.4)</td>
<td>75 (28.7)</td>
</tr>
<tr>
<td>Total fully compliant weeks (both L &amp; R foot)</td>
<td>6.47 (2.11)</td>
<td>5.66 (2.13)</td>
<td>5.90 (2.32)</td>
</tr>
<tr>
<td>Percent of weeks fully compliant (both L &amp; R foot)</td>
<td>80.8 (26.4)</td>
<td>70.7 (26.5)</td>
<td>73.7 (29.0)</td>
</tr>
<tr>
<td>Photo Accuracy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total satisfactory photos</td>
<td>99 (5.16)</td>
<td>99.3 (4.15)</td>
<td>11.1 (4.64)</td>
</tr>
<tr>
<td>Percent of photos that were satisfactory</td>
<td>74.1 (29.2)</td>
<td>83.7 (18.4)</td>
<td>92.6 (13.1)</td>
</tr>
</tbody>
</table>

Table 4: Regression Analysis – Weekly Completion and Photograph Accuracy by Subject
Note: Using AD as the Reference Group, the Estimated Difference in Photo Accuracy Between AD and OP is:
GLM 2.36 (CI. 1.47-3.88) or GLMM 3.54 (CI. 1.05-3.10)

<table>
<thead>
<tr>
<th></th>
<th>Completion OR (95% CI)</th>
<th>Photo Accuracy OR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GLM</td>
<td>GLMM</td>
</tr>
<tr>
<td></td>
<td>GLM</td>
<td>GLMM</td>
</tr>
<tr>
<td>Intercept</td>
<td>14.82 (8.87-27.53)</td>
<td>42.20 (14.30-132.14)</td>
</tr>
<tr>
<td></td>
<td>GLM</td>
<td>GLMM</td>
</tr>
<tr>
<td>Group</td>
<td>AD</td>
<td>OP</td>
</tr>
<tr>
<td></td>
<td>(0.32-1.47)</td>
<td>(0.74-5.54)</td>
</tr>
<tr>
<td></td>
<td>(0.67-2.87)</td>
<td>(0.47-1.298)</td>
</tr>
<tr>
<td></td>
<td>(1.77-5.54)</td>
<td>(2.79-12.98)</td>
</tr>
<tr>
<td></td>
<td>(2.14-6.89)</td>
<td>(7.58-25.60)</td>
</tr>
<tr>
<td></td>
<td>GLM</td>
<td>GLMM</td>
</tr>
<tr>
<td></td>
<td>GLM</td>
<td>GLMM</td>
</tr>
<tr>
<td>Side</td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td></td>
<td>(reference)</td>
<td>(reference)</td>
</tr>
<tr>
<td></td>
<td>(reference)</td>
<td>(reference)</td>
</tr>
<tr>
<td></td>
<td>(0.63-1.15)</td>
<td>(0.83-1.15)</td>
</tr>
<tr>
<td></td>
<td>(0.59-1.14)</td>
<td>(0.78-1.14)</td>
</tr>
</tbody>
</table>

*** p < 0.001
of participants per group was 30 in SP, 29 in AD, and 29 in OP. Participant characteristics for each group are given in Table 2. The completion rate was 77% across all participants and study groups. There were no significant differences in completion rates among individual groups (83.5% SP, 74.4% AD, 75.0% OP). Table 3 summarizes individual response rates and compliance by group. In addition, Table 3 presents the results of the longitudinal regression analysis of daily compliance. None of these analyses found a statistically significant difference in participation among study groups.

82.8% of photographs submitted were deemed adequate for clinical care (74.1% in SP, 83.7% in AD, 92.6% in OP). Table 3 summarizes the total number of adequate photographs, and the percentage of adequate photographs by group. Table 4 summarizes the results of the longitudinal regression analysis predicting individual photograph accuracy. In the GLM model, photograph accuracy was better in the AD group compared to the SP group, odds ratio 1.77 (1.24-2.55), and accuracy in the OP group was greater than both the SP group, odds ratio 4.18 (2.70-6.68), and the AD group, odds ratio 2.36 (1.47-3.88). However, in the GLMM model, after controlling for within-subject correlation, the OP group was more likely to return adequate photographs compared to the SP group, odds ratio 3.54 (1.05-13.10), and the SP group, odds ratio 7.58 (2.32-25.60), but the difference between the SP and AD groups was not significant. We found no evidence that left or right photographs were more likely to be adequate.

Among reviewers of the adequacy of the photographs, inter-rater reliability (IRR) was excellent (0.92, p-value <0.001). There were 25 (2.29%) discrepancies that needed to be assessed by an independent reviewer (PS). Likewise, excellent reliability existed when analyzing agreement for all individual image factors (0.82 – 0.98, all p-values <0.001). The two strongest predictors of a photograph adequacy were lighting and focus.

Seventy-two out of 88 subjects (81.8%) completed the final questionnaire. Across all subjects the average reported overall difficulty of capturing photographs was 2.04, on a scale from 1 to 5 with 1 being the easiest, with 70.8% of subjects providing a response of 1 or 2. There was also little difficulty reported with sending pictures by text messages with an average response of 1.19. There was no significant difference in reported difficulty among groups in capturing or sending photos. Ninety-six percent of participants using the selfie stick reported it made it easier for them to take pictures of their feet. Patient preference for frequency of sending photographs of their feet to their healthcare provider was “daily” (50.0%) if patients had an ulcer and “once per week” (51.4%) if they did not have an ulcer. There was no significant difference among groups in terms of preferred frequency. Subjects were also allowed to provide general comments on their experience with our communication platform (Table 5).

Subjects were asked “What suggestions do you have about the process of taking pictures of your feet and texting them to your healthcare provider?” Positive experiences were reflected in statements such as “the reminders were beneficial,” it was “a very easy process,” and they “liked that there was no time deadline for sending in the photos.” Negative experiences were reflected in statements such as “lighting was hard to get.” Suggestions included “maybe put a time limit so people remember to send pictures, or add an incentive for sending the pictures in on time” and “getting a second reminder text would be helpful.”

People in the SP group said that “taking photos of your own feet was very difficult. It would probably be hard for older people to get in the pose,” “needed longer arms,” and it was “hard to hold camera and do by myself.” The AD group provided comments such as “easy enough to do” and “very satisfied with the selfie stick.” The negative experiences reported by this group mostly centered on the use of the selfie stick itself, with comments such as “didn’t like the selfie stick at all,” “the other options for the study would have been easier,” and “it was hard not getting your face in the picture.” Suggestions for improvement included “needed a longer selfie stick.” The OP group report that the process was “convenient,” and they “liked having someone else do it.” The negative comments consisted of “timing was hard to get someone to take the photos,” “didn’t always have someone there,” and “didn’t want to rely on others to take the picture.”

**DISCUSSION**

Our results showed that a cohort of patients with diabetes were willing and able to, first, effectively take weekly photographs of their feet in their home environment using their own mobile phones, and second, transmit these photographs from their mobile phones to our research team via texting. The vast majority of photographs captured the entire plantar aspect of the foot and 82.8% were judged by our research team to be adequate for clinical-surveillance purposes. Most patients were consistently able to take adequate photographs of their own feet. However, the proportion of adequate photographs was greater for subjects who used selfie sticks and was greater still for subjects who had another adult take the photographs.

The majority of diabetic foot ulcers are preventable and increased monitoring along with applying therapeutic footwear can help prevent recurrent diabetic foot
While interventions to prevent recurrent ulcers may initially be effective, over longer periods of time, the effectiveness of these interventions may decline. Given the increasing ubiquity of mobile phones and text messaging, our approach may provide an effective approach for reminding patients to take photographs of their feet and to transmit them to a clinical service for review. Several prior studies have shown that patients are comfortable using text messaging and that text messaging is an effective approach to remind patients to transmit information to healthcare providers. Our previous study found that patients are willing to send photographs of their wounds. Our study only lasted for eight weeks but a majority of subjects indicated that they would be willing to continue interacting with our surveillance system, or a similar one, on a weekly basis as part of their usual care. In addition, more than 70% of subjects reported a willingness to send images more frequently (i.e., more frequent than once per week) if they had an active diabetic foot ulcer.

Other investigators have proposed effective patient-directed home-monitoring approaches for diabetic foot ulcers, but some of these approaches require additional equipment. In contrast, photographs taken with a phone are easy to take in the home environment and require no special equipment. Because our approach relies on texting, the subject does not need to download an app that needs to be updated or customized for different mobile-operating systems. Only a mobile phone with a camera and a phone plan that supports texting with media is needed. Another advantage to our approach is that it is asynchronous. Patients and healthcare providers, unlike in traditional telehealth approaches, do not have to interact in real time. Patients can take photographs of their feet.

Table 5. Patient Reported Comments of Mobile Imaging Communication Platform

<table>
<thead>
<tr>
<th>Positive</th>
<th>Negative (continued)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Loved getting feedback! Angles were difficult to position, hard finding a comfortable way to do it.</td>
<td>• Finding someone and explaining how to do it was the most difficult.</td>
</tr>
<tr>
<td>• None, easy enough to do.</td>
<td>• Didn’t like the selfie stick at all.</td>
</tr>
<tr>
<td>• Nothing, reminder was beneficial.</td>
<td>• Lighting was hard to get.</td>
</tr>
<tr>
<td>• Went very well.</td>
<td>• Getting a second reminder text would be helpful; hard to take photographs on the dominant foot.</td>
</tr>
<tr>
<td>• Liked having someone else take photographs. Texting was easy. Would like for there to be follow-up from provider on pictures.</td>
<td>• Very inconvenient schedule</td>
</tr>
<tr>
<td>• None, very easy</td>
<td>• Need longer arms.</td>
</tr>
<tr>
<td>• No, very straight forward</td>
<td>• Would rather take photographs by self, the process was relatively easy, always had a hard time finding someone to take the pictures, would rather have the reminder text say “send us a picture of each of your feet” instead of one at a time.</td>
</tr>
<tr>
<td>• Convenient</td>
<td>• 3rd party would be easiest. Lighting and keeping face out of the picture was difficult.</td>
</tr>
<tr>
<td>• Very satisfied with the selfie stick.</td>
<td>• Didn’t always have someone there.</td>
</tr>
<tr>
<td>• Pretty easy</td>
<td>• Lighting was difficult to do, hard keeping face out of picture.</td>
</tr>
<tr>
<td>• Pretty easy, concerned with ability to see calluses and dry skin</td>
<td>• Different method of taking the pictures, had a hard time manipulating the camera and not getting face in the photo.</td>
</tr>
<tr>
<td>• Very easy process. Like that there was no time deadline for sending in the photographs/</td>
<td>• Very difficult, hard to hold camera and to do by self.</td>
</tr>
<tr>
<td>• No, very easy process</td>
<td>• More detail on what is helpful from a picture. Would have liked information about lighting/angle/distance from foot etc.</td>
</tr>
<tr>
<td>• This is awesome! Was better than going in for a visit. Easier to take them by yourself.</td>
<td>• Longer selfie stick.</td>
</tr>
<tr>
<td>• None, very simple</td>
<td>• Did not like selfie stick. Other options for the study would have been easier. Hard not getting face in the picture, difficult with bad vision. Got an iPhone 7 during the study.</td>
</tr>
<tr>
<td>• None, very easy</td>
<td>• Very difficult, hard to hold camera and to do by self.</td>
</tr>
<tr>
<td>• Could be hard for older or less healthy people with bad knees</td>
<td>• More detail on what is helpful from a picture. Would have liked information about lighting/angle/distance from foot etc.</td>
</tr>
<tr>
<td>• None, worked out pretty well.</td>
<td>• Longer selfie stick.</td>
</tr>
</tbody>
</table>

Neutral

• Maybe put a time limit so remembers to send the pictures. Add an incentive for sending the pictures in on time.
• Taking the photographs by yourself would be hard. Also hard to find someone to take the photographs for you. Quite easy. Reminder was great.
• Reminders if you forgot to send the photograph later that day (every 4 hours). Would be unable to do for anyone with a disability or arthritis.
• More reminders would be helpful.
• Every week is a lot. Very easy to do.

Negative

• Taking photographs of your own feet was difficult. Would probably be hard for older people to get in the pose.
• More feedback, volume button is easier to use when taking pictures.
• Difficult with work schedule
• Timing was hard to get someone to take a photograph when the text arrived, wanted a reminder
• Would have liked to use the selfie stick so would have to rely on others to take the picture

• Finding someone and explaining how to do it was the most difficult.
• Didn’t like the selfie stick at all.
• Lighting was hard to get.
• Getting a second reminder text would be helpful; hard to take photographs on the dominant foot.
• Very inconvenient schedule
• Need longer arms.
• Would rather take photographs by self, the process was relatively easy, always had a hard time finding someone to take the pictures, would rather have the reminder text say “send us a picture of each of your feet” instead of one at a time.
• 3rd party would be easiest. Lighting and keeping face out of the picture was difficult.
• Didn’t always have someone there.
• Lighting was difficult to do, hard keeping face out of picture.
• Different method of taking the pictures, had a hard time manipulating the camera and not getting face in the photo.
• Very difficult, hard to hold camera and to do by self.
• More detail on what is helpful from a picture. Would have liked information about lighting/angle/distance from foot etc.
• Longer selfie stick.
• Did not like selfie stick. Other options for the study would have been easier. Hard not getting face in the picture, difficult with bad vision. Got an iPhone 7 during the study.
• Huge pain, hard to position, wanted to do the other options.
• Selfie stick was not long enough, would just take a picture and hoped for the best - could not really see what I was doing while using the selfie stick.
• Difficult to find someone to take pictures when traveling for business.
• Tough for fat guys to do it; hard to look around and see it.
• Keeping face out of the photo.
• Hard to hold phone far enough away. “Run out of arm”
• Texts came while doing something - would’ve liked more reminders.
• Use email, iMessage, something other than text.
• Remembering to take the pictures when with other person.
• Lighting and getting whole foot in picture was challenging, otherwise overall pretty easy.
• Didn’t like the selfie stick at all.
• Hard to hold phone far enough away. “Run out of arm”
• Words came while doing something - would’ve liked more reminders.
• Use email, iMessage, something other than text.
• Remembering to take the pictures when with other person.
• Lighting and getting whole foot in picture was challenging, otherwise overall pretty easy.
• Didn’t like the selfie stick at all.
at times and locations convenient to them and similarly healthcare providers can review the photographs at convenient times. Most photographs submitted were adequate for clinical use, a result consistent with previous studies that found that most photographs of skin lesions and chronic venous ulcers taken by patients with mobile phones were satisfactory for clinical use.24-26 In our study, photographs judged to be inadequate typically had problems with either lighting or focus. These barriers to high image quality may be resolved with better patient education for image capture or possibly by the use of adjunct lighting modalities. After transmission of the photograph, our approach requires a member of the healthcare team to review the photograph. Given recent advances in classifying images, it may be possible to build systems for evaluating not only the adequacy of the photographs for ulcer monitoring but also the existence of ulcers or even calluses at risk for transforming into ulcers. Indeed other groups have demonstrated classifications capable of identifying skin cancers.27-30 However, even without a system for reviewing photographs, having patients take serial photographs of their own feet may help encourage patients with diabetes to inspect their feet on a regular basis, a goal of diabetes-care guidelines. We found that having another person take the photographs increased the adequacy of the submitted photographs, and involving caregivers and family members to help with diabetic foot monitoring may increase the sustainability of our approach. Indeed, there are benefits of involving caregivers in management plans, and in future work we could send reminders to caregivers or family members as well as patients themselves. However, if patients do not have someone to take photographs, our results suggest that a selfie stick may be almost as useful. Also, based on our survey responses, we may be able to increase response rates with follow-up reminders for patients who forget to send photographs after the initial request.

Our work has limitations. First, the results of our single center study may not be generalizable to other populations. Second, although we recorded which foot was being photographed, we did not record the handedness of the patients. Especially for self-taken photographs, handedness may have an effect on photograph quality. There may have been some left-handed patients in the study, confounding the handedness results. Third, some patients in the AD group complained that the selfie stick was not long enough for tall or overweight patients. Thus, the selfie stick might have been more effective if longer selfie sticks were available. Fourth, cameras in smartphones have varying resolution, and we did not consider the resolution of the camera in our analysis. In general, forward-facing cameras have lower resolution than backward-facing cameras. Thus, photos in the OP group could have had better results, in part, due to the backward-facing camera used. Nevertheless, the forward-facing cameras did deliver photos of adequate clinical quality in the majority of cases, despite their lower resolution. Fifth, we did not provide any instruction regarding lighting conditions. If we had, the number of quality photographs may have increased. Finally, we did not ask patients if they previously examined their feet on a regular basis; patients who volunteered for this study may be more likely to examine their feet in general.

Despite our limitations, we show that patients with diabetes are capable of taking clinically adequate photographs of their feet. Future work will need to determine the long-term sustainability of texting reminders to assist the home surveillance of diabetic foot ulcers using photographs and the potential importance of involving a trusted individual in the general foot care of the patient. In addition, future work should examine the long-term health impact of this intervention.

ACKNOWLEDGMENT

The authors would like to thank Poorani Sekar, MD (PS) for helping to evaluate photos for this project.

REFERENCES


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ABSTRACT

Background: Treatment of diabetes costs the United States an estimated $245 billion annually; one-third of which is related to the treatment of diabetic foot ulcers (DFUs). We present a safe, efficacious, and economically prudent model for the outpatient treatment of uncomplicated DFUs.

Methods: 77 patients (mean age = 54 years, range 31 to 83) with uncomplicated DFUs prospectively enrolled from September 2008 through February 2012. All patients received an initial sharp debridement by one of two orthopaedic foot and ankle fellowship trained surgeons. Ulcer dressings, offloading devices, and debridement procedures were standardized. Patients were evaluated every two weeks by research nurses who utilized a clinical management algorithm and performed conservative sharp wound debridement (CSWD).

Results: Average time to clinical healing was 6.0 weeks. There were no complications of CSWD performed by nurses. The sensitivity for the timely identification of wound deterioration was 100%, specificity = 86.49%, PPV = 68.75% and NPV = 100% with an overall accuracy of 89.58%. The estimated cost savings in this model by having nurses perform CSWD was $223.26 per encounter, which, when extrapolated to national estimates, amounts to $1.56 billion to $2.49 billion in potential annual savings across six to ten-week treatment periods, respectively.

Conclusion: CSWD of DFUs by nurses in a vertically integrated multidisciplinary team is a safe, effective, and fiscally responsible clinical practice. This clinical model on a national scale could result in significant healthcare savings. Surgeons and other licensed independent practitioners would have more time for evaluating and treating more complex and operative patients; nurses would be practicing closer to the full extent of their education and training as allowed in most states.

Level of Evidence: III

Keywords: financial cost of diabetic foot ulcers, nurses debridement procedures, conservative sharp wound debridement, diabetic foot ulcers

INTRODUCTION

Diabetes and its complications are placing an increasing strain on the U.S. healthcare system and society. In a 2014 National Diabetes Statistics Report, the CDC estimated that 29.1 million people were affected within the United States with a total annual cost of $245 billion, including $176 billion in direct medical costs and $69 billion in reduced productivity. Of the $176 billion in direct medical costs, approximately one third ($58 billion) is linked to the treatment of diabetic foot ulcers (DFUs). In the United States, more than 60% of atraumatic lower extremity amputations occur in diabetic individuals and 80% of those are preceded by an ulcer. In addition to being a significant source of morbidity and mortality within this population, diabetic foot ulcers are a key contributor to the economic burden on the healthcare system. The prevalence of foot ulcers in diabetic patients is estimated to be 8% annually. According to the Department of Health and Human Services, Medicare beneficiaries with a DFU are seen in an outpatient setting 14 times per year and hospitalized about 1.5 times per year.

Offloading of ulcers through the use of total contact casting (TCC) or pressure reducing diabetic walking boots has proven to be effective treatment options for diabetic foot ulcers. Appropriate offloading treatment includes sharp debridement of the ulcer and callous. In the United States, this task has typically been the responsibility of the physician, podiatrist, or other licensed independent practitioner such as Advance Registered Nurse Practitioner (ARNP) or Physician Assistant (PA).

Nursing scope of practice laws are discussed in broad
We propose a safe, efficacious, and fiscally responsible model for the outpatient treatment of uncomplicated diabetic foot ulcers by allowing nurses to perform evaluation and management using a clinical management algorithm and to perform conservative sharp wound debridement after undergoing a standardized training protocol.

METHODS

This study is a part of a larger five-year prospective NIH funded study (1R01NR0098448, PI: SG) to identify the effect of ulcer bioburden in predicting the development of infection-related complications. Subjects were evaluated by one of two orthopaedic foot and ankle surgeons who determined patients were candidates for TCC treatment. Informed consent was gained according to the IRB protocol within the larger study. An off-the-shelf diabetic walking boot was used if the patient declined a cast. Patients were enrolled only after giving written consent according to a specific protocol/script. Baseline data was collected which included: age, sex, race, type 1 vs. 2 diabetes mellitus (DM), duration of diabetes (years), duration of the ulcer (days), toe brachial pressure index (TBPI), ankle brachial index (ABI), ulcer location, ulcer dimensions (depth, width, surface area, volume), Hgb A1C, blood glucose, white blood cell (WBC) count, erythrocyte sedimentation rate (ESR), C-reactive protein (CRP), and presence or absence of neuropathy with monofilament testing. Patients were excluded from this study if they presented with (1) significant ischemia (i.e., TBPI or ABI < 0.5); (2) signs or symptoms of active infection (i.e., increasing pain, erythema, heat, edema, or purulent exudate) or osteomyelitis (i.e., positive radiograph or MRI, if radiograph was equivocal according to protocol); and (3) treatment with systemic antibiotics in the prior two weeks. Patients who met all inclusion criteria, except for recent antibiotic use, were instructed to stop their antibiotics if clinically appropriate, and enrolled under a delayed protocol two weeks later.

Initial sharp debridement was performed in a clinic setting by one of two orthopaedic surgeons, or a nurse (RN/BSN/MSN) under direct surgeon supervision, if within their training period according to a written protocol; this included three observations and a minimum of three satisfactory proctored debridement procedures. Patients were placed in a TCC (n=72) or a diabetic walking boot when cast phobia prohibited a TCC (n=5). Patients were evaluated by nursing research assistants (RN, BSN, MSN) every two weeks. Casts were removed, and wounds were assessed and debrided by nurses, according to protocol. Data were collected, and high-quality digital photographs were taken of the ulcer prior to performing CSWD. All cast application and removal were performed by a single experienced cast technician. This protocol was performed until healing of the wound or the 26-week time point. The patients were reassessed at eight-weeks by the orthopaedic surgeons. If wound deterioration was identified at any visit during the nursing care period, patients were referred back to the orthopaedic surgeon according to the clinical management algorithm (CMA).

No nurses had previous experience performing CSWD. This protocol was approved by, and done in accordance with, the Iowa Board of Nursing Declaratory Ruling No. 91, and the University of Iowa Hospitals and Clinics Institutional Review Board.

CSWD Procedure included:

1. Cleanse the wound with sterile saline soaked gauze.
2. Remove the callous with a sterile scalpel.
3. Excise callous until punctate bleeding tissue is seen.
4. Observe the wound for up to 15 minutes for bleeding.
5. If bleeding continues after 15 minutes, contact physician team member.

Medical decision making for the nurse evaluations was guided by the CMA. This directed urgent referral back to the Orthopaedic surgeon or Emergency Department if wound deterioration was identified; signs of cellulitis or abscess, increased ulcer size, fever, worsening inflammatory markers or increasing white blood count were indicators of deterioration. The ulcer size, depth and appearance were documented in an Access database (Microsoft Inc, Redmond, WA).

To determine the sensitivity and specificity of the nurse’s medical decision making using the CMA, a retrospective blinded review of photographs from each nursing encounter was performed by two orthopaedic foot and ankle surgeons. Patient images were randomized and a PowerPoint (Microsoft Inc, Redmond, WA) slide show was used for review of photographs of 48 patients (16 cases and 32 controls) in chronological order. The reviewing surgeons used consensus to score each photo, in a single setting, as either improved/unchanged or regressed. The surgeons graded each case series of photographs in chronological order as unchanged/improved or regressed. Cases were counted as true positive or true negative when surgeons and nurses agreed. Cases in which the nurse’s interpretation of the CMA identified a wound as deteriorating, but the photo...
was deemed improved/unchanged by the surgeon’s evaluation, were counted as false positives. Since all other patients healed uneventfully, it was assumed there were no false negatives.

A cost analysis was performed based on local Center for Medicare Services (CMS) reimbursement rates of Evaluation and Management (E&M) and Current Procedural Terminology (CPT) coding. Prior to and after the study period, a patient was seen in an orthopaedic foot and ankle clinic, with E&M code 99204 for the initial visit and 99213 for all subsequent visits. During the study period, the initial visit with E&M code 99204 was still performed by the physician; nursing visits were coded as unbillable 99211; and the last visit with the physician was coded 99213. In an eight-week treatment protocol, visits with surgeons occurred at the initial and eight-week visit and with the nurses at weeks two, four and six. Facility fees are constant for all visits. Procedural billing for total contact casting (CPT 29445) could be performed by all providers and therefore was not included in the calculations. Reimbursement was estimated based on 100% Medicare reimbursement in the home area (AAOS CodeX).

To determine the feasibility of having a nursing based CSWD system for diabetic ulcer debridement, surveys were sent to 51 state boards of nursing (50 states plus Washington, DC). Surveys queried if CSWD was considered part of nursing practice in a given state. Follow-up emails and phone calls were conducted to encourage completion.

RESULTS

Ninety-six patients met the inclusion criteria and were screened for eligibility from September 2008 through February 2012. Twelve of these were subsequently excluded due to: osteomyelitis (n=6), long-term antibiotics for chronic infections (e.g., chronic urinary tract infection; n=3), ischemia (TBPI or ABI ≤ 0.5; n=1), clinical signs of active infection (n=1), and inability to use the off-loading device (n=1). The remaining 84 patients (average age = 54 years, range 31 to 83, SD 11.64) were enrolled in the study; 17 (20%) were enrolled under the delayed protocol, which required a surgeon visit at the eight-week mark, ulcers healing between six and eight weeks generated the same charges. Nurses performed 307 debridement procedures during this study period, saving an estimated $68,540 in local healthcare dollars. When extrapolated to a national scale, with an estimated 29.1 to 34 million diabetics within the United States and an annual ulcer incidence of 8%, this could result in $1.56 billion to $2.49 billion in annual cost savings for a six to ten-week treatment period.

Thirty-six of 51 (71%) state boards of nursing responded to the survey with 33/36 (92%) defining CSWD as within their nursing scope of practice.

DISCUSSION

Diabetes is a growing epidemic, and with a predicted physician shortage of 61,700 – 94,700 by the year 2025, other members of the healthcare team will need to take a larger role in the management of these complex patients. Increasing the role of nurses to perform CSWD will help reduce the burden of the pending physician shortage.

One of the keys to a successful screening test is having a high sensitivity to reduce the risk of missing or delaying a diagnosis. Guided by the design of the CMA which was intended to be conservative and had the desired effect of favoring false positives (referral back to surgeons) over false negatives (missed cases of wound regression). Safety of nurses performing CSWD was demonstrated during this study period, saving an estimated $68,540 in local healthcare dollars. When extrapolated to a national scale, with an estimated 29.1 to 34 million diabetics within the United States and an annual ulcer incidence of 8%, this could result in $1.56 billion to $2.49 billion in annual cost savings for a six to ten-week treatment period.

In addition to timely healing of ulcers, a critical component to controlling cost associated with management of diabetic foot ulcers is to limit inpatient admissions and amputations. The mean number of admissions among Medicare patients with a prevalent DFU was 0.25 from...
Amputations also impact costs; amputation rates from 2.4% to 4.8% have been reported. Only one patient in our study (1.3%) required hospitalization for an amputation during the course of this 26 week study. All other patients were successfully managed in an outpatient setting for the duration of the study.

Medicare expenditures for patients with DFU are, on average, three times higher than diabetic patients without an ulcer. With an estimated 29.1 million within the United States and an annual ulcer prevalence of 8.1%, annual Medicare/Medicaid cost savings would be in excess of $1.56 Billion, using the six-week (three visit) model utilized in this study. Our average time to healing (6.0 weeks) is consistent with other published series on total contact casting.

The team approach to care of the diabetic foot is not new. Numerous studies have shown the benefits of multidisciplinary approach to diabetic foot care to include reduced inpatient admissions and incidence of amputation. In Australia, Canada, and Great Britain, nurses routinely perform CSWD for the care of wounds freeing up physicians to see more acute/new patients or perform other more complicated procedures/surgeries. Our model of DFU care demonstrates that the efficient use of resources in a vertically integrated multidisciplinary team allowed us to deliver high quality and cost-effective care with an emphasis of allowing each practitioner to practice at the top of their license. This study falls in line with the Center for Medicare and Medicaid Services “focus on improving outcomes, beneficiaries’ experience of care, and population health, while also aiming to reduce healthcare costs.”

There are limitations to this study. We did not account for the nursing salaries with a reported national average of $27/hr. for a RN. This series represents a best-case scenario, as we included only non-infected ulcers in patients with relatively normal perfusion. Including patients with more complex ulcers and extended treatment courses would lead to even larger savings with our model. Additionally, our rate of hospitalization and amputation (1.3%) would increase if more complex ulcers were included. Financial calculations were performed assuming a 100% capture rate and we assumed that all DFUs were amenable to CSWD and TCC treatment.

CONCLUSIONS

CSWD of DFU’s by trained nurses in this study of TCC treatment resulted in an average time to healing of 6.0 weeks. The use of a standardized clinical management algorithm resulted in medical decision making by nurses (RN, BSN, MSN who had no prior experience with sharp wound debridement) that detected wound deterioration with 100% sensitivity and 89.58% accuracy. No complications or prolonged bleeding of 307 nurse sharp wound debridement occurred. This practice is supported by thirty-four of thirty-six state boards of nursing who responded to the survey.

Implementation of this clinical model on a national scale could result in significant annual healthcare savings. It would allow nurses to practice to a fuller extent of their education and training, and free surgeons and other licensed independent practitioners to evaluate and treat more complex and operative patients.

ACKNOWLEDGMENT
The authors would like to thank Mark Mason, MHA for his assistance with E&M/CPT coding analysis and Joshua Tennant MD, for his contributions to study design and development.

REFERENCES
THE HANDSHAKE TEST: A NONVERBAL ASSESSMENT OF COPING STRATEGIES AND FUNCTIONAL STATUS IN PATIENTS WITH ATRAUMATIC UPPER-EXTREMITY CONDITIONS

Louis C Grandizio, DO; Lisa Follett, BS; Lauren Skudalski, BA; C. Liam Dwyer, MD; Joel C Klena, MD

ABSTRACT
Background: Maladaptive coping strategies can lead to less functional improvement after upper-extremity surgery. It remains uncertain how well surgeons can recognize signs of less effective coping strategies in patients in the absence of formalized questionnaires. Our purpose is to determine if the “Handshake Test” can be used to identify patients with less effective coping strategies. We hypothesize that a simple physical examination finding (a refusal or inability to shake hands) is associated with higher pain level, maladaptive coping strategies and decreased functional status.

Methods: We prospectively analyzed 246 consecutive new patients presenting to one of three surgeons with atraumatic upper-extremity conditions. Patients completed a pain scale (NPRS) and PROMIS instruments including Self-Efficacy (SE) for Managing Symptoms, Pain Interference (PI) and Upper Extremity (UE). Each surgeon recorded a refusal to shake hands as part of a normal greeting, referred to as a “positive Handshake Test”.

Results: 200 patients (81%) patients completed all outcome measures and were included in our analysis. 8% demonstrated a positive Handshake Test. Patients with a positive Handshake Test were more likely to use tobacco; otherwise baseline demographics were similar between the two groups. Patients with a positive Handshake Test demonstrated higher pain scores (NPRS and PROMIS PI), lower levels of self-efficacy and worse self-reported functional status on the PROMIS UE.

Conclusions: For patients with atraumatic upper-extremity conditions, those with a positive Handshake Test report higher pain levels, lower self-efficacy, and decreased self-reported functional status than patients who can perform a handshake.

This simple test can aid in identifying patients with less effective coping strategies, allowing surgeons to guide patients towards interventions to improve both illness behavior and functional outcomes.

Level of Evidence: II

Keywords: coping strategies, pain catastrophizing, hand surgery, physical examination, upper-extremity surgery

INTRODUCTION
Less effective coping mechanisms, low resiliency and decreased self-efficacy are associated with poor functional outcomes after upper extremity surgery. While formal measures of coping skills can aid in identifying maladaptive coping strategies, they are not routinely administered in orthopedic clinics. Furthermore, it is uncertain how well physicians are able to identify verbal and nonverbal indicators of maladaptive coping strategies. Previous investigations have identified hand postures that can be associated with pain catastrophizing and kinesophobia; however, interpretation of these postures can be subjective.

The purpose of this investigation is to determine if patients with atraumatic upper-extremity conditions who refuse to shake hands possess less effective coping strategies and functional status. We hypothesize that a simple physical examination finding, which we refer to as the “Handshake Test” can be used to identify patients with maladaptive coping strategies. This examination is performed as part of normal greeting, where the surgeon notes whether a patient is able or unable to shake hands. To our knowledge, this examination maneuver has not been previously described as an assessment coping strategies and functional status.

METHODS
Institutional Review Board approval was obtained for this study. We prospectively analyzed 246 consecutive new patients 18 years of age and older who presented to one of three fellowship-trained hand and upper-extremity surgeons with an atraumatic upper-extremity complaint. All patients were seen in the outpatient clinic in a rural, academic, Level I trauma center. We excluded patients presenting with acute traumatic injuries (defined as <6 weeks from time of injury), patients with infection and...
those with acute ischemia. Baseline demographics were recorded for each patient. Prior to seeing the surgeon on the day of the clinic visit, each patient completed a Numeric Pain Rating Scale (NPRS) and PROMIS instruments which included the PROMIS Self-Efficacy (SE) for Managing Symptoms Short-Form 4a, PROMIS Pain Interference (PI) Short-Form 4a and the PROMIS Upper Extremity (UE) Short-Form 7a. Surgeons were blinded to the results of NPRS and PROMIS scores prior to seeing the patient. PROMIS instruments, which range from 0-100, utilize a T-score metric and higher scores indicate more of the concept being assessed. The established mean for these instruments is 50 within the general population and there is a standard deviation (SD) of 10. PROMIS SE is a validated instrument and higher PROMIS SE scores indicate higher levels of patient self-efficacy. In chronic musculoskeletal pain, higher levels of self-efficacy are associated with lower pain intensity and improved physical function.

To perform the examination maneuver, each surgeon recorded a refusal to shake hands as part of a normal greeting (positive Handshake Test). Patients who were able to shake hands were considered to have a negative Handshake Test. We classified patients as having a negative Handshake Test if they made any contact with the surgeon’s hand during the handshake. A positive Handshake Test was recorded if the patient made no contact with the surgeon’s hand during the handshake or if they shook with the opposite hand. The right-handed handshake was initiated at the start of the encounter as part of a normal greeting once the surgeon entered the patient’s room. The surgeon would extend their hand to initiate the handshake, but if the patient refused to bring their hand away from their body the surgeon would not “force” the handshake. For patients with left upper-extremity complaints, a left-handed handshake was initiated at the start of the physical examination. The surgeon would tell the patient that they were going to ask them to shake hands with their left hand prior to initiating the handshake.

Descriptive statistics were used for baseline demographics. We used Student-t testing and chi-square testing to compare the means or percentages between the two groups (positive or negative Handshake Test). Since it is uncommon to perform a handshake left-handed, we performed a separate analysis of patients with complaints involving the right upper-extremity. Differences of P <0.05 were considered statistically significant.

Table 1. Baseline Demographics for All Included Patients Comparing Those With a Positive and Negative Handshake Test

<table>
<thead>
<tr>
<th></th>
<th>(+) HANDSHAKE TEST</th>
<th>(-) HANDSHAKE TEST</th>
<th>P-VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients, n(%)</td>
<td>20 (10%)</td>
<td>180 (90%)</td>
<td></td>
</tr>
<tr>
<td>Age, years(SD)</td>
<td>51 (14)</td>
<td>55 (15)</td>
<td>0.1575</td>
</tr>
<tr>
<td>Male, n(%)</td>
<td>8 (40%)</td>
<td>80 (44%)</td>
<td>0.8867</td>
</tr>
<tr>
<td>Laterality right, n(%)</td>
<td>16 (80%)</td>
<td>110 (61%)</td>
<td>0.1569</td>
</tr>
<tr>
<td>Bilateral symptoms, n(%)</td>
<td>2 (10%)</td>
<td>40 (22%)</td>
<td>0.3252</td>
</tr>
<tr>
<td>Dominant arm involved, n(%)</td>
<td>15 (75%)</td>
<td>114 (63%)</td>
<td>0.4306</td>
</tr>
<tr>
<td>Tobacco use, n(%)</td>
<td>14 (70%)</td>
<td>77 (50%)</td>
<td>0.0373</td>
</tr>
<tr>
<td>Work Comp, n(%)</td>
<td>1 (5%)</td>
<td>5 (3%)</td>
<td>0.8901</td>
</tr>
</tbody>
</table>

Table 2. Distribution of Diagnoses by Anatomic Region for Patients in Both Groups

<table>
<thead>
<tr>
<th></th>
<th>(+) HANDSHAKE TEST</th>
<th>(-) HANDSHAKE TEST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Patients, n</td>
<td>20</td>
<td>180</td>
</tr>
<tr>
<td>Total Diagnoses, n</td>
<td>21</td>
<td>205</td>
</tr>
<tr>
<td>Diagnoses per Patient</td>
<td>1.05</td>
<td>1.14</td>
</tr>
<tr>
<td>SHOULDER</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patients with Shoulder Diagnosis</td>
<td>10</td>
<td>53</td>
</tr>
<tr>
<td>% of Patients with Shoulder Diagnosis</td>
<td>48%</td>
<td>26%</td>
</tr>
<tr>
<td>ELBOW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patients with Elbow Diagnosis</td>
<td>2</td>
<td>32</td>
</tr>
<tr>
<td>% of Patients with Elbow Diagnosis</td>
<td>9%</td>
<td>16%</td>
</tr>
<tr>
<td>Patients with:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cubital Tunnel Syndrome, n</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>Tendinopathy, n</td>
<td>1</td>
<td>19</td>
</tr>
<tr>
<td>Olecranon bursitis, n</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Other, n</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>HAND / WRIST</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patients with Hand/Wrist Diagnosis</td>
<td>9</td>
<td>103</td>
</tr>
<tr>
<td>% of Patients with Hand/Wrist Diagnosis</td>
<td>43%</td>
<td>50%</td>
</tr>
<tr>
<td>Patients with:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CTS, n</td>
<td>3</td>
<td>37</td>
</tr>
<tr>
<td>TD, n</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>TMC arthritis, n</td>
<td>1</td>
<td>13</td>
</tr>
<tr>
<td>Mass, n</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>DeQuervains, n</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td>Hand/Wrist Arthritis, n</td>
<td>2</td>
<td>13</td>
</tr>
<tr>
<td>Other, n</td>
<td>0</td>
<td>13</td>
</tr>
</tbody>
</table>
RESULTS

Of the 246 patients prospectively evaluated, 200 (81%) patients completed all outcome measures and were included in our analysis. Twenty of the 246 patients (8%) refused to shake hands (positive Handshake Test). Twenty percent (4/20) of the positive Handshake Tests involved the left hand. There was no statistically significant difference with respect to the rates of determining a positive Handshake Test between the three surgeons (4%, 6%, 14%; P=0.1444). Table 1 includes baseline demographics between the two groups. Patients with a positive Handshake Test were more likely have had a history of any tobacco use (70% vs 50%; P=0.0373).

Table 2 includes diagnoses by anatomic region for patients in both groups. Patients with a positive Handshake Test were more likely to have a diagnosis involving the shoulder, but these results were not statistically significant (P=0.0657). For patients with a positive Handshake Test, the most common diagnoses were rotator cuff syndrome, carpal tunnel syndrome and trigger digits.

Table 3 contains the NPRS scores and PROMIS scores between the two groups. Patients with a positive Handshake Test demonstrated higher NPRS scores (7.6 vs 4.8), lower PROMIS UE scores (24.5 vs 36.8), higher PROMIS PI scores (69.9 vs 59.6) and lower PROMIS SE scores (35.4 vs 44.8). All of these results were statistically significant. Table 4 includes a comparison of the NPRS scores and PROMIS scores for patients with right upper-extremity complaints.

DISCUSSION

For patients with atraumatic upper-extremity complaints, a positive Handshake Test (refusal to shake hands) is associated with higher pain intensity and worse self-reported functional status. This simple physical examination finding, which we noted in 8% of patients in our series, can be used as a reliable nonverbal indicator of less effective coping strategies. Waddell et al. helped introduce the concept of “nonorganic” physical signs in low-back pain, suggesting that patients demonstrating these five examination signs required further psychological assessment. However, subsequent evaluations of the “Waddell Signs” have demonstrated that while they do correlate with higher pain intensity, they do not correlate with psychological distress in patients with low back pain. We note that compared to patients who are able to shake hands, those with a positive Handshake Test demonstrate higher levels of pain catastrophization, lower levels of self-efficacy and worse self-reported function.

While both verbal and nonverbal patient cues can indicate maladaptive coping strategies, there is a paucity of literature analyzing the ability of hand and upper-extremity surgeons to actually recognize these cues. Medical oncologists, who deal with psychological distress on a regular basis, have difficulty recognizing distress in their patient population, demonstrating a 60% rate of disagreement. Furthermore, while there are a number of questionnaires available to measure coping strategies and resilience, they are infrequently administered in orthopedic clinics. Even in the absence of distributed questionnaires, the Handshake Test allows for surgeons to assess function, pain and illness behavior in a simplistic and objective way. This can be especially important considering that the ability of upper-extremity surgeons to recognize verbal and nonverbal indicators of maladaptive coping strategies is not well defined.

Wilkens et al. determined that protective hand postures were associated with both catastrophic thinking and kinesophobia in patients with traumatic hand and wrist injuries. These authors observed seven distinct hand postures associated with less-effective coping strategies. However, the physicians in the investigation had specific training for diagnosing the hand postures. The authors acknowledged the subjective nature of these assessments and did not assess the reliability of the observations. The utilization of a familiar and easily reproducible handshake greeting does not require additional training and is easy to incorporate into an examination even for patients with left-sided complaints.
There are some limitations to our study. While higher levels of pain interference and low self-efficacy (maladaptive coping strategies) are associated with psychological distress, our study did not specifically include measures of anxiety and depression. We agree with observations by previous authors, who have noted that some patients are inherently uncomfortable with the implications of psychologic assessments and thus may not provide honest answers.

Other limitations of our study include an assessment by only three surgeons, all of whom were male. However, we did not find any statistically significant differences in the rate of positive Handshake Tests among the surgeons in our series. In addition to some of the cultures concerns regarding the use of handshakes, there is the potential for pathogen transmission related to handshakes. However, since most physical examinations of the upper limb include touching the hands, some of these concerns may not be as relevant to upper-extremity surgery. Strengths of this investigation include a prospective, blinded methodology and the inclusion of multiple patient reported outcome measures.

For patients with atraumatic upper-extremity conditions, a positive Handshake Test (refusal to shake hands) is associated with high pain levels, low self-efficacy, and decreased self-reported functional status when compared to patients who can perform a handshake. This simple clinical test can aid in identifying patients with maladaptive coping strategies, allowing surgeons to guide these patients towards interventions and strategies to improve both illness behavior and functional outcomes.

REFERENCES
ABSTRACT

Introduction: A commonly utilized method of measuring femoral stem migration in total hip arthroplasty (THA) on plain anteroposterior (AP) pelvis radiograph with referenced image magnification has not been rigorously evaluated. This study aims to validate the reproducibility of the methods used in this technique.

Methods: A retrospective study of the standardized AP pelvis radiographs of patients who had undergone THA utilizing a Corail® femoral stem was performed from June 2012 through December 2017. Radiological evaluation (head diameter, stem length, and stem seating length) were undertaken at three clinical follow-up times. Each radiographic measurement of each radiograph was repeated five times. Outcomes investigated included inter- and intra-radiograph reproducibility evaluation and radiographic image magnification. The stem length error and stem subsidence were also evaluated.

Results: Two hundred THA patients met the inclusion/exclusion criteria. The intra-radiograph reproducibility of the stem length and head diameter measurements have at least “good” reproducibility with repeated measurements falling within 0.5 mm for both measurements. The reliability for femoral stem seating length measurements has “questionable/poor” reproducibility. The inter-radiograph reproducibility was, however, substantially lower. High level of unreliable measurements with values less than 0.0 mm for both femoral stem length errors (55%) and femoral stem subsidence (32%) measurements. Less than 45% accuracy (femoral stem length error: 33%; femoral stem subsidence: 44%) to within 3 mm error.

Conclusions: This study demonstrates that the assessment of radiographic implant migration after THA made on a sequence of plain AP pelvis radiograph have poor reproducibility.

Level of Evidence: III

Keywords: plain radiograph, reproducibility, displacement measurement, radiological image magnification

INTRODUCTION

According to the American Joint Replacement Registry, more than 277,000 primary hip replacement procedures were performed in the United States in 2016, and this number is projected to increase to 572,000 procedures per year by 2030. Implant subsidence is one criteria utilized to monitor for prosthesis loosening in total hip arthroplasty (THA). Diagnostic procedures to check for implant loosening are based on the clinical situation and symptoms, the radiological follow up and the degree to which these radiographic images are scrutinized for implant subsidence. Surgeons commonly monitor these patients for implant subsidence as there are multiple studies in the literature citing early migration of greater than 2 - 3 mm has been shown to be a predictor of later aseptic failure of the prosthesis. In reported studies, the 2 - 3 mm subsidence measurements were calibrated to correct for magnification using a referenced landmark such as femoral head implant size or acetabular cup diameter. With such small differences being critical, the accuracy of evaluation methods is essential for the longevity of a total joint.

Although advanced imaging techniques such as computed tomography (CT) and magnetic resonance imaging (MRI) have a role in this setting, serial plain anteroposterior (AP) pelvis and lateral hip radiographs remain the mainstay for the initial evaluation of hip arthroplasty. Whether modern digitized or more traditional radiographs area used, most surgeons follow these images in a sequential fashion over time while correcting for image magnification (femoral head or cup size). Subsidence is evaluated by measuring the distal migration of the tip of the stem relative to a reference landmark.
However, these radiographs provide a two-dimensional (projected) representation of a three-dimensional object, and unfortunately, the accuracy is difficult to assess because the real subsidence of the implant is not known. Previous studies have evaluated the validity and reliability for measuring displacement on plain radiographs in different parts of the body, and all suggested that caution should be utilized. Several radiological techniques have been developed utilizing different reference lines and of varying accuracy. Some of these have employed either the femoral head implant or acetabular cup size to calculate radiographic image magnification and subsequently implant migration. A simple and commonly used method is to generate a “magnification factor” for a given radiograph by comparing measured femoral head or cup size to the known size. This factor is then used to modify the measured subsidence. While this technique would allow for calculation of a magnification factor for the head or cup, it is likely limited in its extrapolation to measurements made regarding the stem. This is a result of its inability to account for flexion/extension and rotational changes in position of the lower extremity as well as changes in distance and angle between the x-ray emitter and the femoral stem. All of these could occur over the acquisition of serial radiographs and would affect the radiographically projected implant length and subsequent measures of subsidence. To our knowledge, there are few studies that have rigorously evaluated or discussed the best way to measure the implant subsidence in THA. The specific aim of this study was to validate the reproducibility of using serial digitized plain AP pelvis radiographs to perform radiological displacement measurements and image magnification.

METHODS
Institutional Review Board approval was obtained for the study. This retrospective study (Level 3) reviewed the standardized AP pelvis radiographs of patients who had undergone THA utilizing a conventional Corail® femoral stem (DePuy Synthes, Warsaw, IN). The standardized AP pelvis radiographs in this study were taken in a supine position with lower extremities internally rotated by 15 - 20 degrees to accommodate femoral anteversion. The study sample was selected based on patients who had undergone THA from June 2012 through December 2017 from numerous hospitals within a selected single institute. Subjects with inadequate follow-up (less than three follow-ups), and inadequate AP radiographs such as radiographs with only partial femoral stem or partial femoral head visualization, and/or without both proximal femurs visible on radiograph image were excluded from the study.

A retrospective chart review was performed including documentation of gender, age, body mass index (BMI), hip surgery site, femoral stem size, and femoral head size. All radiographs were evaluated using Sectra IDS7 PAC system (Sectra AB, Linköping, SWEDEN) with a measurement resolution of 0.1 mm. An independent examiner, who was an orthopedic research scientist with more than 10 years of radiographic evaluation experience in orthopedic medicine and was not involved in the care of the patients, evaluated the radiographic measurements for each radiographic image from three time points, which were provided in a randomized order. These radiographic measurements included measurement of femoral head diameter, femoral stem length, and femoral stem seating length (Figure 1). The femoral head diameter was measured using a circle shape around the femoral head, the femoral stem length of the implant was measured from the tip of the proximal end to the distal tip of the stem, and the femoral stem seating length was measured between the lesser trochanter and the distal tip of the stem. Standardized magnification (zoom in) was utilized to “landmark” the most superior and most inferior aspects of the femoral stem, and similar for the femoral head diameter and femoral stem seating length. After recorded all the measurements, the measurement on the radiographs were cleared and zoom out to normal view. This process was repeated five times with at least one day between repeated measurements. These values were labeled as “radiographic” head diameter, stem length, and stem seating length as they represented the raw values measured from the radiograph.

A magnification factor (Mag) was generated by
comparing the radiographic femoral head diameter to the known implant size.

\[
\text{Mag} = \frac{\text{radiographic femoral head diameter}}{\text{actual head diameter}}
\]  
EQN 1

The radiographic stem lengths were then calculated using the generated Mag to arrive at a "calibrated femoral stem length".

\[
\text{calibrated femoral stem length} = \left( \frac{\text{radiographic femoral stem length}}{\text{Mag}} \right)
\]  
EQN 2

Femoral stem length error was defined as the difference between the calibrated femoral stem length and the actual known stem length.

\[
\text{femoral stem length error} = \left( \text{calibrated femoral stem length} - \text{actual stem length} \right)
\]  
EQN 3

The femoral stem seating length measured on the radiographs was modified using the generated Mag to arrive at a calibrated seating length.

\[
\text{calibrated stem seating length} = \left( \frac{\text{radiographic stem seating length}}{\text{Mag}} \right)
\]  
EQN 4

The femoral stem subsidence was defined as the difference between the follow-up post-operative calibrated stem seating length and the initial post-operative calibrated stem seating length.

\[
\text{femoral stem subsidence} = \left( \text{follow-up post-operative calibrated stem length} - \text{initial post-operative stem seating length} \right)
\]  
EQN 5

Statistical Analysis

Descriptive statistics of the mean, standard deviation, 95% confidence interval, and range were determined for the subject’s demographics and all clinical variables. Data retrieved from the radiographic measurements were analyzed using a histogram to evaluate the frequency distribution of the absolute differences between the five repeated measured values for each radiograph to represent the majority of the measurement error. A frequency distribution of more than 90% as “excellent” reliability, 80% to 90% as “good reliability, 70% to 80% as “acceptable” reliability, and values less than 70% as “questionable/poor” reliability. An absolute difference of less than 0.5 mm was defined as an “excellent” repeatability, 0.5 mm to 1.0 mm as “fair” repeatability, and values greater than 1.0 mm as “poor” repeatability. Data entry and analysis were accomplished with Microsoft Excel 2016 (Microsoft, Redmond, Washington).

RESULTS

A total of 200 THA patients (100 male 100 female) were included and reviewed. The mean age was 65 ± 10 years and the mean BMI was 31.5 ± 6.6 kg/m² (Table 1). A histogram analysis of repeated radiographic measurement errors of the same radiographs is shown in Figure 2. Repeated measurements of the same radiographs displayed a "good" repeated measurements reliability for femoral head diameter (84%) and an “excellent” repeated measurements reliability for femoral stem length (95%) measurements within 0.5 mm error difference in measurements. The mean absolute differences for these two measurement were 0.30 ± 0.26 mm (range: 0.0 – 2.6 mm, 95% CI: 0.01 mm) and 0.18 ± 0.18 mm (range: 0.0 – 1.0 mm, 95% CI: 0.00 mm), respectively (Table 2). The repeated measurements reliability for femoral stem seating length measurements was less consistent than the other two measurements above (reliability: 53% within 0.5 mm error; mean absolute difference: 0.68 ± 0.63 mm; range: 0.0 – 6.8 mm; 95% CI: 0.02 mm; Table 2).

A histogram analysis of femoral stem length errors and femoral stem subsidence is shown in Figure 3. The results of this study observed a high level of unreliable measurements with values less than 0.0 mm for both femoral stem length errors (55%) and femoral stem subsidence (32%) measurements. With the subsidence measurement differences of 2 – 3 mm reported being critical to clinical outcomes, there was less than 44% accuracy (femoral stem length error: 33%, and femoral stem subsidence: 44%) to within 3 mm error. The mean absolute differences for these two measurement were 0.3 ± 4.0 mm (range: -19.8 – 24.4 mm, 95% CI: 0.1 mm) and

<table>
<thead>
<tr>
<th>Table 1. Patient Demographics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Age (years, mean ± SD) (range)</td>
</tr>
<tr>
<td>BMI (kg/m², mean ± SD) (range)</td>
</tr>
<tr>
<td>Side</td>
</tr>
<tr>
<td>Left</td>
</tr>
<tr>
<td>Right</td>
</tr>
</tbody>
</table>

Figure 2. Histogram analysis of radiographic measurement errors between each repeated measurements of femoral stem length, femoral head diameter, and femoral stem seating length.
It is common practice to monitor for implant subsidence in THA patients, as there are multiple studies in the literature citing early migration of more than 2 - 3 mm as being predictive of later aseptic failure of the prosthesis. It is well known that magnification in radiographic images produces a slightly larger image on film than the original image. For femoral stem subsidence evaluation, there have been several studies which have suggested using either the femoral head implant size or the acetabular cup diameter to calculate the radiographic image magnification, as these variables are not affected by flexion or rotation of the hip during the individual radiograph examinations. Unfortunately, the femoral stem is not on the same plane as the femoral head or the acetabular cup during the AP pelvis radiograph examinations and therefore subject to more measurement error. The results of this study indicated that this issue can be present when evaluating either the same radiographic image or on a sequence of radiographic images.

Malchau et al. assessed the accuracy of migration measurements on conventional and digitized radiographs of THA by comparing the results with radiostereometry (RSA), and their results showed variations from 4 mm to 12 mm in measurement of stem migration, depending on the choice of the reference landmarks on conventional radiographs. The most accurate measurements for determining migration are those that are close together on the femur and the stem and in the same plane. Walker et al. reported the theoretical basis of a method to measure axial migration of femoral components of THA, and their results indicated that reference points lying closer to each other on stem and femur, are best for determining migration. Their conclusion also stated that of serial AP pelvis radiographs to evaluate THA patient's femoral stem subsidence.

**Table 2. Intra-Radiographic Measurements Reliability Data**

<table>
<thead>
<tr>
<th>Reliability</th>
<th>Repeatability</th>
<th>Radiographic Femoral Head Diameter</th>
<th>Radiographic Femoral Stem Length</th>
<th>Radiographic Femoral Stem Seating Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.5 mm</td>
<td>84% (good)</td>
<td>95% (excellent)</td>
<td>53% (questionable/poor)</td>
<td></td>
</tr>
<tr>
<td>0.5 - 1.0 mm</td>
<td>14%</td>
<td>5%</td>
<td>28%</td>
<td></td>
</tr>
<tr>
<td>&gt; 1.0 mm</td>
<td>2%</td>
<td>0%</td>
<td>20%</td>
<td></td>
</tr>
<tr>
<td>Mean absolute difference (mm, mean ± SD) (range)</td>
<td>0.30 ± 0.26 (0.0 - 2.6)</td>
<td>0.18 ± 0.18 (0.0 - 1.0)</td>
<td>0.68 ± 0.63 (0.0 - 6.8)</td>
<td></td>
</tr>
<tr>
<td>95% Confidence Interval (mm)</td>
<td>0.007</td>
<td>0.004</td>
<td>0.016</td>
<td></td>
</tr>
</tbody>
</table>

**Table 3. Femoral Stem Length Errors and Femoral Stem Subsidence Reliability Data**

<table>
<thead>
<tr>
<th>Femoral Stem Length Error</th>
<th>Femoral Stem Subsidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0 mm</td>
<td>55%</td>
</tr>
<tr>
<td>0 - 1 mm</td>
<td>8%</td>
</tr>
<tr>
<td>1 - 2 mm</td>
<td>15%</td>
</tr>
<tr>
<td>2 - 3 mm</td>
<td>10%</td>
</tr>
<tr>
<td>&gt; 3 mm</td>
<td>13%</td>
</tr>
<tr>
<td>Mean absolute difference (mm) (± SD) (range)</td>
<td>0.34 ± 0.01 (-19.8 – 24.4)</td>
</tr>
<tr>
<td>95% Confidence Interval (mm)</td>
<td>0.14</td>
</tr>
</tbody>
</table>

1.3 ± 3.2 mm (range: -13.5 – 17.3 mm, 95% CI: 0.3 mm), respectively (Table 3).

**DISCUSSION**

The objectives of this research were to evaluate the reliability of common measurements taken on plain hip radiographs, as well as to look at measurement errors of the same components when evaluated over serial radiographs using common calibrated magnification techniques. This study demonstrated that commonly used assessment markers of radiographic implant migration after THA made on sequential plain AP pelvis radiographs have poor inter-radiograph reproducibility and can lead to clinically relevant errors of measurement. A sample calculation of femoral stem subsidence of a patient shown in Table 4 demonstrated the potential error (instead of stem subsidence, the calculated result showed stem raised). These results raise concerns about the use of serial AP pelvis radiographs to evaluate THA patient’s femoral stem subsidence.

It is common practice to monitor for implant subsidence in THA patients, as there are multiple studies in the literature citing early migration of more than 2 - 3 mm as being predictive of later aseptic failure of the prosthesis. It is well known that magnification in radiographic images produces a slightly larger image on film than the original image. For femoral stem subsidence evaluation, there have been several studies which have suggested using either the femoral head implant size or the acetabular cup diameter to calculate the radiographic image magnification, as these variables are not affected by flexion or rotation of the hip during the individual radiograph examinations. Unfortunately, the femoral stem is not on the same plane as the femoral head or the acetabular cup during the AP pelvis radiograph examinations and therefore subject to more measurement error. The results of this study indicated that this issue can be present when evaluating either the same radiographic image or on a sequence of radiographic images.

Malchau et al. assessed the accuracy of migration measurements on conventional and digitized radiographs of THA by comparing the results with radiostereometry (RSA), and their results showed variations from 4 mm to 12 mm in measurement of stem migration, depending on the choice of the reference landmarks on conventional radiographs. The most accurate measurements for determining migration are those that are close together on the femur and the stem and in the same plane. Walker et al. reported the theoretical basis of a method to measure axial migration of femoral components of THA, and their results indicated that reference points lying closer to each other on stem and femur, are best for determining migration. Their conclusion also stated that...
Table 4. Sample Calculation of Femoral Stem Subsidence Error of a Patient Using Magnification Factor Based the Femoral Head Diameter

<table>
<thead>
<tr>
<th></th>
<th>Initial Post-Operative</th>
<th>10-Month Post-Operative</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mag</strong></td>
<td>( \left( \frac{\text{radiographic femoral head diameter}}{\text{actual head diameter}} \right) )</td>
<td>( \left( \frac{\text{radiographic femoral head diameter}}{\text{actual head diameter}} \right) )</td>
</tr>
<tr>
<td></td>
<td>( \left( \frac{32.4 \text{ mm}}{28 \text{ mm}} \right) = 1.16 )</td>
<td>( \left( \frac{34.5 \text{ mm}}{28 \text{ mm}} \right) = 1.23 )</td>
</tr>
<tr>
<td><strong>Calibrated femoral stem length</strong></td>
<td>( \left( \frac{\text{radiographic femoral stem length}}{\text{Mag}} \right) )</td>
<td>( \left( \frac{\text{radiographic femoral stem length}}{\text{Mag}} \right) )</td>
</tr>
<tr>
<td></td>
<td>( \left( \frac{177.8 \text{ mm}}{1.16} \right) = 153.7 \text{ mm} )</td>
<td>( \left( \frac{181.0 \text{ mm}}{1.23} \right) = 146.9 \text{ mm} )</td>
</tr>
<tr>
<td><strong>Stem length error</strong></td>
<td>( (\text{calibrated stem length} - \text{actual stem length}) )</td>
<td>( (\text{calibrated stem length} - \text{actual stem length}) )</td>
</tr>
<tr>
<td></td>
<td>( (153.7 \text{ mm} - 150 \text{ mm}) )</td>
<td>( (146.9 \text{ mm} - 150 \text{ mm}) )</td>
</tr>
<tr>
<td></td>
<td>( = 3.7 \text{ mm} )</td>
<td>( = -3.1 \text{ mm} )</td>
</tr>
<tr>
<td><strong>Using Femoral Head Mag</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Calibrated Stem seating length</strong></td>
<td>( \left( \frac{\text{radiographic stem seating length}}{\text{Mag}} \right) )</td>
<td>( \left( \frac{\text{radiographic stem seating length}}{\text{Mag}} \right) )</td>
</tr>
<tr>
<td></td>
<td>( \left( \frac{118.4 \text{ mm}}{1.16} \right) = 102.3 \text{ mm} )</td>
<td>( \left( \frac{121.0 \text{ mm}}{1.23} \right) = 98.2 \text{ mm} )</td>
</tr>
</tbody>
</table>

**Femoral stem subsidence** = \( 98.2 \text{ mm} - 102.3 \text{ mm} = -4.12 \text{ mm} \)

*Actual head diameter = 28 mm; Actual stem length = 150 mm; Stem seating length = the stem length from the middle of the lesser trochanter and bottom edge of the stem.*
faults in measuring implant migration are most frequently caused by variations in the flexion and rotation of the hip joint during the individual radiograph examinations. Their results showed that the maximum errors due to any combination of rotation and flexion were 0.37 mm for 10° of position change in any direction between successive radiographs. The results of this study agreed with previous studies that measuring displacement on plain radiographs is not reliable regardless of selecting fixated references for the radiographic image magnification. This may be because plain radiographs provide a two-dimensional projected representation of a three-dimensional object.

Even though flexion and extension as well as rotation of the hip can effect radiographic errors in measurement, the most important factors are (1) the distance between the X-ray tube and the film, and (2) distance between the object and the film (Figure 4). The position of the X-ray tube has a strong influence on how the structures appear on the image. The further away the X-ray tube is from the film, the less magnified the image. Standardized AP pelvis radiographs are taken in the supine position at a source-to-film distance of 102 - 122 cm with the X-ray beam centered on the superior aspect of the pubic symphysis and perpendicular to the patient. While felt to be small, the 20 cm difference will affect the radiographic image magnification. Similarly, the vertical distance between the implant and the film will also have significant influence how the structures appear on the image (Figure 4).

Albers et al. used OrthoView (OrthoView LLC, Jacksonville, FL) software, which facilitated calculation of image magnification, to determine the implant subsidence as measured by the distance between the summit of the lesser trochanter and bottom edge of the stem at six weeks postoperatively compared to the latest follow-up imaging. According to Pillai et al. study, the OrthoView software has 80% accuracy within one size of the actual component used. A change of one femoral stem size, however, is a 5 mm difference in stem length and one femoral head implant size difference is a 4 mm change in diameter. Therefore, when looking for values of subsidence where 2 - 3 mm is felt to be clinically relevant; the accuracy of OrthoView may not be sufficient.

Roentgen stereophotogrammetric analysis (RSA) can possible be another potential of assessment of implant migration measurement tools in THA, especially regarding accuracy that has been reported within 0.2 mm for implant subsidence and the three-dimensional (3-D) reconstructions aid significantly in evaluating post-operative implant migration and the rate of migration. However, this is not being used for routine post-operative follow-up due to concerns of cost, as small radio-opaque markers are introduced into the bone and the prosthesis to serve as well-defined artificial landmarks.

This study had certain limitations to consider. First, the sample size was small, which prevented applying tests of significance due to a low power. Second, the radiographs were recorded from numerous hospitals even though within a single institute, which could potentially have minor differences in radiographic techniques. Third, only one selected THA implant was evaluated, which could limit the generalizability to other systems. Forth, femoral stem seating length was measured from the lesser trochanter of which sometimes difficult to visualize in radiographic images depending on the orientation of the femur, this could potential add additional error to the measurement. Despite these limitations, the outcomes of this study are valuable because this study sheds light on the limitations of utilizing serial digitized plain radiographs to perform radiological displacement measurements. Further evaluation is required to support our findings.

CONCLUSIONS

In conclusion, this study demonstrates that the assessment of radiographic implant migration after THA made on a sequence of plain AP pelvis radiograph utilizing femoral head based magnification factors is concerning. Our results indicate that measurement errors are most likely to be expected which may lead to incorrect interpretations of clinical radiographs. Clinicians should recognize these limitations when measuring implant migration and should cautiously interpret clinical results of implant stability where displacement is measured on plain radiographs.

ACKNOWLEDGMENT

The authors want to acknowledge the EDA (Enterprise Data and Analytics) team from Sanford Health for their support on data pulling from our institute.
REFERENCES


ABSTRACT

Background: The use of navigation remains a controversial topic in knee arthroplasty. The purpose of this study is to evaluate current rates of utilization of navigation in unicompartmental knee arthroplasty (UKA) in the United States, as well as the incidence of short-term complications and operative times between navigated and non-navigated UKA.

Methods: A query of the National Surgical Quality Improvement Project (NSQIP) database was used to identify cases of primary UKA during years 2006-2017. Additional common procedural terminology (CPT) codes were used to identify cases in which navigation was utilized. Operative time, length of stay, and short-term outcomes were compared. Propensity score matching was used to minimize differences in demographics and comorbidities between the navigation and non-navigation cohorts.

Results: A total of 10,586 cases of UKA were identified; 343 of these cases (3.2%) utilized navigation. The unadjusted rate of any complication for the entire cohort was 3.6%. Navigated UKA had mean operative times 8 minutes longer than non-navigated UKA (92.1 min vs. 84.3 min; p<0.001). There was no difference in overall complication rates between the matched navigated (3.5%) and non-navigated (3.2%) cohorts (p=0.65). There was no difference in rates of readmission (0.31% vs. 0.58%; p=0.31), reoperation (0.29% vs. 0.29%; p=1.00), and mean length of stay (1.3 ± 1.6 days vs. 1.2 ± 1.9 days; p=0.15).

Conclusion: UKA utilizing navigation had a mean operative time 8 minutes longer than non-navigated UKA. We found no difference in rates of short-term complications, readmission, reoperation, or mean length of stay between navigated and non-navigated UKA.

Level of Evidence: III

Keywords: outcomes, computer, navigation, unicompartmental knee arthroplasty

INTRODUCTION

The use of console-based and hand-held navigation remains a controversial topic in knee reconstruction. Since the technology became available for use in the 1990s, navigation has failed to gain widespread traction amongst surgeons that perform total knee arthroplasty (TKA) and unicompartmental knee arthroplasty (UKA). From 2010-2014, utilization of imageless navigation in TKA decreased by 38.3% in the United States; current national rates of utilization of navigation in UKA are not known.

Proponents of navigation cite improved implant positioning and improved limb alignment relative to non-navigated procedures, decreased risk of perioperative transfusion, and high rates of implant survivorship. The clinical significance of improved limb and implant alignment in terms of patient-reported outcomes and implant survival remains controversial. Additionally, the use of navigation may come at a higher overall cost per surgery, especially in low volume centers, and longer operative times.

The purpose of this study is to evaluate current rates of utilization of navigation in UKA in the United States. Additionally, we compare the incidence of short term complications, perioperative blood transfusions, and operative times between navigated and non-navigated UKA. We hypothesized that the rate of use of navigation in UKA will be similar to rates in TKA, approximately 3-5% of all cases, and that there would be no difference in rate of short term complications, perioperative blood transfusions, and operative times between navigated and non-navigated UKA.

METHODS

This study was granted exemption status from the institutional review board. A query of the American College of Surgeons National Surgical Quality Improvement Project (ACS-NSQIP) database was performed for patients
Table 1. Preoperative Patient Demographics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Non-navigated UKA (n=10,243)</th>
<th>Navigated UKA (n=343)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demographics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age, mean (SD)</td>
<td>64.1 (10.6)</td>
<td>64.9 (9.8)</td>
</tr>
<tr>
<td>Gender, % female</td>
<td>51.7%</td>
<td>52.2%</td>
</tr>
<tr>
<td>Race, %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>77.7</td>
<td>93.6</td>
</tr>
<tr>
<td>Black</td>
<td>3.6</td>
<td>3.2</td>
</tr>
<tr>
<td>Other</td>
<td>18.7</td>
<td>3.2</td>
</tr>
<tr>
<td>Preoperative conditions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI (kg/m²), mean (SD)</td>
<td>31.6 (6.3)</td>
<td>31.6 (5.7)</td>
</tr>
<tr>
<td>Functional status, %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Independent</td>
<td>98.7</td>
<td>99.7</td>
</tr>
<tr>
<td>Dependent</td>
<td>1.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Diabetes mellitus, %</td>
<td>15.2</td>
<td>15.7</td>
</tr>
<tr>
<td>Smoking, %</td>
<td>9.9</td>
<td>9.9</td>
</tr>
<tr>
<td>Dyspnea, %</td>
<td>4.6</td>
<td>5.8</td>
</tr>
<tr>
<td>COPD, %</td>
<td>2.8</td>
<td>2.6</td>
</tr>
<tr>
<td>Congestive heart failure (CHF), %</td>
<td>1.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Prior MI, %</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Hypertension, %</td>
<td>56.8</td>
<td>58.6</td>
</tr>
<tr>
<td>Chronic kidney disease (CKD), %</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>End-stage renal disease (ESRD), %</td>
<td>1.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Metastatic cancer, %</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Prior wound infection, %</td>
<td>2.3</td>
<td>3.2</td>
</tr>
<tr>
<td>Steroid use, %</td>
<td>1.7</td>
<td>6.2</td>
</tr>
<tr>
<td>Bleeding disorder, %</td>
<td>1.8</td>
<td>2.0</td>
</tr>
<tr>
<td>Preoperative blood transfusion, %</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Sepsis, %</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Prior operation within 30 days, %</td>
<td>1.0</td>
<td>0.0</td>
</tr>
<tr>
<td>ASA Class, %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 - no disturbance</td>
<td>3.7</td>
<td>3.2</td>
</tr>
<tr>
<td>2 - mild disturbance</td>
<td>57.6</td>
<td>58.6</td>
</tr>
<tr>
<td>3 - severe disturbance</td>
<td>37.8</td>
<td>37.3</td>
</tr>
<tr>
<td>4 - life threatening disturbance</td>
<td>9.0</td>
<td>9.0</td>
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<td>Preoperative laboratory values</td>
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<td>Creatinine, mean (SD)</td>
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<td>Albumin, mean (SD)</td>
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<td>2.0</td>
</tr>
<tr>
<td>WBC, mean (SD)</td>
<td>6.4</td>
<td>6.2</td>
</tr>
<tr>
<td>Hematocrit, mean (SD)</td>
<td>38.5</td>
<td>38.1</td>
</tr>
<tr>
<td>Platelets, mean (SD)</td>
<td>218.9</td>
<td>216.2</td>
</tr>
<tr>
<td>Anesthesia type</td>
<td></td>
<td></td>
</tr>
<tr>
<td>General, %</td>
<td>46.6</td>
<td>30.3</td>
</tr>
<tr>
<td>Spinal, %</td>
<td>38.1</td>
<td>36.7</td>
</tr>
<tr>
<td>Epidural, %</td>
<td>7.7</td>
<td>9.0</td>
</tr>
<tr>
<td>Regional (non-spinal), %</td>
<td>10.3</td>
<td>19.5</td>
</tr>
<tr>
<td>Other, %</td>
<td>4.3</td>
<td>12.6</td>
</tr>
</tbody>
</table>

UKA = unicompartmental knee arthroplasty; BMI = body mass index; SD = standard deviation; WBC = white blood cell count; ASA = American Society of Anesthesiologists.

who had undergone primary UKA (Common Procedural Terminology [CPT] code 27446) during years 2006-2017. Additional CPT codes of 0055T (CT/MRI navigation), and 20985 (image-less navigation) were used to identify cases in which navigation was utilized. There were three cases with associated CPT code 0054T (fluoroscopic navigation); these cases were excluded from analysis. Patients undergoing revision surgery and emergency surgery were excluded from this study.

NSQIP database utilizes data submitted by participating institutions. Methods for data collection and curation of the NSQIP database, as well as specific inclusion and exclusion criteria for the database have been described previously. Studies aimed at auditing and assessing the quality of data within national databases have demonstrated the NSQIP database to be a reliable source of data with high rates of inter-rater reliability. Data in the NSQIP database is reviewed and audited semiannually.

Patient Demographics

Patient-specific and case-specific variables utilized for this study are demonstrated in Table 1. Exhaustive descriptions of all variables in the NSQIP database are located within the NSQIP user guide.

Outcomes

ACS-NSQIP collects patient morbidity and mortality outcomes to 30 days after the index surgery. Per the ACS-NSQIP user guide, reporting of all outcomes (either positive or negative) is mandatory for all participating centers and records entered into NSQIP, as such, no outcomes are omitted from analysis. In the present study, we report 15 clinical outcome variables that we believe to be most clinically relevant to patients undergoing UKA; these variables are listed in Table 2. Additional outcome variables, including peripheral nerve injury, were not included in the study, as the methods of collection of this variable were deemed erroneous by the NSQIP PUF.

Statistical Analysis

Propensity score matching is a powerful statistical procedure for reducing selection bias due to confounding factors between study groups. Previous studies have used these methods in orthopedics cohorts. In this study, we conducted a one-to-one propensity score matching for patients in which navigation was utilized against cases in which no navigation was used. Multivariate logistic regression was built to predict the probability of everyone to select an equal number of subjects with comparable characteristics for both groups, controlling baseline difference in patient characteristics for age, race, BMI, ASA class, postoperative disposition, and diabetes status.
A Hosmer and Lemeshow goodness-of-fit test was used to detect the fitness of the model. Univariate analysis was used to detect the difference between additional procedure group and none additional procedure group on demographic, comorbidities, and 30 days complication outcomes before and after matching procedure, using Chi-square statistics for categorical variables and Wilcoxon sum rank test for continuous variables. Linear regression analysis was used to examine temporal trends. Complications were defined by variables listed in Table 2. All statistical analysis was performed using the SAS 9.4 (Cary, NC). Statistical significance was set at p<0.05.

**RESULTS**

A total of 10,586 cases of UKA were identified; 343 of these cases (3.2%) utilized navigation. Comparing the non-navigated and navigated cohorts, there was no difference in age (64.1 ± 10.6 years vs. 64.9 ± 9.8 years; p=0.12), body mass index (BMI) (31.6 ± 6.3 kg/m2 vs. 31.6 ± 5.7 kg/m2; p=0.75), gender (51.7% female vs. 52.2% female; p=0.85), incidence of diabetes (15.2% vs. 15.3%; p=0.78), smoking (9.9% vs. 9.9%; p=0.98), and chronic obstructive pulmonary disease (COPD) (2.9% vs. 2.6%) (Table 1). The only difference in patient demographics and comorbidities between the cohorts was a higher preoperative white blood cell count in the non-navigated cohort relative to the navigated cohort (6.36 k/mm3 vs. 6.17 k/mm3; p=0.04).

The unadjusted rate of any complication for the entire cohort was 3.6%. Common 30-day complications in the entire cohort included superficial wound dehiscence (0.61%), urinary tract infection (UTI) (0.59%), requiring a blood transfusion (0.53%), and deep vein thrombosis (DVT) (0.37%) (Table 1). Following propensity score matching, there was no difference in overall complication rates between the matched non-navigated and navigated cohorts (3.2% vs. 3.6%; p=0.65) (Table 2). Rates of specific complications within each respective cohort are present in Table 2. There was no difference in rates of readmission between the matched non-navigated and navigated cohorts (3.2% vs. 3.6%; p=0.65) (Table 2). Rates of specific complications within each respective cohort are present in Table 2. There was no difference in rates of readmission between the matched non-navigated and navigated cohorts (3.2% vs. 3.6%; p=0.65) (Table 2). Rates of specific complications within each respective cohort are present in Table 2. There was no difference in rates of readmission between the matched non-navigated and navigated cohorts (3.2% vs. 3.6%; p=0.65) (Table 2). Rates of specific complications within each respective cohort are present in Table 2. There was no difference in rates of readmission between the matched non-navigated and navigated cohorts (3.2% vs. 3.6%; p=0.65) (Table 2). Rates of specific complications within each respective cohort are present in Table 2. There was no difference in rates of readmission between the matched non-navigated and navigated cohorts (3.2% vs. 3.6%; p=0.65) (Table 2). Rates of specific complications within each respective cohort are present in Table 2. There was no difference in rates of readmission between the matched non-navigated and navigated cohorts (3.2% vs. 3.6%; p=0.65) (Table 2). Rates of specific complications within each respective cohort are present in Table 2. There was no difference in rates of readmission between the matched non-navigated and navigated cohorts (3.2% vs. 3.6%; p=0.65) (Table 2). Rates of specific complications within each respective cohort are present in Table 2. There was no difference in rates of readmission between the matched non-navigated and navigated cohorts (3.2% vs. 3.6%; p=0.65) (Table 2). Rates of specific complications within each respective cohort are present in Table 2. There was no difference in rates of readmission between the matched non-navigated and navigated cohorts (3.2% vs. 3.6%; p=0.65) (Table 2). Rates of specific complications within each respective cohort are present in Table 2. There was no difference in rates of readmission between the matched non-navigated and navigated cohorts (3.2% vs. 3.6%; p=0.65) (Table 2). Rates of specific complications within each respective cohort are present in Table 2. There was no difference in rates of readmission between the matched non-navigated and navigated cohorts (3.2% vs. 3.6%; p=0.65) (Table 2). Rates of specific complications within each respective cohort are present in Table 2. There was no difference in rates of readmission between the matched non-navigated and navigated cohorts (3.2% vs. 3.6%; p=0.65) (Table 2). Rates of specific complications within each respective cohort are present in Table 2. There was no difference in rates of readmission between the matched non-navigated and navigated cohorts (3.2% vs. 3.6%; p=0.65) (Table 2). Rates of specific complications within each respective cohort are present in Table 2. There was no difference in rates of readmission between the matched non-navigated and navigated cohorts (3.2% vs. 3.6%; p=0.65) (Table 2). Rates of specific complications within each respective cohort are present in Table 2.

<table>
<thead>
<tr>
<th>Complications, %</th>
<th>Non-navigated UKA Unadjusted</th>
<th>Matched</th>
<th>Navigated UKA Unadjusted</th>
<th>Matched</th>
<th>p value</th>
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<tr>
<td>Any</td>
<td>3.55</td>
<td>3.21</td>
<td>3.55</td>
<td>.36</td>
<td>.65</td>
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<tr>
<td>Superficial wound infection</td>
<td>.61</td>
<td>29</td>
<td>29</td>
<td>.72</td>
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<tr>
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<td>0</td>
<td>0</td>
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<tr>
<td>Organ space infection</td>
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<td>29</td>
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<td>.53</td>
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<tr>
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<tr>
<td>Pneumonia</td>
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<td>29</td>
<td>.47</td>
<td></td>
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<tr>
<td>Reintubation</td>
<td>.06</td>
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<td>0</td>
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<tr>
<td>Pulmonary embolism</td>
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<tr>
<td>UTI</td>
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<td>58</td>
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<td>.72</td>
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<tr>
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<tr>
<td>MI</td>
<td>.12</td>
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<td>0</td>
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<tr>
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<tr>
<td>Shock</td>
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<td>0</td>
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<td>1</td>
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<tr>
<td>Operative time, min, mean (SD)</td>
<td>87.5 (36.4)</td>
<td>84.3 (29)</td>
<td>92.1 (29.3)</td>
<td>&lt;.001</td>
<td>&lt;.001</td>
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<tr>
<td>LOS, days, mean (SD)</td>
<td>1.8 (2.2)</td>
<td>1.3 (1.6)</td>
<td>1.2 (1.9)</td>
<td>&lt;0.001</td>
<td>.15</td>
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<tr>
<td>Readmission, %</td>
<td>.31</td>
<td>0</td>
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<td>.31</td>
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<td>Reoperation, %</td>
<td>.74</td>
<td>29</td>
<td>29</td>
<td>.52</td>
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</tbody>
</table>

UTI – urinary tract infection; MI – myocardial infarction; DVT – deep vein thrombosis; SD – standard deviation; LOS – length of stay.
1.5% to 5.7% (Table 3, Figure 1). There was a statistically significant increase in the rate of navigation from 2006 to 2017 (p<0.001). However, when excluding years 2006 from 2009, the increase in navigation utilization from 2.1% in 2010 to 4.5% in 2017 was not statistically significant (p=0.18).

DISCUSSION
Navigation has been shown to improve limb and implant alignment following primary UKA. However, the clinical implications of this improved alignment remain unclear. Short and medium-term outcome studies suggest that the survival benefit may be marginal and that navigation may offer better clinical outcomes only in select patient populations. The impact of these potential benefits must be weighed against the costs of navigation use, namely, the potential for longer operative times and increased rates of complication. While the present study did not examine measures of patient pain, function, or long term outcome, we did evaluate potential effects of navigation use on operative time and short term outcomes, including wound complications and deep infections.

In the present study, we evaluated the rate of utilization of navigation in primary UKA. From 2006 to 2017, the mean rate of navigation utilization within the NSQIP database was 3.2%. The rate of navigation utilization increased significantly over the entire study period (Table 3; Figure 1); however when evaluating only years with ≥1 UKA, the trend was no longer statistically significant. In a retrospective review of primary TKA in the ACS-NSQIP database, Ghosn et al. demonstrated a navigation utilization rate of 4.96% in 2010 and 3.06% in 2014, a 38% decrease. In contrast, Antonios et al. found an increase in the rate of utilization of navigation in primary TKA from 1.2% in 2005 to 6.3% in 2014. In their study, Antonios et al. noted the presence of significant regional variation within navigation utilization, with higher rates of computer utilization in the Western US.

A common detraction regarding the use of computer navigation is the concern that it increases operative time without an increase in clinical benefit. In a cohort of 296 patients undergoing primary UKA, Jenny et al. found operative times to be 20 minutes longer in the navigation group. A 2013 meta-analysis by Weber et al. noted operative times to be 15.4 minutes longer in the navigated cohort relative to the non-navigated cohort. Nair et al. in a 2014 systematic review, also noted longer operative times in navigated UKAs. In the present study, we found a statistically significant difference in operative times, with navigated UKA, on average, taking 5-8 minutes longer than non-navigated UKA. With respect to operative times in primary TKA, the literature is widely variable, with studies demonstrating no difference in operative times between navigated and non-navigated groups, others demonstrating faster operative times in navigated cohorts and others still with faster operative times in non-navigated cohorts.

Overall rates of short-term (≤90 days postoperatively) complication following UKA are estimated to be 3.2-5.6%. Complication profiles between UKA performed on an inpatient versus outcome basis are thought to be similar. In the present study, we noted an overall complication rate of 3.6% in the first 30 days following UKA (Table 2). There was no significant difference in rate of complication between navigated and non-navigated UKA (Table 2). Further, there was no difference in rates of readmission or reoperation. In a cohort of over 10,000 patients from a Medicare claims database, Chona et al. found no difference in rates of revision operation or need for repeat arthrotomy within 2 years between navigated and non-navigated UKA. They also demonstrated no difference in rates of deep venous thrombosis (DVT) between navigated and non-navigated cohorts.

The present study has several limitations. First, this study is a retrospective review of a prospectively collected database. While the ACS-NSQIP is vetted for accuracy
multiple times a year, it is still subject to errors in data collection, collation, and transcription.\textsuperscript{2,3} The study is also subject to coding inaccuracies at the time of surgery. While this study utilizes propensity score matching, we are unable to account for all patient specific variables. Further, we are unable to account for surgeon-specific variables that may influence patient outcomes: surgeon experience, operative technique, and postoperative protocols. It is important to reiterate that this study does not examine measures of patient pain, function, or clinical outcomes beyond 30 days, where the use of navigation may or may not translate into clinical benefit. Finally, it is important to note that we, the authors, have no way of validating the data within the NSQIP database outside of the internal measures NSQIP already uses, and to this end, we have no way of knowing how many cases of UKA were coded as not using navigation that did use navigation, or vice versa.

In conclusion, the rate of utilization of computer navigation during UKA appears to be increasing; however, overall rates of utilization remain low around 3-5%. Based on data from a large clinical registry, we found no difference in rates of short term complications, reoperation, or readmission following navigated versus non-navigated UKA. Mean operative times in the navigated UKA cohort were eight minutes longer than the non-navigated cohort. Further studies elucidating the clinical benefit and cost effectiveness of navigation are needed.

REFERENCES


ABSTRACT

Background: As the population ages, rate of total knee arthroplasty increases and thus, it is important to maximize efficiency and minimize risk. Identifying patients who are at higher risk for transfusion can help streamline care provided and minimize superfluous, costly hemoglobin monitoring in low risk patients.

Methods: Adult patients who underwent total knee arthroplasty (TKA) in 2015 were identified in the National Surgical Quality Improvement Project (NSQIP) database. Patients were divided into two cohorts: those who required transfusion post operatively and those who did not. Patient demographics and comorbidities were compared using univariate analysis; and multivariate analysis was used to determine risk factors for short-term complications.

Results: Of 48,055 TKA patients, 3.0% required transfusion. The patients who required transfusion were older, had higher BMI, higher rates of comorbidities and were more frequently ASA class 3-4 (p<0.005). Univariate analysis revealed that patients who required transfusion had higher rates of any complication (9.19% v. 4.23%, p<0.001). Multivariate regression analysis identified the following as risk factors for transfusion requirement: Black race (adjusted odds ratio [OR] 1.2, 95% confidence interval [CI] 1.01-1.4), COPD (OR 1.6, 95% CI 1.3-2.0), corticosteroids (OR 1.4, 95% CI 1.1-1.8), bleeding disorder (OR 1.4, CI 1.1-1.9), ASA class 4 (OR 2.3, CI 1.5-4.8), operative time >2 hours (OR 1.3, 95% CI 1.2-1.5) and lack of functional independence (OR 1.6, 95% CI 1.1-2.3).

Conclusions: In a cohort of patients undergoing primary TKA in 2015, history of COPD, black race, operative time, steroid use, bleeding disorder, lack of functional independence and ASA class 3-4 were independent predictors of need for blood transfusion. Additionally, we found that patients who received transfusion demonstrated a significantly higher rate of the following: any complication, pneumonia, urinary tract infection, septic shock, deep vein thrombosis, renal insufficiency, cardiac arrest, myocardial infarction, unplanned readmission, reoperation and mortality. Presence of these risk factors in TKA patients could represent an indication for hemoglobin monitoring post-operatively.

Level of Evidence: IV

Keywords: total knee arthroplasty, risk factors, transfusion, blood transfusion

INTRODUCTION

As the US population ages, the demand for total knee replacement rises; the rate of total knee arthroplasty increased nearly 3-fold between 1990 and 2002. Surgeons continually seek new methods to streamline perioperative care. This process is also encouraged by the transition from a fee-for-service based design to an episode of care model. An attractive initiative in optimizing safety and efficiency is the potential to offer individualized care to patients based on risk factors. In this regard, an important target focuses on the risk of allogenic blood transfusion. The rate of red blood cell (RBC) transfusion historically has been reported to be up to 35% following total knee arthroplasty. With modern perioperative practices, this rate has been significantly diminished. Nevertheless, many surgeons continue to monitor hemoglobin and hematocrit postoperatively as a routine practice. Patient care post-operatively can be made more efficient and less costly by adoption of a restrictive hemoglobin monitoring protocol. In such a protocol, only patients with an elevated risk for transfusion post-operatively would need lab testing. Knowing risk factors for blood transfusion after surgery can help identify patients who could benefit from hemoglobin testing post-operatively. Previous studies have shown that age, ASA class, preoperative hemoglobin, initial postoperative hemoglobin, change in pre to postoperative hemoglobin and adherence to strict transfusion triggers are significant predictors of perioperative blood transfusion. Few
have evaluated independent risk factors for blood transfusion. The goal of this study was to compare patient characteristics in two cohorts—transfused and not transfused—in order to identify risk factors that may help surgeons identify patients who are at risk of requiring peri-operative blood transfusions.

**METHODS**

**Data Collection and Patient Selection**

All patients who underwent primary total knee replacement in 2015 were identified using the American College of Surgeons—National Surgical Quality Improvement program (ACS-NSQIP) database. Current procedural terminology codes (CPT) codes for primary total knee arthroplasty (27447) were used. A total of 48,055 patients were identified. Patients were divided into two groups: those who received a blood transfusion during their hospital stay and those who did not. Patients were excluded if the surgery was non-elective, non-primary, or if they discharged on post-operative day zero. Records were available for 46,630 patients who did not receive transfusion and 1,425 patients who did receive transfusion.

**Variables**

Patient characteristics included the following: demographics, pre-operative health variables and comorbidities, pre-operative laboratory values, and operative variables (Table 1). Demographics included age, sex, race (white, black, other) and smoking status. Pre-operative health variables included the following: body mass index (BMI) and recent weight loss (loss of 10% of total body weight in the previous 6 months). The following comorbidities were also included: diabetes mellitus, chronic obstructive pulmonary disease (COPD), congestive heart failure (CHF), hemodialysis use, corticosteroid use, bleeding disorder, pre-operative blood transfusion, and pre-operative sepsis. Pre-operative laboratory values included white blood cell count, hematocrit, platelet count, creatinine, serum albumin and international normalized ratio (INR). Operative variables included American Society of Anesthesiologists (ASA) class, length of operation and length of stay.

**Outcomes**

The following 30-day complications were analyzed: wound complications (superficial, deep, organ space infection, wound dehiscence), pulmonary complications (pneumonia, unplanned intubation), venous thromboembolism (deep vein thrombosis, pulmonary embolism), cardiac complication (acute myocardial infarction, cardiac arrest requiring resuscitation), renal complications (acute renal failure or insufficiency defined as a rise in Cr >2 mg/dL above baseline), neurologic...

<table>
<thead>
<tr>
<th>Table 1. Demographic Characteristics, Preoperative Comorbidities, Preoperative Laboratory Values, and Operative Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Demographics</strong></td>
</tr>
<tr>
<td>Age (yr)</td>
</tr>
<tr>
<td>Female sex (%)</td>
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<tr>
<td>Race (%)</td>
</tr>
<tr>
<td><strong>Preoperative Comorbidities</strong></td>
</tr>
<tr>
<td>BMI (kg/m2)</td>
</tr>
<tr>
<td>Recent Weight Loss (%)</td>
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<tr>
<td>Diabetes Mellitus (%)</td>
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<td>Smoking (%)</td>
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<tr>
<td>Chronic Obstructive Pulmonary Disease (%)</td>
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<td>Steroids (%)</td>
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<tr>
<td>Bleeding Disorder (%)</td>
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<tr>
<td>Preoperative Blood Transfusion (%)</td>
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<td>Open Wound or Infection (%)</td>
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<td>Pre-op Sepsis (%)</td>
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<tr>
<td><strong>Preoperative Laboratory Values</strong></td>
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<tr>
<td>White Blood-Cell Count (103 cells/µL)</td>
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<tr>
<td>Hematocrit (%)</td>
</tr>
<tr>
<td>Platelets (per µL)</td>
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<tr>
<td>Creatinine (mg/dL)</td>
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<tr>
<td>Serum Albumin (g/dL)</td>
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<td>International Normalized Ratio</td>
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<tr>
<td><strong>Operative Variables</strong></td>
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<tr>
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<tr>
<td>1 (no disturbance)</td>
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<td>2 (mild disturbance)</td>
</tr>
<tr>
<td>3 (severe disturbance)</td>
</tr>
<tr>
<td>4 (life-threatening disturbance)</td>
</tr>
<tr>
<td>Length of Operation</td>
</tr>
<tr>
<td>Length of Stay</td>
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</table>

*Presented as mean and associated standard deviation.
complication (stroke, coma lasting >24 hours, peripheral nerve injury), urinary tract infection, sepsis, septic shock, unplanned readmission, reoperation, and mortality. 'Any complication' was defined as the presence of 1 or more of the above complications (Table 2).

**Statistical Analysis**

SAS software, version 9.4 (SAS Institute, Inc. of Cary, North Carolina) was used for data analysis. Two sample independent t-tests were used for between group comparisons of continuous variables. Chi-square test was used to determine difference between categorical variables for the univariate analysis. Next, separate multivariate logistic regression models for transfusion were used to determine the effects of the confounding variables identified from the univariate analysis with a p-value above 0.1. P-values were reported with the level of significance set at p<0.05 in the univariate model. Results from the multivariate logistic regression model are reported as an adjusted odds ratio and its associated 95% confidence interval.

**RESULTS**

A total of 48,055 total knee arthroplasty patients were identified. Of these, 3% received a transfusion and 97% did not. Patients who received transfusion were older, had higher rates of diabetes mellitus (DM), chronic obstructive pulmonary disease (COPD), congestive heart failure (CHF), dialysis, corticosteroid use, bleeding disorders and preoperative blood transfusions. Patients who received transfusion had lower preoperative hematocrit, white blood cell count, and serum albumin and higher creatinine and INR. Those who received a transfusion had longer length of operation and length of stay. Finally, patients who received transfusion were more frequently ASA class 3 or 4 (p<0.001 for all comparisons) (Table 1).

Univariate analysis revealed that patients who received transfusion had a significantly higher rate of the following: any complication (9.19% versus 4.23%, p <0.0001) as well as pneumonia (1.68% versus 0.32%, p<0.0001), urinary tract infection (1.40% versus 0.71%, p= 0.002), septic shock (0.56% versus 0.05%, P<0.001), DVT (1.54% versus 0.79%, p= 0.002), renal insufficiency (0.63% versus 0.11%,<0.0001), cardiac arrest (0.49% versus 0.05%, p<0.0001), myocardial infarction (0.91% versus 0.18%, p <0.0001), unplanned intubation (0.77% versus 0.09%, p=0.001), unplanned readmission (5.40% versus 3.10%, P <0.0001), reoperation (2.32% versus 1.6%, p <0.0001), mortality (0.56% versus 0.08%, p<0.0001), operative time (108.6 min versus 92.67 minutes, p<0.0001) and length of hospital stay (3.97 days versus 2.80 days, p <0.0001).

Multivariate regression analysis identified the following as risk factors for transfusion requirement:

- Black race (adjusted odds ratio [OR] 1.2, 95% confidence interval [CI] 1.01-1.4), COPD (OR 1.6, 95% CI 1.3-2.0), corticosteroids (OR 1.4, 95% CI 1.1-1.8), bleeding disorder (OR 1.4, CI 1.1-1.9), ASA class 4 (OR 2.3, CI 1.5-4.8), operative time >2 hours (OR 1.3, 95% CI 1.2-1.5) and lack of functional independence (OR 1.6, 95% CI 1.1-2.3) (Table 3).

**DISCUSSION**

While modern TKA produces excellent clinical results, surgeons continually seek adaptations that will enhance their efficiency while maintaining patient safety and reducing cost of care. Given the cost associated with reflex lab testing in post-operative patients, we sought to identify independent risk factors that place specific patients at increased risk for transfusion in the ACS-NSQIP database. Previous studies have shown that age,
ASA class, preoperative hemoglobin, initial postoperative hemoglobin, change in pre to postoperative hemoglobin and adherence to transfusion triggers are significant predictors of perioperative blood transfusion. Similarly, a simple risk assessment model can be generated to identify patients who need post-operative hemoglobin monitoring. Our findings, including these independent risk factors, can be used to generate such a model. Our results indicate that the following are independent risk factors for post-operative transfusion requirement: Black race, history of COPD, corticosteroid use, history of bleeding disorder, operative time >2 hours, lack of functional independence and ASA class 3 and 4.

Several of the limitations of our study are common to large database research: the data were collected retrospectively; the data are also dependent on accuracy of coding. An additional limitation is the inclusion of only 1 year of NSQIP data; while this decreased variability in transfusion protocols, it also limits the volume of data. There are likely factors that place a patient at higher risk for transfusion that we did not consider or that are not included in the NSQIP database. Finally, our cohort does not include patients who were readmitted for acute blood loss anemia or those who had asymptomatic acute blood loss anemia and received transfusion outside of the immediate peri-operative period. Further research is needed to develop and test the proposed risk assessment model for post-operative hemoglobin monitoring restricted to high risk patients.

CONCLUSIONS

In a cohort of patients undergoing primary TKA in 2015, history of comorbidities including COPD, corticosteroid use, bleeding disorder, black race, lack of functional independence, operative time >2 hours and ASA class 3-4 were independent predictors of need for blood transfusion. The results of this study indicate that risk factors exist which can help guide surgeons in selective hemoglobin monitoring in the post-operative period. Judicious use of laboratory testing can be an adjunct practice for cost-containment after total joint arthroplasty.

![Table 3. Multivariable Regression Analysis for Blood Transfusion](image)

<table>
<thead>
<tr>
<th></th>
<th>Adjusted Odds Ratio</th>
<th>95% Confidence Interval</th>
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<tbody>
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<tr>
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<td>Ref</td>
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<td>1.920</td>
<td>1.142-3.227</td>
</tr>
<tr>
<td>4+</td>
<td>2.626</td>
<td>1.447-4.765</td>
</tr>
<tr>
<td>Operative Time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;2 hours</td>
<td>Ref</td>
<td>Ref</td>
</tr>
<tr>
<td>&gt;2 hours</td>
<td>1.341</td>
<td>1.188-1.513</td>
</tr>
<tr>
<td>Functional Status</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Independent</td>
<td>1.594</td>
<td>1.116-2.275</td>
</tr>
<tr>
<td>Not Independent</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ASA class, preoperative hemoglobin, initial postoperative hemoglobin, and adherence to transfusion triggers are significant predictors of perioperative blood transfusion. We found that while controlling for confounding demographics and comorbidities, Black race, history of COPD, corticosteroid use, and bleeding disorder are independent risk factors for transfusion requirement. Additionally, we found that patients who received transfusion demonstrated a significantly higher rate of the following: any complication, pneumonia, urinary tract infection, septic shock, deep vein thrombosis, renal insufficiency, cardiac arrest, myocardial infarction, unplanned infarction, unplanned intubation, unplanned readmission, reoperation and mortality. We are unable to comment on whether this is a cause and effect relationship.

Risk stratification has repeatedly been cited as an important tool for differentiating the quality of outcomes following frequently performed procedures, specifically, costly procedures such as TKA. Individual risk assessment models have been created for DVT prophylaxis, allotting relative weights to risk factors (hypercoagulability, metastatic cancer, stroke, sepsis, COPD) and assigning a relative risk to individual patients. Similarly, a simple risk assessment model can be generated to identify patients who need post-operative hemoglobin monitoring.

<table>
<thead>
<tr>
<th></th>
<th>Adjusted Odds Ratio</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;50</td>
<td>Ref</td>
<td>Ref</td>
</tr>
<tr>
<td>≥80</td>
<td>1.319</td>
<td>0.992-1.753</td>
</tr>
<tr>
<td>Female Sex</td>
<td>1.000</td>
<td>0.903-1.107</td>
</tr>
<tr>
<td>Race</td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>Ref</td>
<td>Ref</td>
</tr>
<tr>
<td>Black</td>
<td>1.194</td>
<td>1.013-1.402</td>
</tr>
<tr>
<td>Other</td>
<td>0.576</td>
<td>0.406-0.819</td>
</tr>
<tr>
<td>Diabetes</td>
<td>1.079</td>
<td>0.951-1.224</td>
</tr>
<tr>
<td>COPD</td>
<td>1.608</td>
<td>1.311-1.972</td>
</tr>
<tr>
<td>Congestive Heart Failure</td>
<td>1.050</td>
<td>0.525-2.101</td>
</tr>
<tr>
<td>Corticosteroids</td>
<td>1.434</td>
<td>1.149-1.789</td>
</tr>
<tr>
<td>Bleeding Disorder</td>
<td>1.415</td>
<td>1.081-1.854</td>
</tr>
<tr>
<td>ASA Classification</td>
<td></td>
<td></td>
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<tr>
<td>1</td>
<td>Ref</td>
<td>Ref</td>
</tr>
<tr>
<td>2</td>
<td>1.440</td>
<td>0.857-2.419</td>
</tr>
<tr>
<td>3</td>
<td>1.920</td>
<td>1.142-3.227</td>
</tr>
<tr>
<td>4+</td>
<td>2.626</td>
<td>1.447-4.765</td>
</tr>
<tr>
<td>Operative Time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;2 hours</td>
<td>Ref</td>
<td>Ref</td>
</tr>
<tr>
<td>&gt;2 hours</td>
<td>1.341</td>
<td>1.188-1.513</td>
</tr>
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<td>Functional Status</td>
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</tr>
<tr>
<td>Independent</td>
<td>1.594</td>
<td>1.116-2.275</td>
</tr>
</tbody>
</table>
REFERENCES


ABSTRACT

Background: Reduction of variations may streamline healthcare delivery, improve patient outcomes, and minimize cost. The purpose of this study was to characterize variations in surgical rates and hospital costs for treatment of pediatric distal radius fractures (DRFs) using Pediatric Health Information System (PHIS) database.

Methods: The PHIS database was queried from 2009-2013 for DRFs in patients 4-18 years of age. Patients who underwent surgical treatment with internal fixation were identified using surgical CPT codes and/or ICD-9 procedure codes. 25 children's hospitals were included. Surgical rates and hospital costs were modeled. Rates were adjusted and standardized for gender, age, presence of other diagnoses, and year.

Results: The aggregate rate of surgery for treatment of DRF was 2.65% and for open surgery was 0.81%. The standardized surgical rates for the 25 hospitals ranged widely, from 1.45% to 13.8% and for open surgical treatment from 0.51% to 4.27%. Six of the 25 hospitals had rates significantly higher than the aggregate for surgical treatment. Standardized hospital costs per patient ranged from $361 to $1,088 (2013 US dollars) across the hospitals with fairly uniform distribution.

Conclusions: In the United States, there is great variability in practice and hospital costs of treatment of distal radius fractures. Further characterization of the root causes of these variations, and the effect, if any, on patient outcomes, is needed to improve value delivery in pediatric orthopaedic care.

Level of Evidence: II

Keywords: pediatric distal radius fracture, economic decision-making, value, PHIS

INTRODUCTION

There has been an unsustainable rise in the cost of healthcare, and with that rise, an increased emphasis on value-based healthcare. Value is generally defined as the ratio of benefits over costs, where benefits include health outcomes and patient satisfaction. Wide geographic variability of both benefits and costs can make the value equation a difficult one to compute and compare. Costs of healthcare can often be non-transparent, even to patients and providers. There has been a call for decreasing variability and establishing standards of care, particularly for common diagnoses and procedures, to optimize clinical outcomes, streamline costs, and ultimately improve value.

Pediatric distal radius fractures (DRFs) are among the most common injuries treated by orthopaedic surgeons, and constitute up to 20% of all pediatric fractures. As such, DRFs constitute a particular opportunity to evaluate value-based care in children. However, the diagnosis of “distal radius fracture” encompasses a spectrum of fracture patterns and treatment options. DRFs are comprised of torus fractures, metaphyseal fractures, physeal fractures, and intra-articular fractures. Treatment options include applying a removable splint, casting with or without reduction, and surgical fixation with open or closed reduction. Institutional efforts to decrease treatment variability have been successful; however, assessment of regional and/or national variability has not been performed. By identifying variations of treatment and cost of DRFs, care of these injuries can be streamlined, thus potentially improving outcomes and increasing value.

The purpose of this study was to assess national variation in hospital costs and surgical rates in the care of distal radius fractures across a large cohort of U.S. pediatric hospitals, utilizing the Pediatric Health Information System (PHIS) database.

METHODS

Data for this study were obtained from the Pediatric Health Information System (PHIS), an administrative database that contains inpatient, emergency department, ambulatory surgery and observation encounter-level
data from over 49 not-for-profit, tertiary care pediatric hospitals in the United States. These hospitals are affiliated with the Children’s Hospital Association. Data quality and reliability are assured through a joint effort between the Children’s Hospital Association and participating hospitals. Data are de-identified at the time of data submission and are subjected to a number of reliability and validity checks before being included in the database. Institutional Review Board approval was obtained for our own institutional review of our PHIS data related to this project, with a waiver of individual patient consent. This article does not contain any studies with human participants performed by any of the authors.

The target population was children aged 4-18 years with a DRF diagnosis during 2009-2013. DRF was defined by ICD-9 Diagnosis Codes 813.41, 813.42, 813.44, 813.45, 813.47. These codes include only closed fractures. The first (index) encounter must have included an emergency department visit, but all encounters within the first 60 days of the index encounter were considered a single episode of care.

We excluded patients who did not first present to the Emergency Department (ED), as many patients are sent to a tertiary pediatric hospital after failure of conservative measures at a different institution. Since PHIS does not include outpatient encounters, we were unable to identify all such patients. While including patients who did not first present to the ED would have captured those who went to surgery, doing so would have skewed the data toward operative intervention. As such, the cohort of patients included in this study were those who initially presented to their institution’s Emergency Department with a closed distal radius fracture; some of these patients went on to have surgery for their injury (“surgical” patients) and

### Table 1. Description of Cohort

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>N (%)</th>
<th>Range [a]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Patients</td>
<td>64,477 (100)</td>
<td>937 to 6,611</td>
</tr>
<tr>
<td><strong>Surgery</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>62,770 (97.3%)</td>
<td></td>
</tr>
<tr>
<td>Any Surgery</td>
<td>1,707 (2.65%)</td>
<td>0.69% to 18.0%</td>
</tr>
<tr>
<td>Closed Surgery</td>
<td>1,183 (1.83%)</td>
<td></td>
</tr>
<tr>
<td>Open Surgery</td>
<td>524 (0.81%)</td>
<td>0.30% to 6.66%</td>
</tr>
<tr>
<td><strong>Hospital Cost, $</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median (IQR)</td>
<td>675 (425, 1,137)</td>
<td>304 to 1,211</td>
</tr>
<tr>
<td>Geometric Mean</td>
<td>704</td>
<td>394 to 1,166</td>
</tr>
<tr>
<td>Mean (±SD)</td>
<td>1,263 (±4,515)</td>
<td>756 to 2,115</td>
</tr>
<tr>
<td><strong>Gender</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>23,470 (36%)</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>41,007 (64%)</td>
<td></td>
</tr>
<tr>
<td><strong>Age, years</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-10</td>
<td>40,134 (62%)</td>
<td></td>
</tr>
<tr>
<td>11-14</td>
<td>20,627 (32%)</td>
<td></td>
</tr>
<tr>
<td>15-18</td>
<td>3,716 (6%)</td>
<td></td>
</tr>
<tr>
<td><strong>Other Diagnoses</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>50,179 (78%)</td>
<td></td>
</tr>
<tr>
<td>Non-Chronic</td>
<td>10,128 (16%)</td>
<td></td>
</tr>
<tr>
<td>Chronic</td>
<td>4,170 (6%)</td>
<td></td>
</tr>
<tr>
<td><strong>Year</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>12,335 (19%)</td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>12,720 (20%)</td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td>13,015 (20%)</td>
<td></td>
</tr>
<tr>
<td>2012</td>
<td>13,470 (21%)</td>
<td></td>
</tr>
<tr>
<td>2013</td>
<td>12,937 (20%)</td>
<td></td>
</tr>
</tbody>
</table>

[a] Range across 25 hospitals.

IQR: interquartile range; SD: standard deviation

### Table 2. Surgery Rates, by Patient Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>N</th>
<th>Surgery Rate (%)</th>
<th>Unadjusted OR (95% CI)</th>
<th>Adjusted OR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gender</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>23,470</td>
<td>470 (2.00%)</td>
<td>1.0 (reference)</td>
<td>1.0 (reference)</td>
</tr>
<tr>
<td>Male</td>
<td>41,007</td>
<td>1,237 (3.02%)</td>
<td>1.49 (1.34, 1.67)</td>
<td>1.26 (1.12, 1.41)</td>
</tr>
<tr>
<td><strong>p&lt;0.0001</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Age, years</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-10</td>
<td>40,134</td>
<td>808 (2.01%)</td>
<td>1.0 (reference)</td>
<td>1.0 (reference)</td>
</tr>
<tr>
<td>11-14</td>
<td>20,627</td>
<td>661 (3.20%)</td>
<td>1.63 (1.46, 1.81)</td>
<td>1.47 (1.31, 1.64)</td>
</tr>
<tr>
<td>15-18</td>
<td>3,716</td>
<td>238 (6.40%)</td>
<td>3.30 (2.83, 3.86)</td>
<td>2.78 (2.37, 3.26)</td>
</tr>
<tr>
<td><strong>p&lt;0.0001</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Other Diagnoses</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>50,179</td>
<td>818 (1.63%)</td>
<td>1.0 (reference)</td>
<td>1.0 (reference)</td>
</tr>
<tr>
<td>Non-Chronic</td>
<td>10,128</td>
<td>545 (5.38%)</td>
<td>4.43 (3.92, 5.01)</td>
<td>4.34 (3.84, 4.91)</td>
</tr>
<tr>
<td>Chronic</td>
<td>4,170</td>
<td>344 (8.25%)</td>
<td>6.42 (5.56, 7.41)</td>
<td>5.97 (5.17, 6.91)</td>
</tr>
<tr>
<td><strong>p&lt;0.0001</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Year</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>12,335</td>
<td>329 (2.67%)</td>
<td>1.0 (reference)</td>
<td>1.0 (reference)</td>
</tr>
<tr>
<td>2010</td>
<td>12,720</td>
<td>329 (2.59%)</td>
<td>0.97 (0.83, 1.14)</td>
<td>0.94 (0.80, 1.10)</td>
</tr>
<tr>
<td>2011</td>
<td>13,015</td>
<td>331 (2.54%)</td>
<td>0.99 (0.84, 1.15)</td>
<td>0.91 (0.77, 1.06)</td>
</tr>
<tr>
<td>2012</td>
<td>13,470</td>
<td>364 (2.70%)</td>
<td>1.05 (0.90, 1.22)</td>
<td>0.96 (0.82, 1.12)</td>
</tr>
<tr>
<td>2013</td>
<td>12,937</td>
<td>354 (2.74%)</td>
<td>0.93 (0.80, 1.09)</td>
<td>0.85 (0.72, 0.99)</td>
</tr>
<tr>
<td><strong>p=0.64</strong></td>
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</tr>
<tr>
<td><strong>p=0.31</strong></td>
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</table>

OR: odds ratio. CI: confidence interval

with a DRF diagnosis during 2009-2013. DRF was defined by ICD-9 Diagnosis Codes 813.41, 813.42, 813.44, 813.45, 813.47. These codes include only closed fractures. The first (index) encounter must have included an emergency department visit, but all encounters within the first 60 days of the index encounter were considered a single episode of care.
most did not ("non-surgical" patients). Patients who were referred directly to the clinic or for surgery, and did not present to the Emergency Department at any time, were not included in this study. However, we acknowledge that patients who fail conservative management at an outside institution could have been referred through the ED (and not directly to clinic) and would thus skew the data toward operative intervention.

In PHIS, total hospital cost is based on the ratio of cost to charges submitted by the hospitals on their respective Medicare cost reports. Hospital costs for all encounters within an episode of care were summed for a total cost, which was adjusted to 2013 dollars using the Consumer Price Index. These costs do not include personnel fees such as professional costs for physician services, indirect costs, or patient-related costs.

Surgical reduction with fixation was defined by ICD-9 Procedure codes 7912, 7932 and/or Current Procedure Terminology (CPT) codes 25606, 25607, 25608, and 25609. While widely used by surgeons, CPT codes are not reported routinely to PHIS by some hospitals, and of all surgical procedures identified, more than 97% were documented either by ICD-9 codes or by both ICD-9 and CPT codes. Surgical rates estimated for each institution using only ICD-9 Procedure codes and estimated using only CPT codes were highly correlated (corr=.968, p<0.001). ICD-9 Procedure code 7912 and CPT code 25606 were classified as closed surgery (closed reduction with percutaneous pin), and the other codes as open surgery (open reduction with internal fixation). A small number of patients (<0.1%) were excluded from the analysis because of internal data inconsistencies, such as codes for both open and closed surgery.

Using ICD-9 Diagnosis Codes, each patient was categorized as having no diagnoses (other than DRF), other non-chronic diagnoses, or at least one chronic diagnosis. The distinction between chronic and non-chronic diagnoses was based on the Agency for Healthcare Research and Quality’s Chronic Condition Indicator system.

Within each hospital, the observed surgical rate was calculated as the number treated surgically divided by the total number of DRF fractures. Adjusted surgical rates for each hospital were estimated using mixed effects logistic regression with a random hospital effect. Patient characteristics included as fixed effects in the model were: gender, age (categories chosen a priori: 4-10, 11-14, 15-18 years), other diagnoses (none, non chronic, chronic), and year of initial encounter (2009-2013, modeled as a categorical variable). Details of fracture severity and/or displacement are not available in PHIS. The associations between patient characteristics and surgical rates were expressed as odds ratios with confidence intervals derived from the mixed logistic regression models. We report both unadjusted and adjusted associations based on models which include one patient characteristic at a time (unadjusted) or a single model including all characteristics (adjusted). All of the model-based estimates, including the unadjusted associations between patient characteristics and surgical rates, account for clustering by hospital through the use of the random hospital effect.

Model-based predicted surgical rates for each hospital were based on the adjusted model. These rates were standardized for the aggregate distributions of all characteristics by first calculating a predicted rate for a single “average” patient (fixed effects estimate) and then adding each hospital’s predicted random effect. The intent of this standardization was to remove variation in surgical rates between hospitals that is due to variation in the types of patients they are treating, when comparing hospitals. The estimates were calibrated so that the fixed-effects estimate for this average patient matched the aggregate observed rate for all patients in all hospitals combined. Finally, we calculated 95% confidence intervals for the standardized rate at each hospital. Hospitals whose lower confidence limit was greater than the aggregate had rates significantly higher than the aggregate, with the analogous interpretation for those whose upper limit was less than the aggregate. This analysis was performed for overall surgical rate (open or closed surgery) and for open surgical rate.

For purposes of analyzing total hospital cost, we conducted an analysis similar to the surgical rate analysis, with the following modifications. Surgery (categorized as none, closed, open) was included as a predictor in the model. Since cost is a continuous outcome variable, a linear model was used instead of the logistic model. The logarithm of cost had a distribution much closer to
Table 3. Open Surgery Rates, by Patient Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>N</th>
<th>Open Surgery no. (%)</th>
<th>Unadjusted OR(95% CI)</th>
<th>Adjusted OR(95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>23,470</td>
<td>127(0.54%)</td>
<td>1.0 (reference)</td>
<td>1.0 (reference)</td>
</tr>
<tr>
<td>Male</td>
<td>41,007</td>
<td>397(0.97%)</td>
<td>1.74(1.42, 2.13)</td>
<td>1.29(1.05, 1.59)</td>
</tr>
<tr>
<td>p&lt;0.0001</td>
<td>p&lt;0.0001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age, years</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-10</td>
<td>40,134</td>
<td>186(0.46%)</td>
<td>1.0 (reference)</td>
<td>1.0 (reference)</td>
</tr>
<tr>
<td>11-14</td>
<td>20,627</td>
<td>214(1.04%)</td>
<td>2.23(1.83, 2.72)</td>
<td>2.01(1.64, 2.46)</td>
</tr>
<tr>
<td>15-18</td>
<td>3,716</td>
<td>124(3.34%)</td>
<td>7.17(5.67, 9.06)</td>
<td>6.10(4.79, 7.76)</td>
</tr>
<tr>
<td>p&lt;0.0001</td>
<td>p&lt;0.0001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other Diagnoses</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>None</td>
<td>50,179</td>
<td>266(0.53%)</td>
<td>1.0 (reference)</td>
<td>1.0 (reference)</td>
</tr>
<tr>
<td>Non-Chronic</td>
<td>10,128</td>
<td>153(1.51%)</td>
<td>3.23(2.61, 4.00)</td>
<td>3.06(2.47, 3.79)</td>
</tr>
<tr>
<td>Chronic</td>
<td>4,170</td>
<td>105(2.52%)</td>
<td>5.43(4.25, 6.93)</td>
<td>4.80(3.75, 6.14)</td>
</tr>
<tr>
<td>p&lt;0.0001</td>
<td>p&lt;0.0001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>12,335</td>
<td>107(0.87%)</td>
<td>1.0 (reference)</td>
<td>1.0 (reference)</td>
</tr>
<tr>
<td>2010</td>
<td>12,720</td>
<td>105(0.83%)</td>
<td>0.95(0.72, 1.24)</td>
<td>0.94(0.71, 1.24)</td>
</tr>
<tr>
<td>2011</td>
<td>13,015</td>
<td>101(0.78%)</td>
<td>0.92(0.70, 1.20)</td>
<td>0.87(0.66, 1.15)</td>
</tr>
<tr>
<td>2012</td>
<td>13,470</td>
<td>115(0.85%)</td>
<td>1.03(0.79, 1.35)</td>
<td>0.98(0.75, 1.29)</td>
</tr>
<tr>
<td>2013</td>
<td>12,937</td>
<td>96(0.74%)</td>
<td>0.79(0.60, 1.05)</td>
<td>0.73(0.55, 0.97)</td>
</tr>
<tr>
<td>p=0.38</td>
<td>p=0.19</td>
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</table>

OR: odds ratio, CI: confidence interval

normal, so log(cost) was used as the outcome variable in the model, but results were transformed back to dollars for presentation. Accordingly, the associations between patient factors and cost were expressed as relative costs (percentage increase or decrease) and the model-based standardized costs can be interpreted as geometric means.

All analyses were conducted with SAS and SAS/STAT software, version 9.4, including the MIXED and GLIMMIX procedures for the mixed model analyses. P-values are two-sided and considered significant when <0.05.

RESULTS

We initially extracted 85,983 encounters from 80,934 patients at 30 hospitals for which the data elements reported to PHIS during 2009-2013 included those that were required for our analysis. Our final data set consisted of 64,477 patients from 25 hospitals. All data from five hospitals with inadequate CPT and/or ICD-9 Procedure data (12,967 patients) were excluded, as were 3,409 patients whose index encounter did not include an emergency department visit. The remaining exclusions (0.09% of encounters; 0.10% of patients) were due to missing or inconsistent data. Table 1 summarizes the aggregate patient characteristics, surgical rates, and hospital cost data for the 25 hospitals. Overall, 2.65% of patients had surgery, 0.81% had open surgery, and both the geometric mean and median total hospital costs were about $700.

Associations between patient characteristics and the overall surgical rate are summarized in Table 2. The surgical rate for males was higher than for females, with an adjusted OR of 1.26. There was an association between surgery and older age (adjusted OR=2.78 for 15-18 years vs. 4-10 years), and with other diagnoses other than DRF (adjusted ORs 4.34 and 5.97). There was no evidence of a change in surgical rate over time. The standardized surgical rates for the 25 hospitals ranged widely, from 1.45% to 13.8% (Figure 1). Six of the 25 hospitals had rates significantly higher than the aggregate rate of 2.65% and 10 hospitals had significantly lower rates. The rate for three hospitals was 3 or more times the aggregate.

The analysis of open surgery yielded similar results (Table 3, Figure 2). The standardized rates ranged from 0.51% to 4.27%, with 5 hospitals significantly lower and 4 higher than the aggregate of 0.81%. The rate for two hospitals was 3 or more times the aggregate.

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For purposes of modeling hospital cost, we included surgery as a predictor in the model in addition to gender, age, other diagnoses, and year (Table 4). As anticipated, hospital costs were much higher for patients who had surgery compared with patients treated non-operatively (adjusted estimates: 531.3% higher for closed surgery, 836.5% higher for open surgery). Patients with diagnoses...
Table 4. Hospital Cost, by Patient Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>N</th>
<th>Cost ($)</th>
<th>Median (IQR)</th>
<th>Unadjusted Relative Cost (95% CI)</th>
<th>Adjusted Relative Cost (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gender</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>23,470</td>
<td>621</td>
<td>(387,1018)</td>
<td>0.0% (reference)</td>
<td>0.0% (reference)</td>
</tr>
<tr>
<td>Male</td>
<td>41,007</td>
<td>715</td>
<td>(449,1200)</td>
<td>14.2% (12.5%, 15.9%)</td>
<td>11.1% (9.6%, 12.7%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>p&lt;0.0001</td>
<td>p&lt;0.0001</td>
</tr>
<tr>
<td><strong>Age, years</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-10</td>
<td>40,134</td>
<td>666</td>
<td>(418,1114)</td>
<td>0.0% (reference)</td>
<td>0.0% (reference)</td>
</tr>
<tr>
<td>11-14</td>
<td>20,627</td>
<td>692</td>
<td>(435,1171)</td>
<td>6.8% (5.1%, 8.4%)</td>
<td>1.3% (-0.1%, 2.8%)</td>
</tr>
<tr>
<td>15-18</td>
<td>3,716</td>
<td>710</td>
<td>(448,1261)</td>
<td>17.9% (14.4%, 21.6%)</td>
<td>2.2% (-0.7%, 5.2%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>p&lt;0.0001</td>
<td>p=0.10</td>
</tr>
<tr>
<td><strong>Other Diagnoses</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>50,179</td>
<td>652</td>
<td>(403,1049)</td>
<td>0.0% (reference)</td>
<td>0.0% (reference)</td>
</tr>
<tr>
<td>Non-Chronic</td>
<td>10,128</td>
<td>818</td>
<td>(528,1688)</td>
<td>61.3% (57.9%, 64.8%)</td>
<td>47.0% (44.1%, 49.9%)</td>
</tr>
<tr>
<td>Chronic</td>
<td>4,170</td>
<td>773</td>
<td>(424,1795)</td>
<td>71.0% (66.1%, 76.0%)</td>
<td>47.0% (43.0%, 51.0%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>p&lt;0.0001</td>
<td>p=0.0001</td>
</tr>
<tr>
<td><strong>Year</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>12,335</td>
<td>627</td>
<td>(396,975)</td>
<td>0.0% (reference)</td>
<td>0.0% (reference)</td>
</tr>
<tr>
<td>2010</td>
<td>12,720</td>
<td>656</td>
<td>(423,1027)</td>
<td>10.9% (8.4%, 13.4%)</td>
<td>8.4% (6.1%, 10.6%)</td>
</tr>
<tr>
<td>2011</td>
<td>13,015</td>
<td>660</td>
<td>(402,1040)</td>
<td>13.9% (11.4%, 16.5%)</td>
<td>11.1% (8.9%, 13.4%)</td>
</tr>
<tr>
<td>2012</td>
<td>13,470</td>
<td>761</td>
<td>(451,1316)</td>
<td>29.4% (26.6%, 32.3%)</td>
<td>26.1% (23.6%, 28.7%)</td>
</tr>
<tr>
<td>2013</td>
<td>12,937</td>
<td>748</td>
<td>(449,1294)</td>
<td>30.6% (27.6%, 33.5%)</td>
<td>29.3% (26.7%, 32.0%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>p&lt;0.0001</td>
<td>p&lt;0.0001</td>
</tr>
<tr>
<td><strong>Surgery</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>62,770</td>
<td>664</td>
<td>(418,1081)</td>
<td>0.0% (reference)</td>
<td>0.0% (reference)</td>
</tr>
<tr>
<td>Closed</td>
<td>1,183</td>
<td>4178</td>
<td>(2970,5745)</td>
<td>621.2% (586.2%, 658.1%)</td>
<td>531.3% (501.1%, 563.0%)</td>
</tr>
<tr>
<td>Open</td>
<td>524</td>
<td>6175</td>
<td>(4594,9338)</td>
<td>956.2% (880.9%, 1037.3%)</td>
<td>836.5% (771.0%, 907.0%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>p&lt;0.0001</td>
<td>p&lt;0.0001</td>
</tr>
</tbody>
</table>

IQR: interquartile range; CI: confidence interval

in addition to DRF had about 50% higher costs, and there was approximately a 30% increase from 2009 to 2013 (adjusted for inflation). There was also a small but significant increment in hospital cost (11.1%) associated with males compared with females but no association with age in the adjusted analysis. Standardized hospital costs ranged from $361 to $1,088 across the 25 hospitals, with a fairly uniform distribution across this range (Figure 3). This contrasts with surgical rates, which tended to cluster in a narrow range for most hospitals.

**DISCUSSION**

In this analysis of over 60,000 patients treated at 25 U.S. pediatric hospitals, we found considerable variation in both rates of surgery and hospital costs for treatment of pediatric distal radius fractures. A few institutions had a much higher rate of surgery than the aggregate rate of 2.65%. It is interesting that the rate of surgery and open surgery was fairly consistent across the majority of institutions, with a marked increase in the rates in only a few. Hospital costs, however, were more uniformly spread across an approximately three-fold range.

The overall value of surgery requires an assessment of both incremental hospital costs and outcomes; this study only examined the hospital cost and variability of surgical care and is unable to address the question of which intervention for a particular patient’s fracture – closed, open or no surgery – is the most cost-effective, or whether the surgical rate for any particular hospital is inappropriately low or high. While this study can assess the variability in the use of surgery and hospital costs, we cannot assess the variability of outcome, and thus are missing an important component of the value equation.

There were a number of limitations to the current investigation. First and foremost, PHIS is an administrative database, and as such the data gathered lack specific clinical information including important patient characteristics, details of treatment, or clinical
outcomes. As noted above, further analysis is needed to evaluate the influence of patient-specific factors— including concomitant diagnoses—on surgical rates and hospital costs. Second, hospital cost information contained within the PHIS database represents only a portion of the total cost of fracture care. For example, services provided and hospital costs incurred beyond the defined episode of care and/or outside the initial treating institution may not be adequately captured in this analysis. This would also include professional fees for surgeons, therapists, and other allied health providers. Patient-related costs such as travel expenses, child-care expenses, and time off from work are also not included in our cost information. Furthermore, only patients who presented initially through the Emergency Department were included in efforts to capture first presentation of acute fractures; however some patients who failed conservative treatment at an outside institution may have been referred to the ED for secondary care, thus imparting some selection bias. Conversely, some patients with a fresh fracture may have initially presented to clinic or ambulatory settings. As a result, the true surgical rate may be higher than reported here.

However, database utilization does allow aggregate assessment of a large volume of patients across various geographic regions and can produce generalizable information representative of the population of interest.13 Third, in this study we standardized the surgical rates and hospital costs to the same “average” patient across all hospitals. However, there is limited information in PHIS on which to standardize (e.g., no measure of fracture severity). Therefore some of the observed hospital variation may be due to unmeasured variation in fracture severity across institutions. Likewise, some of the small but statistically significant associations between patient characteristics and surgery or hospital cost could well be due to residual confounding. The coding and reporting of surgical procedural billing codes (ICD-9 procedure codes versus CPT codes) may vary by institution; we have tried to control for this variability but some residual slight skew may remain. In addition, the very high correlation between surgical rates for each institution estimated using only ICD-9 procedure codes and rates estimated using only CPT codes (corr=0.968, p<0.0001) suggests that this source of institutional variation was unlikely to have a meaningful effect on our results. The hospitals in our analysis are all similar in many ways, including all being pediatric tertiary-care hospitals, and the patients analyzed all had an Emergency Department encounter. Therefore, our estimated surgical rates and costs may not be representative of a wider class of US pediatric hospitals and patients. However, the similarity of hospitals and patients that is a product of our study design does suggest that the variation in surgical rates and hospital costs that we observed could be under-estimates of the variation across a wider class of hospitals and patients. Finally as noted above, clinical outcomes were not assessed.

Despite these limitations, an important first step in providing value-based care is measurement and assessment of variation. This investigation provides information regarding the overall rate of surgery and hospital costs in pediatric DRF care in U.S. pediatric hospitals as well as the distribution of variation. Future analysis should strive to establish target surgical rates and characterize the effects of variations on patient outcomes and cost.

REFERENCES


ABSTRACT

Background: Recent literature supports minimalist approaches such as splinting for pediatric buckle fractures of the wrist. Uptake of this practice, however, has lagged behind the evidence. Barriers to implementation of this strategy necessitate further investigation, and caregiver and patient preferences represent an obstacle that has not been previously evaluated. This study sought to examine caregiver and patient treatment preferences and factors influencing care decisions for buckle fractures of the wrist. We hypothesized that the majority of caregivers and patients prefer cast immobilization for buckle fractures of the wrist.

Methods: A 22-item caregiver survey was created to assess demographics, treatment preferences and influential factors. The survey was completed by a convenience sample of caregivers presenting with patients of any diagnosis to our pediatric orthopaedic clinic.

Results: 297 surveys were collected predominantly from mothers (81.2%) caring for 2.4 (SD 1.3) children. Forty-one percent had previously cared for a child with a fracture. Caregivers accompanied patients who were 9.0 +/- 5.0 years old, 34% of whom were actively being treated for an orthopaedic injury. Caregiver immobilization preferences for buckle fractures of the wrist were: no preference (43.1%), cast (32.3%) and splint (24.6%). The doctor’s recommendation was the most influential factor on this decision while the child’s gender was the least of the factors assessed. Those who rated treatment durability and child’s activity level higher were associated with a preference for casting, while those who rated comfort higher were associated with a preference for splinting.

Discussion: This study is the first to characterize caregiver preferences regarding immobilization devices in the realm of buckle fractures of the wrist. Findings identified that preferences are mixed, with the interest in casting being less than anticipated. Factors influencing caregiver preference include the doctor’s recommendation, durability, the patient’s activity level, and comfort. Findings can help guide treatment discussions for providers seeking to implement splint-based immobilization strategies.

Level of Evidence: III

Keywords: buckle fracture, torus fracture, splint, cast

INTRODUCTION

Fractures of the distal forearm are common injuries seen in childhood and adolescence with increasing incidence. Torus (buckle) fractures of the distal forearm are among the more common variants of these injuries and are characterized by an inherent stability that has enabled a recent shift towards treatment methods other than casts which were traditionally employed in the acute management of most types of pediatric forearm fractures. Although buckle fractures were historically managed with cast immobilization and routine radiographic monitoring, evidence emerging in the last two decades demonstrates that treatment with removable immobilization (i.e. splinting) and minimal clinical and no radiographic follow-up produces the same outcome as historical treatment protocols. While the minimalist approach to treatment is equally effective and decreases healthcare costs and patient burden, it has not been implemented into clinical practice in all settings and is not the preferred method of treatment among many specialist providers.

Despite the evidence supporting a new standard of care for the treatment of pediatric buckle fractures in this minimalist fashion, adoption has been slow and barriers to implementation still remain. Prior work by this group and other investigators has sought to identify these barriers. Boutis et al. demonstrated that patient compliance and
Table 1. Caregiver and Child Characteristics

<table>
<thead>
<tr>
<th>Subject - Response Variable</th>
<th>Mean (SD) or N (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caregiver - Relationship to child at visit:</td>
<td></td>
</tr>
<tr>
<td>Mother</td>
<td>241 (81.1%)</td>
</tr>
<tr>
<td>Father</td>
<td>38 (12.8%)</td>
</tr>
<tr>
<td>Grandparent</td>
<td>10 (3.4%)</td>
</tr>
<tr>
<td>Other (Stepparent, Legal Guardian, Uncle/Aunt)</td>
<td>8 (2.7%)</td>
</tr>
<tr>
<td>Caregiver - How many children do you care for?</td>
<td>24 (1.3)</td>
</tr>
<tr>
<td>Caregiver - Prior experience caring for a child with a fracture</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>123 (41.4%)</td>
</tr>
<tr>
<td>No</td>
<td>174 (58.6%)</td>
</tr>
<tr>
<td>Child - Age</td>
<td>9.1 (5.0)</td>
</tr>
<tr>
<td>Child - Gender</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>146 (49.2%)</td>
</tr>
<tr>
<td>Female</td>
<td>151 (50.8%)</td>
</tr>
<tr>
<td>Child - Currently undergoing fracture management?</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>84 (28.3%)</td>
</tr>
<tr>
<td>No</td>
<td>196 (66.0%)</td>
</tr>
<tr>
<td>Unsure</td>
<td>17 (5.7%)</td>
</tr>
<tr>
<td>Child - Caregiver-rated child activity level (1-5)</td>
<td>3.9 (1.1)</td>
</tr>
</tbody>
</table>

Methods

A cross-sectional survey of a convenience sample of caregivers presenting to our pediatric orthopaedic clinic was designed and performed in order to investigate immobilization preferences and factors of influence. Survey reporting was performed in accordance with the Checklist for Reporting Results of Internet E-Surveys.²¹

Survey Design and Content

A survey was developed after literature review and investigator discussions to formulate questions addressing study aims. Survey questions were reviewed by investigators and two non-investigators for clarity prior to completion. The final survey was composed of 22 items divided into two sections: 1) Demographic/Visit-related (12 questions) and 2) Treatment Preference/Influential Factor (10 questions). The second section was preceded by a clarification statement that described and included pictures of immobilization options (cast and splint) and provided a brief statement regarding the equivalence of outcomes with each option. The full survey is included in the Appendix 1. The study was approved by the [blinded] Institutional Review Board.

Study Population

The target population for this survey study was a convenience sample of caregivers presenting with patients for any reason to the pediatric orthopaedic clinic. Solicitations for survey completion were made from September 2016 to March 2017 in a de-identified manner. Responses from caregivers completing the survey on successive follow-up visits and incomplete surveys were excluded (n = 103). Given the broad range of children’s ages and cognitive abilities, we elected to address all survey questions to caregivers for consistency. Therefore, questions regarding the child’s preferences were based on the caregiver’s perception.

Survey Administration

Survey functionality and usability was assessed via trial completion using the website link and online form prior to clinic use. The survey was closed and accessible to caregivers only during their clinical encounter. It was opened by staff via desktop link on clinic computer workstation after patients were roomed. Survey completion was encouraged during time spent waiting for the provider so as not to slow down clinic flow.

Questions were non-adaptive and presented in a set order with each survey section on a separate page. Participation was optional and surveys were collected in a de-identified manner without linkage to the patient or clinical encounter. No incentives were provided for participation. Survey responses were collected and managed using REDCap (Research Electronic Data Capture)²² tools hosted at our institution. REDCap is a secure, web-based application designed to support data capture for research studies.

Statistical Analyses

Statistical analyses were performed using JMP® PRO Version 13.0 [SAS Institute, Cary, NC]. Descriptive statistics were used to analyze the demographics of the caregivers completing the survey. The distribution of preferences and influencer ratings were calculated. Demographic and influential factors associated with
specific immobilization preferences were identified with bivariate analyses using student t-tests for continuous variables and chi square testing for categorical variables. A p-value <0.05 was considered significant.

RESULTS

Respondents Demographics

A total of 297 completed unique caregiver surveys were collected regarding caregiver/child dyads. The demographics of surveyed caregivers and their children are detailed in Table 1. The majority of respondents identified as the mother of the child attending the clinic visit and cared for more than two children. Fewer than half (41.4%) had previously cared for a child with a fracture. Children of the surveyed caregivers had a mean age of 9 years old. The gender distribution of these children was nearly equal and most were not actively being treated for a fracture or other orthopaedic injury. The caregiver-rated activity level (Likert Scale 1-Low to 5-High) of this cohort of children was 3.9 (SD 1.1).

Caregiver and Perceived Child Preferences

For the presented clinical scenario of a buckle fracture of the wrist, caregiver immobilization preferences were:

<table>
<thead>
<tr>
<th>Subject</th>
<th>Factor of Influence</th>
<th>Cast Preference</th>
<th>Non-Cast Preference</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caregiver</td>
<td>Doctor’s recommendation</td>
<td>4.36 (1.05)</td>
<td>4.39 (1.05)</td>
<td>0.827</td>
</tr>
<tr>
<td></td>
<td>Comfort</td>
<td>4.10 (1.08)</td>
<td>4.25 (1.07)</td>
<td>0.265</td>
</tr>
<tr>
<td></td>
<td>Durability</td>
<td>4.39 (0.97)</td>
<td>4.02 (1.10)</td>
<td>0.006</td>
</tr>
<tr>
<td></td>
<td>Child's activity level</td>
<td>3.97 (1.24)</td>
<td>3.51 (1.40)</td>
<td>0.006</td>
</tr>
<tr>
<td></td>
<td>Anticipated wear compliance</td>
<td>3.69 (1.44)</td>
<td>3.59 (1.38)</td>
<td>0.563</td>
</tr>
<tr>
<td></td>
<td>Child's preference</td>
<td>3.16 (1.48)</td>
<td>2.25 (1.36)</td>
<td>0.593</td>
</tr>
<tr>
<td></td>
<td>Child's other medical problems</td>
<td>3.17 (1.63)</td>
<td>3.15 (1.50)</td>
<td>0.928</td>
</tr>
<tr>
<td></td>
<td>Prior experiences</td>
<td>3.17 (1.51)</td>
<td>3.04 (1.53)</td>
<td>0.500</td>
</tr>
<tr>
<td></td>
<td>Cost</td>
<td>2.83 (1.54)</td>
<td>3.17 (1.46)</td>
<td>0.065</td>
</tr>
<tr>
<td></td>
<td>Gender</td>
<td>2.33 (1.63)</td>
<td>2.20 (1.56)</td>
<td>0.510</td>
</tr>
<tr>
<td>Child (Caregiver-reported)</td>
<td>Comfort</td>
<td>4.15 (1.00)</td>
<td>4.21 (1.14)</td>
<td>0.659</td>
</tr>
<tr>
<td></td>
<td>Ease of removal</td>
<td>3.50 (1.37)</td>
<td>3.69 (1.32)</td>
<td>0.261</td>
</tr>
<tr>
<td></td>
<td>Appearance</td>
<td>3.29 (1.39)</td>
<td>2.84 (1.52)</td>
<td>0.018</td>
</tr>
</tbody>
</table>

Significant p-values are bolded.

No Preference - 128 (43.1%), Cast - 96 (32.3%), and Splint - 73 (24.6%). Caregiver-reported child preferences were: No Preference - 117 (39.4%), Splint – 94 (31.6%) and Cast – 86 (29.0%). Caregiver immobilization preference was significantly associated with the preference recorded for their child (p<0.001).

Factors Influencing Preferences

The factors examined of potential influence on caregiver and child preferences are listed in the survey contained in Appendix 1. Overall, the most influential factor for caregivers was the doctor’s recommendation (Mean Rating: 4.38) while the most influential factor for children was perceived to be comfort (Mean Rating: 4.20). The least influential factor for caregivers was the child’s gender (Mean Rating 2.25) while appearance was seen as least important for children (Mean Rating: 2.97).

Mean factor of influence ratings for individuals with a cast or splint preference are listed in Tables 2 and 3, respectively. Bivariate testing demonstrated that increased child’s activity level (p=0.006) and greater rated importance of durability (p=0.006) were associated with a caregiver’s preference for cast. In contrast, greater rated importance of comfort was associated
with a preference for splint (p<0.01). Higher ratings for appearance were associated with a child’s preference for cast, while importance of comfort and ease of removal were associated with a splint preference in this cohort. Cast and splint preference showed no association with any of the other studied demographic or treatment variables. An additional sub-analysis of only caregivers with children actively being treated for a broken bone at the time of survey completion showed no association with immobilization preference (p>0.05).

**DISCUSSION**

This study’s findings indicate that caregivers and children may not have as strong of a preference for casting as was anticipated based on the experience of many of our institution’s providers. Furthermore, multiple factors including the doctor’s recommendation, durability and comfort were noted to have an impact on this immobilization preference. High caregiver-reported child activity level and the importance of durability were associated with caregiver preference for cast while the importance of comfort was associated with preference for splint. These findings help to explain the rationale for caregiver preferences in addition to quantifying an often ignored factor affecting provider practices in areas of clinical equipoise.

The treatment of pediatric buckle fractures of the distal forearm using removable immobilization with limited follow-up is associated with lower costs and greater convenience and function without significant differences in outcome compared to traditional cast management. Nevertheless, a shift in the standard of care to this minimalist approach has been precluded, ostensibly by a variety of obstacles. In areas of actual or perceived treatment equivalence, numerous factors can impact provider decision making regarding management. Barriers to broader implementation of splint-based strategies were explored in recent provider survey studies by Boutis and colleagues. The most commonly cited concerns across these two surveys were regarding compliance, potential complications, and access to commercial devices. While both surveys explored a variety of potential provider-focused barriers, neither examined barriers related to the preferences of the patient and caregiver.

The true impact of patient and caregiver preferences on provider decision-making is unknown. However, the reported experience of many providers suggests there remains a perception of superiority of casting among patients and caregiver. A recent (unpublished) survey at our own institution supported this notion, indicating these preferences may play a critical role in the provider decision-making process, particularly in this area of clinical equipoise. The findings of this study help to characterize the extent of this overlooked implementation barrier.

This study did not identify an overwhelming preference for casting, contrary to our predictions based on clinical experience. In fact, both caregivers and children more commonly had ‘no preference’ regarding wrist immobilization than splint or cast options. Therefore, providers concerned of widespread caregiver and patient cast preference should take heed of these findings and not allow false assumptions to hinder their utilization of splinting strategies. Still, nearly ⅓ of caregivers and children expressed a preference for a cast despite informing them of equivalent outcomes. This group, therefore, represents the potential barrier to implementing splinting strategies - the family that must be “talked out” of a cast. Study findings may additionally help to inform a fruitful discussion in this setting.

In addition to assessing immobilization preferences, this study also examined the factors perceived to have the greatest impact on this decision. Of the factors surveyed, the doctor’s recommendation was one of the most influential factors on caregiver preference should further encourage providers to make an evidenced-based decision of minimalistic treatment that is discussed and explained to the caregiver and patient. Information regarding other highly rated factors of influence including comfort, durability, child’s activity level and wear compliance may also be emphasized in discussions with families.

For providers interested in implementing splinting strategies for buckle fractures of the wrist, the need to talk a family out of a cast may be met with some angst. This conversation can be time consuming, and emphasis on convenience and cost may not always be well received by a family with an acutely injured child. For some providers, this is not viewed as an effective use of time during the course of a long clinic day given the equivalence in outcomes of both immobilization devices. But the bigger picture benefits to patient, caregiver and healthcare system should not be forgotten. In this setting, it may behoove the provider to emphasize that a splint is very durable in addition to being comfortable, even in a highly active child. While splint compliance concerns exist among providers and caregivers, we must also remember - and remind our patients - of the hazards of poor compliance with appropriate cast care such as getting the cast wet or sticking objects inside. Ultimately, an informed treatment decision made in agreement with the family is the preferred outcome.

**Limitations**

This survey investigation of caregiver immobilization preference has some limitations. Chiefly, survey responses were based on the presented scenario and immobilization...
preferences may be affected by an acute injury. And while we obtained a high number of responses, the data obtained may be subject to non-responder bias, which cannot be formally assessed due to the use of a convenience sample design. Some notable variables that may influence caregiver and patient opinions regarding immobilization (e.g. option for cast color and/or waterproof cast material) were not formally explored in this investigation. Though important factors, it was felt that further subtyping of casts may add to survey complexity and limit study feasibility. Finally, for consistency, child preferences were assessed via caregiver survey given the variable age and cognitive ability of patients seen in this setting. Therefore, the child’s true opinion may not have been accurately captured in all cases.

**Future Directions**

Although our findings suggest that provider recommendation of splint treatment will be sufficient in the majority of circumstances, further study is warranted to confirm these results in a cohort of acutely injured buckle fracture patients. Additionally, further work is needed to deconstruct the barriers to implementation of this evidence-based treatment strategy. Individual institutions have made progress addressing provider-based barriers through quality improvement methodology, while provider education through group discussion appears to have increased awareness at our own institution regarding the appropriateness of splinting. Efforts to broaden the recommendations of the Choosing Wisely campaign to include the appropriateness of splinting, something that has already been implemented in the United Kingdom’s National Institute for Health and Care Excellence (NICE) guidance, may also aid in this process.

**CONCLUSIONS**

A strong preference for cast immobilization of buckle fractures of the distal forearm was not found in this survey study, contrary to the reported experience of providers. Factors most influential to caregiver preference regarding immobilization in this injury setting included the doctor’s recommendation, comfort and durability. Caregivers rating their children as more active and those focused on durability preferred casts while those more concerned about comfort were more interested in splints. Providers seeking to more broadly implement splint-based immobilization for buckle fracture can utilize this knowledge to guide treatment discussions.

**REFERENCES**


20. Do not use a rigid cast for torus fractures of the distal radius. | NICE.
APPENDIX 1. Caregiver Survey

Section 1: Demographics / Visit Related

1. Have you completed this survey before in a recent visit?
   ○ Yes  ○ No

2. How many children do you care for? ______________

3. How old is your child? ____________ (If you are here with several children, please respond with the age of the child who has an appointment)

4. Please select the ages of all the children who are under your care
   ○ Less than one  ○ 4  ○ 8  ○ 12  ○ 16
   ○ 1  ○ 5  ○ 9  ○ 13  ○ 17
   ○ 2  ○ 6  ○ 10  ○ 14  ○ 18 or older
   ○ 3  ○ 7  ○ 11  ○ 15

5. What is your child’s gender? (If you are here with several children, please respond with the gender of the child who has an appointment)
   ○ Female  ○ Male

6. Have any of your children ever broken a bone?
   ○ Yes  ○ No

   How many times (not including today)? __________________________________

   (Write the total number of broken bones experienced by all of your children. Please write “0” if none of your children have ever broken a bone.)

7. What treatment(s) did your child’s broken bone receive? (Please select all that apply)
   ○ Splint  ○ Cast  ○ Surgery  ○ Other  ○ Not Applicable- my children have never broken a bone

   Please describe any other treatments your children have received for broken bones:

8. On a scale of 1-5 (5 being most active), how physically active is your child?
   ○ 1 (Inactive)  ○ 2  ○ 3 (Moderately active)  ○ 4  ○ 5 (Highly active)

9. Is your child currently here for treatment of a broken bone?
   ○ Yes  ○ No  ○ Not sure (awaiting diagnosis)

10. If your child is here for treatment of a broken bone, Awaiting treatment how is it being managed? (If it is being managed with multiple treatments, please select all that apply)
   ○ Splint  ○ Cast  ○ Surgery  ○ Other Please list other types of management:

11. What is your relationship to the patient?
   ○ Mother  ○ Father  ○ Grandmother  ○ Grandfather
   ○ Other - What is your relationship to the patient:__________________________

Section 2: Splint vs. Cast Preference

In orthopaedics, when wrist immobilization is required, splints and casts are both commonly used. A splint is a partially rigid device affixed with tape or Velcro. It can be removed at home often without requiring a doctor’s visit. A cast is a circumferentially rigid device (hard all around) made with fiberglass or plaster that remains in place for weeks at a time and requires a doctor’s visit to be removed. For some fracture types in children (e.g. incomplete fracture of the wrist), evidence suggests that the injury can be safely treated with either a splint or a cast with no difference in long term outcomes.

If your child sustained this type of fracture and you were offered the choice between a splint or a cast, which would you choose?
   ○ Splint  ○ Cast  ○ No preference
Please indicate how strongly each of the factors influence this decision for you. (5 point Likert scale with 1 being not influential and 5 being extremely influential)

<table>
<thead>
<tr>
<th>Factor</th>
<th>1 (Not Influential)</th>
<th>2 (Moderately Influential)</th>
<th>3 (Extremely Influential)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doctor’s recommendation</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Durability</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Comfort</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Cost</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Prior experiences with either device</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>My child’s gender</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>My child’s activity level</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>My child’s other medical problems</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Anticipated wear compliance</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Other (If applicable, please select any number on the scale and answer the question that appears below)</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

Please describe the Other factor(s) that would influence your decision, and rate each factor on the same 1-5 scale as above.

If your child were given the choice of a splint or a cast, please indicate how strongly each of the following factors would influence your child’s decision (5 point Likert scale with 1 being not influential and 5 being extremely influential):

<table>
<thead>
<tr>
<th>Factor</th>
<th>1 (Not Influential)</th>
<th>2 (Moderately Influential)</th>
<th>3 (Extremely Influential)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appearance (color options, getting signed by friends, etc.)</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Comfort</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Ease of removal (i.e. cast saw at doctor’s visit vs. self-removal at home)</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Other</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

Please describe the other factors that you believe would influence your child’s decision, and rate each factor on the same 1-5 scale as above.

Which do you think your child would prefer?

- Splint
- Cast
- No Preference

B.A. Williams, N.E. Palumbo, S.A. Phillips, L.C. Blakemore
ABSTRACT

Background: Medicare regulations require that physical therapists report functional limitations and severity modifiers utilizing a claims-based data collection tool. The Modified Outpatient Physical Therapy Improvement in Movement Assessment Log (mOPTIMAL) captures key constructs about patient confidence and difficulty but has not been evaluated for responsiveness/reliability during a routine clinical encounter with patients who have shoulder pathology. The purposes of this retrospective study are to 1) explore if mOPTIMAL changes after a single session with a physical therapist, and 2) determine if the tool is reliable among people with non-operative shoulder pain.

Methods: We included 106 individuals (58% female; mean age 45.8; range: 18-94 yrs.) with “non-operative” shoulder pathology who were seen in outpatient physical therapy from 2011 to 2012. Subjects completed a mOPTIMAL survey and a pain scale before and immediately after the initial physical therapy visit. The mOPTIMAL is a patient-centered instrument that assesses how much “Difficulty” and “Confidence” a client has in performing each of 24 functional tasks and three cognitive tasks using a generic assessment scale. Cronbach’s Alpha, and Intra-class Correlations were used to assess responsiveness, internal consistency, and reliability, respectively.

Results: After a single visit, participants reported improved Confidence with sleeping, dressing/bathing, throwing, carrying, and lifting (adjusted for ceiling effects; p<0.002) but no change in pain. Cronbach’s Alpha and Intra-class Correlations were excellent (0.821-0.923; 0.967, respectively).

Conclusions: mOPTIMAL is a reliable and responsive tool with excellent internal consistency. This observational study revealed that patient Confidence may change independent of Pain after a single physical therapy visit. Taken together, the mOPTIMAL appears to be an excellent tool to report severity modifiers in compliance with Medicare regulations.

Level of Evidence: IV

Keywords: function, patient-centered measures, physical therapy, optimal, psychometrics, measurement

INTRODUCTION

Quality improvement initiatives and pay for performance reimbursement strategies emphasize the need for high quality patient centered measures when completing the electronic medical record. Medicare regulations require that physical therapists report functional limitations and severity/complexity modifiers utilizing “a claims-based data collection strategy.” Based on its ease of use, the Outpatient Physical Therapy Improvement in Movement Assessment Log (OPTIMAL) may be an acceptable tool to meet this need.

The OPTIMAL is a patient centered instrument that assesses how much “Difficulty” and “Confidence” a client has in performing a battery of functional tasks. T-tests, Cronbach’s Alpha, and Intra-class Correlations were used to assess responsiveness, internal consistency, and reliability, respectively.

Results: After a single visit, participants reported improved confidence with sleeping, dressing/bathing, throwing, carrying, and lifting (adjusted for ceiling effects; p<0.002) but no change in pain. Cronbach’s Alpha and Intra-class Correlations were excellent (0.821-0.923; 0.967, respectively).

Conclusions: mOPTIMAL is a reliable and responsive tool with excellent internal consistency. This observational study revealed that patient Confidence may change independent of Pain after a single physical therapy visit. Taken together, the mOPTIMAL appears to be an excellent tool to report severity modifiers in compliance with Medicare regulations.

Level of Evidence: IV

Keywords: function, patient-centered measures, physical therapy, optimal, psychometrics, measurement
therapy treatment session on patient confidence in people with non-operative shoulder pain.

Although our primary goal in exploring these retrospective data was to assess the psychometric properties of the mOPTIMAL, we also questioned whether Confidence would be sensitive to change after a single visit with a physical therapist. We reasoned that a patient’s Confidence may improve when the patient either becomes educated about his/her condition or believes he/she is on the “right track” in terms of management. We would not expect change after a single visit on various items of functional difficulty associated with long term adaptations and secondary impairments (i.e. muscle atrophy).21,24 but may observe a change in Confidence after a single visit.

Because 21 percent of all Medicare patients seeking outpatient physical therapy have shoulder pathology (second only to the lumbar area23) we sought to examine this dataset as part of our standards of practice and quality assurance program. At our tertiary healthcare center, we previously modified the OPTIMAL, as described in this report, and developed a consensus-based intervention as part of our standards of practice initiative to minimize variation. Importantly, many patients with non-operative shoulder conditions are treated with a single physical therapy visit within our healthcare center.

Accordingly, the purposes of this retrospective study are to: 1) explore if certain domains of the mOPTIMAL systematically change after a single session with a physical therapist, and, 2) determine if the tool is internally consistent and reliable among people with non-operative shoulder pain. Our underlying premise for mining these data was that any systematic change after the single visit may be more obvious in a patient’s perception of Confidence, while patient perception of Difficulty in performing a task may be less likely to change. We also expected that the assessments for most domains would be highly reproducible, even if separated by a single encounter with a physical therapist.

METHODS

Subjects

The use of the retrospective de-identified data explored in this study was approved by the University of Iowa Human Subjects Institutional Review Board. We report on 106 adult patients (62 females) with an average age of 45.8 years (range 19-84 years), average body mass index (BMI) of 29.0 kg/m² (range 19.1-57.1 kg/m²), average height of 1.69 m, and average mass of 81.52 kg. Participants were patients with “non-operative shoulder pain” referred for outpatient physical therapy at our academic medical center over the course of one year (2011-12). We included patients who had received past physical therapy or corticosteroid injections to the shoulder. We excluded subjects who had prior surgery to their involved shoulder or the shoulder was not the source of the pain. In total, 106 subjects completed the Pre and Posttests with the mOPTIMAL. The most common medical diagnosis was “Shoulder Pain” (n=54) followed by “Impingement” (n=18) and “Rotator Cuff Tendonitis” (n=11).

Instrument Modification

The changes in Medicare reporting guidelines necessitated a review of the patient reported functional outcome tools used across our department. Our Physical Therapy Department has a long history of developing clinical rehabilitation measurements26 to be incorporated into the electronic medical record for observational outcomes research.1 We also strive to develop consensus based physical therapist interventions to minimize variation in practice.26 The mOPTIMAL outcome tool was developed from the template of the original OPTIMAL. Both the Confidence and Difficulty subscales were retained. Only six of the original 24 OPTIMAL items were specific to upper extremity activities.3 Because of our interest in patients with shoulder pathology, we eliminated the items which were meant to analyze trunk and lower extremity function (Items 1-18). We added four items that were determined to be pertinent information regarding upper extremity function as determined by eight expert clinicians (physical therapists) with an average of 18 years of experience treating people with shoulder pathology. The result was a list of 10 functional items (the original six: pushing, pulling, reaching, lifting, grasping, and carrying, plus the four items we added: dressing/ bathing, sleeping, throwing, and driving) on which patients would assess their Confidence and Difficulty. The activity, sleep, is a common cause of concern for clients with shoulder pain and was considered important by the clinical experts.

We assessed Confidence and Difficulty using the 5-point Likert Scale as originally designed for the OPTIMAL. Because the OPTIMAL does not include pain, we added a standard 10-point Likert Scale with 0 representing “no pain” and 10 representing a “very painful” condition. The patients were asked to assess their pain for that day. The modified OPTIMAL form used in this study is included in Supplemental Digital Content (Appendix 1).

Physical Therapy Visit Procedure

The initial physical therapy interaction was, on average, 45 minutes in length. When a patient with “non-operative shoulder pain” checked in for their appointment, a receptionist administered the mOPTIMAL form and provided an informational sheet describing the importance of patient centered outcome measures as a standard assessment in our department. The patient was
led to a private exam room where the therapist performed their standard physical therapy evaluation consisting of observation, palpation, range of motion, strength measures as appropriate, and special testing as needed. Each assessment verified that the patient’s shoulder complex was the origin of their discomfort as opposed to radicular spinal pain or pain of a referred nature. Fourteen patients were excluded from this retrospective analysis because of radicular signs or uncertainty about the source of the shoulder pain.

Our consensus based single physical therapist treatment plan consists of four distinct phases: Pain Relief, Early Strengthening, Advanced Strengthening, and Return to Activity. Our guidelines did not discourage therapists from customizing their prescribed treatments and perform specific interventions as deemed necessary under the general treatment categories. The frequency of scheduled physical therapy follow-up visits was not dictated by these guidelines but was left to the discretion of the treating therapist.

As verified in our retrospective evaluation forms, all initial physical therapy interactions consisted of a patient interview, evaluation, and some initial form of treatment, most often a form of treatment the patient could replicate independently at home. Therapists answered questions the patients had regarding their condition. At the conclusion of the session, patients returned to the reception desk where they completed a post-treatment mOPTIMAL survey.

Data Collection
Upon review we identified 106 patients who met our inclusion criteria that completed the mOPTIMAL before and immediately following their single physical therapy encounter.

Data Analysis
The mOPTIMAL scale ranges from 1 (“Able to do without any Difficulty”) to 5 (“Unable to Do”). Similarly, a number 1 on the Confidence scale indicates poor confidence with a specific task. The average Difficulty and average Confidence scores were calculated for each patient across the 10 functional tasks. If patients did not feel an item was relevant to their situation, they indicated that it was not applicable. In all, only 142 (3.3%) of the 4240 measurements were scored as “does not apply”.

Responsiveness to a single PT visit
A Students Dependent T-test with a Bonferroni adjustment was used to determine if there was a systematic change in the patients’ Difficulty and Confidence with each task after the single visit with a physical therapist. Because 20 comparisons (10 functional tasks, Difficulty and Confidence scales) were carried out, we adjusted our p-value to 0.0025 (0.05/20). We excluded two items that had over 30% of the sample showing a ceiling effect on initial evaluation.

Reliability of the mOPTIMAL
Pearson Product-moment Correlations were calculated to determine the relationship between the Pre and Posttest conditions. Intra-class correlations (ICC, 2.K) were calculated to assess the degree of agreement in the repeated measures. In addition, a Cronbach’s Alpha was calculated to assess the internal consistency of the 10 test items within the mOPTIMAL. All Data analysis was carried out using SPSS.

RESULTS

Single Visit Change in Confidence, Difficulty, and Pain
The aggregate descriptive changes in Confidence and Difficulty after the single physical therapy visit are presented in Table 1. The overall mean Confidence score was significantly improved (p=0.041) after a single visit, while the overall Difficulty and Pain scores were not systematically changed (p=0.244).

An analysis of each of the 10 task items, adjusted for the number of tests, revealed that the patients’ Confidence with sleeping demonstrated the greatest improvement after the single visit (t=3.44, DF=105, p = 0.0008). When we accounted for the subjects who were fully confident with sleeping in their pre-assessment (ceiling effect), the change remained highly significant (t=3.43, DF=82, p<0.0001; Table 2). In addition, the patients’ Confidence for lifting, carrying, throwing, and dressing/bathing significantly improved after adjusting for pre-assessment ceiling effects (Figures 1A, 1B; p<0.001, p<0.0001, p<0.0001, and p<0.0001, respectively). Prior to adjusting for ceiling effects, there were no items significantly changed for the Difficulty scale. However, after we adjusted for ceiling effects, the change in patients’ Difficulty scores for lifting and carrying were significantly improved (p<0.001 and 0.0001, respectively) (Figure 1C, 1D).
excellent for Confidence and Difficulty (Cronbach’s Alpha ranged from 0.821 to 0.904).

**DISCUSSION**

Our analysis suggests that Confidence, with the ability to sleep, showed a systematic change (improvement) after a single encounter with a physical therapist for patients with non-operative shoulder pain; while Difficulty in performing functional tasks did not change. When we adjusted for ceiling effects people did perceive they would have less Difficulty lifting and carrying objects. Both systematic changes in perception may reflect the educational component of a session with a physical therapist. The level of pain showed no change after the single session. Taken together, this retrospective analysis supports that the mOPTIMAL is a reliable and internally consistent tool to assess 10 key functional activities (including sleeping) in people with non-operative shoulder pain. A trend that certain domains, like patient confidence, may be impacted by a single visit with a physical therapist is interesting, but not conclusive without further assessment with control conditions.

Nonetheless, the observation that there was a systematic change, primarily with patient confidence, is an interesting concept. There is strong evidence in the literature that patients develop an alliance with their physical therapist, and this alliance impacts patient outcome after eight weeks of treatment. Recently, a single session with a physical therapist has been shown to alter movement strategies patients use for lifting, with a corresponding decrease in pain back pain. But to our knowledge this is the first report that a single physical therapy encounter may influence patient perception of an impending outcome in response to treatment. Because

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**Table 2. Analysis of Individual OPTIMAL Task Items Before and After Ceiling Effect Correction**

<table>
<thead>
<tr>
<th>Function</th>
<th>Subscale</th>
<th>Effect Size (N=106)</th>
<th>Significance (N=106)</th>
<th>Effect Size (adjusted for ceiling)</th>
<th>Significance (adjusted for ceiling)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pushing</td>
<td>Difficulty</td>
<td>-0.01</td>
<td>NS</td>
<td>0.52</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>Confidence</td>
<td>0.05</td>
<td>NS</td>
<td>0.55</td>
<td>NS</td>
</tr>
<tr>
<td>Pulling</td>
<td>Difficulty</td>
<td>0.04</td>
<td>NS</td>
<td>0.53</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>Confidence</td>
<td>0.06</td>
<td>NS</td>
<td>0.48</td>
<td>NS</td>
</tr>
<tr>
<td>Reaching</td>
<td>Difficulty</td>
<td>0.11</td>
<td>NS</td>
<td>0.30</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>Confidence</td>
<td>0.18</td>
<td>NS</td>
<td>0.49</td>
<td>NS</td>
</tr>
<tr>
<td>Lifting</td>
<td>Difficulty</td>
<td>0.16</td>
<td>NS</td>
<td>0.55</td>
<td>S*</td>
</tr>
<tr>
<td></td>
<td>Confidence</td>
<td>0.12</td>
<td>NS</td>
<td>0.60</td>
<td>S*</td>
</tr>
<tr>
<td>Carrying</td>
<td>Difficulty</td>
<td>0.17</td>
<td>NS</td>
<td>0.79</td>
<td>S*</td>
</tr>
<tr>
<td></td>
<td>Confidence</td>
<td>0.10</td>
<td>NS</td>
<td>0.70</td>
<td>S*</td>
</tr>
<tr>
<td>Bathing</td>
<td>Difficulty</td>
<td>0.03</td>
<td>NS</td>
<td>0.48</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>Confidence</td>
<td>0.14</td>
<td>NS</td>
<td>0.87</td>
<td>S*</td>
</tr>
<tr>
<td>Sleeping</td>
<td>Difficulty</td>
<td>0.05</td>
<td>S*</td>
<td>0.39</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>Confidence</td>
<td>0.29</td>
<td>S*</td>
<td>0.88</td>
<td>S*</td>
</tr>
<tr>
<td>Throwing</td>
<td>Difficulty</td>
<td>0.05</td>
<td>NS</td>
<td>0.49</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>Confidence</td>
<td>0.11</td>
<td>NS</td>
<td>0.80</td>
<td>S*</td>
</tr>
</tbody>
</table>

Values are the mean effect size for post-visit versus pre-visit scores. S*=significant at p < 0.0025; NS= not significant.

We analyzed Pain using a 10-point Likert Scale. Paired t-tests did not demonstrate any significant differences between Pre (Mean= 4.29 + 2.38) and Post (Mean=4.18 + 2.41) pain measures (p=0.741) after an encounter with a physical therapist.

**Reliability of the mOPTIMAL Assessment Tool**

A total of 106 patients with “non-operative shoulder pain” completed the Pre and Post assessments separated by a single encounter with a physical therapist. Pain ratings demonstrated a high degree of agreement between Pre and Post assessments with an overall intraclass correlation (ICC (2,1)) value of 0.962 (95% CI=0.942-0.973). The mOPTIMAL subscale for Difficulty was highly reproducible with an ICC (2,k) value of 0.943 (95% CI=0.912-0.963). The lowest ICC (2,k) value was 0.824 (95% CI=0.731-0.87) for Confidence, suggesting a lower level of reliability or the presence of a systematic change after the single physical therapy visit. Pearson correlations comparing patient ratings before and after the physical therapy visit largely mirrored ICC results. Correlations for the 10 Difficulty tasks varied from 0.765 to 0.831; while Pre to Post correlations for Confidence were again the lowest (0.594 to 0.713). The Pearson correlation for Pain was high (0.964) suggesting that pain was not changed after the single visit with a physical therapist.

The internal consistency for the mOPTIMAL was
this is a retrospective observational study, the therapists and patients were not biased by factors that may influence clinical behaviors when both the patient and provider are informed that a study is being undertaken through the consent process. However, because we have no control condition, we cannot be assured that a meeting with a lay person, or merely asking the patient to read information about sleep, would trigger a similar change in confidence with sleep. Importantly, this study does support that the mOPTIMAL is responsive to a systematic change, regardless of the underlying cause; and the mOPTIMAL is a highly reliable outcome assessment tool with excellent internal consistency. Indeed, this survey may be ideal for documenting complexity as recommended by the Medicare standards.

The underlying psychological constructs that influence patient responses to single encounters are not fully developed in the literature and warrant review. For example, Mintken et al.\textsuperscript{31,32} found a single session of mobilization, an active, hands-on event, produced a significant reduction in pain, fear avoidance, and kinesiophobia for patients with shoulder pain. The construct “patient confidence” was not examined. While evaluating the reliability of outcome questionnaires for patients with low back pain, neither Williams and Myers\textsuperscript{6} nor Yamada et al.\textsuperscript{33} found any changes in patient confidence as the result of a single physical therapy encounter. This lack of change in confidence for patients with spine pathology may be related to the greater interplay between patient psychology and disorders of the spine.\textsuperscript{22,34,35} A single bout of exercise testing and instruction was shown to improve self-efficacy scores and predict adherence to a general exercise program in a group of older adults.\textsuperscript{36,37} In patients with musculoskeletal pain, Mosely et al.\textsuperscript{38,39} demonstrated a single educational session, focused on the neurophysiology of pain, can alter pain and pain attitudes in patients with chronic low back pain. We also know that pre-operative educational sessions are commonly used to moderate patient expectation prior to total joint arthroplasty.\textsuperscript{15} Although these studies demonstrate the effect of a single interaction, none of these previous studies measured the patient’s confidence in performing specific tasks.

Disordered sleep has a significant effect on health care utilization and costs.\textsuperscript{40,41} The ability to sleep was identified by our group and others\textsuperscript{42} as an integral component in promoting health in people with shoulder pathology. Our independent panel of physical therapists agreed that pathology to the shoulder directly disrupts the quality of sleep for many clients. Importantly, there are strong correlations among anxiety, depression, pain, and sleep disturbances in patients with shoulder pathology.\textsuperscript{43} From a mechanical perspective, passive tension on the rotator cuff at night or changes in sub acromial pressure in various positions common during sleep are important considerations for people with shoulder pathology.\textsuperscript{44} Our expert panel of physical therapists appear to have been clinically astute when recommending that we add sleep to the mOPTIMAL during our quality assurance development program. Interestingly, confidence with the ability to sleep, was the one item that had a moderate effect size,\textsuperscript{45} after just a single session with a physical therapist. Previous reports using the general OPTIMAL detected small effect sizes,\textsuperscript{5} however, those studies included all musculoskeletal conditions and were not limited to people with shoulder pathology. Moreover, we modified the original OPTIMAL to better focus on activities related to the upper extremity. Because this is a retrospective analysis and the first report using this mOPTIMAL in people with shoulder pathology, our outcomes are not directly comparable to many previous reports using the OPTIMAL.\textsuperscript{3,46}

We also explored other variables that may assist us in understanding the perceived response to improved ability to sleep. We found no relationship between sleep confidence scores and gender, shoulder pathology, treating therapist, or initial difficulty and confidence scores. We did discover that participants who demonstrated the most improved confidence with sleep had a slightly lower BMI (27.1 kg/m\textsuperscript{2} vs 29 kg/m\textsuperscript{2}) and had slightly lower initial pain scores (3.90 vs 4.29). Among this subset, sleeping confidence improved more than 1 point (a 20% improvement) as the result of a single physical therapy visit. In the absence of a strict control group, we are unable to state that the intervention offered by the physical therapist was critical to this outcome and therefore further investigation is warranted.

As part of this report, we identify three features that are new to the OPTIMAL assessment tool that we adopted as part of our standard of care program. First, the belief that participants commonly gain confidence because of the skills/traits of health care providers offers an important area of future investigation. The “fear of the unknown,” once addressed, may ultimately impact a client’s confidence and expectations to improve in various health related constructs. In this respect, even the initial visit may have a profound impact on easing patient fears and improving confidence that his/her condition will improve with treatment. Second, we re-instituted Pain as a separate construct so we could evaluate the extent to which difficulty and pain are reproducibly measured over a single physical therapy visit, i.e. a time frame over which improvements would be unlikely to occur. Third, we added additional test items that we believed were more germane for patients with upper extremity pathology.

Based on the outcomes of this analysis, we believe
that mOPTIMAL is intuitive and easy to implement in the clinical center. In addition, mOPTIMAL allows the Difficulty and Confidence subscales to be applied to any functional task important to the patient, thus the opportunity for the assessment to become patient centered rather than physician, physical therapist, or institution centered.

In summary, the mOPTIMAL is a psychometrically sound measurement tool that is responsive to systematic change after an encounter with a physical therapist. The mOPTIMAL may be well suited to meet the Medicare severity/complexity documentation requirement for people with non-operative shoulder impairment.

REFERENCES

A Reliable and Responsive Assessment Tool (mOPTIMAL) for Shoulder Pain


APPENDIX 1: Modified Optimal Survey

<table>
<thead>
<tr>
<th>Instructions: Please circle the level of Difficulty you have for each activity today.</th>
<th>Able to do without any Difficulty</th>
<th>Able to do with little Difficulty</th>
<th>Able to do with moderate Difficulty</th>
<th>Able to do with much Difficulty</th>
<th>Unable to do</th>
<th>Not Applicable</th>
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<td>9</td>
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<th>Very confident in my ability to perform</th>
<th>Moderate Confidence</th>
<th>Some Confidence</th>
<th>Not confident in my ability to perform</th>
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Please rate your overall shoulder pain today.

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UNSTABLE LUMBAR SPINE OSTEOMYELITIS CAUSED BY TRANS-FORAMINAL MIGRATION OF LAPAROSCOPIC ADJUSTABLE GASTRIC BAND CONNECTION TUBING: A CASE REPORT

Jocelyn Compton, MD; John Yanik, MD; Nathan Hendrickson, MD; Naina Bagrodia, MD; Peter Nau, MD; Andrew J. Pugley, MD

ABSTRACT

Background: Disconnection of the tubing between the port and LAGB is a well-known complication in general surgery and accounts for up to 17% of LAGB complications. Typically, when this complication occurs patients present with abdominal or pelvic complaints. A complication of spinal infection due to trans-foraminal migration has not been previously reported. The aim of this study is to highlight an unusual infection of the thoracolumbar spine due to laparoscopic adjustable gastric band (LAGB) intragastric erosion, and migration into the lumbar spine causing epidural abscesses, discitis, and osteomyelitis. This case underscores the importance of a thorough surgical history, complete imaging, and multi-disciplinary approach in management of complex spine infections.

Methods: We report a case of LAGB tubing migration into the spinal canal through the left L2-L3 neural foramen resulting in symptomatic epidural abscesses and osteomyelitis.

Results: Although dislodgement and migration of LAGB tubing has been reported previously, this is the first report of trans-foraminal migration and erosion of lumbar vertebrae, causing osteomyelitis of the spine and epidural abscess formation, subsequent instability and neurologic deficit requiring urgent operative intervention.

Conclusions: Dislodgement and migration of LAGB tubing is a known complication. While it most commonly leads to abdominal and pelvic sequelae, in rare circumstances it may acutely affect the spine. Careful history, imaging, and multidisciplinary approach are paramount for the successful management.

Level of Evidence: V

Keywords: laparoscopic adjustable gastric band, infection, epidural abscess

INTRODUCTION

Laparoscopic adjustable gastric banding (LAGB) for the treatment of obesity has demonstrated significant complications including port site infection, intragastric band erosion, and tubing disconnection. Disengagement of the connection tubing between the access port and the LAGB accounts for 17-21% of complications associated with LAGB.

Although several case reports have described abdominal and pelvic complications due to tubing disconnection, there has not yet been a report of spinal complications due to erosion or migration. The purpose of this report is to describe an unusual cause of epidural abscess and spine osteomyelitis and discitis due to LAGB tubing disconnection and migration through the left L2-L3 neural foramen.

METHODS

Case Presentation

A 55 year old man with LAGB placement six years prior presented after two months of acute low back pain radiating to the left anterior thigh. He exhibited no muscle weakness or long-track signs. One month prior he underwent L2-3 laminectomy and medial facetectomy for drainage of an epidural abscess which had been diagnosed on MRI. The patient had since developed septic bacteremia due to methicillin-sensitive Staphylococcus aureus. The patient’s low back pain and radicular symptoms recurred and he required a second lumbar irrigation and debridement. X-rays following that procedure revealed malposition of the LAGB tubing (Figure 1).

The patient reported that one year prior to presentation he was in a car accident resulting in avulsion of the LAGB subcutaneous port. The patient cut the tubing, removed the port, and self-reduced the disconnected tubing into his abdomen.

Full imaging (Figure 1-3) including plain radiographs, spinal CT, abdomen and pelvis CT, and an MRI of the spine revealed L2-L3 discitis, osteomyelitis, and an epidural abscess at L2-L3. The LAGB tubing was noted to...
Figure 1. Plain x-ray on presentation.

Figure 2. CT scan showing passage of the tube through the left L2-L3 neural foramen.

Figure 3. MRI demonstrating osteomyelitis, discitis, and an epidural abscess at the L2-L3 level.

Figure 4. Esophagogastroduodenoscopy (EGD) showing erosion of the LAGB band into the stomach.

Figure 5. LAGB tubing traversing the left L2-L3 neural foramen.

Figure 6. Removal of the LAGB tubing from the left L2-L3 neural foramen.

Figure 7. Transection of the LAGB tubing under traction.

Figure 8. Post-operative x-rays of the spine showing anterior fusion and T12-L5 posterior spinal fusion.

Figure 9. Removed LAGB in its entirety.
course through the left L2-L3 neural foramen to the level of the L2 vertebral body anterior to the epidural space. Diagnostic esophagogastroduodenoscopy (EGD) revealed that the LAGB itself had also eroded through the gastric lining and into the stomach (Figure 4).

**Operation**

Operative intervention was coordinated between orthopedic spine, general surgery, and gastroenterology.

The patient was first positioned prone and his prior midline incision was extended from T12 to L5. Scar tissue and infected material was meticulously excised. Bilateral pedicle screws were placed at T12, L1, L2, L3, L4, and L5. Central decompression and removal of epidural phlegmon was performed. The dissection was then carried laterally off the left transverse processes of L2 and L3 until the psoas was released. The LAGB tubing was identified on the anterior aspect of the left L3 transverse process (Figure 5). The tubing was followed to the neural foramen and removed carefully so as to avoid a dural tear (Figure 6). Tension was then applied to the LAGB tubing and it was cut as proximally as possible (Figure 7). A partial corpectomy of L2 was performed to remove infectious tissue. Anterior fusion with a cage, allograft, and bone morphogenetic protein was then performed, followed by T12-L5 posterior fusion and closure (Figure 8).

The patient was then positioned supine. The minimally invasive surgical team and the gastrointestinal specialists performed a diagnostic laparoscopy revealing minimal adhesions and no evidence of intra-abdominal complications. The tubing was identified and traced to the LAGB. Under EGD from within the stomach, the LAGB was released using endoscopic scissors. The LAGB was removed in its entirety through an abdominal portal (Figure 9). The gastrostomy was then closed, taking care to avoid torsion on the stomach.

The patient remained neurovasculary intact following the procedure. He was treated with intravenous antibiotics and discharged without post-operative event.

**DISCUSSION**

We report an infection of the spine due to LAGB intra-gastric erosion with concurrent LAGB tubing disconnection and migration into the lumbar spine. Although intra-gastric erosion of LAGB is a well-documented complication, simultaneous disconnection and migration of LAGB tubing into adjacent structures is rare. Multiple case reports cite erosion of the small bowel, large bowel, or migration into the pelvis with signs and symptoms consistent with an acute abdomen.\(^9\)\(^{10}\) To our knowledge, this is the first case of a devastating spine infection caused by LAGB tubing migration.

This case emphasizes the importance of obtaining a thorough patient history, and adequate cross-sectional imaging when evaluating patients with spinal infections. Although this patient underwent MRI on initial presentation, the tubing complication was not noted on MRI alone. X-ray and CT later revealed the malposition of the tubing through the neural foramen and into the spinal canal. This case also highlights the importance of a multi-disciplinary approach when addressing rare and unusual complications.

**REFERENCES**

ABSTRACT

Background: To determine if children with Osteochondritis Dessicans (OCD) lesions of the distal femur are more likely to have a co-morbid diagnosis of Attention Deficit/Hyperactivity Disorder (ADHD) than age matched controls and to assess the impact of ADHD on OCD outcomes.

Methods: A retrospective chart review of patients treated at a single tertiary care hospital between 2000-2012 was performed. Charts were reviewed for a diagnosis of OCD of the distal femur in all skeletally immature patients (males < 16 years and females < 14 years). These were then screened for a comorbid diagnosis of ADHD. Age-matched controls with anterior knee pain without OCD were then reviewed to determine if ADHD was more common in the OCD population. Treatment and outcomes of the OCD lesions were then compared in children with and without ADHD.

Results: The prevalence of ADHD was 23% in patients with OCD lesions and was significantly greater than the 11% found in the anterior knee pain age-matched controls (p<0.05). The average grade of lesions at presentation was similar in both groups (2.2 ADHD vs 2.1 no ADHD) however, at final follow-up, the average OCD grade was significantly worse for children with ADHD (1.4 vs 0.7, p<0.004).

Conclusion: There is a significantly higher prevalence of ADHD in children with OCD lesions compared with age-matched controls. This study suggests children that with osteochondritis dessicans and ADHD may not have as favorable treatment course as children without the hyperactivity disorder.

Level of Evidence: III

Keywords: osteochondritis dessicans, adhd, attention deficit hyperactivity disorder, ocd, distal femur

INTRODUCTION

Osteochondritis Dissecans (OCD) is a term used to describe the separation of a segment of articular cartilage and subchondral bone from the remaining articular surface. Juvenile OCD (JOCD) describes a lesion found in skeletally immature children with the highest incidence occurring between the ages of 10 and 20. While OCD lesions can occur in other joints, the most common location is the knee joint on the lateral half of the medial femoral condyle. Knee OCD lesions are found more frequently in children involved in organized sports and is twice as common in males as in females. The incidence of JOCD has been on the rise concordant with increasing participation in youth athletics.

To the authors’ knowledge, no evaluation of pathologic hyperactivity has ever been linked as a potential cause or risk factor in developing an OCD lesion. However, similar orthopedic pathologies that involve altered blood supply, such as Legg-Calve-Perthes disease, have shown an association with such behaviors. Thus, our objective was to determine if the behavioral condition of Attention Deficit and Hyperactivity Disorder and/or its treatment effects a patient’s likelihood for developing and healing osteochondritis dissecans lesions of the distal femur.

METHODS

After Institutional Review Board approval for this study, a retrospective chart and radiographic review of consecutive patients treated for JOCD of the knee at a single tertiary care institution (2000-2012) was performed. Inclusion criteria included diagnosis of OCD of distal femur, skeletal immaturity which is typically males less than or equal to 16 years of age and females less than or equal to 14 years of age. All included individuals had confirmed open tibial and femoral physes on radiographic review. Exclusion criteria included males older than 16 years of age and females older than 14 years of age. Patients with cartilage defects from acute trauma, OCD...
lesions outside the femur, and patients initially treated at an outside hospital were also excluded.

Data collected included patient age, gender, height, weight, BMI, behavioral comorbidities, medications, treatment (nonoperative vs. operative), state of the physis, radiographic size of lesion, follow-up length, and radiographic grade of lesion based on plain radiographs or MRI. A single reviewer (K.D.) reviewed all plain radiographs and/or MRI at presentation and final follow-up. The accuracy of measurements on plain films has previously been confirmed.

Patient age was determined by their chronological age at the initial visit. Length of follow-up was determined from the time of their initial clinic visit to final clinic visit. At each visit patient height and weight measurements were taken and BMI was calculated. Individuals with ADHD were identified by a previous definitive diagnosis within the medical record or by reported use of stimulant medication typically used to treat ADHD. Treatment at the initial visit was recorded as operative or non-operative. Further chart review determined if the patient failed the initial non-operative treatment and crossed over to surgical treatment.

To determine the prevalence of ADHD in our general patient population, we used age-matched controls that presented to the clinic with a diagnosis of anterior knee pain. Radiographs confirmed these controls did not have JOCD of the knee. In a similar fashion, individuals with ADHD were identified by a previous definitive diagnosis within the medical record or by reported use of stimulant medication typically used to treat ADHD.

OCD Measurements: All OCD lesions were graded according to the Clanton Classification: Grade 1, depressed osteochondral fracture; Grade 2, osteochondral fragment attached by an osseous bridge; Grade 3, detached non-displaced fragment; and Grade 4, displaced fragment. Plain radiographs or MRI were utilized to determine whether the physis was closed or open. Length of the fragment was determined by measuring the OCD lesion with the ruler function on the PACS system (McKesson, San Francisco, CA) on the lateral x-ray or the widest measurement on sagittal MRI images. Width of the fragment was determined by measuring the OCD lesion with the ruler function on the PACS system on the AP x-ray or the widest measurement on coronal MRI images. The area of the lesions was calculated by multiplying the length and width determined of the lesion (Figure 1a and 1b), a method that was tested and validated by Wall et al.

Statistical Analysis:
The prevalence of ADHD among controls and patients with OCD lesions was compared using a chi-squared test. Age, height, weight, and body mass index were compared between groups using the standard t-test. Gender, race, and success of non-operative treatment were compared between groups using Fisher’s exact test. Lesion characteristics over time (length, width, area, and grade), follow-up time, and surgery were compared using Repeated Measures ANOVA.

RESULTS
Eighty-two patients met the inclusion criteria from chart review. Nineteen patients (23%) with OCD also had a diagnosis of ADHD. The prevalence of ADHD among age- matched controls with a diagnosis of anterior knee pain but no OCD was 11% (9/80). The difference in the prevalence of ADHD between patients with anterior knee pain and OCDs was significant (p<0.05). No differences in age, height, weight, BMI, or race, was found between those children with and without ADHD and OCD lesions (Table 1).

With regards to the OCD lesions, there was no difference in the length, width, area, or grade at presentation between cohorts (Table 2). However, at final follow-up the average OCD grade was significantly worse for children with ADHD (1.4 vs 0.7 p=0.004). Children without ADHD demonstrated a significant improvement in the grade of their lesions over time (2.1 to 0.7, p<0.001), whereas the children with ADHD only trended towards an improvement in grade over time (2.2 to 1.4 p=0.06). There was no significant difference in follow-up length for the patients with and without ADHD (1.56 to 1.50 years p=0.88).

The percentage of children requiring surgery was similar between groups with 55% of children with ADHD and 57% of children without ADHD. Of the patients initially offered non-operative treatments for their OCD lesion, 47% (8/17) of children with ADHD failed non-operative treatment compared with 33% (17/51) of children without ADHD, although this was not statistically significant (p=0.39).
ADHD and OCD is there a connection?

Table 1. Demographic Characteristics of Children with OCD Lesions

<table>
<thead>
<tr>
<th></th>
<th>ADHD (n=19)</th>
<th>No ADHD (n=63)</th>
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<td>Age (yr)</td>
<td>13.6 (20)</td>
<td>13.4 (20)</td>
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<tr>
<td>Height (in)</td>
<td>64.7 (66)</td>
<td>63.6 (5.8)</td>
<td>0.54</td>
</tr>
<tr>
<td>Weight (lb)</td>
<td>131.5 (47.5)</td>
<td>124.8 (36.7)</td>
<td>0.58</td>
</tr>
<tr>
<td>BMI</td>
<td>21.4 (4.8)</td>
<td>21.2 (3.7)</td>
<td>0.86</td>
</tr>
<tr>
<td>Female Gender (%)</td>
<td>0 (0.0)</td>
<td>16 (25.4)</td>
<td>0.02</td>
</tr>
<tr>
<td>Caucasian Race (%)</td>
<td>13 (68.4)</td>
<td>56 (88.9)</td>
<td>0.07</td>
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</table>

Age, Height, Weight, and BMI using standard t-test.
Gender and Race using Fisher’s exact test.
* = Statistically significant (p<0.05). Reported as mean (SD), or n (%)

DISCUSSION

The incidence of OCD lesion and attention deficit hyperactivity disorder (ADHD) have both been on the rise. The results of this study suggest that ADHD may be more common in children with OCD lesions than other generalized knee conditions such as anterior knee pain. It also suggests that the comorbidity may tend to worse OCD outcomes. Although the exact etiology of OCD lesions still remains controversial, the most accepted etiology of OCD lesions is acute or repetitive microtrauma resulting in a stress fracture of the subchondral bone as this has been shown to occur in athletes. While OCD lesions have not been linked to ADHD or its treatment, ADHD medications (stimulants), have been linked to mild growth suppression. As both non-operative and operative OCD treatment require children to remain non-weightbearing for extended periods of time (weeks to months); the diminished healing in those with ADHD may be directly due to the stimulants effect on blood supply and bone healing or indirectly through behavioral difficulty complying with treatment recommendations.

We are not the first to make a connection between ADHD and orthopedic conditions. Previously ADHD was thought to be a risk factor in the development of Legg-Calve-Perthes (LCP) disease as 33% of children with LCP were found to have a diagnosis of ADHD, compared to the 5% incidence of ADHD in the general population at the time. A more recent study shows that perhaps the link is not with ADHD per se, but rather between a generalized behavioral disorder and LCP. Another study found that ADHD was present in 75% of children with a diagnosis of Osgood-Schlatter Disease (OSD). Whereas still others have noticed increased fracture rates in children with ADHD. Our current data was similar to that in these previous studies, as a three-fold increase in the diagnosis of ADHD in children with OCD lesions compared to the prevalence of ADHD among the general population (7%) and a two-fold difference between patients with OCD and anterior knee pain, (23% vs 11%; p < 0.05).

This study does have limitations. It was retrospective in nature and there was no formal protocol in determining the treatment of the patients. Diagnosis of ADHD was made on chart review determined by the reported “problem” or “medication” list, so there was no formal confirmation of the psychiatric diagnosis. There were also no females in the ADHD group, but when the male subpopulation was analyzed (data not shown), similar results were obtained. A future prospective study with standardized treatment protocol for patients with OCD lesions and standardized criteria for the diagnosis of ADHD is warranted to confirm the results of this study.

In conclusion, we believe that there is a relationship between the diagnosis of ADHD and OCD lesions. From the current study we are unable to say whether this is due to the behavioral effects or treatments used to treat ADHD. When evaluating patients with OCD, we suggest obtaining a thorough history to determine if the patient has the diagnosis of ADHD as this may influence the outcome of treatment. Surgeons should be aware that children with OCD and ADHD might fare worse than their counterparts without ADHD regardless of treatment. Future prospective trials with controlled treatment protocols are warranted to better determine the relationship of ADHD in children with OCD lesions.

ACKNOWLEDGMENT

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REFERENCES

ADHD and OCD is there a connection?


ABSTRACT

Background: Haemophilus parainfluenzae (H. parainfluenzae) is a gram-negative rod that inhabits the oral cavity. It is a common cause of respiratory tract infections and rarely is responsible for musculoskeletal infections in immunocompetent hosts. We present a case of a 17-year-old male whose postoperative course following arthroscopic all-inside meniscus repair was complicated with H. parainfluenzae septic arthritis. The infection was successfully cleared with two arthroscopic irrigation and debridements and antibiotic therapy. The patient successfully returned to full-contact high school football at five months postoperatively. To our knowledge, this represents the first reported case of H. parainfluenzae infection following an orthopaedic procedure in an adolescent.

Level of Evidence: IV

Keywords: meniscus, haemophilus parainfluenzae, arthroscopy, infection, septic arthritis, knee

INTRODUCTION

Septic arthritis is considered an orthopaedic emergency and may cause lasting morbidity due to the sequelae of chondral damage leading to irreversible joint destruction.1 Timely recognition and treatment is imperative to avoid long-term damage. Traditionally, the treatment of septic arthritis requires intraarticular surgical irrigation and debridement as well as the administration of intravenous antibiotics.

Haemophilus parainfluenzae (H. parainfluenzae) is a gram-negative rod found in oral flora and frequently associated with respiratory infections. H. parainfluenzae is an extremely unusual agent of musculoskeletal infection in immunocompetent hosts and has been implicated as the causative agent in only a few documented cases.2,3 Here, we present a case of a healthy 17-year-old male whose postoperative course following all-inside meniscus repair was complicated by H. parainfluenzae septic arthritis.

CLINICAL CASE SUMMARY

A healthy 17-year-old male presented four weeks after sustaining a twisting injury to his right knee while wrestling at a high school tournament. Upon presentation, the patient reported right knee mechanical symptoms and pain at the medial joint line exacerbated by motion. On physical examination, the patient was tender to palpation over the medial joint line, with positive McMurray and Thessaly tests. He had full range of motion without ligamentous instability. Plain radiographs revealed a large joint effusion but were negative for fracture. Magnetic resonance imaging (MRI) demonstrated a three centimeter (cm) longitudinal peripheral posterior medial meniscus tear of the right knee. After failing six weeks of non-operative intervention (physical therapy and non-steroidal anti-inflammatory medication), the patient was indicated for arthroscopic all-inside meniscus repair.

In the operating room, hair around the operative site was clipped and skin was prepped using DuraPrep Solution. First, a diagnostic arthroscopy was performed using standard portals and confirmed the three cm longitudinal posterior medial meniscus tear. Three FasT-Fix 360 (Smith & Nephew, Andover, Massachusetts) all-inside sutures were used to repair the meniscus tear. The FasT-Fix needle was set to a depth of 16 millimeters (mm) for each vertical mattress suture. It was noted that the most anterior meniscus suture needle punctured the skin over the medial joint line; however, the device was withdrawn and the button appropriately deployed subcutaneously. After satisfactory meniscal repair, portals were closed with nylon suture. No tourniquet was utilized during the procedure and the total operative time was 41 minutes. The patient was discharged home on the day of surgery without incident. Postoperatively, the patient was instructed to wear a hinged knee brace locked in full extension when ambulating and allowed to perform active range of motion from 0-90° when seated or supine.

The patient subsequently presented to the emergency department 25 days after his initial surgery reporting two days of progressively worsening knee pain, swelling, and inability to bear weight. Of note, he had an upper respiratory infection two days prior as well. He endorsed

1Rugers Robert Wood Johnson Medical School, New Brunswick, NJ
2University of Iowa Hospitals and Clinics, Iowa City, IA
Corresponding Author: Dr. Jaqueline E. Baron;
Email: jacqueline-baron@uiowa.edu
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night sweats, decreased appetite, and was febrile (39.9°C). Laboratory tests revealed an elevated white blood cell count (20,300 with 80.8% neutrophils), an elevated erythrocyte sedimentation rate (ESR) of 34 mm/hr, and an elevated C-reactive protein (CRP) of 13.6 mg/L. Right knee arthrocentesis was performed which revealed 6,200 total nucleated cells with 93% neutrophils, no crystals (monosodium urate or calcium pyrophosphate dihydrate), and negative gram stain. He was ultimately reassured and discharged home without antibiotics. His synovial fluid cultures became positive for *H. parainfluenzae* after 36 hours of growth. Due to the rarity of the pathogen, repeat knee arthrocentesis was performed in clinic, which confirmed the diagnosis of *H. parainfluenzae* septic arthritis. The second aspirate was only notable for an interval increase in total nucleated cells to 13,900 with 91% neutrophils. The patient was admitted for arthroscopic irrigation and debridement of the right knee with drain placement. In the operating room, the previous meniscus repair was found to be intact. There were no intra-articular signs of infection; however, a small erythematosus area was noted over the medial joint line where the all-inside suture device punctured skin. A small incision was made over the area of concern without expression of purulent or infectious appearing material. Intraoperative cultures again confirmed the diagnosis of *H. parainfluenzae* septic arthritis. He was treated with cefazolin perioperatively and transitioned to ampicillin postoperatively at a dose of 2,000 mg every six hours at the recommendation of the Pediatric Infectious Disease team.

The patient’s clinical course was unremarkable until four days after irrigation and debridement when he reported new-onset fatigue, and his CRP increased from 3.6 mg/L to 6.3 mg/L over 24 hours. Given the increase in CRP and concerning systemic symptoms, the decision was made to return to the operating room for repeat irrigation and debridement of the right knee. Repeat aspiration prior to the second arthroscopic irrigation and debridement procedure was not performed. Intraoperative cultures taken during the second irrigation and debridement demonstrated no growth. The patient was discharged home five weeks after his initial meniscal repair surgery and completed a 21-day course of oral amoxicillin. At six weeks following his initial meniscal repair, full resolution of his right knee pain and swelling was reported. On examination, the patient’s passive range of motion was 0-120° with a 5° extensor lag with straight leg raise. His range of motion returned to normal four months later and he returned to full sporting activity without further incident. Six months after surgery, he started as quarterback for his high school football team and played all season without any knee-related complications.

**DISCUSSION**

We present a case of a healthy 17-year-old male whose postoperative course following arthroscopic all-inside meniscal repair was complicated by *H. parainfluenzae* septic arthritis. To our knowledge, this represents the first reported case of *H. parainfluenzae* infection following an orthopaedic procedure in an adolescent.

Knee arthroscopy is a commonly performed, minimally invasive, and relatively safe procedure. Potential complications have been well-documented in the literature and include hemorrhrosis, infection, and venous thromboembolic events. Complication rates for all patients after knee arthroscopy are low, with reported rates ranging from 0.56% to 8.2%. The infection rate after arthroscopic all-inside meniscal repair using the FasT-Fix device has been reported to range between 3.3%-4.0% in several small case series. Martin et al. delineated the risk factors for 30-day morbidity and mortality following knee arthroscopy and identified African-American race, prior operation within 30-days, increased American Society of Anesthesiologists (ASA) class, and operative time greater than 1.5 hours as predictive factors for complication. In a study of 1,002 pediatric and adolescent knee arthroscopies, a complication rate of 14.7% was found, with septic arthritis present in 0.3% of cases. Prolonged anesthesia and tourniquet times were identified as factors predictive of morbidity.

Despite the high prevalence of *Haemophilus* as a member of normal oral flora, its low pathogenic potential makes this species an infrequent cause of disease, especially following orthopaedic procedures. *H. parainfluenzae* is a fastidious organism with many requirements to ensure culture growth, including chocolate agar with factor V in the media. Improper culture media may prohibit the diagnosis of septic arthritis secondary to unusual pathogenic agents.

Cobo et al. published a review of 18 cases of *H. parainfluenzae* musculoskeletal infection. Of these 18 reported cases, only three of these cases involved prior orthopaedic surgical interventions, specifically total knee arthroplasty (2) and total hip arthroplasty (1) procedures (age range: 65-78 years). Eight of the reported cases involved the knee, and 39% lacked clinically identifiable risk factors for *H. parainfluenzae* infection. The serum WBC count was elevated in 11 patients while the CRP was elevated in only 10 patients at the time of diagnosis. The oral cavity was identified as a possible source of *H. parainfluenzae* septic arthritis in 28% of cases. Only one case in this series was secondary to a cutaneous infection. Overall, *H. parainfluenzae* septic arthritis can present a diagnostic challenge as it typically produces a lower than normal total nucleated cell count on arthrocentesis and may take a few days to grow in culture. Additionally,
as demonstrated in the previous review by Cobo et al., systemic inflammatory labs may be normal or only slightly elevated in these cases.7 A high index of suspicion is often needed for a prompt diagnosis.

Upon review of the literature, only two cases of septic arthritis of the knee in adolescents attributed to *H. parainfluenzae* were identified.8,9 Both of these cases did not occur following knee arthroscopy and one case was deemed presumptive *H. parainfluenzae* septic arthritis as the organism was never isolated from the knee. The first adolescent patient, an 18-year-old male, presented with a painful knee suspicious for gonococcal septic arthritis.8 He was afebrile on presentation, with a warm and swollen right knee. Furthermore, he had a painful left elbow and associated gonococcal urethritis. Following aspiration of the knee, initial gram stain and joint cultures were negative with only a few neutrophils present. However, *H. parainfluenzae* was isolated from his blood. His symptoms resolved after two days of penicillin therapy intravenously. Notably, chocolate agar medium was not used to assess the joint culture with the authors deeming the case ‘presumptive’ septic arthritis secondary to *H. parainfluenzae*.9 The diagnosis of septic arthritis in this case is questionable given the negative culture and resolution of symptoms with only 48 hours of intravenous antibiotics. The second case was that of an otherwise healthy 12-year-old male diagnosed with septic arthritis of a native knee.8 He presented afebrile with a 24-hour history of knee pain, swelling, and inability to weight bear. Laboratory tests were notable for an elevated WBC count of 38,750.8 While initial gram staining was negative, cultures from the joint aspirate grew Gram-negative coccobacilli on hospital day two, confirmed with re-culture with chocolate agar, and later identified as *H. parainfluenzae*. This patient was successfully treated with arthroscopic irrigation and debridement as well as 10-days of intravenous cefotaxime followed by three weeks of oral amoxicillin.

The origin of *H. parainfluenzae* in our case remains uncertain. While repairing the meniscus, the FasT-Fix needle was noted to have punctured the skin. This may be seeded the joint with the organism if the preoperative skin preparation was ineffective. This route of transmission remains unlikely as *H. parainfluenzae* is typically found in the respiratory tract and other micro-organisms such as Staphylococcus species are much more prevalent as skin flora. Of note, the patient did report an upper respiratory illness two days prior to presentation. Blood cultures were never drawn with hematogenous seeding of the joint a definite possibility. Overall, short-term outcomes in the 18 previously documented cases of *H. parainfluenzae* infection in the literature have been positive, with 72.2% of patients reporting complete resolution of symptoms and return to baseline activity levels.2 Longer follow-up is needed to further delineate long term outcomes following *H. parainfluenzae* septic arthritis of the knee.

**CONCLUSION**

The timely diagnosis and treatment of septic arthritis is paramount to prevent cartilage damage and joint destruction. Atypical pathogens pose a diagnostic challenge due to atypical laboratory values, variable culture requirements, and delayed culture growth. Here, we present a case of unusual septic arthritis of the knee secondary to the respiratory pathogen *H. parainfluenzae* in a 17-year-old male following arthroscopic all-inside meniscus repair. Following surgical irrigation and debridement and intravenous antibiotics, an excellent outcome was achieved with return to full contact sporting activities at five months following surgery.

**REFERENCES**


**ABSTRACT**

Background: Some NCAA conferences now require a press box-based Medical Observer for all football games to identify injuries missed by on-field providers. The objective of this study was to determine whether a Medical Observer identified injuries missed by the on-field medical personnel.

Methods: This was a comparative observational study of injury identification methods which was done at nine NCAA football games. The athletes on a single institution’s varsity football team participated. Eight games and one bowl game were studied. Observers were sports medicine Fellows (Orthopaedic, Primary Care). Injury logs were kept by the Medical Observer to document game day injuries. The athletic training staff collected injury reports in the days following games. These were compared with game day injury logs to identify any injuries that were not reported to the medical staff during competition.

Results: A total of 41 game injuries were identified (4.56 injuries/game). 29 injuries (29/41; 71%) were identified by both the sideline medical providers and the Observer. 29% were identified by only the sideline medical providers and no injuries were identified by only the Observer. A total of 95 game-related injuries were evaluated in the training room on the day after each game. 27 injuries (27/95; 28%) had been identified during the game (9 [33%] by the sideline medical team and 18 [67%] by both the sideline medical team and the Observer). Fourteen game injuries were not severe enough to require care the following day. There were 68 (68/95; 72%) delayed self-reported injuries treated by the training room staff the next day.

Conclusions: A press box-based Medical Observer did not identify any injuries missed by the on-field medical staff. This study did, however, identify a large number of unreported game-day injuries that were treated the following day.

Level of Evidence: II

Keywords: concussion, football, injury prevention, medical observer, missed injury

**INTRODUCTION**

American football at all levels accounts for over 1.5 million injuries each year.1 These injuries range from minor sprains and strains, torn ligaments and tendons, to more serious conditions such as exertional heat illness, long bone fractures, spine injuries, and concussions.2 Traumatic injuries pose the threat of enduring beyond a player’s athletic career and affecting his or her livelihood down the road through osteoarthritis, neurodegeneration, or depression.3,5

Concussions, for example, may have prolonged consequences for those affected, and have been highlighted recently in both the medical literature and by the media. Concussions make up at least 6.8% of all collegiate football injuries,4 and the true incidence is likely higher due to underreporting.6 Although the specifics of return-to-play protocols are debated,7,8 it is widely agreed that repetitive brain trauma can lead to a number of long-term sequelae.9

There has been increasing concern that concussions and other football injuries are being unreported by players or being missed by medical staff during competition, putting players at further risk of long-term complications.8
The University of Florida started a pilot program in 2014 that placed a medical provider in the press box during home games to watch for concussions and other missed injuries. This initiative has been adopted by many conferences but is not standardized to all conferences. The BIG TEN and the Southeastern Conference currently use one independent certified athletic trainer to watch both teams and monitor for head and neck injuries. The Atlantic Coast Conference (ACC) mandated that a Medical Observer (MO) who was a member of the team’s medical staff must be present at all games this season. ACC Commissioner John Swofford mandated that two medical professionals be designated to watch from the press box during every game, with “the sole purpose of observing from on high, if you will, what’s taking place on the field that somebody on the sidelines might not be able to see.” We are unaware of any published reports regarding the results of this new initiative at any other institutions.

During the 2015 football season, this role at Duke University was delegated to the Orthopaedic and Primary Care Sports Medicine Fellow Physicians. During home games, a single Orthopaedic Sports Medicine Fellow was assigned the role of the Medical Observer for the entire game, while both an Orthopaedic and a Primary Care Sports Medicine fellow worked the sideline. During away games, one Primary Care and one Orthopaedic Sports Medicine fellow split the responsibilities of sideline and Medical Observer duties, switching at half time. The purpose of this study was to evaluate whether the Medical Observer was able to fulfill the expected duty of identifying injuries missed by the on-field medical personnel. We hypothesized that the Medical Observer would not identify injuries that were missed by the referee, the sideline medical providers, or both or injuries that were unreported by athletes during the game.

METHODS

New guidelines from the ACC require teams to provide a Medical Observer in the press box for all home and away games (Figure 1). For the 2015 season, 13 games (12 regular season plus one bowl game) were monitored. The role of this Medical Observer is to report any potentially missed injuries to the team physicians and athletic trainers on the sideline via direct head set communications or dedicated hardwired ring-down phone. This policy was established at the beginning of the football season. A provisional log was developed for the Medical Observer to record any player injuries seen by the Medical Observer, and to record whether the injuries were communicated to the sideline staff. These logs were kept for the first four games of the season, but they failed to designate whether the medical providers on the field already identified the injuries, and thus were not included in our final dataset.

After institutional review board approval was obtained (after the fourth game), more specific data was collected prospectively to identify the effectiveness of the newly mandated Medical Observer policy within the ACC (Table 1). Specifically, the Medical Observer would document:

- Injuries identified by both the sideline medical providers and the Medical Observer. We hypothesized that this would identify the majority of injuries. The Observer would document two scenarios: 1) when the player was injured on the field and the medical provider goes out to the player and 2) when players were obviously injured and made their way to the sideline for care.

- Injuries that were identified by the medical providers on the sidelines but NOT by the Medical Observer. This includes subtle injuries that occur during play that were reported by the player to a sideline medical provider after the play or series and asked to be evaluated.

- Injuries that were MISSED by sideline medical providers and referees but were IDENTIFIED by the Medical Observer.

After discussion with the medical staff, criteria were set outlining when the Medical Observer would use the head set to communicate to the sideline medical team. Abnormal player behavior (limping, stumbling, etc) was used identify a potential injury. Because the purpose of this study is to evaluate the ability of the Medical Observer to effectively identify missed injuries, injuries were reported by the Medical Observer to the sideline medical team on the following occasions:

1. There is an injury seen by the Medical Observer, no one else has identified the injury over the radio, and the player is about to line up for participation in the next play.
ACC Mandatory College Football Medical Observer. A Necessary Addition to the Medical Team?

2. There is an injury seen by the Medical Observer, no one else has identified the injury over the radio, the player goes to the sideline and does NOT seek medical attention.

To maximize accuracy of data, all sideline medical providers (physicians, athletic trainers, physical therapists, etc.) agreed to state clearly over headset communications each time they identified an injury and when any player reported to them with an injury related complaint. This would allow the Medical Observer to document on the data log that the injury was identified by both sideline medical providers and the Medical Observer, or just by the sideline medical providers. Additionally, a daily injury report was kept by the athletic training staff and updated after each athletic training room session. This was used to identify any injuries from the game that were not reported by a player to the sideline medical staff.

RESULTS

Data were collected using the new data collection form for eight regular season games and one post-season bowl game. During the nine games, 41 injuries (from 38 players) were logged (4.56 injuries per game). Twenty-nine (29/41; 71%) were identified by both the sideline medical providers and the Medical Observer. Twelve injuries (12/41; 29%) were identified by only the sideline medical providers. There were no injuries that were identified by only the Medical Observer.

The game-reported Medical Observer logs were compared to injury reports from the athletic training room on the days following games. A total of 95 game-day injuries were evaluated in the athletic training room the week after each of the nine games. Of the 41 injuries documented in the Medical Observer log on game day, 27 were subsequently seen in injury clinic, while 14 did not need to receive further treatment in the subsequent injury clinic. These numbers are further broken down based on who observed the injuries (Table 2). The other 68 injuries were self-reported in the athletic training room the day following the game in which they were occurred.

In the athletic training room visits after the game, an injury system was used by the athletic training staff, which stratified injuries as minor, moderate, or significant. Players considered to have “minor” injuries were able to continue with full activities, those graded as “moderate” were limited in practice or were game-time decisions, and those with “significant” injuries were injuries that would preclude them from football activities until further evaluated. Many of these “minor” injuries include injuries such as small strains and contusions. Of the 27 injuries seen by the medical staff during games and subsequently evaluated during injury clinic, 8 were considered minor injuries and 19 significant injuries. Of the 8 minor injuries, three (3/8; 38%) were identified only by sideline providers, while 5 (5/8; 62%) were identified by both sideline providers and the Medical Observer. Of the 19 significant injuries, six (6/19; 32%) were seen only by sideline providers, while 13 (13/19; 68%) were seen by both. Fourteen identified injuries from games did not appear on any of the subsequent injury reports, four (4/14; 29%) of which were identified only by sideline providers, and 10 (10/14; 71%) of which were identified by both
sideline medical providers and the Medical Observer. Of those fourteen, four injuries occurred during the bowl game and thus players were unable to attend next-day injury clinic, while the other ten were presumed to be insignificant injuries. Of the 95 self-reported injuries the day after the game, 45 were classified as minor, one moderate, and 49 as significant injuries. A comparison of identified game day injuries versus those self-reported in injury clinic is represented in Table 3.

Six players suffered concussions as a result of in-game action; four were reported by both the Medical Observer and sideline staff. One of the unreported concussions occurred on the final play of the game, 45 were classified as minor, one moderate, and 49 as significant injuries. A comparison of identified game day injuries versus those self-reported in injury clinic is represented in Table 3.

Table 3. Comparison of Identified Game Day Injuries vs Delayed Self-Reported Injuries

<table>
<thead>
<tr>
<th></th>
<th>Injury clinic total injuries</th>
<th>Identified game day</th>
<th>Delayed self-reported</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild</td>
<td>45</td>
<td>8</td>
<td>37</td>
</tr>
<tr>
<td>Moderate</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Significant</td>
<td>49</td>
<td>19</td>
<td>30</td>
</tr>
<tr>
<td>Total</td>
<td>95</td>
<td>27 (27/41; 66%)</td>
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We found that 72% (68 of 95 injuries) of players waited to self-report their injuries the day after the game. This was a surprisingly high rate and an unexpected finding of our study. In fact, this may possibly be the most important finding to come out of this study and cannot be understated. At our institution, this has completely validated our next-day injury clinic to evaluate any player who feels injured. In regard to the utility of a Medical Observer, however, the type of injuries that are usually missed has a direct impact on the ability of this Observer to contribute. For example, if the most commonly “missed” injuries are joint sprains and other minor injuries, it is unlikely that immediate treatment will lead to faster recovery. Furthermore, most catastrophic injuries and orthopedic injuries needing immediate medical attention will cause players to stay on the ground and stop game play, thus negating the need for the Medical Observer.

Even though our Medical Observers did not identify any “missed” injuries this season, we understand this could change moving forward as more games are observed. As previously discussed, concussions have received an increased amount of attention recently, and are often unreported by players. Of the six concussions identified in the 2015 season, four were identified and evaluated at the time of incident, one occurred on the final play of the game and was evaluated in the locker room immediately following that game. The other was self-reported by the player in the athletic training room the day following the game but was not seen by any staff when it occurred. In addition, one player was evaluated on the sideline due to concern by the Medical Observer for a concussion, but he was deemed not to have a concussion and was allowed to return to the game.

DISCUSSION

Our data through the first season supports our hypothesis that the Medical Observer would not identify injuries missed by the medical staff on the field. The sideline medical providers were much more efficient at identifying injuries than the Medical Observer, who did not identify any “missed” injuries. Even though the Medical Observer position was mandated with good intentions, several questions must be raised about its ability to meaningfully contribute to player health and safety.

Missed injuries in sporting events can lead to significant disability, injury progression, and prolonged rehabilitation time, but the actual incidence of missed injuries, specifically in supervised sporting events, is unknown.
Observers from their athletic training staff who were not sideline medical staff. Other ACC schools used Medical away games, and they had direct communication with the University used its own physicians as Medical Observers in injury histories or other ongoing medical issues. Duke sidelines for other injuries and are not familiar with player the authority to stop the game for head and neck injuries, Medical Observers of SEC and BIG TEN games have team and not required at out-of-conference road games. athletic trainers who are not affiliated with either on the conference. The SEC and BIG TEN use certified medicine physician, one board certified family practice sports medicine physician, and two sports medicine fellow physicians. Other schools may not have as many medical providers on the sidelines and may benefit more by using a Medical Observer than indicated by our results. Additionally, the size of the medical staff is different at each school. At home football games, Duke University has 11 medical providers on the sidelines: four certified athletic trainers, one athletic trainer student, two licensed physical therapists, one board certified orthopedic sports medicine physician, one board certified family practice sports medicine physician, and two sports medicine fellow physicians. Other schools may not have as many medical providers on the sidelines and may benefit more by using a Medical Observer than indicated by our results.

Furthermore, regarding collection of data, the decision was made to include subtle injuries reported by the player to the sideline medical provider after the play or series in the “Seen by providers NOT by medical observer” column. While some could argue that these were ultimately “missed” injuries, they were reported by the player acutely and therefore not truly missed in the spirit of this article. With the speed of the game and use of two way handheld communication, it would have been very difficult to differentiate which of these were actually seen by the sideline medical staff and which were player reported. It is important to note; however, that none of these injuries were seen by the Medical Observer. Lastly, in regards to data, as stated in the Methods section, our data set does not include the first four games of the season. Data and logs were kept for the first four games of the season, but they failed to designate whether the medical providers on the field already identified the injuries, and thus were not included in our final dataset.

There are also several limitations to the use of a Medical Observer from the policy level. First, the credentials and role of the Medical Observer vary greatly depending on the conference. The SEC and BIG TEN use certified athletic trainers who are not affiliated with either team and not required at out-of-conference road games. Medical Observers of SEC and BIG TEN games have the authority to stop the game for head and neck injuries, but they are not in contact with the medical staff on the sidelines for other injuries and are not familiar with player injury histories or other ongoing medical issues. Duke University used its own physicians as Medical Observers throughout the 2015 football season at both home and away games, and they had direct communication with the sideline medical staff. Other ACC schools used Medical Observers from their athletic training staff who were not physicians. The ACC’s model of utilizing members of the players’ care team has the benefit of these providers being aware of the player’s injury history. It could, however, pose potential conflicts of interest and fear of retribution for stopping play that would not likely be present in the SEC and BIG TEN model. Though this concern was not felt to exist during this initial experience, this potentially could pose a problem depending on the environment of the team.

Additionally, the size of the medical staff is different at each school. At home football games, Duke University has 11 medical providers on the sidelines: four certified athletic trainers, one athletic trainer student, two licensed physical therapists, one board certified orthopedic sports medicine physician, one board certified family practice sports medicine physician, and two sports medicine fellow physicians. Other schools may not have as many medical providers on the sidelines and may benefit more by using a Medical Observer than indicated by our results.

The inconsistency of implementation was further noted in the facilities made available to the Medical Observer. Our experience varied greatly depending on the stadium. Many designated positions were outside of a press box with only handheld communications down to the field and no access to any audiovisual support. This contrasted greatly with other locations where Observers were placed inside the press box with access to both live and delayed-feed widescreen video, and/or control of a multi-angle video replay system as well as excellent visualization of the entire field.

The role of the Medical Observer may need to be more clearly defined if there is to be uniformity throughout the NCAA in the future. Forthcoming studies should consider what specific injuries the Medical Observer should be looking for, and should present a list of expected, observable signs that can be seen from the booth. The Medical Observer may also benefit from being assigned a certain group of players or area of the field to watch, i.e., those with the highest occurrence of injuries or those who are least visible to the sideline staff. There is still much to be learned about the potential of the Medical Observer and good reason for these studies to be a priority. It may prove to be well worth the extra position if the Observer can contribute to the safety of players. According to Steve Shaw, the SEC coordinator of football officials, “I think it will be very rare when the Medical Observer takes impact in the game...but in that situation where they might, it could save a player from worse injury or concussion…”

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ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION: A COMPARATIVE CLINICAL STUDY BETWEEN ADJUSTABLE AND FIXED LENGTH SUSPENSION DEVICES

Bastian Uribe-Echevarria, MD; Justin A. Magnuson, BA; Annunziato Amendola, MD; Matthew J. Bollier, MD; Brian R. Wolf, MD, MS; Carolyn M. Hettrich, MD, MPH

ABSTRACT

Background: Adjustable-length cortical suspension devices provide technical advantages over fixed-length devices for femoral graft fixation during anterior cruciate ligament (ACL) reconstruction but have shown increased lengthening during cyclic loading in biomechanical studies. The purpose of this study was to prospectively measure graft elongation in vivo along with patient reported outcomes.

Methods: Thirty-seven skeletally mature patients diagnosed with anterior cruciate insufficiency who underwent ACL reconstruction using autogenous hamstring graft were included in this study. Thirteen patients received an ACL reconstruction using a fixed loop device (FL) and twenty-four patients were treated with an adjustable-length device (AL) based on surgeon preference. Bilateral knee laxity was measured with a KT1000 Arthrometer before surgery and immediately after surgery with the patient under anesthesia, and at the 6-week, 3-month, and 6-month clinical follow-up appointments. All measurements were made by the same operator with maximum force testing. Differences between the affected knee and the contralateral knee were measured. Patient reported outcomes were collected at 6 and 24 months post-operatively.

Results: No difference was found between the FL and AL groups in either knee laxity or patient reported outcomes. Average side-to-side difference at 6 months was 1.8 ± 2.6 mm for the FL group and 1.7 ± 2.4 mm for the AL group (p=.874). One patient in the FL group (7.7%) and two in the AL group (9.5%) had a side to side difference in laxity greater 5 mm. Patient reported outcomes did not differ between groups and no patients underwent revision surgery.

Conclusions: The adjustable-length cortical suspension device (AL) did not demonstrate increased laxity as compared to fixed-length devices. There was no difference in patient reported outcomes between the groups.

Level of Evidence: IV

Keywords: anterior cruciate ligament, soft tissue graft, cortical suspension, cortical button, tightrope, endobutton

INTRODUCTION

The outcome of anterior cruciate ligament (ACL) reconstruction depends on many surgical factors including tunnel position, graft tension, and fixation techniques.1 Anatomic positioning of femoral and tibial bone tunnels attempts to approximate native knee kinematics, allowing appropriate graft tension throughout range of motion.2 Along with maintaining appropriate tunnel positioning, graft-fixation devices must provide sufficient fixation to ensure that graft tension is maintained until incorporation of the graft to native bone.3,4 Hamstring tendons are one of the most popular grafts used for ACL reconstruction; however, controversy exists about the best graft fixation.

Common soft tissue ACL reconstruction femoral fixation implants include interference screws, cortical suspension devices, and cross pins. Previous work has shown trends in mechanical behavior for most of the fixation mechanisms, with positive clinical outcomes for all three types of devices.5 Cortical-cancellous suspension fixation with transcondylar devices seems to offer the best results in terms of graft elongation, fixation strength, and stiffness, but tends to show high rates of intra- and postoperative complications.5,7 Interference devices may allow for relatively higher graft slippage and failure at lower ultimate loads when used to secure hamstring tendon grafts.5,8

Fixed-length cortical suspension devices have been shown to be a good option for soft tissue graft fixation in biomechanical studies in terms of limiting graft slippage and providing sufficient fixation strength.5,8 However,
there are technical challenges in measuring and inserting the device that may result in insufficient graft length in the femoral tunnel for incorporation. This is aggravated by shorter femoral tunnels with anatomic femoral tunnel placement, increasing the risk for insufficient graft length in the femoral tunnel for incorporation.\(^5\)

Adjustable-length suspension can provide greater ease of insertion by obviating the need to calculate the loop length, allows complete graft fill of the femoral tunnel, and allows the same implant to be used regardless of tunnel placement or depth.\(^9,11\) The potential disadvantage of the adjustable-length design is loop lengthening after fixation, which can lead to graft loosening and consequently surgical failure.\(^5\)

The objective of this study was to compare side-to-side knee laxity and outcomes after primary ACL reconstruction with hamstring autograft between adjustable-length or fixed-length cortical suspension devices. We hypothesized that there would be increased knee laxity in the adjustable-length suspension as compared to fixed-length suspension, but no difference in patient reported outcomes or failure rates.

**METHODS**

Institutional review board approval was obtained at the University of Iowa for this prospective non-randomized case control study comparing groups of patients undergoing ACL reconstruction surgery with either fixed-length (FL) or adjustable-length femoral cortical suspension devices. The fixed-length device in this study was the EndoButton (Smith&Nephew, Andover, Massachusetts), and the adjustable-length device was the TightRope (Arthrex, Naples, Florida).

The study included all skeletally mature patients who were diagnosed with anterior cruciate insufficiency and elected to undergo ACL reconstruction using an autogenous hamstring graft between July 2014 and March 2015. Exclusion criteria were previous knee surgery, multi-ligament injuries, contralateral ACL deficiency or reconstruction, or connective tissue disorders.

Patients consenting to participate in the study had their knee laxity measured in both their reconstructed knee as well as with side-to-side comparison measured with a KT1000™ Arthrometer (MEDmetric, San Diego, California) at maximum force by a single trained orthopaedic surgeon who was present for each surgical case. Measurements were done immediately before and after surgery with the patient under anesthesia (either general or spinal), and then postoperatively at six weeks, three months and six months after surgery. All measurements were done by the same surgeon to reduce bias caused by the low inter-rater reliability of the KT 1000 arthrometer.\(^12,13\) These timepoints were all measured as an attempt to cover the initial rehabilitation period through tunnel incorporation and healing. Differences in laxity were compared using t-tests.

The study included the patients of four fellowship trained surgeons in our sports medicine group (AA, MJB, CMH, BRW). The patients were divided into two groups, Fixed-Length (FL) or Adjustable-Length (AL), based on surgeon preference. One surgeon used only FL, two only used AL, and one used both. The surgeon preferring the fixed-length fixation device used a medial portal technique and the other three surgeons utilized an outside-in technique, using a Flipcutter (Arthrex Inc., Naples, Florida). Femoral and tibial tunnels were created within the center of the native femoral and tibial ACL footprints. Both adjustable-loop or fixed-loop cortical suspension devices were used according to the manufacturer’s guidelines. The grafts were manually tensioned. Tibial fixation consisted of an interference screw, except for three patients, in which an All-Inside® technique (Arthrex Inc., Naples, Florida) was used with double femoral and tibial adjustable loop fixation.

Patient reported outcomes (PROs) were collected preoperatively as well as at six and twenty-four months post-operatively. PROs included the Marx Activity Scale, Knee Injury and Osteoarthritis Outcome Scale (KOOS), Short Form-36 (SF-36), and EQ5D. PROs were analyzed using t-tests to compare baseline to 6 month, and 24 month scores between FL and AL groups. Change scores (baseline to 6-month and baseline to 24-month timepoints) were also calculated independently for each of the KOOS subscales and compared with t-tests, which allowed the highest sensitivity for detecting any differences between groups. KOOS subscales were also compared with Fisher exact tests to analyze the percentage of patients who achieved the threshold patient acceptable symptomatic state (PASS) for ACL reconstruction as described by Muller et al.\(^14\)

**RESULTS**

A total of thirty-seven patients were enrolled. Thirteen patients (35.1%) were in the FL group: seven females, eight right knees. AL group consisted of twenty-four patients (64.9%): thirteen females, eleven right knees. Of all patients, seventeen had concomitant surgery (thirteen in the AL group and four in the FL group) for a total of twenty-one procedures, as detailed further in Table 1. Three patients of the AL group were lost to follow-up after their initial pre and postoperative testing, resulting in follow-up rates for the 24 month PROs of 100% in the FL group and 87.5% in the AL group.

There was no significant difference between maximum side-to-side KT-1000 arthrometer testing immediately after surgery and at six months postoperatively between
A groups (Figure 1). The FL group showed an increase of 2.5 ± 2.3 mm (median 2.0 mm) from postoperative testing to testing at six months, and the AL group showed an increase in 2.8 ± 2.8 mm (median 2.0 mm) with a p-value of 0.759 between the two groups. One patient in the FL group (7.7%) and two in the AL group (9.5%) showed a 6-month side-to-side difference in laxity over 5 mm (p=.855). No patients underwent revision surgery.

Preoperatively, the FL group had significantly higher side-to-side laxity (6.5 mm vs 4.7 mm, p=.034). Both groups had less laxity than the contralateral side immediately after surgery, with laxity progressively increasing at six weeks, three months and six months, although no post-operative timepoint had significant side-to-side differences between FL and AL (Figure 1). Average side-to-side difference at six months was 1.8 ± 2.6 mm for the FL group and 1.7 ± 2.4 mm for the AL group (p=.874).

Six and 24-month questionnaires were completed by 81.1% and 75.0% of patients respectively. Table 2 summarizes differences in PROs at preoperative baseline, 6 months, and 24 months. No significant differences were noted between FL and AL groups at baseline. The only significant difference noted at six months Table 1. Demographics, Tunnel Diameter, and Concomitant Procedures

<table>
<thead>
<tr>
<th></th>
<th>AL Group</th>
<th>FL Group</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>24</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>31.3 ± 11.7</td>
<td>33.9 ± 11.2</td>
<td>0.510</td>
</tr>
<tr>
<td>Gender Female</td>
<td>13 (54%)</td>
<td>7 (54%)</td>
<td>0.985</td>
</tr>
<tr>
<td>Laterality Right</td>
<td>11 (46%)</td>
<td>8 (62%)</td>
<td>0.570</td>
</tr>
<tr>
<td>Femoral Tunnel Diameter</td>
<td>9.3 ± 0.8 mm</td>
<td>8.4 ± 0.7 mm</td>
<td>0.002</td>
</tr>
<tr>
<td>Patients with Concomitant Procedures</td>
<td>13 (54%)</td>
<td>4 (31%)</td>
<td>0.173</td>
</tr>
<tr>
<td>Medial Partial Meniscectomy</td>
<td>5 (21%)</td>
<td>2 (16%)</td>
<td></td>
</tr>
<tr>
<td>Medial Meniscus Repair</td>
<td>2 (8%)</td>
<td>2 (15%)</td>
<td></td>
</tr>
<tr>
<td>Lateral Partial Meniscectomy</td>
<td>5 (21%)</td>
<td>1 (8%)</td>
<td></td>
</tr>
<tr>
<td>Lateral Meniscus Repair</td>
<td>0 (0%)</td>
<td>1 (8%)</td>
<td></td>
</tr>
<tr>
<td>Plicectomy</td>
<td>1 (4%)</td>
<td>0 (0%)</td>
<td></td>
</tr>
<tr>
<td>Loose body removal</td>
<td>1 (4%)</td>
<td>0 (0%)</td>
<td></td>
</tr>
<tr>
<td>Patellar Chondroplasty</td>
<td>1 (4%)</td>
<td>0 (0%)</td>
<td></td>
</tr>
</tbody>
</table>

P values calculated using t-tests and chi-squared tests

Table 2. Patient Reported Outcomes at Baseline, 6 Months, and 24 Monthsa

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>6 Month</th>
<th>24 Month</th>
</tr>
</thead>
<tbody>
<tr>
<td>KOOS Symptoms</td>
<td>FL AL</td>
<td>P value</td>
<td>FL AL</td>
</tr>
<tr>
<td>Koos Pain</td>
<td>51.5 ± 15.5</td>
<td>54.5 ± 15.9</td>
<td>.595</td>
</tr>
<tr>
<td>Koos ADL</td>
<td>62.0 ± 11.9</td>
<td>61.3 ± 21.3</td>
<td>.919</td>
</tr>
<tr>
<td>Koos Sport</td>
<td>70.5 ± 12.0</td>
<td>71.7 ± 18.9</td>
<td>.858</td>
</tr>
<tr>
<td>Koos QOL</td>
<td>21.7 ± 17.8</td>
<td>26.3 ± 22.0</td>
<td>.533</td>
</tr>
<tr>
<td>Marx Activity</td>
<td>31.6 ± 16.8</td>
<td>35.4 ± 18.2</td>
<td>.549</td>
</tr>
<tr>
<td>EQ5D</td>
<td>11.3 ± 5.0</td>
<td>12.7 ± 3.7</td>
<td>.379</td>
</tr>
<tr>
<td>SF-36 PCS</td>
<td>80.1 ± 14.0</td>
<td>82.3 ± 13.1</td>
<td>.644</td>
</tr>
<tr>
<td>SF-36 MCS</td>
<td>38.5 ± 13.4</td>
<td>42.1 ± 11.7</td>
<td>.450</td>
</tr>
<tr>
<td></td>
<td>57.7 ± 6.0</td>
<td>56.1 ± 7.1</td>
<td>.547</td>
</tr>
</tbody>
</table>

aReported as mean ± SD. P values calculated using independent samples t-tests. ADL = activities of daily living; QOL = quality of life. PCS = physical component summary. MCS = mental component summary

Figure 1. Side-to-side differences in KT-1000 arthrometer measurements (brackets represent 95% confidence intervals; p values from independent samples t test).
was a higher KOOS Quality of Life score in the AL group (67.4 vs 50.3, p=0.032). However, both groups were again found to be similar at 24-month follow-up with no significant differences identified for any PROs. Marx activity decreased at both time points but was similar for both groups. KOOS scores were calculated for FL and AL groups and are summarized in Table 3. Analysis showed both similar baseline scores and improvement. Additionally, similar percentages of each group achieved the patient acceptable symptomatic state for each of the KOOS subscales, as shown in Table 4.

### DISCUSSION

The aim of our study was to prospectively investigate the in vivo effects of different types of cortical suspension in patients undergoing ACL reconstruction using hamstring autograft. Our study found that there were no significant differences in side-to-side knee laxity in patients using fixed-length versus adjustable-length cortical fixation devices at any timepoint. Additionally, we observed no differences in PRO scores at six months and twenty-four months following surgery.

Previous in vitro studies have shown increased laxity with adjustable-length fixation devices, and this effect of cyclic loading on these devices is an area of clinical concern, due to potential elongation during the acute postoperative period leading to decreased graft tension as well as graft slippage within the bone tunnel. These can both negatively affect postoperative healing and clinical outcomes because of increased knee laxity.

A possible explanation for these results is the unloading of the suture during cyclic preconditioning performed by Barrow et al. and showed an increase in loop lengthening during cyclic testing in the adjustable-length devices. This was partially caused by suture slippage in the adjustable-length loop. The Arthrex TightRope reached clinical failure of 3 mm lengthening after fewer cycles than the Biomet ToggleLoc (2576 ± 73), while the Smith & Nephew Endobutton reached clinical failure of 3 mm lengthening after fewer cycles than the Biomet ToggleLoc (2576 ± 73), while the Smith & Nephew Endobutton did not reach clinical failure during cyclic testing. With the free suture ends tied, after 4500 cycles, the Arthrex TightRope had a significant decrease in lengthening but not sufficiently to prevent failure.

The elongation of the devices is particularly concerning given the relatively small loads under which it began to occur. At a normal pace, the native ACL is subjected to forces of 303 N during level-ground ambulation and up to 445 N during walking on a downhill slope, which are higher than the forces at which elongation occurred during these studies.

A possible explanation for these results is the unloading of the suture during cyclic preconditioning at 10-50N. The literature shows that there is complete unloading of the ACL during certain phases of normal walking or rehabilitation. Biomechanical cadaveric

| Table 3. KOOS Change Scores at 6 and 24 Months from Preoperative Baselinea |
|-----------------|------|------|------|
|                  | FL   | AL   | P value |
| KOOS Symptoms    |      |      |        |
| Baseline         | 51.5 ± 15.5 | 54.5 ± 15.9 | 0.595  |
| 6-month change   | -21.4 ± 18.4 | +15.8 ± 22.5 | 0.492  |
| 24-month change  | -23.3 ± 9.4  | -23.7 ± 11.1 | 0.924  |
| KOOS Pain        |      |      |        |
| Baseline         | 62.0 ± 11.9 | 61.3 ± 21.3 | 0.904  |
| 6-month change   | -18.7 ± 13.6 | -20.6 ± 20.1 | 0.786  |
| 24-month change  | -25.7 ± 14.9 | -25.7 ± 14.3 | 0.993  |
| KOOS ADL         |      |      |        |
| Baseline         | 70.6 ± 12.0 | 71.7 ± 18.9 | 0.858  |
| 6-month change   | -19.8 ± 17.1 | +17.7 ± 18.9 | 0.748  |
| 24-month change  | -29.8 ± 13.6 | -21.4 ± 12.8 | 0.137  |
| KOOS Sport       |      |      |        |
| Baseline         | 21.7 ± 17.8 | 26.3 ± 22.0 | 0.533  |
| 6-month change   | +41.8 ± 25.8 | +34.7 ± 26.3 | 0.488  |
| 24-month change  | -59.4 ± 23.8 | -53.4 ± 24.6 | 0.568  |
| KOOS QOL         |      |      |        |
| Baseline         | 31.6 ± 16.8 | 35.4 ± 18.2 | 0.549  |
| 6-month change   | -20.5 ± 27.4 | -32.2 ± 24.5 | 0.246  |
| 24-month change  | -46.6 ± 13.0 | -37.3 ± 22.8 | 0.291  |

*Reported as mean ± SD. P values calculated using independent samples t-tests. ADL = activities of daily living. QOL = quality of life.

| Table 4. Percentage of Patients Who Achieved the Patient Acceptable Symptomatic State (PASS) by 24 Months for Each of the KOOS Subscales |
|-----------------|------|------|------|
| KOOS Symptoms   |      |      |      |
| (57.1)          | FL   | AL   | P value |
| 87.5%           | 100% | 0.296 |
| KOOS Pain       | (88.9)|      |      |
| 75%             | 63.2%| 0.676 |
| KOOS ADL        | (100)|      |      |
| 37.5%           | 31.6%| 0.999 |
| KOOS Sport      | (75) |      |      |
| 87.5%           | 73.7%| 0.633 |
| KOOS QOL        | (62.5)|      |      |
| 75%             | 74.1%| 0.999 |

*P values calculated using Fisher exact tests. PASS for each subscale listed in parentheses.
studies have shown that the in situ loads on the whole ACL during passive flexion between 0° and 90° is less than 10 N.\textsuperscript{19} Approaching 0 N.\textsuperscript{20,21} Measurements in cadavers and in vivo have shown that the strain levels for both bands of the ACL were at or below zero between 10° and 110° of passive flexion.\textsuperscript{22,23} A biomechanical study using live quadruped models showed that ACL forces dropped to zero during the swing phase in all trials,\textsuperscript{24} and studies based on 3D calculated models also show the ACL strain dropped to zero during the first portion of the swing phase.\textsuperscript{16} Thus, if the unloading of the sutures produces suboptimal fixation strength and increases slippage, this could yield negative clinical outcomes.

One potential criticism of the biomechanical studies is the direction of the applied load. Parallel loads to the tunnel axis are likely to produce higher forces than the actual forces that the implant would see in vivo. This is in accordance with most previous biomechanical studies, but differs from clinical conditions.\textsuperscript{9} These testing protocols subjected the implants and specimens to more strain than they would see in vivo. The results can show differences in the performance of the implants, but the clinical differences may be less substantial.\textsuperscript{11} Additionally, increased laxity in the FL group could be the result of in vitro studies representing only a portion of the overall ACL graft displacement. In vivo, the soft tissue grafts are also subject to graft elongation, graft slippage, or cutout of the femoral bone, all of which probably contribute to further displacement of the ACL construct, resulting in an increase in laxity greater than the one reported for FL in biomechanical studies.

More recent literature supports our findings, with adjustable-length devices achieving comparable results to fixed-length devices.\textsuperscript{25} The effects of graft lengthening in a patient population was investigated in a retrospective study by Boyle et al.\textsuperscript{26} Comparing adjustable-loop and fixed-loop cortical suspension devices. The study included a consecutive series of 188 patients (73 AL and 115 FL). Their study showed no significant differences in maximum side-to-side difference in KT-1000 testing at six months of 1.51 mm (AL) vs. 1.79 mm (FL). They also observed no significant difference between the two groups in the rate of graft failure (10% vs. 11%, p = 0.71). Similarly, our study showed no significant difference in laxity between the two groups at any time point following surgery. Both groups had less laxity than the contralateral knee immediately after surgery, with the grafts progressively loosening over the post-operative course.

A study by Choi et al. retrospectively compared clinical and radiographic outcomes between the Arthrex TightRope and the Smith & Nephew EndoButton.\textsuperscript{25} The study found no difference in radiographic femoral or tibial tunnel widening and no difference in Lysholm scores or Tegner activity scale.

Similarly, our study found no difference in patient reported outcomes between TightRope and EndoButton. Baseline, 6-month, and 24-month scores showed no difference in outcomes based on KOOS, Marx activity, SF-36, and EQ5D scores. Change in KOOS and the 24-month PASS rates were also similar between the groups, further suggesting that implant choice has no effect on the rate of improvement and clinical outcomes.

Limitations of our study include only gathering KT data until the 6-month time point. We did not collect KT data past this point because soft tissue incorporation should occur between 8-12 weeks after surgery\textsuperscript{11,26} with progressive soft tissue to bone healing up to six months postoperatively. Any further increase in laxity after this point is not likely to result from femoral cortical suspension slippage. We also do not know the causes for the three patients that had laxity of greater than 5 mm. These did not present until their 6-month clinical follow up, and the patients did not report any increased laxity or known injury. The relatively small size of the study may also be a limitation, although we felt that collection of KT 1000 data by a single surgeon was a more important factor than enrolling a larger cohort with multiple surgeons measuring, due to the low inter-rater reliability of KT 1000 measurements. Therefore, these findings should be interpreted within the context of limitations with the KT 1000 arthrometer. Further, the study was non-randomized, and implant choice along with technique was dictated by surgeon preference, leading to a larger number of patients treated with adjustable-length implants. No patients in this study required revision surgery.

**CONCLUSION**

There was no difference in side-to-side knee laxity between adjustable and fixed-length suspension devices in vivo, indicating that the adjustable-length devices are safe and effective, withstanding loads from the early rehabilitation period. Patient reported outcomes improved in both groups compared to pre-operatively and were equivalent at 6 and 24 months post-operatively. Therefore, implant type should be dictated by the operating surgeon based on personal preference and expertise.

**REFERENCES**


ABSTRACT

Background: Femoroacetabular impingement (FAI), particularly cam-type, is now well accepted as a risk factor for the development of hip osteoarthritis (OA). However, many hips with FAI morphology will never develop hip pain or OA, identifying that our current understanding of FAI disease progression remains limited. The purposes of this retrospective case-control study were to (1) report the patient and disease characteristics of patients with rapidly progressive FAI requiring hip arthroplasty by the age of 40 and (2) to identify patient and imaging factors associated with rapidly progressive FAI.

Methods: Cases were retrospectively identified from an arthroplasty registry as patients 40 years old or younger with underlying FAI deformity and end stage OA requiring primary total hip arthroplasty. Patients were excluded for known DDH, AVN, SCFE, inflammatory arthritis, and previous ipsilateral surgery. Controls were identified from a hip preservation database as patients with symptomatic FAI undergoing surgical intervention over the same time period, and were matched 2:1 by gender and age. Alpha angles were calculated on frog-leg lateral and anteroposterior (AP) radiographs with both inclusion and exclusion of any osteophytic prominences (representing minimum and maximal possible underlying FAI morphology). Patient characteristics, radiographic parameters, and baseline patient reported outcomes were compared between the two groups using student’s t-tests.

Results: The rapidly progressive FAI cohort of 31 patients had a mean age of 35.8 years at surgery and was 39% female and 61% male. Alpha angles were significantly larger compared to controls when osteophytes were included (Frog: 74.7±10.8 vs. 57.2±12.7°, p<0.001; AP: 91.7±10.7 vs. 61.2±19.4°, p<0.001), but not when osteophytes were excluded (Frog: 61.2±11.1 vs. 57.2±12.7°, p=0.15; AP: 64.9±17.1 vs. 61.3±19.4°, p=0.38). Except for UCLA activity score, all baseline outcome measures were significantly lower for rapidly progressive FAI cases (p<0.001 for all).

Conclusions: When compared to controls with symptomatic FAI, rapidly progressive cases did not demonstrate major differences in cam deformity magnitude. Thus severity of bony deformity may only be one aspect of a multifactorial etiology of hip OA progression in FAI.

Level of Evidence: III

Keywords: hip osteoarthritis, hip arthroscopy, femoroacetabular impingement

INTRODUCTION

Femoroacetabular impingement (FAI), particularly cam-type, is increasingly recognized as one of the two most common causes of hip osteoarthritis (OA), as well as pain in the pre-arthritic state secondary to labral and cartilage pathology. However, our understanding of the role of various factors in the pathophysiology of FAI remains limited with significant gaps in knowledge. Several studies have documented a high prevalence of FAI in asymptomatic patients, with a higher frequency of deformity in populations of athletes (66% with cam, 51% pincer, 57% mixed) compared to purely asymptomatic individuals (22% cam, 55% pincer, 8% mixed). Thus many, and perhaps most hips with FAI morphology will never develop hip pain or OA. In a systematic review comparing these patient populations when symptomatic, Mascarenhas et al. found that athletes and non-athletes had a similar prevalence of cam deformity. However, cam deformities in symptomatic non-athletes were significantly larger compared to athletes (mean alpha angle 67 vs. 56°, respectively), suggesting deformity severity may play a role in symptom generation and disease progression.

The association of the cam-type FAI deformity with the development of OA is supported by several population-based studies. In a prospective cohort study...
study of over 1,400 symptomatic hips without clear preexisting osteoarthritis, patients with moderate and severe cam deformity (AP alpha angle >60° and 83°, respectively) more commonly developed incident and end stage arthritis. However, while FAI appears to be a risk factor for OA, only 7% of patients (mean age 55.9 years) developed OA during the 5 year study period, highlighting that our understanding of the determinants of FAI disease progression remains relatively limited. While some patients with radiographic evidence of early OA and coexistent FAI deformity rapidly progress to end-stage OA at a young age, others with similar deformity have demonstrated lack of significant disease progression at 10 years of follow up. It remains unclear which patients with symptomatic FAI deformity are at greatest risk to develop OA that rapidly progresses, whether severity of bony deformity is the predominant driver of disease, and what other patient factors contribute to disease progression.

The purpose of the current study was (1) to describe a cohort of patients 40 years of age and younger with end-stage OA attributed to underlying FAI and (2) to identify patient characteristics associated with rapidly progressive FAI, by comparing them to age matched controls with symptomatic FAI (without radiographic evidence of advanced OA).

**METHODS**

We performed a retrospective case-control study approved by our institutional IRB (# 201704064). Cases were identified using our institution’s arthroplasty registry, which at the time of our search contained records for 8,318 hip arthroplasties in 6,642 patients at our institution (Figure 1). Amongst these cases, the senior author performed 413 primary total hip replacements in patients less than or equal to 40 years old with end-stage OA during a 10-year period (August 2006 -July 2016). Exclusion criteria were then applied in order to remove patients with underlying etiologies other than FAI leading to their OA (hip dysplasia with lateral center edge angle <20°, avascular necrosis, posttraumatic arthritis, slipped capital femoral epiphysis, Legg-Calvé-Perthes Disease, inflammatory arthritides, and previous ipsilateral surgeries). A total of 55 potential cases remained after exclusion and underwent radiographic review for evidence of FAI and to confirm no evidence of any exclusionary criteria/conditions. A total of 24 additional hips were excluded because of radiographic evidence of previously listed conditions. This included three additional hips with acetabular protrusio (two female, one male; age 19-24 years) that were excluded due to the focus on the current study on cam-type FAI. An alpha angle of 50° was utilized a cutoff for cam-type FAI, after exclusion of any other associated causes. The final cohort included 31 cases that were identified as having both end-stage OA and FAI deformities, a cohort we will refer to as having “rapidly progressive FAI.” Controls were identified from an institutional hip preservation database. Patients were considered for inclusion if they had symptomatic cam-type FAI (cam or combined type) and had elected to undergo hip preservation surgery over the same 10-year period as the cases of primary THA. Hip preservation surgery was performed arthroscopically or with an open surgical hip dislocation and included femoral osteoplasty and/or acetabular rim trimming, chondroplasty, and labral repair or debridement as indicated on a case-by-case basis. The same aforementioned exclusion criteria were applied to this population, with the additional criterion that patients did not have radiographic evidence of osteoarthritis (Tonnis OA Grade >2). A total of 710 hips remained for potential inclusion, and controls were randomly selected in a 2:1 fashion by matching sex and age at time of surgery (±2 years). Body Mass Index (BMI) and alpha angle were not matched so that this variable could be compared between cases and controls to identify a potential role in pathophysiology of OA. A total of 62 controls were identified and similarly underwent radiographic review to confirm absence of the aforementioned exclusionary conditions.

One reader analyzed AP pelvis and frog lateral radiographs for all cases and controls. The intraobserver and interobserver reliability of radiographic analysis including the alpha angle has been previously demonstrated by our group with intraobserver/
interobserver intraclass correlation coefficients (ICC) of 0.76/0.21 for alpha angle measurements on frog leg lateral radiographs and 0.88/0.64 for lateral center edge angle measurements on AP radiographs. Cam FAI morphology severity was characterized utilizing the alpha angle. Alpha angles were measured on both frog-leg lateral and AP radiographs to assess the magnitude of both anterior and more lateral deformities. With the presence of osteophytes, osteoarthritis can influence the presence and appearance of FAI deformities by increasing the alpha angle in some cases. In order to account for this, alpha angles were calculated with both inclusion and exclusion of any osteophytes (reactive cam) (Figure 2). Thus the maximum alpha angle represents the maximal potential FAI severity (if no osteophytic component is actually present), while the minimum alpha angle represents the minimum potential FAI severity (if an osteophytic presence is accounting for the prominence). Of note, frog leg lateral radiographs were not available for two cases. As such, these patients and their matched controls were excluded from analysis of frog leg lateral alpha angles.

Co-existing pincer FAI morphology severity was characterized utilizing the lateral center edge angle (LCEA). While LCEA may also be affected by underlying OA, differentiation of potential osteophytes is less clear so no attempt at differentiation was performed. The presence of a crossover sign was not assessed given the difficulty in assessing this parameter in the presence of OA, as well as the limited associated with osteoarthritis and prevalence of this finding in normal hips.

Patient characteristics and baseline patient reported outcomes were compared between the two groups, comparing preoperative UCLA, modified Harris Hip score, WOMAC pain, stiffness, and physical function scores. Two cases did not have documented preoperative clinical outcome measures, and were removed from average calculations along with their matched controls. Two-tailed T-tests used for statistical comparisons for radiographic and clinical scoring measures (p-value ≤ 0.05).

RESULTS

The rapidly progressive FAI cohort of 31 patients was 39% female and 61% male. The mean age of this group at time of surgery was 35.8 years (range 22-40: 29% ages 20-25, 35.5% ages 25-30, 13% ages 30-35, 22.5% ages 35-40). The average male and female age at time of surgery was 36.3 and 34.2 years, respectively. The mean minimum alpha angle (with exclusion of possible osteophytes) on frog lateral radiographs was 61.2±11.1° and maximum alpha angle (with inclusion of possible osteophytes) was 74.7±10.8°. When comparing male and female cases, males had larger maximum values (minimum: 62.8° vs. 58.7°, p=0.34; maximum: 78.3° vs. 68.9°, p=0.02). The mean minimum alpha angle (with exclusion of possible osteophytes) on AP radiographs was 64.9±17.1° and maximum alpha angle (with inclusion of possible osteophytes) was 91.7±10.7° (Table 1). The measured alpha angles on AP radiographs were significantly larger in males at both the minimum and maximum values (minimum: 70.6° vs. 56.0°, p=0.02; maximum: 96.1° vs. 84.8°, p<0.01). The presence of possible osteophytes resulted in at least a 5-degree increase in alpha angle on frog leg lateral and AP radiographs in 76% and 79% of cases, respectively. Overall, 72% of patients had a frog leg lateral alpha angle greater than 55° with osteophytes excluded, and 93% when included.

Additionally, the mean LCEA in cases was 30.4±11.0°. 26% (8/31) of patients had a lateral center edge angle greater than 40°. In hips with LCEA less than 40°, 74% had native alpha angles >55° on frog leg lateral radiographs.

<table>
<thead>
<tr>
<th>Table 1. Alpha Angles, Cases vs. Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Frog Leg Lateral Alpha Angle (deg)</td>
</tr>
<tr>
<td>Cases: Minimum Alpha Angle</td>
</tr>
<tr>
<td>61.2±11.1</td>
</tr>
<tr>
<td>Cases: Maximum Alpha Angle</td>
</tr>
<tr>
<td>74.7±10.8*</td>
</tr>
<tr>
<td>FAI Controls</td>
</tr>
<tr>
<td>52.7±12.7</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>AP Alpha Angle (deg)</td>
</tr>
<tr>
<td>Cases: Minimum Alpha Angle</td>
</tr>
<tr>
<td>64.9±17.1</td>
</tr>
<tr>
<td>Cases: Maximum Alpha Angle</td>
</tr>
<tr>
<td>91.7±10.7*</td>
</tr>
<tr>
<td>FAI Controls</td>
</tr>
<tr>
<td>61.3±19.4</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Percentage with Mild Frog Cam Deformity (50-55 deg)</td>
</tr>
<tr>
<td>Cases: Minimum Alpha Angle</td>
</tr>
<tr>
<td>27.6</td>
</tr>
<tr>
<td>Cases: Maximum Alpha Angle</td>
</tr>
<tr>
<td>69</td>
</tr>
<tr>
<td>FAI Controls</td>
</tr>
<tr>
<td>48.3</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Percentage with Moderate Frog Cam Deformity (55-63 deg)</td>
</tr>
<tr>
<td>Cases: Minimum Alpha Angle</td>
</tr>
<tr>
<td>41.4</td>
</tr>
<tr>
<td>Cases: Maximum Alpha Angle</td>
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</tr>
<tr>
<td>FAI Controls</td>
</tr>
<tr>
<td>172</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Percentage with Severe Frog Cam Deformity (63 deg)</td>
</tr>
<tr>
<td>Cases: Minimum Alpha Angle</td>
</tr>
<tr>
<td>31</td>
</tr>
<tr>
<td>Cases: Maximum Alpha Angle</td>
</tr>
<tr>
<td>89.7</td>
</tr>
<tr>
<td>FAI Controls</td>
</tr>
<tr>
<td>345</td>
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</table>

Comparisons of alpha angles between cases and controls were significantly different when osteophytes were included in the measurements, but not when excluded (p-value ≤ 0.05).
DISCUSSION

This study reports the characteristics of a patient population with end-stage OA due to apparent underlying FAI in patients 40 years old and younger. This population had slightly more males (61%) than females, a distribution similar to that reported in the average population presenting with symptomatic impingement (57% male).20 Surprisingly many hips with end-stage OA had relatively mild cam deformities (after exclusion of osteophytes). Additionally, in patients with native frog leg lateral alpha angles (without osteophytic inclusion) less than 55°, only 25% (2/8) had an LCEA greater than 40°, highlighting that some patients progressed to end-stage arthritis without large magnitude cam or pincer deformities. Lastly, after exclusion of osteophytes, the alpha angles of cases and controls did not differ. This finding underscores the role of other potential factors, including obesity, in the pathophysiology of FAI progression.

Our study has several weaknesses including its retrospective assessment at a single time point. The retrospective nature of the study is inherent for the rare outcome and ability to acquire a meaningful cohort of patients with this condition. The retrospective nature of the study made more detailed assessment of range of motion, participation in athletics, and femoral version not possible. Cases and controls in the current study were assessed at a single age-matched time-point. This allows for assessment of the patient and radiographic characteristics of hips at a single time point in the disease process and thus allows comparison between a more aggressive and less aggressive FAI time course. Additionally, while FAI was attributed as the cause of OA after exclusion of other potential causes, the retrospective nature of the study limits any ability to precisely attribute FAI as the true cause of OA, rather than just a coexisting morphology. For cases, most importantly this means the presence and severity of FAI are assessed in the presence of end-stage OA. Through the radiographic analysis in the current study, the influence of osteophytes on measurements was minimized. Longitudinal population-based studies that follow patients over time would be ideal for characterization of deformity prior to the development of OA, but are impractical in the current study focus given the resources required and rare outcome. Additionally, the assessment of patient characteristics at a single time point within a case-control study also has limitations. For example, BMI was assessed in cases in the presence of end-stage OA without the ability to define if BMI was potentially confounded by hip pain for several years prior to undergoing surgery. Thus we demonstrate the association of BMI with hip OA but fail to establish any causal relationship.

The present work also compares two points of the spectrum of FAI presentations, comparing similarly aged cases of severe OA requiring arthroplasty to symptomatic controls amenable to hip preservation surgery. The goal of this comparison was to potentially identify factors associated with rapid progression in order to better understand the pathophysiology of FAI in this subset of patients. It is currently not well understood what relative role FAI deformity severity and patient characteristics play in the development of OA. The current study demonstrates that radiographic deformity alone does not explain rapid progression. In fact, most FAI hips progressing to OA have fairly mild to moderate deformities (69% of cases when osteophytes were excluded). When excluding osteophytes from the alpha angle evaluation, there was no measurable difference between the size of cam deformities between cases and controls. Similarly, cases and controls had similar percentages of patients with severe cam deformity, defined by alpha angles greater than 63°. Additionally, no difference in the presence of pincer-type global overcoverage defined as...
a LCEA greater than 40° was present between cases and controls. Although cases had significantly larger cam deformity with inclusion of osteophytes, it is possible that these deformities were not the original stimulus for the degenerative cascade, and were not responsible for the earlier stages of disease progression. The radiographic analysis utilized in the study helps to estimate the range of true underlying deformity in the setting OA through a best case and worst case approach (with exclusion or inclusion of possible osteophytes). Even when possible osteophytes are included, many hips with apparent mild FAI deformities have progressed to OA at a very young age. It is however important to consider the limitations of our limited radiographic analysis. As our understanding of key determinants of outcomes in hip preservation surgery has improved, there has been a better appreciation for the impact of detailed three-dimensional anatomy including femoral and acetabular version on impingement. Three-dimensional low-dose CT is increasingly utilized for preoperative assessment and may someday be replaced by three-dimensional MRI reconstructions of bony anatomy. In the current study, given the retrospective nature, it was not feasible to have three-dimensional CT data in the current population, but factors including femoral version may indeed play an important role.

Although FAI has been well established as a risk factor for the onset of osteoarthritis, our findings illustrate that the rate and risk of arthritic progression cannot be explained by the magnitude of cam deformity alone. Our results are supported by several studies documenting populations of patients with radiographic FAI deformity that fail to progress to end-stage arthritis. In a single center study of patients younger than 55 who had undergone unilateral THA, Wyles et al. retrospectively evaluated the radiographs of the contralateral hips of 172 patients. Only hips with baseline Tonnis Grade 0 scoring and at least 10 year of radiographic follow up were analyzed. In this population, 74 patients were identified to have FAI, compared to 48 with dysplasia and 40 with normal morphology. The authors found that hips with both normal morphology or FAI (without concomitant DDH) progressed similarly as evaluated with Tonnis grading. Although the authors did not quantify alpha angles or the magnitude of cam deformities, their work importantly demonstrates not all FAI deformities destine a hip for rapid onset of end stage OA. Similarly, Bardakos et al. analyzed 43 hips with “pistol-grip” deformities and Tonnis grade 1 or 2, comparing AP radiographs 10 years apart and demonstrated 65% of patients demonstrated progression of OA. OA Progression was associated with the presence of a posterior wall sign (39% vs. 7%, p=0.02) and lower medial proximal femoral angle (81° vs. 87°, p=0.004), but not alpha angle magnitude.

Collectively, these findings support that cam deformities are a single component of a complex, multifactorial explanation for rapidly progressive FAI. The determinates of disease progression likely involve several factors, including obesity, activity history, genetic/biologic predispositions, and other bony abnormalities such as femoral and acetabular version that contribute to FAI. In the current study, we demonstrate higher BMI and prevalence of obesity in cases, compared to controls. However, a higher BMI may be partially confounded by the development of OA and the greater morbidity associated with this and its effects of general health. In the current study, no difference in UCLA activity score was seen between case and controls at the time of surgical intervention. Future studies would be useful to characterize activity level at a younger age and involvement in competitive athletics. Overall, the current study emphasizes the strong effect these often overlooked factors may have on the pathophysiology of FAI. This is additionally supported by the number of asymptomatic hips with FAI morphology that will never develop hip pain or OA.

REFERENCES

ABSTRACT

Background: The use of hip arthroscopy (HA) for the management of intra-articular hip pathology has increased greatly, with a 600% increase in utilization from 2006-2010. Studies have demonstrated good to excellent outcomes in patients undergoing hip arthroscopy for treatment of femoroacetabular impingement (FAI) syndrome. However, some patients undergoing primary hip arthroscopy will require revision hip arthroscopy (revision HA) or conversion to total hip arthroplasty (THA). The purpose of the present study was to evaluate the association between hip arthroscopy failure and (1) osteoarthritis, (2) age > 40 years, and (3) psychiatric comorbidities.

Methods: The Humana Inc. insurance claims database was used to identify patients undergoing hip arthroscopy between 2007 and 2015, with query by CPT (current procedural terminology code) of more than 25 million deidentified insurance and Medicare beneficiary claims. Following primary hip arthroscopy, patients were longitudinally tracked for subsequent ipsilateral hip arthroscopy (revision HA) or total hip arthroplasty (THA) with a minimum of 1-year clinical follow-up from the primary HA procedure. Hip arthroscopy failure (HA failure) was defined specifically as patients who underwent a revision HA or THA with a minimum of 1-year of clinical follow-up from the primary HA procedure. Variables assessed included presence of pre-existing osteoarthritis, age < 40 years or age > 40 years, and presence of preoperatively diagnosed psychiatric comorbidities including depression or anxiety. The relationships between revision HA, THA, or HA failure and these variables were assessed utilizing univariate and multiple logistic regression analysis. Independent predictors of revision ipsilateral hip arthroscopy and subsequent hip arthroplasty were identified using multiple logistic regression.

Results: In total, 785 patients (64.1% female) underwent primary hip arthroscopy. The overall failure rate with a minimum of 1-year clinical follow-up from the index HA procedure was 18% (140/785; 8% (63/785) revision hip arthroscopy, 10% (82/785) THA). Multivariable logistic regression analysis identified psychiatric comorbidities (Odds Ratio [OR] 2.8, 95% Confidence Interval [CI] 1.2-6.2, p<0.01) as the only independent predictor of hip arthroscopy failure (revision HA or THA). Independent predictors of revision HA included both psychiatric comorbidity (OR 2.8, 95% CI 1.2-6.2, p<0.01) and age < 40 years (OR 2.6, 95% CI 1.4-5.0, p<0.01), while age > 40 years (OR 3.09, 1.47-7.25, p<0.005), smoking (OR 2.05, 95% CI, 1.68-1.88, p=0.02), and osteoarthritis (OR 3.24, 95% CI 1.98-5.43, p<0.001) predicted conversion to THA.

Conclusion: The hip arthroscopy failure rate of 18% in the present study is alarmingly high, a figure much higher than reported in previously published series. Patient factors associated with conversion to THA included age > 40 years, smoking, and pre-existing osteoarthritis. The presence of psychiatric comorbidities, specifically depression and anxiety, was independently associated with revision HA and overall HA failure.

Level of Evidence: III

Keywords: FAI, femoroacetabular impingement, hip scope, hip arthroscopy, outcome, failure, hip, revision, THA, arthroplasty, osteoarthritis, smoking, psychiatric, depression, anxiety

INTRODUCTION

The use of hip arthroscopy (HA) for the management of intra-articular hip pathology has increased greatly, with more than a 600% increase in utilization from 2006-2010. Studies have demonstrated good to excellent outcomes in patients undergoing hip arthroscopy for treatment of femoroacetabular impingement (FAI) syndrome with appropriate bony offset correction and
treatment of soft tissue. However, a subset of patients undergoing primary hip arthroscopy will eventually require revision hip arthroscopy (revision HA) or conversion to total hip arthroplasty (THA), with reported rates in the literature ranging from 1.2%-8% and 1.7%-5.6%, respectively. Further investigation into the causes of revision HA and conversion to THA is therefore of significant clinical interest, with persistent deformity, recurrent or persistent labral tears, chondral lesions, and the presence of osteoarthritis serving as potential factors leading to revision or poor clinical outcomes.

In addition to surgical and technical factors, several patient factors, including preoperative opioid use, smoking, obesity, and psychiatric comorbidities, specifically the presence of depression or anxiety, have been postulated to affect clinical outcomes and increase the risk of subsequent revision HA or conversion to THA. Prior literature has suggested that pre-existing hip osteoarthritis and age may influence success rates following hip arthroscopy, while the association between pre-existing medical comorbidities and hip arthroscopy failure, especially psychiatric comorbidities, remain poorly elucidated in the literature.

While intra-articular technical factors leading to failure after HA have been previously reported, there remains a paucity of data on patient demographic variables and psychiatric comorbidities that may significantly influence outcomes. The purpose of the present study was to evaluate the association between osteoarthritis, age > 40 years, and the association between psychiatric disorders, specifically anxiety and depression, with failure after index HA procedure. HA failure was defined as subsequent ipsilateral revision HA or conversion to THA with a minimum of 1-year of clinical follow-up from the index HA procedure using a large database of de-identified Humana and Medicare recipients. We hypothesized that age > 40 years and pre-existing osteoarthritis would be associated with increased conversion to THA following hip arthroscopy. Additionally, it was hypothesized that there would be a positive association between psychiatric diagnoses and failure rates after primary HA, with increased revision HA or THA rates in patients with psychiatric comorbidities diagnosed preoperatively prior to the index procedure.

METHODS

Data Source
The Humana Inc., administrative claims dataset was accessed using the PearlDiver Research Program (PearlDiver Inc, Fort Wayne, IN). The Humana Inc. administrative claims dataset contains over 25 million de-identified, HIPAA (Health Insurance Portability and Accountability Act) compliant medical billing records from patients across the United States, including commercially insured patients and Medicare advantage beneficiaries. The dataset permits longitudinal tracking of patients, procedures, and medical diagnoses. All data within this database are Health Insurance Portability and Accountability Act compliant and were therefore deemed exempt from Institutional Review Board approval.

Study Design and Cohort Definition
Patients active in the dataset between 2007 and 2015 that underwent primary hip arthroscopy procedures were identified using Common Procedural Terminology (CPT) codes (Appendix 1). Only patients enrolled with the insurance provider for a minimum of three months prior to and one year following their index hip arthroscopy were included. Laterality modifiers were utilized to identify patients who underwent left or right hip arthroscopy. Patients who had bilateral hip arthroscopies during the study period were excluded to prevent multiple procedures from confounding our analysis of preoperative opioid prescriptions. Patients were tracked for the presence of an ipsilateral hip arthroscopy and/or ipsilateral conversion to total hip arthroplasty. Patient demographics and preoperative comorbidities were identified for the entire cohort using ICD-9 codes. Variables recorded included age, sex, presence of a diagnosis (Appendix 2) of anxiety and/or depression, obesity, smoking status, diabetes, pre-existing hip osteoarthritis and preoperative opioid use defined as opioid prescription filling within three months prior to the index hip arthroscopy procedure. Patients were tracked over time for the occurrence of ipsilateral revision HA or ipsilateral THA using CPT code and laterality modifiers to ensure that revision HA or THA was performed on the same hip as the previous hip arthroscopy. Subgroups analysis based on age < 40 years and age > 40 years at the time of primary hip arthroscopy were employed to investigate the association between age group and HA failure. This categorical distinction in age (40 years) was determined based on prior literature. Basic demographic data (age and sex) of the entire cohort was also identified. During the study period, 2,567 patients underwent primary HA and were available for analysis. Subsequently, filters for active patient follow-up were applied, which yielded 1,436 active patients who had a minimum of three months preoperative and 1-year postoperative follow-up. After the application of laterality modifiers to the hip arthroscopy CPT codes, 785 patients (30.58%, 785/2567) were remaining for the longitudinal analysis of subsequent revision HA, ipsilateral THA, and overall HA failure.

Outcomes
The outcomes of interest included ipsilateral revision HA and conversion to THA. Overall HA failure was
defined as a revision HA and/or conversion to THA with a minimum of 1-year of clinical follow-up from the index HA procedure. The impact of each demographic and comorbidity variable on the incidence of the three outcomes of interest was also evaluated.

**Statistical Analysis**

Univariate analysis was performed to determine the association between patient variables and HA failure. Multivariate logistic regression to account for multiple patient-variables was performed to determine Odds Ratios (OR) and the corresponding 95% Confidence Intervals (CI) for the association of each variable on revision HA, THA, and overall HA failure. Statistical analysis was performed utilizing the R© statistical package in the PearlDiver research program (www.pearldiverinc.com; PearlDiver Inc, Fort Wayne, IN). Statistical significance was defined as p<0.05.

**RESULTS**

Female (503, 64.1% female) and male (282, 35.9%) patients underwent index HA. The top three largest age groups that underwent primary hip scope were ages 40-44 (11.3%), 45-49 (11.3%), and 50-54 (11.04%) years. Patients most commonly underwent labral resection (CPT code 29862). The overall failure rate was 18% with 1-year minimum of clinical follow-up from the index HA procedure, with revision HA (8%, 63/785) and THA (10%, 82/785) represented. Table 1 depicts the demographics of patients undergoing HA in the present study.

Risk factors for revision HA, THA, or overall HA failure were assessed (Table 2). In total, 82 patients underwent subsequent conversion to THA (10%, 82/785). Risk factors for conversion to THA included smoking (OR 2.61, 95% CI 1.46-4.52, p<0.01), diabetes (OR 2.04, 95% CI 1.09-3.65, p<0.02), osteoarthritis (OR 3.24, 95% CI 1.98-5.43, p<0.01), psychiatric comorbidities (OR 2.09, 0.98-4.09, p<0.04), and age > 40 years (OR 4.74, 2.4-11.1, p<0.01). In the present study, 18% of patients (140/785) required either ipsilateral revision HA or ipsilateral THA, or both procedures (HA failure). Risk factors for HA failure included age < 40 years (OR 1.33, 95% CI 0.87-2.04, p=0.19), psychiatric comorbidities (OR 2.72, 95% CI 1.50-4.79, p<0.01), smoking (OR 1.94, 95% CI 1.16-3.15, p<0.01), and osteoarthritis (OR 1.59, 95% CI 1.08-2.34, p=0.02).

Independent predictive variables associated with failure after HA were identified, including revision HA, conversion to THA, or overall HA failure (Table 3). Psychiatric comorbidities (OR 2.81, 95% CI 1.18-6.15, p<0.01) and age < 40 (OR 2.58, 95% CI 1.46-4.59, p<0.01) were independently associated with revision HA. Independent variables associated with conversion to THA included smoking (OR 2.61, 1.46-4.52, p<0.01), osteoarthritis (OR 3.24, 1.98-5.43, p<0.01) and age

### Table 1. Demographics of Hip Arthroscopy Patients

<table>
<thead>
<tr>
<th>Demographic Factor</th>
<th>Primary HA</th>
<th>Revision HA</th>
<th>THA</th>
<th>HA Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>282 (36%)</td>
<td>18 (28.6%)</td>
<td>27</td>
<td>43 (30.7%)</td>
</tr>
<tr>
<td>Female</td>
<td>503 (64.1%)</td>
<td>43 (30.7%)</td>
<td>55</td>
<td>97 (69.3%)</td>
</tr>
<tr>
<td>Age &lt; 40</td>
<td>265 (33.8%)</td>
<td>261 (46.5%)</td>
<td>&lt;0.01</td>
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</tr>
<tr>
<td>Age &gt; 40</td>
<td>520 (66.2%)</td>
<td>30 (7.6%)</td>
<td>*</td>
<td>99 (70.7%)</td>
</tr>
<tr>
<td>Total</td>
<td>785</td>
<td>63</td>
<td>82</td>
<td>140</td>
</tr>
<tr>
<td>% of Total</td>
<td>100%</td>
<td>8%</td>
<td>10%</td>
<td>18%</td>
</tr>
</tbody>
</table>

Due to limitations from Pearl Diver, with < 11 patients, value could not be calculated.

### Table 2: Risk Factors for HA Failure

<table>
<thead>
<tr>
<th>Variable</th>
<th>Odds Ratio (OR), (95% Confidence Interval, p-value)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Revision HA</td>
</tr>
<tr>
<td>Preoperative Narcotic Use</td>
<td>0.89 (0.49-1.57, 0.09)</td>
</tr>
<tr>
<td>Smoking</td>
<td>1.2 (0.51-2.5, 0.65)</td>
</tr>
<tr>
<td>Diabetes</td>
<td>0.74 (0.25-1.74, 0.53)</td>
</tr>
<tr>
<td>Obesity</td>
<td>1.43 (0.61-3.0, 0.37)</td>
</tr>
<tr>
<td>Osteoarthritis</td>
<td>0.59 (0.31-1.07, 0.09)</td>
</tr>
<tr>
<td>Psychiatric Comorbidities</td>
<td>2.61 (1.14-5.46, &lt;0.01)</td>
</tr>
<tr>
<td>Age &lt; 40</td>
<td>2.58 (1.46-4.59, &lt;0.01)</td>
</tr>
<tr>
<td>Male Sex</td>
<td>0.82 (0.44-1.47, 0.52)</td>
</tr>
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</table>

### Table 3: Variables Independently Associated with HA Failure

<table>
<thead>
<tr>
<th>Variable</th>
<th>Odds Ratio (OR), (95% Confidence Interval, p-value)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Revision HA</td>
</tr>
<tr>
<td>Preoperative Narcotic Use</td>
<td>0.921 (0.5-1.67, 0.79)</td>
</tr>
<tr>
<td>Smoking</td>
<td>1.2 (0.49-2.67, 0.67)</td>
</tr>
<tr>
<td>Diabetes</td>
<td>0.76 (0.23-2.10, 0.63)</td>
</tr>
<tr>
<td>Obesity</td>
<td>1.91 (0.74-4.48, 0.15)</td>
</tr>
<tr>
<td>Osteoarthritis</td>
<td>0.71 (0.35-1.37, 0.32)</td>
</tr>
<tr>
<td>Psychiatric Comorbidities</td>
<td>2.81 (1.18-6.15, 0.01)</td>
</tr>
<tr>
<td>Age &lt; 40</td>
<td>2.59 (1.38-4.96, &lt;0.01)</td>
</tr>
<tr>
<td>Male Sex</td>
<td>0.76 (0.40-1.40, 0.39)</td>
</tr>
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</table>
> 40 years (OR 3.09, 1.47-7.25, p<0.01). Psychiatric comorbidities were (2.72, 95% CI 1.50-4.79, p<0.01) found to be independently associated with hip scope failure while controlling for other factors frequently associated with failure using the multiple logistic regression model.

**DISCUSSION**

The purpose of the present study was to evaluate factors associated with revision HA, conversion to THA, and overall HA failure with a minimum of 1-year clinical follow-up from the primary hip arthroscopy procedure. In the current study, results indicated an 18% failure rate following HA with a minimum of 1-year of clinical follow-up from the index HA procedure using a large, national administrative claims dataset of 785 patients undergoing an index hip arthroscopy procedure. In total, 8% of patients underwent revision HA and 10% underwent conversion to total hip arthroplasty (THA) with 1-year minimum of clinical follow-up from the index HA procedure. Revision hip arthroscopy was associated with age < 40 years and preoperative psychiatric comorbidities. The presence of pre-existing osteoarthritis, age > 40 years, and smoking significantly increased the risk of conversion to THA. Additionally, the presence of psychiatric comorbidities at the time of the index HA, particularly depression and anxiety, was independently associated with overall hip arthroscopy failure, despite controlling for additional variables frequently associated with HA failure.

Risk factors for revision hip arthroscopy have previously been reported in the literature and include female sex, age under 40 years, absence of a labral tear, and index procedure performed by a low volume surgeon. While the majority of patients undergoing hip arthroscopy are younger than age 40 years, primary HA in older patients > age 40 years is still commonly performed. A recent systematic review and meta-analysis of outcomes after hip arthroscopy in femoroacetabular impingement by Minkara et al. demonstrated that while patients with a pooled mean age of 29.9 ±1.9 years were undergoing hip arthroscopy across 1911 patients (1981 hips), a wide range of ages were represented, with patients undergoing hip arthroscopy into their 4th, 5th, and 6th decades. Scott et al. demonstrated that 3,320 patients > age 65 years underwent primary HA from 2005-2014, with Medicare beneficiaries > 60 years of age undergoing primary HA at a rate of 200% increase from 2007-2011. The current study demonstrated that age < 40 years served as an independent predictive variable leading to increased rates of revision hip arthroscopy after index HA procedure, which has previously been reported by Kester et al. One explanatory possibility that we postulate for this finding is the increasing tendency to undergo revision HA for younger patients < 40 years of age in the case of primary HA failure, with conversion to THA more commonly presented as a surgical alternative for patients of advanced age (> 40 years) in the setting of primary HA failure and persistent symptoms. As the growing body of literature expands to identify factors associated with positive outcomes following primary HA with mid-term and long-term follow-up, age along with patient-reported outcomes (PROs), intraoperative, or surgical factors may explain these disparate revision HA rates and offer opportunities to guide surgical management following primary HA across a more well-defined spectrum of patient ages and risk factors.

Rates for conversion to THA after primary hip arthroscopy have been reported to range from 1.7%-5.6%, with rates higher in the setting of pre-existing osteoarthritis and age > 50 years. Bogunovic et al. identified hip osteoarthritis as the second most common reason for failure after HA. Radiographic evidence of osteoarthritis has been correlated with higher failure rates after HA for FAI with increased conversion to total hip arthroplasty. Larson et al. further demonstrated a 52% failure rate with >50% loss of joint space or <2mm of joint space. Given a rapid increase in hip arthroscopy rates in an increasingly older patient population, further characterization of OA radiographically may aid in selecting patients for operative intervention and predicting failure rates after HA. Importantly, our results suggest that the presence of OA is independently associated with subsequent conversion to THA and should be taken into consideration when indicating patients for hip arthroscopy. Patient selection has been highlighted as an important factor in surgical indications, with age > 50 years suggested by Phillipon et al. to greatly decrease hip survival outcomes after hip arthroscopy procedures. The results of the current study indicate that older patients (age > 40 years) are at an increased risk of poor outcomes following primary HA, an earlier age than typically reported. Our results further suggest that preoperative smoking may influence conversion rates to THA.

Westermann et al. previously reported that smoking may influence hip outcomes postoperatively in the setting of femoroacetabular impingement and Kamath et al. reported that smoking was a negative predictor of good or excellent outcomes following hip surgery. Preoperative demographic and pathological risk factors including increased age, preoperative smoking, and presence of osteoarthritis should therefore be discussed as part of a shared decision-making process between the patient and the surgeon regarding whether or not to proceed with hip arthroscopy if these risk factors are present.

Furthermore, our results suggest that the presence of pre-existing psychiatric comorbidities may also influence rates of revision hip arthroscopy. Aside from a
Is the Actual Failure Rate of Hip Arthroscopy Higher than Most Published Series?

limited number of studies, there is a paucity of literature regarding the influence of psychiatric pathologies on hip arthroscopy outcomes.\textsuperscript{18,19} Lansdown et al. reported that the presence of a mental health disorder was associated with lower patient-reported outcomes (PROs) before and after surgical management of FAI.\textsuperscript{31} Data from the Military Health System Data Repository indicated that the severity of mental health disorders may also intensify after arthroscopic hip surgery\textsuperscript{35} and may predispose these patients to subsequent HA failure. Recognizing that the presence of psychiatric comorbidities may be independently associated with HA failure is necessary in order to alert providers to the importance of adequate screening and patient selection during the shared decision-making process for operative intervention. Identification of patient risk factors, such as depression and anxiety, has been noted to improve outcomes after orthopedic procedures.\textsuperscript{36} Additional resources directed to screening and increased recognition of mental health comorbidities may lead to improved surgical outcomes.\textsuperscript{37,38}

The present study has several limitations. Perhaps the largest limitation inherent in the current study is the inability to control for surgical quality. The retrospective, observational nature of the cohort may narrow generalizability. The nature of the cohort from the Humana database limited the authors’ ability to account and control for all confounders. In addition, the diagnoses in this study were subject to the accuracy of the documentation and coding practices across all participating institutions.\textsuperscript{40} More specific delineation of groups with participants <11 could not be specified due to limitations from the PearlDiver Database to ensure compliance with HIPPA. Further, the presence of osteoarthritis may not always be clinically diagnosed and documented and the use of the ICD-9 code as a proxy for the presence of OA may have underrepresented the true proportion of OA among patients in this analysis. ICD-9 codes are unable to delineate laterality when assessing the database for revision hip scope procedure and pre-existing osteoarthritis. In addition, the present study is descriptive and inferential and did not report PROs (Patient-Reported Outcomes) or functional outcomes after primary HA. The results represented in the current work were limited to patients active within the Humana claims database at the time of the initial query, with a minimum of 1-year clinical follow-up from the index HA procedure. Patients may have undergone HA failure, revision HA, or conversion to THA with less than 1-year of clinical follow-up available in the database, introducing the possibility that the rates presented here are an underrepresentation of true HA failure rates. Further investigations with additional mid-term and long-term follow-up from the primary HA procedure may be warranted to further delineate failure rates following primary HA.

CONCLUSION
The hip arthroscopy failure rate of 18% in the present study is alarmingly high, a figure much higher than reported in previously published series. Patient factors associated with conversion to THA included age > 40 years, smoking, and pre-existing osteoarthritis. The presence of psychiatric comorbidities, specifically depression and anxiety, was independently associated with revision HA and overall HA failure.

REFERENCES


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APPENDIX 1: Hip Arthroscopy and Additional Procedures by CPT Code

<table>
<thead>
<tr>
<th>Procedure</th>
<th>CPT Codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Hip Arthroscopy</td>
<td>29860, 29861, 29862, 29863, 29914, 29915, 29916</td>
</tr>
<tr>
<td>Revision Hip Arthroscopy (HA)</td>
<td>29860, 29861, 29862, 29863, 29914, 29915, 29916</td>
</tr>
<tr>
<td>Total Hip Arthroplasty (THA)</td>
<td>27130</td>
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</table>


APPENDIX 2: Preoperative Comorbidities for Patients Undergoing Hip Arthroscopy

<table>
<thead>
<tr>
<th>Preoperative Comorbidities</th>
<th>ICD 9/10 Codes†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depression</td>
<td>266.20-266.26, 296.30-296.36</td>
</tr>
<tr>
<td>Anxiety</td>
<td>300.02</td>
</tr>
<tr>
<td>Obesity</td>
<td>27800, V853, V8530, V8539, V27801, V854, V8541, V8545</td>
</tr>
<tr>
<td>Tobacco Use</td>
<td>3051</td>
</tr>
<tr>
<td>Diabetes</td>
<td>25000-25003, 25010-25013, 25020-25023, 25030-25033, 25040-25043, 25050-25053, 25060-25063, 25070-25073, 25080-25083, 25090-25093</td>
</tr>
<tr>
<td>Pre-existing Hip Osteoarthritis (OA)</td>
<td>715.15, 715.25, 715.35, 715.95</td>
</tr>
</tbody>
</table>

†ICD 9/10 Code: International Classification of Disease Codes; 9th and 10th edition codes are represented.
ABSTRACT
Background: The authors present three cases of high-level athletes with successful return to competitive collegiate athletics following distal femoral osteotomy for knee lateral compartment overload.

Conclusion: Distal femoral varus osteotomy (DFO) is used to treat valgus knee malalignment and to offload the lateral knee compartment in the setting of symptomatic cartilage or meniscus pathology. DFO can be considered a viable treatment for collegiate athletes, with satisfactory outcomes and ability to return to sport participation at pre-injury functional levels.

Level of Evidence: IV
Keywords: sport, athletes, athlete, collegiate, youth, adolescent, DFO, distal femoral varus osteotomy, valgus, knee, malalignment, medial, tear, meniscus, meniscectomy, cartilage, lateral compartment, osteotomy, outcomes, alignment, return to sport

INTRODUCTION
Lateral meniscus tears are more common among youth athletes than medial tears and often result in partial to subtotal meniscectomy. This can occur with, or subsequently result in, injury or degeneration of the articular cartilage in the lateral compartment. In the young active patient this can be a difficult clinical situation. Meniscus transplant is generally not recommended in patients attempting to return to sport and articular cartilage restoration in the athlete is challenging. It is generally agreed that mechanical axis malalignment accentuates knee symptoms related to meniscus and cartilage pathology. Correcting malalignment can offload a symptomatic knee compartment and potentially enhance the ability of an athlete to return to higher level activities. DFO is indicated for symptomatic valgus knee malalignment or to offload the lateral compartment in conjunction with cartilage restoration surgery.

However, there is a paucity of literature reporting return to sport (RTS) following DFO for the treatment of isolated lateral compartment symptoms related to cartilage and meniscus pathology with valgus deformity. To our knowledge, no prior study has reported return to high-level collegiate sports following DFO. We present a case series of three patients who returned to collegiate contact sports following DFO at preoperative performance levels. All DFO surgeries were performed to shift the weight bearing axis out of the lateral compartment to the medial tibial spine.

The patients were informed that data regarding these cases would be collected and submitted for publication, and all provided consent.

CLINICAL CASE SUMMARIES
Case 1
A 17-year-old high-level high school basketball player presented for evaluation of right knee pain six months following a partial lateral meniscectomy for a radial meniscal tear sustained during basketball practice. He complained of lateral knee pain, swelling, catching and locking, exacerbated with activity. Standing radiographs revealed right lower extremity valgus alignment of 8° (Figure 1). MRI demonstrated a recurrent lateral meniscal tear with propagation. The patient was indicated for repeat diagnostic arthroscopy, partial meniscectomy, and DFO.

At the time of surgery, diagnostic arthroscopy revealed diffuse synovitis, several small cartilaginous loose bodies and a degenerative appearing horizontal tear in the mid-body of the lateral meniscus in the same area as his prior partial meniscectomy. There was also grade 2 chondromalacia of the lateral femoral condyle directly above the area of the meniscal injury and grade 1-2 early chondromalacia of the lateral tibial plateau. A partial synovectomy and chondroplasty of the lateral femoral condyle were performed with partial meniscectomy to stable and viable meniscus tissue. A DFO was then performed using a 15-mm opening wedge Arthrex Puddu plate, fixed with bicortical 4.5 mm fully threaded screws proximally, and 6.5 mm screws distally, with femoral head...
Diagnostic arthroscopy revealed only 25% of the lateral meniscus remained with grade II chondromalacia on the tibial plateau and lateral femoral condyle; debridement of the meniscal tear was done and microfracture was performed on the lateral femoral condyle. Surgeons then proceeded with DFO, using a 10-mm opening wedge Arthrex Puddu plate and femoral head allograft. The procedure was complicated by fracture propagation through the medial cortex of the femur, and an additional 3.5mm locking plate was placed at the distal medial femoral cortex (Figure 3) to augment fixation.

Postoperatively, the patient was maintained non-weight bearing for six weeks in a hinged knee brace locked in extension when upright and allowing 0-90° motion while seated. He was maintained non-weightbearing for six weeks (Figure 2) and then progressed to weightbearing as tolerated (WBAT) in the brace until 10 weeks. He continued formal physical therapy for five months, and at 10 months, returned to high-level basketball to conclude his high school basketball career as an elite-level recruit. He obtained a scholarship to play Division I collegiate basketball as a starter, completing two full seasons without limitations, and continues to play Division I collegiate basketball. After 1-year of clinical follow-up, the patient reported no further symptoms.

Case 2

A 19-year-old Division I collegiate women’s basketball player with history of prior ACL reconstruction with a hamstring autograft and two previous partial lateral meniscectomies presented 2 years following ACL reconstruction with knee pain. Examination demonstrated a moderate effusion with lateral joint line tenderness and a stable ligamentous exam. MRI revealed further lateral meniscus tear with a displaced fragment in the lateral gutter, and a small focal chondral injury on the lateral femoral condyle; ACL graft was found to be intact. Standing radiographs demonstrated valgus alignment with early arthritic changes in the lateral compartment. The patient tried conservative management with use of a lateral unloader brace for three months, but continued to experience recurrent lateral knee pain, locking, and swelling. She was indicated for arthroscopy and DFO.

Diagonal arthroscopy revealed only 25% of the lateral meniscus remained with grade II chondromalacia on the tibial plateau and lateral femoral condyle; debridement of the meniscal tear was done and microfracture was performed on the lateral femoral condyle. Surgeons then proceeded with DFO, using a 10-mm opening wedge Arthrex Puddu plate and femoral head allograft. The procedure was complicated by fracture propagation through the medial cortex of the femur, and an additional 3.5mm locking plate was placed at the distal medial femoral cortex (Figure 3) to augment fixation.

Postoperatively, the patient was maintained non-weight bearing for six weeks in a hinged knee brace locked in extension when upright and allowing 0-90° motion while seated. She then progressed to toe-touch weight bearing for two weeks until progressing to WBAT in the brace until three months postoperatively. The patient was cleared for full return to activity without the brace at nine months postoperatively. She played Division I basketball during her freshman season prior to undergoing DFO. She subsequently underwent hardware removal at nine months postoperatively and was released to full sporting activities without limitations. The patient transferred schools and was able to complete a season of Division II collegiate basketball as a starting player (Figure 4). After 1-year of clinical follow-up, radiographs demonstrated stable alignment and the patient was asymptomatic.

Case 3

A 21-year-old woman’s collegiate Division I basketball player with a history of two prior left knee arthroscopies
with partial lateral meniscectomy presented with 1.5 years of left lateral knee pain and swelling nonresponsive to conservative measures. Standing radiographs demonstrated 8° of valgus alignment (Figure 5) and MRI revealed a chondral defect on the lateral femoral condyle. The patient was indicated for a DFO.

DFO was performed using a 7.5-mm Puddu plate (Arthrex) for fixation, with Osferion bone grafting. The patient was placed in a hinged knee brace postoperatively, locked in extension while up, with 0-90° degrees motion seated, and was maintained non-weight bearing for five weeks. She progressed to WBAT at six weeks postoperatively and began formal physical therapy. At six months, the patient returned to Division I collegiate basketball without restrictions. She continued her career as a collegiate basketball player, and returned to play the second half of her final collegiate season (Figure 6). After 4-years of clinical follow-up, radiographs demonstrated stable alignment and the patient was asymptomatic.

DISCUSSION

Lateral meniscectomy in the setting of valgus knee alignment in young athletes poses a risk for subsequent lateral knee compartment articular cartilage degeneration.9 The three clinical cases presented in this report all involved prior lateral meniscectomy in the setting of valgus malalignment of the knee. Although not always feasible depending on the type of meniscus tearing present, meniscal repair should be considered whenever it is a viable alternative to lateral meniscectomy, especially among youth athletes.10 Repair with meniscus healing can provide long term cartilage protection, with reported failure rates of 6-28%,11 often less in adolescent populations.12 Lateral meniscectomy is often the appropriate treatment given the meniscus tear pattern. However, this predisposes the knee to higher risk of articular cartilage wear and damage, especially when valgus mechanical alignment is present.

DFO is a treatment option for younger and more active patients with a symptomatic lateral knee compartment.13 DFO offers the opportunity to offload damaged cartilage and meniscus.14 In the setting of valgus alignment and lateral meniscus insufficiency, DFO is one of the few treatment options for the athletic patient who, due to high activity level, is not indicated for meniscus transplant and may also be performed with cartilage restoration surgery.1 Limited data exists delineating rates of return to high-level athletics following DFO.

Return to sport has previously been assessed after high tibial osteotomy (HTO), demonstrating RTS rates of 86-90%.15,16 However, high impact activities such as soccer, jogging, and tennis had a reduced RTS compared to low-impact activities such as swimming or cycling. In a systematic review of 19 studies that examined return to work and sport after HTO, 13 studies reported return to the same or higher level of sport in 378 patients, with 7/13 patients (54%) returning to sport at an elite level.17 Active patients with valgus deformity have been shown to benefit from DFO to decrease pain and regain function.13 Drexler et al. documented survivorship for distal femoral varus osteotomy combined with fresh osteochondral allograft, with results of good or excellent outcomes for most patients and low conversion rates to TKA.14 RTS following DFO has been reported at rates of 58-80%, at a mean of 11 months postoperatively.7,18 Previous literature has reported a 77% overall RTS rate, with 50% RTS by 15 weeks and 71% RTS by 6 months.8 However, few studies in the literature have assessed RTS at the elite or collegiate level.

CONCLUSION

Return to sport at the collegiate level following DFO is feasible with mid-term follow-up. Further studies are warranted to assess RTS in additional sports and contact activities using standardized measure of sport level, intensity, frequency, and duration. Meniscal preservation should be attempted for repairable lateral meniscus injuries in young athletes, especially those with pathologic overloading of the lateral compartment.

REFERENCES


ABSTRACT

Background: We conducted a retrospective review of geriatric hip fractures at our institution evaluating how a change in practice to 2-octyl cyanoacrylate adhesive (Dermabond®) with polyester mesh (Prineo®) and elimination of the 2-week follow-up visit impacts quality and efficiency of care after hip fracture. Our aim was to determine the impact of simplified wound closure and extended clinical follow-up on the number of outpatient calls to nurses and wound complications.

Methods: Patients included in this assessment were aged ≥65 years who underwent surgical fixation or hip replacement for proximal femur fracture during a one-year period preceding and following the implementation of Prineo® usage in wound closure (January 1 2017 to December 31, 2018). Information on demographics, comorbidities, nutritional screening, discharge location, wound complications, follow-up rates, and number of call-ins to the on-call nursing line within 6 weeks of surgery were collected via chart review. Cohort demographics and categorical outcomes were compared using Chi Square analysis and Wilcoxon Rank Sum test for continuous variables. The relationships between demographics, wound closure, fracture characteristics, and postoperative SSI was modeled with logistic regression.

Results: A total of 208 (n = 110 pre-practice change) patients were included in this analysis. No differences in age, sex, comorbidity rates, or race were identified between groups at baseline (p >.05). Outcomes analysis of Discharge Disposition, Length of Hospital Stay, SSI, 30 Day Mortality and Readmission found no significant differences between groups. Utilization of the nursing call service did not vary between groups within 6-weeks of surgery (p >.05).

Conclusions: The findings from this study underscore the utility of this closure system in hip fracture wound care and are in concurrence with other studies of Prineo® system that found no significant increase in wound complications up to 6 weeks after surgery.

Clinical Relevance: The benefits of this surgical site closure system include the elimination of a 2-week follow-up and consequential reduction in unnecessary visits. Future analysis is needed to assess more long-term follow-up, determine the cost savings impact of this practice, potential SSI reduction, and assess its application in other surgical settings.

Level of Evidence: IV

Keywords: hip fracture, trauma, geriatric care

INTRODUCTION

The incidence of geriatric hip fracture is steadily increasing and poses a significant burden on our healthcare system.1,2 There is a need to improve efficiency of managing these injuries. The cost of treating hip fractures can be attributed to preoperative medical work up, surgical treatment, postoperative care including in-home nursing and nursing facilities, and clinical follow up.3 Expedited surgical fixation has shown significant cost savings.4 Considering the ubiquity of hip fractures in the United States, minor changes in efficiency of hip fracture management could contribute to large nationwide healthcare savings. As the predominate surgical specialty managing fixation of these fractures orthopedic surgeons are uniquely positioned to influence the development of more efficient care for this patient population.

Geriatric patients sustaining hip fractures often have significant medical comorbidities and functional limitations at baseline which can limit healing and recovery.1 The injury results in muscle atrophy and worsening imbalance. Patients commonly are discharged to a skilled nursing facility.1 Currently, the multitude of post-operative clinic visits places a significant burden on the family and healthcare system as these patients have significant difficulty with mobilization after the injury. Often patients will require specialized medical transport.
Table 1. Comparison Table for Demographics Between Groups (4 Patients had 2 Surgeries)

<table>
<thead>
<tr>
<th>Measure</th>
<th>Pre-Prineo® (n=110)</th>
<th>Post-Prineo® (n=98)</th>
<th>P-value</th>
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<tr>
<td>Age</td>
<td>81.5±8.5</td>
<td>82±9.0</td>
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<td>BMI</td>
<td>25±5.9</td>
<td>25±5.0</td>
<td>0.6117</td>
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<td>Gender</td>
<td>76 (69.1%)</td>
<td>65 (66.3%)</td>
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<td>Race:</td>
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<td></td>
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<tr>
<td>Asian</td>
<td>0</td>
<td>1 (1.0%)</td>
<td>0.02208</td>
</tr>
<tr>
<td>White</td>
<td>110 (100%)</td>
<td>96 (98.0%)</td>
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<tr>
<td>Unreported</td>
<td>0</td>
<td>1 (1.0%)</td>
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<td>Smoker</td>
<td>9 (8.2%)</td>
<td>5 (5.1%)</td>
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<td>Diabetes</td>
<td>28 (25.5%)</td>
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<td>Dyspnea</td>
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<td>Independent</td>
<td>100 (90.9%)</td>
<td>88 (89.8%)</td>
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<td>COPD</td>
<td>15 (13.6%)</td>
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<td>Congestive heart failure</td>
<td>4 (3.6%)</td>
<td>8 (8.2%)</td>
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<td>HTN</td>
<td>87 (79.1%)</td>
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<td>Acute renal failure</td>
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<td>2 (2.0%)</td>
<td>1.0000</td>
</tr>
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<td>Dialysis</td>
<td>2 (1.8%)</td>
<td>3 (3.1%)</td>
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<td>Open wound</td>
<td>9 (8.2%)</td>
<td>8 (8.2%)</td>
<td>0.9961</td>
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<td>Steroid use</td>
<td>12 (10.9%)</td>
<td>13 (13.3%)</td>
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<td>ASA:</td>
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<td>2</td>
<td>26 (23.6%)</td>
<td>19 (19.3%)</td>
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<tr>
<td>3</td>
<td>65 (59.0%)</td>
<td>60 (61.2%)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>19 (17.2%)</td>
<td>17 (17.35%)</td>
<td></td>
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<tr>
<td>5</td>
<td>0</td>
<td>2 (2.04%)</td>
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<tr>
<td>LOS</td>
<td>5 (4.3%)</td>
<td>6 (6.31)</td>
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<td>Discharge disposition:</td>
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<tr>
<td>Died</td>
<td>2 (1.8%)</td>
<td>4 (4.08%)</td>
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<td>2 (1.8%)</td>
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<td>Home hospice</td>
<td>12 (10.1%)</td>
<td>11 (11.22%)</td>
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<tr>
<td>Home rehab</td>
<td>3 (2.73%)</td>
<td>2 (2.04%)</td>
<td></td>
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<tr>
<td>Separate acute care</td>
<td>2 (1.82%)</td>
<td>3 (3.06%)</td>
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<tr>
<td>Skilled care, not home</td>
<td>88 (80.0%)</td>
<td>77 (78.57%)</td>
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<tr>
<td>Still in hospital &gt;30 days</td>
<td>1 (9.1%)</td>
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<td>Discharge disposition:</td>
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<td></td>
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<tr>
<td>Home</td>
<td>14 (12.73%)</td>
<td>11 (11.22%)</td>
<td>0.7394</td>
</tr>
<tr>
<td>Not home</td>
<td>96 (98.27%)</td>
<td>87 (88.78%)</td>
<td></td>
</tr>
<tr>
<td>30 Day mortality</td>
<td>5 (4.0%)</td>
<td>8 (8.2%)</td>
<td>0.2819</td>
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<tr>
<td>Readmission</td>
<td>9 (8.2%)</td>
<td>10 (10.2%)</td>
<td>0.6133</td>
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</table>

even by ambulance. Reduction in unnecessary clinical follow-up will save on transportation costs and reduce burden on the care facility and family.

Our institution identified this issue and implemented a protocol that included wound closure with a 2-octyl cyanoacrylate adhesive (Dermabond®) and polyester mesh (Prineo®) dressing that could be removed at home or at a skilled facility and eliminated the 2-week follow up visit in January 2017. This presented the opportunity to retrospectively evaluate how this change in practice impacted the number of calls to our orthopedic on-call nursing line for issues or questions and the incidence of wound complications. We hypothesized that the use of the Prineo® skin closure system would not result in increased risk of superficial and deep surgical site infections (SSI) or increase the number of nursing calls within the first six weeks following surgery.

METHODS

We performed a retrospective review from January 1, 2017 to December 31, 2017 (prior to implementation of our hip fracture wound management protocol) and January 1, 2018 to December 31, 2018 (after implementation of the protocol). Patients included in this assessment were those age ≥65 years who underwent surgical fixation or arthroplasty for hip fracture during a one-year period immediately preceding and following the implementation of Prineo® closure (Hip Arthroplasty - 41; Cephalomedullary Nail – 81; Sliding Hip Screw – 20; Cannulated Screw – 66). Patients were identified from the NSQIP (National Surgical Quality Improvement Program) database which collects data prospectively on these patients. This includes 30-day complications after the surgery. SSI were defined according to the NSQIP definition: “purulent drainage; or positive culture; or pain/tenderness; swelling, erythema, warm and opened (unless culture negative).” Medical records were reviewed to document demographic data, comorbidities, confirm adherence to the follow-up protocol, identify complications, and mortality. Demographic data was used to control for variables such as gender, age, smoking, diabetes, comorbid diseases and drug use.

Preoperative demographics were compared between groups receiving suture removal at 2-week clinical follow-up versus Prineo® closure using chi-square or exact tests for categorical variables, as appropriate, and Wilcoxon Rank Sum tests for continuous variables. The relationships between demographics, wound closure, fracture characteristics, and postoperative SSI was modeled with logistic regression. Analyses were completed using SAS statistical software version 9.4 (SAS Institute, Inc., Cary, NC) and a p-value <0.05 considered statistically significant.

Information regarding number of nursing calls and time course was extracted from Epic® August 2018 with IRB approval. For patients that had more than one surgery during the established time period, calls were recorded 6 weeks out from each surgery.
RESULTS

Two hundred eight patients were retrospectively identified following operative fixation between January 2017 and December 2018. Four patients had more than one surgery during this time period, and thus were counted twice. The group demographics can be found in Table 1. There were no significant differences in age, BMI, gender, race or comorbidities between groups. Four superficial SSI and three deep SSI were reported during the selected time period, with no significant difference between groups (p=0.9072; p=0.5064). There was a mean of 1.82 calls pre-Prineo® and 1.85 calls post-Prineo® (SD: .18; .14) per patient to our nursing line from the patient, family, or nursing facility (p=0.8992).

A total number of 92 patients out of 208 called in the first six weeks following surgery, including multiple calls from single individuals. At a maximum, three patients were recorded as calling five times within the first 6 weeks after their surgery. There was no significant difference in number of calls between groups (p=0.8992). Additionally, the average duration from date of surgery to nursing call was 20 days with no difference between groups (p=0.5276) (Table 2 and 3).

DISCUSSION

Geriatric hip fractures are a significant public health problem and a major contributor of morbidity, mortality, and overall healthcare cost in the United States. The burden of managing hip fractures will continue to increase, both nationally and worldwide, in conjunction with our aging population, making the issue of hip fracture care and treatment both a national and global issue. We evaluated the impact of a quality improvement project at our institution to improve efficiency of geriatric hip fracture clinical follow up. We changed our clinical practice from 2-week follow-up for a wound check and suture removal to polyester mesh and adhesive closure removed at home, or in the skilled facility with a first clinical follow up at 6 weeks. Outcomes from one year prior to and after implementation of the practice change was evaluated to determine if there was a difference in number of calls to our nursing line or the incidence of wound complications.

Dermabond® Prineo® skin closure system is a two-part closure technique using a 2-octylcyanoacrylate topical skin adhesive that sets in approximately 60 seconds, combined with a flexible polyester mesh tape and liquid adhesive. In vitro lab studies have demonstrated that this closure system provides an effective barrier against Gram-positive, Gram-negative, motile and nonmotile bacteria with animal studies demonstrating lower rates of bacterial colonization as compared to sutured wound closure. This closure system has the potential to reduce the need for follow-up visits, minimize cosmetic scarring, and provide a watertight, sterile seal, that reduces the risk of wound drainage and infections. We found no differences in wound complications with this closure technique and no increased incidence of calls to our nursing line, even with discontinuation of the 2-week follow up visit.

The use of Dermabond Prineo® closure technique has not been previously evaluated in a hip fracture fixation. However, Dermabond Prineo® has been shown to decrease wound closure time for a range of surgical incisions, including abdominoplasty, circumferential body lift procedures, breast reconstruction, and knee arthroplasty when compared with skin staples and nylon sutures.

It should also be noted that several studies have documented allergic contact dermatitis at an incidence rate ranging from 5% to 1.8%. One study looking at postoperative dermatitis in patients undergoing total knee arthroplasty (TKA) described an erythematous pruritic papular rash that developed 1 to 3 weeks postoperatively in 15 of 912, or 1.7% patients with ranging severity. It was further noted that the rash clears quickly with application of topical steroids with no reported recurrences. If recognized early, it is a mild and easily treated side effect.

Several studies have specifically addressed the rates of SSI complications when using the Dermabond Prineo® suturetting system. One comparison between nylon suturing and Dermabond Prineo® following ankle fracture surgery found that there was no difference in complication rates and corroborated the finding that this closure system significantly reduces operating time, and increases patient satisfaction with scar appearance. However, a second study evaluating the closure system in TKA found the rate of superficial wound complications to be 0.8%, which...
is significantly lower than SSI rates for suturing or staples. A third comparative study for wound closure after spinal surgery found significantly reduced rates of SSI with the use of Dermabond® Prineo® as compared to staples.\textsuperscript{14}

While rare, complications of hip fracture fixation can be severe and costly to both the patient and the health care system at large. Thus, even minor improvements in surgical practices can manifest in significant improvement for the orthopedic field. A retrospective review of 3,563 hip fracture patients in the United Kingdom found SSI rates of 2.3% with 41 (1.2%) deep infections and 39 (1.1%) superficial, nearly half of which were Meticillin-resistant Staphylococcus aureus. Hospital costs, mean length of stay (LOS), and pre-discharge mortality were increased for those with deep SSI as compared with superficial SSI. The study also found that wound infections nearly tripled overall costs and increased the LOS by 54 days, with days in the hospital being the most significant contributor to increased hospital costs of SSI patients.\textsuperscript{15} A second U.K. analysis of 61 cases of proximal femoral fractures over a six-year period found that SSI occurrence more than tripled costs and decreased rates of survival following discharge by a magnitude of 4.5.\textsuperscript{16}

In the U.S., an analysis of orthopedic infections found that SSI translated to an additional 6,140 hospital-days and $9,870,979 in additional hospital expenses.\textsuperscript{17} The 2009 shift in Medicare’s reimbursement for hospital-acquired infections has further amplified the financial burden of SSI and increased interest in reducing preventable infections.

While our study was not sufficiently powered to demonstrate a reduction in infection rates, several aspects of this closure technique have the potential to reduce SSI risk. Wound drainage in TKA was found to be significantly decreased when using 2-octyl cyanoacrylate adhesive as compared to standardized control group.\textsuperscript{18} Furthermore, use of Dermabond® Prineo® reduction in operating time also contributes to decreased joint infection rates.\textsuperscript{19,20} Additionally, the inherent bactericidal properties against Gram-positive bacteria in this closure system may also lead to reduced SSI rates.\textsuperscript{21}

With regards to cost-analysis, the Dermabond® Prineo® system has been identified as a contributing factor to consistently lower costs.\textsuperscript{22} Lower costs are largely attributed to decreased procedure time and postoperative care costs, as well as facilitation in early mobilization due for arthroplasty patients.\textsuperscript{23} One study evaluating a 90-day period shift from sutures and staples to skin closure system hip and knee arthroplasties project an annual hospital budgetary savings ranging from $28,349 to $39,809 when assuming 500 arthroplasties based on 2016 US dollar prices.\textsuperscript{24}

The findings from this study demonstrate Dermabond® Prineo® as an efficacious closure system that eliminates the need for 2-week follow-up with an insignificant increase in nursing calls. Our data are in concurrence with several other studies of Dermabond® Prineo® system that found no increase in infection rates.\textsuperscript{8,21}

**Limitations**

This study was a retrospective study and thus was not able to be controlled or randomized. However, controlling for potentially confounding factors demonstrated that the two groups that were studied did not have any conspicuous differences. Additionally, a total of 19 surgeons were involved in the operations of the 208 patients studied. This adds a level of variation in surgical technique, approach, and skill level that cannot be controlled for. Lastly, the rates of SSI are very low and would require a larger study to find any significant difference in wound complications between closure techniques.

**CONCLUSION**

While the Dermabond® Prineo® closure system has previously been evaluated for a variety of procedures, its efficacy in terms of wound closure and patient impact has not been explicitly evaluated in geriatric patients with hip fractures. Importantly, the use of this closure system can eliminate the need for a 2-week follow-up, reducing the burden of care and cost. The findings of this study can potentially influence the practice of hip fracture operative care and reduce costs and burden of care while increasing patient satisfaction and quality of life. Considering the substantial increase in nationwide hip fractures and consequential morbidity and mortality, increasing effective treatment of hip fractures has potential to significantly impact quality of life and healthcare system costs for patients.

**REFERENCES**


SARCOPENIA IS ASSOCIATED WITH NONUNION OF OPEN TIBIA AND ANKLE FRACTURES

Wyatt Vander Voort, MD; John Davison, MPH; Nathan Hendrickson, MD; Joseph Buckwalter V, MD, PhD; Brian Guetschow, MD; Natalie Glass, PhD, MHCDS; Michael Willey, MD

ABSTRACT

Background: Sarcopenia is a clinical syndrome of diminished muscle mass and function associated with disability, poor surgical outcomes, and mortality. Open fractures of the tibia and ankle have a high risk for complications including nonunion and surgical site infection (SSI). The purpose of this study is to determine if sarcopenia is associated with SSI and nonunion in individuals that sustain open fractures of the tibia and ankle.

Methods: 111 consecutive adults who underwent operative fixation of open fractures of the tibia or ankle from 2006-2017 with preoperative CT of the abdomen and pelvis were retrospectively identified at a single institution. Eleven patients were lost to follow-up. The psoas index (PI = (RPA+LPA)/height^2 (cm^2/m^2)) was calculated from bilateral psoas cross sectional areas measured on axial CT scans at the L3 pedicle. Patients were stratified by the presence of sarcopenia as defined by established gender specific PI cut-offs of <3.85 cm^2/m^2 (women) and <5.45 cm^2/m^2 (men). Records were also abstracted for comorbidities to determine a Charlson Comorbidity Index (CCI) score and postoperative complications including fracture nonunion and SSI. Logistic regression was used to model the relationships between complications, sarcopenia and other factors.

Results: 16/100 (16%) patients met gender specific criteria for the diagnosis of sarcopenia by PI. There was no difference in gender, age, or burden of medical comorbidity according to CCI between the sarcopenic and non-sarcopenic groups (all p>0.05). Nonunion occurred in 6 patients with sarcopenia (38%) and 12 without sarcopenia (18%) (Relative risk=2.42, 95%CI=1.08-5.43, p=0.0314). No association was found between sarcopenia and SSI, BMI, smoking status, ISS, and Gustilo and Anderson (GA) classification of open fracture (all p>0.2). GA classification was strongly associated with infection, with each successive classification having a nearly 3-fold increase in risk (p=0.0217).

Conclusion: Sarcopenia is an independent risk factor for fracture nonunion following operative fixation of open tibia or ankle fracture, but is not predictive of surgical site infection. Gustilo Anderson classification is strongly associated with SSI risk. Psoas index is a straightforward and objective method of identifying sarcopenia in patients with open fractures. Diagnosing sarcopenia in these individuals can inform medical decision making and patient counseling regarding risk for nonunion. Further work is needed to identify effective interventions to improve outcomes in these patients.

Level of Evidence: III

Keywords: non-union, malnutrition, open fractures, psoas index, sarcopenia

INTRODUCTION

Sarcopenia is an age-related condition of diminished skeletal muscle mass and physical function\(^1\) that leads to functional impairment secondary to decreased strength, slow gait speed, poor balance, and loss of independence in completing daily life activities\(^2\,3\). Sarcopenia is part of the clinical spectrum of frailty, and can be assessed by direct measurement of skeletal muscle mass, functional strength (i.e. handgrip dynamometry) or functional assessment (i.e. walking speed)\(^4,5\). Previous research has identified sarcopenia as an independent risk factor for adverse outcomes in critically-ill patients, trauma patients, transplant patients, and patients undergoing oncologic surgery\(^6,9,11\).

Within the realm of orthopaedics, assessment of sarcopenia-related outcomes has been limited to geriatric patients with fractures of the proximal femur or acetabulum. In this population, sarcopenia has been identified in one-fifth of patients and has been linked to increased fracture risk, prolonged hospitalization, and increased one-year mortality\(^6,12,18\). There is a paucity of information on the relationship between sarcopenia and post-operative outcomes in patients following high
Study Population

Surgical records were queried at a level I academic trauma center to identify individuals 18 years and older indicated for operative fixation of traumatic open fractures of the tibia and ankle between June 2006 and September 2017. Patients without preoperative computed tomography (CT) scan including the lumbar spine as part of their trauma work up were excluded. 111 patients met inclusion criteria. Eleven patients were lost to follow-up, leaving 100 patients in the final cohort. For each patient, demographics including age, sex, height, weight, body mass index (BMI, kg/m$^2$), smoking status, and Charlson Comorbidity Index (CCI)** were abstracted from electronic medical records.21 Fracture-specific variables including Gustilo and Anderson (GA)* Open Fracture Classification and Injury Severity Score (ISS) were recorded.22,23 Primary outcomes assessed included postoperative fracture nonunion and surgical site infection. Fracture nonunion was defined as lack of bridging callus at least six months following treatment with clinical evidence such as pain or gross mobility at the fracture site. Surgical site infections were documented based upon the CDC definition of nosocomial surgical site infection.24

Measurement of Sarcopenia

Sarcopenia was assessed by measuring axial cross-sectional area of bilateral psoas muscles at the level of the L3 vertebral body (Figure 1). Psoas area (PA) was estimated as the product of the greatest anterior to posterior and transverse muscle diameters. The psoas index (PI) was calculated as the sum of the right (RPA) and left psoas area (LPA), followed by normalizing by the square of the patient’s height (PI = (RPA + LPA)/height$^2$ in cm$^2$/m$^2$). Patients were classified as either sarcopenic or non-sarcopenic based on gender specific thresholds of 3.85 cm$^2$/m$^2$ for women and 5.45 cm$^2$/m$^2$ for men.

Statistical Analysis

Preoperative demographics were compared between sarcopenic and non-sarcopenic groups using chi-square or exact tests for categorical variables, as appropriate, and Wilcoxon Rank Sum tests for continuous variables. The relationships between demographics, sarcopenia, fracture characteristics, and postoperative SSI or nonunion were modeled with logistic regression. Analyses were completed using SAS statistical software version 9.4 (SAS Institute, Inc., Cary, NC) and a $p$-value <0.05 was considered statistically significant.

RESULTS

Patient Characteristics

A total of 100 individuals (67% male) who underwent operative fixation for traumatic open fractures below the knee who received a preoperative CT scan as part of their trauma work up were identified. The average ISS at presentation was 19.9. The median follow-up time was 20 months

Table 1. General Patient Characteristics Within the Orthopaedic Trauma Cohort

<table>
<thead>
<tr>
<th>Total Cohort (n=100)</th>
<th>Sarcopenic by PI (n=16)</th>
<th>Nonsarcopenic by PI (n=84)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)**</td>
<td>43.3 (17.4)</td>
<td>53.3 (22.73)</td>
<td>37 (18-90)</td>
</tr>
<tr>
<td>BMI (kg/m$^2$)**</td>
<td>30.2 (6.9)</td>
<td>28.7 (7.3)</td>
<td>30.5 (6.8)</td>
</tr>
<tr>
<td>Sex (no. male)</td>
<td>67 (67%)</td>
<td>10 (62.5%)</td>
<td>57 (67.8%)</td>
</tr>
<tr>
<td>Current Smoker*</td>
<td>35 (35%)</td>
<td>7 (43.8%)</td>
<td>28 (33.3%)</td>
</tr>
<tr>
<td>ISS**</td>
<td>19.86 (12.8)</td>
<td>16.31 (10.6)</td>
<td>20.54 (13.2)</td>
</tr>
<tr>
<td>GA* Class**</td>
<td>2.41 (0.63)</td>
<td>2.50 (0.61)</td>
<td>2.39 (0.64)</td>
</tr>
<tr>
<td>CCI**</td>
<td>86.6 (24.8)</td>
<td>76.6 (34.3)</td>
<td>88.5 (22.1)</td>
</tr>
</tbody>
</table>

*Gustilo and Anderson

** these values are given as the mean with standard deviation in parentheses

** these values are given as number of patients with percentage in parentheses

of energy orthopedic trauma. Fractures sustained during high energy trauma, particularly open fractures, are independently associated with an increased risk of surgical site infection and nonunion.19 The purpose of this study was to assess the association of sarcopenia with postoperative surgical site infection and fracture nonunion in a cohort of patients following operative fixation of acute open fractures of the tibia or ankle, and to evaluate the use of CT-measured muscle mass as a risk stratification tool within orthopaedic trauma.
Sarcopenia is Associated with Nonunion of Open Tibia and Ankle Fractures

**DISCUSSION**

The relationship between sarcopenia and postoperative complications in the setting of traumatic open tibia and ankle fracture has not been studied. We report sarcopenia is an independent risk factor for fracture nonunion following open tibia or ankle fracture in adults. Sarcopenia is a marker of frailty characterized by decreasing muscle mass, and has been associated with loss of functionality, poor surgical outcomes, morbidity, and mortality following injury and surgical treatment. Psoas index has been established as a reliable tool for identifying patients with sarcopenia. Unlike other diagnostic methods, cross sectional imaging provides a timely and objective measure of skeletal muscle mass, and sarcopenia has repeatedly been associated with adverse patient outcomes in other patient populations. For these reasons, sarcopenia has been proposed as a risk stratification tool in patients undergoing surgery. Previous studies among emergency general surgery, organ transplantation, and...
Table 4. Relationship Between Surgical Sight Infection and Other Variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>SSI (n=19)</th>
<th>No SSI (n=81)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age**</td>
<td>44.3 (16.0)</td>
<td>43.1 (17.6)</td>
<td>0.880</td>
</tr>
<tr>
<td>BMI**</td>
<td>33.1 (7.99)</td>
<td>29.7 (6.53)</td>
<td>0.101</td>
</tr>
<tr>
<td>Current Smoker</td>
<td>9 (47.4%)</td>
<td>26 (32.1%)</td>
<td>0.213</td>
</tr>
<tr>
<td>Sex (no. male)</td>
<td>11 (57.9%)</td>
<td>56 (69.1%)</td>
<td>0.351</td>
</tr>
<tr>
<td>ISS**</td>
<td>229 (135)</td>
<td>191 (125)</td>
<td>0.247</td>
</tr>
<tr>
<td>CCI**</td>
<td>1.42 (1.60)</td>
<td>1.16 (1.85)</td>
<td>0.573</td>
</tr>
<tr>
<td>GA Class**</td>
<td>2.74 (0.44)</td>
<td>2.33 (0.65)</td>
<td>0.017*</td>
</tr>
</tbody>
</table>

* indicates statistical significance below α = 0.05
** these values are given as the mean with standard deviation in parentheses
† these values are given as number of patients with percentage in parentheses

Univariate logistic regression:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Estimate (beta)</th>
<th>SE</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>0.00220</td>
<td>0.0146</td>
<td>0.8803</td>
</tr>
<tr>
<td>BMI</td>
<td>0.0588</td>
<td>0.0359</td>
<td>0.1014</td>
</tr>
<tr>
<td>Smoking History (yes vs no)</td>
<td>0.3219</td>
<td>0.2587</td>
<td>0.2134</td>
</tr>
<tr>
<td>Gender (female vs male)</td>
<td>0.2441</td>
<td>0.2616</td>
<td>0.3508</td>
</tr>
<tr>
<td>ISS</td>
<td>0.0218</td>
<td>0.0188</td>
<td>0.2471</td>
</tr>
<tr>
<td>CCI</td>
<td>0.0746</td>
<td>0.1323</td>
<td>0.5730</td>
</tr>
<tr>
<td>GA Class</td>
<td>1.2589</td>
<td>0.5276</td>
<td>0.0170</td>
</tr>
</tbody>
</table>

RR for GA class-SSI relationship: RR=2.80 (1.16-6.76), p=0.0217

oncologic surgery patients have validated its use for this purpose.36-12,15,19

Within orthopaedics, recovery from operative fixation for traumatic open fractures requires a significant physiologic reserve. Previous efforts to evaluate the association of sarcopenia with outcomes following orthopedic injury have been limited to elderly patients with fractures of the proximal femur and acetabulum.3,14 The reported prevalence of sarcopenia in these studies ranged from 25-42%, with both studies reporting increased one year mortality among patients with sarcopenia. There was a lower prevalence of sarcopenia in the current cohort, which is expected given the current patient cohort had a mean age of 43 years compared to 70 and 74 years.

With this relationship established, assessing for sarcopenia using PI may improve preoperative risk stratification, allow for improved patient counseling regarding risk of fracture nonunion, and allow for identification of interventions to improve postoperative complications in this population.

We did not observe a relationship between sarcopenia and increasing age. Established as an age-related condition, it appears that other factors may be linked to the development of sarcopenia and frailty. Santilli et. al identified physical disuse and inactivity, malnourishment, chronic inflammatory states, cachexia, and malignancy as processes that contribute to the development of sarcopenia, all of which are not exclusive to the elderly population.4 Within our study population, sarcopenia as established by PI was found in patients as young as 22 years of age.

Our study supports a bimodal distribution of sarcopenia in relation to patient BMI. The average BMI of sarcopenic patients was 28.8 kg/m. Among patients with sarcopenia, five patients were classified as obese (BMI > 30), one of which was morbidly obese (BMI > 40). Sarcopenic obesity represents a distinct process in which both entities are present. The relationship between sarcopenia and obesity is complex, with a continuum between fat accumulation and loss of skeletal muscle mass; sarcopenia reduces physical activity which in turn decreases energy expenditure and increases the risk of obesity.25 Although the traditional clinical picture of an elderly, frail individual is not incorrect, we must also consider the young, obese and inactive patient to be at risk for sarcopenia. These orthopaedic trauma patients should not be excluded from preoperative risk stratification even if they do not fit the traditional clinical picture of an elderly and frail patient. Failure to identify these individuals and address modifiable risk factors at the time of surgery may increase their risk of adverse outcomes post-operatively.

This study is limited by the retrospective nature and cohort size. Our analysis is also limited by the inability to further depict the degree of soft-tissue injury and contamination at the time of surgery.26 Further support of the relationship between sarcopenia and outcomes within this population may be necessary, and could be accomplished with a larger, multi-centered prospective study. In addition, our study is limited by the broad range of traumatic open fractures assessed within this cohort. The physiologic requirement necessary to recover from different fracture types likely varies. Future studies comparing outcomes amongst specific fracture types may help elucidate the relationship between sarcopenia and outcomes after open fractures independent of soft tissue injury and wound contamination.

We report sarcopenia, as measured by psoas index, is an independent risk factor for fracture nonunion following open fracture of the tibia or ankle. Psoas index calculations are readily available from cross sectional imaging routinely employed in trauma patients and allows orthopedic surgeons to more accurately counsel patients regarding risk of adverse outcomes associated with sarcopenia. Further studies are warranted to
elucidate the relationship of sarcopenia with outcomes following orthopedic trauma and identify perioperative interventions to mitigate the increased risk associated with sarcopenia.

REFERENCES


ABSTRACT

Background: Surgical management of geriatric ankle fractures requires unique considerations in addressing operative risks. Prior studies have reached varying conclusions regarding optimal treatment strategies. The primary aim of this study was to determine if surgical fixation following a predetermined treatment protocol was safe and effective. The secondary aim was to determine if immediate weight bearing as tolerated (IWBAT) in a subset of patients was safe or conferred any short-term benefits.

Methods: This retrospective study included all patients over the age 65 treated surgically for an ankle fracture by a single surgeon over a five-year period. A protocol was used including: augmented fixation techniques, IWBAT for select patients, and specific strategies to minimize soft tissue damage. Complications associated with operative treatment were analyzed. A subgroup analysis of patients with isolated ankle injuries was carried out to compare patients made IWBAT to patients made non-weight bearing (NWB) postoperatively.

Results: Thirty-four patients were included in the study. Fracture types were predominantly OTA 44B2 (18/34, 53%) and 44B3 (8/34, 24%). Union rate was 100%. Augmented fixation techniques were used in 14/34, 41% of patients. Twenty-one of 34, 62% of patients were allowed IWBAT. There were 4 complications, 12%: 1 malunion, 1 superficial infection, and 2 wound dehiscence. Two patients returned to the operating room for removal of hardware and irrigation and debridement. In the subgroup analysis, the IWBAT group was discharged to a rehabilitation facility at a significantly lower rate than the NWB group, 25% (4/16) vs 90% (9/10; p=0.0036). There were no differences in the complication rates between the two groups.

Conclusion: Acceptable outcomes can be reliably obtained when following a standardized approach to geriatric ankle fracture management. In addition, immediate weight bearing in select patients does not seem to increase complications and may benefit patients by increasing rate of discharge to home.

Level of Evidence: IV

Keywords: ankle fracture, geriatric, internal fixation, weight bearing, complications

INTRODUCTION

The incidence of low-trauma geriatric ankle fractures is rising at a rapid rate.1 The optimal treatment protocol for unstable ankle fractures in the elderly remains debatable. Closed management and casting was once the mainstay of treatment, but has decreased over time due to higher rates of malunion and nonunion, and lower long-term functional scores compared to surgical fixation.2-6 While operative management can better restore and maintain anatomy; it carries the inherent risks of surgery. This is particularly challenging in geriatric patients, who tend to have higher perioperative risk due to comorbidities, diabetes, peripheral vascular disease, poor bone stock, diminished soft tissue healing, and lower cardiac reserve.2-14 Given this reality, the postoperative complication rate in surgically treated geriatric ankle fractures has been reported as high as 13-59%.3-5,15-18

Treatment protocols in the literature vary and lack consensus regarding many aspects of care such as fixation strategies, weight bearing recommendations, and soft tissue considerations.3-5,15-18 The anecdotal experience of the senior author was that following a predetermined treatment algorithm for geriatric ankle fractures—surgical fixation followed by immediate weight bearing for a subset of patients—seemed to have decreased short-term complications than what has been reported.
while also providing the early ambulation crucial to this specific population.

To validate the anecdotal experience, this study was formulated. The primary aim of the study was to determine if surgical fixation following a predetermined treatment protocol was safe and effective. The secondary aim was to determine if immediate weight bearing as tolerated (IWBAT) in a subset of patients was safe or conferred any short-term benefits.

**METHODS**

Upon receiving Institutional Review Board approval, a retrospective evaluation of the institutional orthopedic patient database was conducted to identify all patients 65 years or older who were treated with open reduction internal fixation of an ankle fracture by the senior author at a level one trauma center from 2012 through 2017. Patients were identified using applicable Current Procedural Terminology (CPT) codes (Table 1). For all included patients, a standardized treatment protocol was used. Data for this analysis was generated by thorough review of patients’ medical charts including their initial evaluation, details of surgical intervention, pre- and postoperative radiographs, and post-operative follow-up. From this demographic data, fracture type, treatment strategy, hospital course, and complications were recorded. The primary outcome of this analysis was short-term complications. Patients with less than six weeks follow-up were excluded. Fractures were classified according to the OTA/AO fracture and dislocation compendium.

### 2.1 Treatment Protocol

All ankle fractures other than stable isolated lateral malleolus fractures were indicated for surgery. All injured ankles were immobilized in a well-padded splint with strict elevation until soft tissue swelling subsided and they were deemed appropriate for surgical fixation. Specific strategies to minimize soft tissue damage were employed. These included scalpel dissection, as opposed to blunt scissor dissection, no tourniquet use, and single layer closure with nylon sutures. A posterolateral incision was used for all distal fibula fractures. Supination external rotation Weber B distal fibula fractures were treated with a posterolateral antiglide plate. In patients with osteoporosis or poor bone stock, 3.5mm quadricortical screws were placed at the apex of the fracture across the tibia for augmented fixation. Syndesmotic injuries were treated in the same fashion. Fractures of the medial malleolus were fixed based on fracture pattern. Vertical fracture patterns were treated with a buttress plate, while horizontal fracture patterns were treated with lag screws. In patients with osteoporosis or poor bone stock, bicortical fixation into the lateral cortex of the distal tibia was achieved with fully threaded cannulated screws for augmented fixation (Figure 1). Large, nondisplaced posterior malleolus fractures were fixed percutaneously with a single anterior to posterior 2.7mm cortical screw (Figure 2). Displaced fractures were treated with open reduction internal fixation through a posterolateral approach and standard buttress plating. All patients were made weight bearing as tolerated in a Controlled Ankle

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**Table 1. CPT Codes Utilized to Identify Patients Undergoing Surgical Treatment of Ankle Fractures**

<table>
<thead>
<tr>
<th>CPT code</th>
<th>Procedure Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>27766</td>
<td>Open treatment of medial malleolus fracture</td>
</tr>
<tr>
<td>27769</td>
<td>Open treatment of posterior malleolus fracture</td>
</tr>
<tr>
<td>27792</td>
<td>Open treatment of distal fibular fracture</td>
</tr>
<tr>
<td>27814</td>
<td>Open treatment of bimalleolar ankle fracture</td>
</tr>
<tr>
<td>27822</td>
<td>Open treatment of trimalleolar ankle fracture medial and/or lateral malleolus; without fixation of posterior lip</td>
</tr>
<tr>
<td>27823</td>
<td>Open treatment of trimalleolar ankle fracture medial and/or lateral malleolus with fixation of posterior lip</td>
</tr>
</tbody>
</table>

CPT = current procedural terminology

---

**Figure 1.** AP radiograph demonstrating ankle fracture fixation construct with 3.5mm quadricortical screw placed at the apex of the lateral malleolus fracture and bicortical cannulated screws in the medial malleolus for augmented fixation.
Treatment Protocol for Geriatric Ankle Fractures

Motion (CAM) Walker Boot unless they met one of the following criteria: large displaced posterior malleolus fragment, complete syndesmotic disruption, profound osteoporosis, or ipsilateral lower extremity injury. Patients who met these criteria were immobilized in a splint and made non-weight bearing (NWB) for 8 weeks.

2.2 Data Analysis

Data were stored in and analyzed with Excel 2011 (Microsoft Corp, Redmond, WA, USA). Clinical characteristics were analyzed using descriptive statistics. A subgroup analysis of patients with only isolated ankle injuries was carried out to compare IWBAT patients to NWB patients. The student t-test was used to evaluate the means for each of the two groups and Fisher exact tests were used to analyze the differences in rates. Significance was set at p<0.05

RESULTS

Thirty-six patients were identified who were 65 years or older and underwent open reduction internal fixation of an ankle fracture by the senior author. The cohort was 78% female (28 women, 8 men), had a mean age of 73.4 years (range, 65 to 97 years), and mean body mass index of 28.1 (range, 17.3 to 37.2 kg/m²) at time of injury. Eight (22.2%; 8/36) had diabetes mellitus and two (5.6%; 2/36) were active smokers. Fracture types were predominantly OTA 44B2 (19/36, 53%) and 44B3 (8/36, 22%; Table 2). Time from injury to surgical fixation was on average 4.1 days (range, 1 to 16 days).

Augmented fixation techniques were used in 15/36 (42%) of patients: 13 patients with lateral malleolus quadricortical screws and seven patients with medial malleolus bicortical screws. Twenty-two (61%; 22/36) patients were cleared for immediate full weight bearing. Patients were discharged on average postoperative day 3.8 and one-third (36%; 13/36) were discharged home while the rest were discharged to a rehabilitation facility. Thirty-four of 36 patients were available for clinical follow-up at least six weeks postoperatively, average 24 weeks (range, 6 to 108 weeks). Fracture union rate was 100%. There were four (12%; 4/34) complications: one malunion, two superficial wound dehiscence, and one superficial infection six weeks from surgery managed successfully with superficial irrigation and debridement and hardware retention. Patients with diabetes showed a higher risk for complications, 25% (2/8) vs 8% (2/26; p=0.21). Complications or return to the operating room were not associated with postoperative weight bearing status.

In the subgroup analysis of patients with only isolated ankle injuries, 16 patients were made IWBAT compared to 10 who were NWB in the acute post-operative period. The two groups were similar in terms of age, sex, BMI, comorbidities, diabetes, smoking status, preadmission ambulatory aids, and preadmission living arrangements.

Table 2. Demographics and Complications

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<td>n=34</td>
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Demographics, n(%)
- Female 26(76)
- OTA 44B2 or 44B3 26(76)
- Augmented Fixation 14(41)
- IWBAT 21(62)

Complications, n(%)
- Nonunion 0(0)
- Malunion 1(3)
- Superficial infection 1(3)
- Superficial dehiscence 2(6)
- Return to OR 2(6)

IWBAT = immediate weight bearing as tolerated
In both of these studies, patients were made non-weight bearing for six to eight weeks postoperatively. In our series, even though two-thirds of patients were allowed immediate post-operative weight bearing, the complication rate was lower (11.8%) than what has been reported. One patient developed a malunion, which was asymptomatic without hardware failure and was observed. Two patients had superficial wound dehiscence, which were treated with local wound care and both healed uneventfully by secondary intention. Lastly, one patient developed a wound infection, which was successfully treated with a return trip to the operating room for a superficial irrigation and debridement with hardware retention. There was no identified association between post-operative weight bearing status and complications; however, this study is likely underpowered to detect such a difference.

An important aspect of the proposed surgical protocol was augmented fixation techniques in patients with poor bone stock. This included frequent use of antiglide or buttress plating, quadricortical screws through the fibula and tibia at the apex of the fracture, and bicortical medial malleolus screws. These techniques offer enhanced fixation and their use is supported in the literature. Schaffer and Manoli conducted biomechanical studies looking at posterolateral antiglide plates vs direct lateral neutralizing plates for short oblique fractures. They found an antiglide plate to be stiffer, stronger, and require more energy to failure compared to a lag screw and neutralization plate. However, the difference was not clinically significant. More recently, in another biomechanical cadaveric study, Minihane et al studied this comparison specifically in the setting of osteoporotic distal fibular fractures and found similar results. When used in an anti-glide manner, one-third tubular plates show increased stability compared to lateral periarticular locking plates. To further neutralize external rotation forces, Panchbhavi et al explored increasing stability with quadricortical screws through the fibula and tibia in an osteoporotic cadaveric biomechanical model. Although their findings did not reach statistical significance, compared to just fibular screws, they found quadricortical screws increased failure torque by 9%; external rotation angle at failure by 24%, and energy observed before failure by 34%. With regards to medial malleolus fixation, Ricci et al investigated lag by design with partially threaded
In a postoperative medical complications as well as one-year patients, finding a significant increase in surgical and specifically at outcomes in 19,648 geriatric ankle fracture large Medicare database study, Kadakia et al looked controlled studies in other orthopedic fields. Besides the obvious savings in health care expenditure, home postoperatively cannot be overstated in the elderly. Sufficiently independent and functional to be discharged safely weight bearing immediately.

The risks and benefits of early weight bearing in geriatric patients after ankle fracture surgery are not well understood. In the younger population, patients with stable osteosynthesis after ankle fracture experienced benefits from IWBAT including quicker return to full unassisted weight bearing, better mobility, decreased calf atrophy, and reduced osteoporotic changes without an increased rate of hardware failure or reduced functional outcomes. In the hip fracture literature, the benefits of early ambulation have clearly been shown in the recovery of elderly patients after surgery. Although the morbidity of ankle fractures may be less than that of hip fractures in the elderly population, protracted immobilization in itself can be detrimental to the overall health of geriatric patients. In geriatric ankle fractures, to our knowledge, there is only one other study comparing early weight bearing to NWB. Lynde et al retrospectively reviewed 211 geriatric ankle fracture patients who underwent open reduction internal fixation. One hundred and sixty-six patients were made NWB and 45 patients were allowed early (<15 days) weight bearing based on surgeon preference. They found no difference in complication rate or hardware failure. This study echoes those findings. However, this study makes an important distinction by removing surgeon bias and replacing it with a standardized protocol. Without differences in complication rates, it was found that the IWBAT group was discharged to home at a significantly higher rate than the NWB group despite being similar in terms of demographics, comorbidities, pre-injury use of ambulatory aids, and pre-injury living situation. The benefit of being sufficiently independent and functional to be discharged home postoperatively cannot be overstated in the elderly. Besides the obvious savings in health care expenditure, discharge to home vs a skilled nursing or rehabilitation facility has been associated with better outcomes in controlled studies in other orthopedic fields. In a large Medicare database study, Kadakia et al looked specifically at outcomes in 19,648 geriatric ankle fracture patients, finding a significant increase in surgical and postoperative medical complications as well as one-year mortality in patients discharged to a facility compared to home. However, this significance was not seen with multivariate analysis suggesting other patient factors may play a more important role in determining one-year mortality following geriatric ankle fractures.

This study has several limitations inherent to any retrospective case series. This was a single surgeon analysis resulting in a relatively small sample size, which may have led to type II errors in detecting differences in outcomes based upon post-operative weight bearing. Furthermore, the evaluation of this treatment protocol was against historical controls rather than a direct comparison. Although we did a subgroup analysis comparing the IWBAT group to the NWB group was conducted, this was based on specific criteria and not randomized. In the subgroup analysis the assumption was made that our criteria for NWB (a disrupted syndesmosis or large posterior malleolus fragment) was not associated with greater injury severity that would impact the patient’s ability to be discharged home, otherwise this could be a confounding variable. Moreover, we did not investigate individual elements of our treatment protocol to determine their specific impact on outcomes. Two of 36 patients did not have appropriate follow up. If both patients had hardware failure, the complication rate would be similar to what has been reported (17%). Lastly, the decision for IWBAT or NWB was based, in part, on subjective criteria as no specific parameters (outside of intraoperative assessment) were employed to indicate the degree of osteoporosis or size of posterior malleolus fragment, which could lead to surgeon’s selection bias. Despite this study supporting immediate weight bearing following surgery for a subset of geriatric ankle fracture patients, a randomized controlled prospective trial looking further at delayed versus immediate postoperative weight bearing is warranted.

**CONCLUSION**

Acceptable outcomes can be reliably obtained when following a standardized approach to geriatric ankle fracture management. Key elements of the studied approach include augmented fixation techniques, immediate weight bearing for select patients, and specific strategies to minimize soft tissue insult. In addition, full weight bearing in select patients does not seem to increase complications and may benefit patients by increasing rate of discharge to home.
REFERENCES


ABSTRACT
Background: Bilateral femur fractures are rare in the pediatric population with few cases reported in the literature. The purpose of this study was to review our institutional experience with a case series of simultaneous bilateral femur fractures to highlight the presentation, treatment, and outcomes of these rare injuries as well as perform a preliminary comparison to similar unilateral femur fractures in order to identify any clinically relevant differences that may guide future management.

Methods: We undertook a retrospective chart review of patients who had presented with simultaneous bilateral femur fractures between 2007 and 2017 with a minimum of 1-year of follow-up. Descriptive information was provided about the case series of bilateral femur fracture patients with subsequent further analysis comparing unilateral and bilateral femur fractures.

Results: Eight patients (7 males, 1 female) were identified after chart review. Mean age at the time of injury was 11 years (8 to 15 years). Mechanism of injury was high energy trauma in 7 of 8 patients. Six of 8 patients presented with at least one significant associated injury. All patients underwent operative fixation bilaterally. Average length of stay was 12 days (range 4-27 days). Four patients required admission to inpatient rehab facility. Complete healing occurred in all patients. One patient experienced unilateral genu valgum deformity treated successfully with growth modulation. Another patient experienced a unilateral bony bar of approximately 20% of the physis which did not result in angular deformity or limb length discrepancy. After comparing to a matched unilateral femur fracture cohort, we found that patients who sustained bilateral femur fractures had a significantly higher number of associated injuries as well as greater length of stay (p<0.05). There was no statistical difference in complications.

Conclusions: Our case series illustrates the presentations and outcomes of this rare injury pattern in children along with a few potential differences that distinguish bilateral femur fractures from unilateral fractures. These results may help guide healthcare personnel in making management decisions regarding this rare injury.

Level of Evidence: IV
Keywords: trauma, femur fracture

INTRODUCTION
Pediatric femur fractures are relatively common injuries with an annual incidence of approximately 19 per 100,000. Bilateral femur fractures are much less common, with an unknown incidence. In the pediatric population, these fractures occur in a bimodal distribution with most occurring at 2-3 years of age as well as 17-18 years of age. Most femur fractures in children are typically caused by high energy trauma such as car accidents or falls, while low energy fractures are rare and usually due to genetic, metabolic, or endocrine disorders. The treatment for these fractures may include traction, cast immobilization, external fixation, or internal fixation using plate and screws or intramedullary nails. Complications following unilateral femur fractures have been well described before and include wound infection, re-fracture, nonunion/malunion, avascular necrosis, growth arrest, and limb-length discrepancy. However, the management and complications following bilateral femur fractures have not been well examined.

The current literature on pediatric bilateral femur fractures is limited to sparse case reports. The purpose of this study was to review our institutional experience with a case series of simultaneous bilateral femur fractures and highlight the presentation, treatment, and outcomes of these rare injuries as well as perform a comparison to similar unilateral femur fractures in order to identify any clinically relevant differences that may guide...
future management. We hypothesized that simultaneous bilateral femur fractures would have initially greater severity at time of presentation due to higher energy trauma and also have worse outcomes and/or a higher incidence of complications.

METHODS

A retrospective review of a prospectively collected institutional femur fracture database was conducted for patients aged 0-18 years who presented with bilateral femur fractures between 2007 and 2017. Institutional review board approval was obtained before performing this study. All patients had a minimum of 1-year follow up. We performed a retrospective review of these patients. Data was collected which included demographics, mechanism of injury, fracture location, pattern, treatment modality, length of stay, physical therapy usage, return to activity, and short/long-term complications. Descriptive information was provided about the case series of bilateral femur fracture patients. Subsequent further analysis was conducted to compare unilateral and bilateral femur fractures in a 2:1 fashion. Unilateral femur fractures that met case matched criteria (identical age, gender, and fracture location) were identified from the same femur fracture database.

Descriptive statistics was performed to obtain frequencies and measures of central tendency (mean, median). All categorical data was initially analyzed using Pearson Chi-Squared test or Fisher’s Exact test for statistical significance. Continuous variables were analyzed using t-test or Mann-Whitney U test, if non-parametric. P<0.05 was considered significant for all statistical tests. Analyses were performed using SPSS (IBM Corp, Armonk, NY) statistical software.

RESULTS

We identified 8 children with simultaneous bilateral femur fractures (Figure 1). The mean age at the time of injury was 10.8±2.7 years (range: 7-15 years). 7 of 8 patients were male. The mechanism of injury was high energy trauma in 7 of 8 patients, including five instances of pedestrians struck by a motor vehicle. One patient sustained bilateral femur fractures after a ground level fall in the setting of Duchenne Muscular Dystrophy and osteoporosis. Six patients had at least one significant associated injury, including four patients with traumatic brain injury (TBI), four patients with intra-abdominal injuries, and two patients with spinal fractures.

All injuries were closed. 12 out of 16 fractures involved the femoral shaft, three involved the distal femur physis, and one was intertrochanteric. All patients underwent operative fixation bilaterally. Method of fracture fixation
Simultaneous Bilateral Femur Fractures in Children

Table 1. Clinical Characteristics of Unilateral vs. Bilateral Femur Fractures

<table>
<thead>
<tr>
<th></th>
<th>Unilateral Cohort</th>
<th>Bilateral Cohort</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Age (years)</td>
<td>10.8</td>
<td>10.1</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Males</td>
<td>14</td>
<td>6</td>
</tr>
<tr>
<td>Females</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Mean Number of Associated Injuries</td>
<td>0.4</td>
<td>2.9</td>
</tr>
<tr>
<td>Mean Length of Stay</td>
<td>4.5 days</td>
<td>12.9 days</td>
</tr>
<tr>
<td>Mean Number of Complications</td>
<td>0.5</td>
<td>0.7</td>
</tr>
</tbody>
</table>

*This table excludes the Duchenne’s patient from the Bilateral cohort.

varied according to patient age as well as fracture location and pattern. Treatment options included rigid/flexible Intramedullary Nailing (IMN), Plate/Screw constructs, and Closed Reduction with Percutaneous Pinning (CRPP). Average length of stay was 12 days (range 4-27 days). Four patients required admission to inpatient rehab facility.

There were no mortalities in the perioperative period or at long term follow up. All fractures went on to union. There were no instances of infection or re-fracture. One patient experienced unilateral genu valgum deformity treated successfully with medial hemi-epiphysiodesis and plating. Another patient experienced a unilateral bony bar of approximately 20% of the physis which did not result in angular deformity or limb length discrepancy. Patients returned to full activity at an average of 5.8 months respectively (range 3-9 months).

One bilateral femur fracture case involving a patient with Duchenne’s muscular dystrophy was excluded from the following comparisons. Subsequent analysis was conducted comparing seven bilateral femur fracture cases to 16 unilateral femur fracture cases that were matched according to age, gender, and fracture location (Table 1). There were no statistically significant differences found between the bilateral and unilateral groups when comparing age and gender. The number of associated injuries at time of presentation was different, with the bilateral fractures cohort having a significantly greater number of associated injuries (p<0.05). Two patients required blood transfusion in the bilateral cohort, one of whom had sustained multiple abdominal injuries. No patients required blood transfusion in the unilateral cohort. Average length of stay in the bilateral group was 12.9 days compared to 4.5 days in the unilateral group, which was found to be statistically significant (p<0.05). The mean number of complications in the unilateral patient cohort was 0.5, compared to 0.7 in the bilateral cohort. The difference in complications between the two groups was not found to be significant (p>0.05). Average number of months required to return to activity was also not significantly different between the bilateral and unilateral groups (p>0.05).

DISCUSSION

Bilateral femur fractures in the pediatric population are rare injuries that have not been well described in the literature so far. Here we presented a case series of 8 such patients, the largest of its kind to our knowledge, along with complications and outcomes following minimum 1-year follow-up. Subsequent comparisons to similarly matched unilateral femur fractures were also made.

As one would expect, patients with bilateral femur fractures had a statistically significant greater number of associated injuries at time of presentation. These associated injuries included traumatic brain injuries, multiple fractures, and cardiothoracic/abdominal injuries. This is most likely attributed to the greater trauma/force sustained in order to produce bilateral fractures in comparison to the force needed to produce a unilateral fracture. High impact pedestrian-motor vehicle accidents were the cause of injury for 6 out of 8 patients in our series. Length of stay was also found to be significantly greater in the bilateral group. Though the mean number of fracture related complications was different in the two groups, this was not found to be statistically significant.

Few cases of bilateral femur fractures have been reported in the literature. Most are related to high speed trauma. Scott et al. reported bilateral proximal femur fractures in a 4-year old following an ATV injury. The patient underwent bilateral open reduction and internal fixation which was complicated by left hip avascular necrosis. Smith reported a case of a 4-year old who presented with bilateral femoral shaft fractures after a high speed MVA. The patient was treated with flexible intramedullary nailing and had an uneventful recovery. Conners and Ochsenschlager also reported a case of a 9-month old child who sustained bilateral femoral shaft fractures after a high-speed motor vehicle accident. The patient was managed with prolonged spica casting. Dhar reported a case of a 9-year old girl who presented with bilateral femoral neck fractures following a motor vehicle accident. The patient was managed with early open reduction and internal fixation with a successful outcome. These reports are consistent with the results of our series, where we noted that most pediatric bilateral femur fractures are associated with high speed trauma, particularly pedestrian struck injuries.

Mortality after bilateral femoral fractures in the adult population ranges from 6-32%. In the adult literature, deep vein thrombosis/pulmonary embolism, hemorrhage,
and pneumonia have been reported as potential serious complications.\(^2\) Although we observed a high incidence of associated injuries in this series, we found no instances of mortality. It is well described that children have different physiologic response to trauma that is functionally and mechanistically different compared to adults.\(^23\) Pediatric patients have decreased systemic inflammatory activation which may be protective against mortality in the polytrauma situation.\(^24\)\(^25\)

There are numerous limitations to this study. Despite being the largest series of patients with bilateral pediatric femur fractures, the sample size remains relatively small and is retrospective in nature. As a result, comparisons to the unilateral group would benefit from a larger cohort. In addition, this was a heterogeneous group of surgeons treating patients over a long period of time at a large, tertiary care hospital which may not be representative of the typical management of these injuries at other institutions. Other limitations include the reliability of analyzing a retrospective database- with results being dependent on the accuracy of medical record data collection and coding which are often subject to physician/other medical professional error and bias. Finally, longer term follow-up is necessary to accurately assess complications.

**CONCLUSION**

This report of 8 patients demonstrates that bilateral femur fractures in the pediatric population are commonly a result of high energy trauma and highlights the importance of careful preoperative evaluation. Although bilateral femur fractures may have worse initial presentation, greater length of stay, and more complicated multi-specialty management, once appropriately treated, their short term outcomes and complications are similar to their unilateral counterparts. We believe that with coordinated pediatric trauma care, successful management is possible as with the majority of patients in this series.

**REFERENCES:**


ABSTRACT

Background: Many US health care institutions have adopted compensation models based on work relative value units (wRVUs) to standardize payments and incentivize providers. Among other factors, a major determinant of payment and wRVU assignments is operative time. Our objective was to determine whether differences in estimated operative times between the Centers for Medicare & Medicaid Services (CMS) and the National Surgical Quality Improvement Program (NSQIP) contribute to payment and wRVU misvaluation for the most common hospital-based hand and upper extremity procedures.

Methods: Data on wRVUs, surgeon payment, and estimated operative times were collected from CMS for 53 procedures. We used regression models to compare relationships between these variables, in addition to actual median operative times as reported in the NSQIP database, from 2011 to 2016. We then determined the relative valuation of each procedure based on operative time.

Results: There was a wide discrepancy between CMS and NSQIP operative times ($R^2=0.49$), with 60% of CMS times being longer than NSQIP times. Payment correlated more strongly with CMS operative times ($R^2=0.55$) than with NSQIP operative times ($R^2=0.24$). Similarly, wRVUs more strongly correlated with CMS operative times ($R^2=0.84$) than with NSQIP operative times ($R^2=0.51$). In general, for trauma-related procedures, any distal radius open reduction internal fixation (ORIF) had the highest valuation while any ORIF proximal to the distal radius had lower valuation in analysis of both databases. While 61% of trauma procedures were highly valued, 70% of elective procedures had a low valuation, including nearly all elective tendon procedures. Notable compensation differences were found between trapeziectomy versus ligament reconstruction and tendon interposition, epicondyle debridement with tendon repair versus denervation, proximal row carpectomy versus four corner fusion, and distal radius open versus percutaneous fixation.

Conclusions: CMS may misvalue payment and wRVU rates of hospital-based hand procedures due to inaccurate operative time estimates. By identifying which procedures are misvalued in terms of payment and wRVU per operative time, providers and payors may be able to address these imbalances and maximize appropriate care delivery incentives.

Level of Evidence: III

Keywords: Centers for Medicare & Medicaid Services, National Surgical Quality Improvement Program, operative time, payment, relative value unit, hand surgery, proximal row carpectomy, ligament reconstruction tendon interposition, four corner

INTRODUCTION

Over the past two decades, reimbursement rates in hand surgery have been declining.1 During the same period, there has been continued pressure for providers to reach and maintain productivity and revenue goals. Many measures of surgeon productivity are based on the work relative value unit (wRVU), a metric that the Centers for Medicare & Medicaid Services (CMS) uses to quantify the work associated with procedures based on Current Procedural Terminology (CPT) codes. Despite the many criticisms of this system2-3 and multiple studies showing a poor correlation with perioperative workload, surgical complexity, and operative time4-10 in various surgical fields, no viable alternative has been presented. Currently, the wRVU-based compensation model continues to be a primary measure of surgeon productivity and forms the basis of many employment contracts.

While wRVU valuation is multifactorial, a major component is based on operative time. CMS estimates operative time for each CPT code based on surveys conducted by surgical specialty societies on behalf of the

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1The John Hopkins University, Department of Orthopedics and Rehabilitation, Baltimore, MD
2Curtis National Hand Center, Union Memorial Hospital, Baltimore, MD
Corresponding Author: Suresh K. Nayar; Phone: (410) 955-9663; Email: snayar2@jhmi.edu
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American Medical Association (AMA). These estimates may not correlate well with actual, “real world” operative times recorded in other databases, such as the National Surgical Quality Improvement Program (NSQIP). NSQIP was developed in part to track hospital complications and serves as a robust resource for perioperative variables from actual patient surgical encounters, including operative time. There have been efforts led by CMS to identify services that are misvalued because of inaccurate operative times. Imbalances between procedure effort and associated reimbursement may potentially create incentives that guide practice patterns away from procedures supported by available evidence.

In this study, we determine how well CMS payment and wRVU allotment for common hospital-based hand procedures correlate to both CMS (estimated by surgical specialty societies on behalf of the AMA) and NSQIP (aggregate of actual recorded operative times taken from patient medical records) operative times. We then determine payment and wRVU rates based on operative time and assess which procedures may have higher or lower valuation based on inconsistencies across these two databases. Our objective was to determine whether inaccuracies in estimated CMS operative times compared to reported NSQIP operative times are associated with payment and wRVU misvaluation for the most common hospital-based hand and upper extremity procedures.

**METHODS**

Work relative value units and physician payment were collected from CMS for all isolated, hospital-based hand and upper extremity procedures (by CPT code). These procedures were performed in a facility, non-office setting. To include the most commonly performed surgeries, we only included surgeries from CMS with total recorded volumes greater than 1,000. These institutions include all facilities, academic and non-academic, that participate in Medicare. These procedures included any orthopaedic trauma distal to the elbow and any elective soft tissue procedures distal to the shoulder joint. This yielded 83 CPT codes. Both operative time (defined as skin incision to closure) and perioperative time (which includes pre-evaluation, positioning, draping, scrubbing, skin incision to closure, and post-service times) estimates from CMS were recorded for these codes.

Median operative times (variable, “optime,” defined as skin incision to closure) were similarly collected from the NSQIP database for 2011 through 2016 using the same list of 83 procedures. Thirty procedures had zero entries in the NSQIP database, giving a final procedure count for 53 CPT codes (Appendices 1 and 2). Median operative time was used to exclude any particular procedure that was excessively long, short, or potentially miscoded. Median time was also used to indirectly reflect average surgeon experience. Only procedure encounters with a single CPT code were used in our analysis. NSQIP does not collect perioperative data for routine hand surgeries with low morbidity and complication rates, such as carpal tunnel release, trigger finger release, and ulnar nerve decompression.

**RESULTS**

wRVU, payment amounts, and operative times for these 53 procedures are shown in Appendices 1 and 2. There was a wide discrepancy between CMS and NSQIP operative times ($R^2=0.49$) (Table 1), with 60% of CMS times being longer than NSQIP times. Payments were more strongly correlated with CMS operative times ($R^2=0.55$) than with NSQIP operative times ($R^2=0.24$). Similarly, wRVUs were more strongly correlated with CMS operative times ($R^2=0.84$) than with NSQIP operative times ($R^2=0.51$). Payments versus operative times are shown in (Figures 1A & B). How far each procedure deviates above or
below the regression line shows the extent to which the procedure has a higher or lower valuation compared to all other procedures analyzed, respectively (Figures 2A and B). In general, for trauma-related procedures, any distal radius open reduction internal fixation (ORIF) was found to be more highly valued while any ORIF proximal to the distal radius was valued relatively lower, according to both CMS and NSQIP operative times. Per NSQIP operative time, 39% of trauma procedures had a valuation lower than the predicted payment (lower than the regression line) in comparison to 70% of elective procedures.

Notable elective procedures where NSQIP operative time was shorter than CMS included: upper extremity muscle flaps (CPT 15736, 50-minute difference) epicondyle debridement with tendon repair (CPT 24359, 25-minute difference), and extensor tendon release (CPT 25000, 14-minute difference). Common elective

Figure 1. Payment versus operative time according to A, Centers for Medicare & Medicaid Services (CMS) and B, National Surgical Quality Improvement Program (NSQIP) data for 53 hand and upper extremity procedures. Data points above the regression lines represent procedures that are compensated at a higher amount per operative time compared with the other procedures analyzed. Conversely, data points below the regression lines are compensated at a lower amount.

Figure 2. Calculated procedure compensation based on Centers for Medicare & Medicaid Services (CMS) and National Surgical Quality Improvement Program (NSQIP) operative time data. CPT codes are divided into A, trauma and B, elective subsets. Codes to the right of the y-axis are more highly-compensated, whereas those to the left have lower compensation. These percentages show how much each procedure deviates from the regression lines shown in Figure 1. For example, an intra-articular distal radius fracture (>3 fragments, code 25609) has an associated payment of $1,286, which is 84% more than that calculated by using NSQIP operative time (Figure 1B) and 29% more than that calculated by using CMS operative time ($998, Figure 1A). IA, intra-articular; EA, extra-articular; ORIF, open reduction internal fixation; amp, amputation; MCPJ, metacarpophalangeal joint; IPJ, interphalangeal joint; CMC, carpometacarpal joint; TFCC, triangular fibrocartilage complex; IC, intercarpal.
procedures where NSQIP operative time was longer than CMS included tendon transplant/transfer at the forearm/wrist (CPT 25310, 22-minute difference), distal ulna excision (CPT 25240, 20-minute difference), and metacarpophalangeal joint arthroplasty (CPT 26531, 32-minute difference). Notable trauma-related procedures where NSQIP operative time was shorter than CMS included: intra-articular distal radius ORIF with >3 fragments (CPT 25609, 45-minute difference), phalangeal percutaneous pinning (CPT 26727, 20-minute difference), and metacarpal (ray) amputation (CPT 26910, 38-minute difference). Trauma procedures where NSQIP operative time was longer than CMS included: metacarpal ORIF (CPT 26615, 10-minute difference), flexor tendon repair in Zone 2 (CPT 26356, 20-minute difference), tendon/muscle repair in the forearm and wrist (CPT 25360, 21-minute difference).

Amongst this list of 53 surgeries, there were pairs of procedures that have similar indications with appreciable differences in valuation. In the discussion, we focus on trapeziectomy versus ligament reconstruction and tendon interposition (LRTI), epicondyle debridement with tendon repair vs. denervation, proximal row carpectomy (PRC) vs. four corner fusion (4CF), and distal radius ORIF versus percutaneous fixation of distal radius fractures (Appendices 1 and 2). While these comparisons do not represent an exhaustive list, there is robust evidence in the literature showing equivalent patient outcomes between these surgeries.

DISCUSSION

For the most common hospital-based hand and upper extremity procedures, there is a wide difference between CMS and NSQIP operative times, indicating potential misvaluation of certain procedures in terms of wRVU and payment per minute of operative time. Although the expected strong correlation between wRVU and CMS operative time was seen in our results, there was a weaker correlation with actual (NSQIP) operative time. Further, poor correlation was observed between payment and NSQIP operative time. Distal radius ORIF tended to be more highly valued while ORIF proximal to the distal radius was less valued. Nearly all tendon procedures had a lower valuation relative to other procedures based on surgical time (Fig. 2), a concerning finding given the extensive post-operative rehabilitation requirements not included in our analysis. The majority (70%) of elective procedures analyzed in the NSQIP database had lower valuation than predicted. A thorough understanding of these findings is important to establish appropriate revenue goals for providers. This may be particularly beneficial in a scenario where a patient has two surgical options with similar or equivocal indications, but when each surgery has different payment rates and wRVU assignments.

The findings in Figure 2A and B illustrate several examples where compensation can be augmented to better align provider and patient incentives. For example, the treatment of thumb CMC arthritis with either simple trapeziectomy (single bone carpectomy without pinning or other fixation) versus trapeziectomy with LRTI has long been debated, yet multiple studies have shown nearly equivalent outcomes for pain, mobility, and strength. Another study showed that LRTI has added risk of infection, reoperation, or other aggressive interventions. Despite this, national trends of LRTI utilization have increased since 2001. In comparing payment and wRVU rates, our study shows that LRTI (CPT 25447, CMC interposition) is the third highest valued elective procedure at +48% (0.16 RVU or $14.34/min) while a single bone carpectomy (CPT 25210) had a relatively low valuation at -33% (0.11 RVU or $7.29/min) per NSQIP operative time (P<0.001 for both RVU and$/min). This comparison also excludes the additional CPT code and compensation for tendon transfer, which further increases the relative value of LRTI. This discrepancy may incentivize LRTI when trapeziectomy alone can be used.

In another example, epicondyle debridement with tendon repair (CPT 24359) was the second highest reimbursing procedure in terms of wRVUs (0.26/min) and payment ($23.60/min), and the third highest valued surgery at +67% per NSQIP operative time. Indications for this procedure include medial or lateral epicondyritis. While most presentations of epicondyritis resolve with conservative treatment, debridement and tendon reattachment may be offered in recalcitrant cases. However, the efficacy of these surgeries has been questioned. A study comparing extensor carpi radialis brevis debridement and repair versus sham treatment (muscle belly exposure only) showed no difference between treatment groups. In a letter to the editor, it was noted that the sham procedure was likely a lateral denervation treatment. Of note, coding as a denervation procedure (CPT 64708) would yield far less payment per CMS operative time at a valuation of -41% compared to +41% for epicondyle debridement.

Our results showed that 70% of elective procedures had relatively low payment in-line with recent findings showing declining hand surgery reimbursement rates. This may help explain the motivation to shift procedures to the in-office/procedure room setting. First, surgeons may offset decreased compensation by negotiating higher professional fees because they are saving insurance companies facility fees by performing these surgeries outside of the hospital. Second, lower payment may
pressure surgeons to seek operative settings where turnover time is minimized to maximize the number of cases performed in an operative day to achieve the same revenue targets. This may also favor the practice of minimizing surgical resources, such as wide-away local anesthesia no tourniquet (WALANT) techniques, that have demonstrated reliable and safe cost-saving measures.28,29 This shift in surgical setting makes it even more challenging to estimate accurate “real world” operative times due to the high degree of heterogeneity in practice and office setting.

One limitation of this study is that NSQIP does not collect perioperative data on several common hand and upper extremity procedures, and therefore a complete analysis for these procedures by operative time cannot be undertaken. For example, NSQIP does not collect data for four-corner fusion (4CF) (CPT 25825). Proximal row carpectomy (PRC) (CPT 25215) and 4CF have both been offered as salvage procedures for wrists with scaphoid nonunion or scapholunate advanced collapse. These procedures have comparable long-term results in terms of grip strength, pain relief, and other subjective measures.30 However, 4CF carries the added risk of nonunion, hardware issues, and dorsal impingement. When analyzed by CMS operative time data, payment for 4CF has a higher valuation of +35% compared to PRC, which is lower at -18%. There were also zero NSQIP entries for percutaneous fixation of distal radius fractures (CPT 25606). Multiple studies have shown nearly equivalent one-year outcomes between percutaneous fixation and volar locking plate fixation despite ORIF costing substantially more than percutaneous fixation.31,32 When analyzed by CMS operative time data, extra-articular distal radius ORIF (CPT 25607) was more highly valued (+77%) than percutaneous fixation (+40%). Although there is some coding heterogeneity for these procedures and the nature of fracture and treatment, this payment difference suggests that percutaneous fixation may be under-compensated.

Other limitations in this study include the inability to capture physician work in the post-operative global care period, which is typically 90 days. This is particularly problematic for tendon procedures because tendon transfers/lengthening can require extensive post-operative rehabilitation and aftercare. We also analyzed CPT codes in isolation from single-code cases when, in practice, multiple codes may be billed in a single case which may decrease per-procedure operative times if a shared surgical approach is used. There is also the possibility that procedures may have been miscoded in the CMS and NSQIP databases. Further, capturing accurate “real world” operative time may be challenging because several factors, such as surgeon experience and type of surgical setting, may affect efficiency. Using NSQIP to estimate operative times may also be inaccurate for other practice types as most NSQIP sites are academic centers or larger institutions; however, as healthcare systems across the country continue to consolidate, NSQIP may become more representative of surgical centers nationally. Finally, we used operative time as a basis for determining procedure valuation. There are other metrics in determining compensation for procedures. However, we aimed to minimize this limitation as we determined valuation of a surgery by comparing payment to similar types of procedures that carry comparable levels of effort, risk, and skill. Although we are unable to directly quantify and include these metrics in our analysis, higher levels of surgeon effort and skill are typically associated with increased operative time.

Despite the limitations of this study and the complex nature of the topic, we have demonstrated multiple scenarios where CMS may misvalue payment and wRVU rates of hospital-based hand procedures due to inaccurate CMS operative time estimates. By revising CMS operative times for certain procedures, associated changes in payment may improve physician compensation models, correct misvaluation-based incentives, and serve as a catalyst to improve the quality and value of elective and trauma-related hand surgery.

REFERENCES


APPENDIX 1. Work relative value units (wRVU) and operative times for common hand and upper extremity procedures by CPT code according to CMS (2015) and NSQIP (2011–2016) data.

Procedures sorted by decreasing wRVU.

<table>
<thead>
<tr>
<th>CPT Code</th>
<th>ACGME Description</th>
<th>wRVUs</th>
<th>Mean CMS-allowed Amount, $</th>
<th>Operative Time, min</th>
<th>Perioperative Time, min</th>
<th>Total Procedures</th>
<th>Operative Time, min</th>
<th>Total Procedures</th>
</tr>
</thead>
<tbody>
<tr>
<td>15736</td>
<td>Muscle flap, upper extremity</td>
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<td>$2,397.50</td>
<td>150</td>
<td>396</td>
<td>1,583</td>
<td>100 (58-171)</td>
<td>386</td>
</tr>
<tr>
<td>25609</td>
<td>Distal radius IA (&gt;3 fragments) ORIF</td>
<td>14.38</td>
<td>$2,860.34</td>
<td>120</td>
<td>358</td>
<td>21,875</td>
<td>75 (55-103)</td>
<td>3765</td>
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<tr>
<td>25320</td>
<td>Carpal stabilization</td>
<td>12.75</td>
<td>$2,888.07</td>
<td>120</td>
<td>452</td>
<td>1,180</td>
<td>90 (63-128)</td>
<td>492</td>
</tr>
<tr>
<td>25575</td>
<td>Radial and ulnar shaft ORIF</td>
<td>12.29</td>
<td>$1,797.80</td>
<td>90</td>
<td>342</td>
<td>1,336</td>
<td>83 (60-138)</td>
<td>725</td>
</tr>
<tr>
<td>25447</td>
<td>Arthroplasty, interposition, IC or CMC</td>
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<td>378</td>
<td>29,021</td>
<td>69 (49-94)</td>
<td>3981</td>
</tr>
<tr>
<td>25608</td>
<td>Distal radius IA (2 fragments) ORIF</td>
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<td>305</td>
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<td>67 (50-91)</td>
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<tr>
<td>25115</td>
<td>Excision of bursa, flexor tendons, wrist</td>
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<td>4,802</td>
<td>27 (18-43)</td>
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<tr>
<td>24666</td>
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<td>286</td>
<td>1,236</td>
<td>92 (68-134)</td>
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<tr>
<td>26746</td>
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<td>$739.02</td>
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<td>303</td>
<td>1,207</td>
<td>57 (37-84)</td>
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<tr>
<td>26356</td>
<td>Repair flexor tendon (Zone 2)</td>
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<td>80 (56-111)</td>
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<td>90</td>
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<td>29,021</td>
<td>69 (49-94)</td>
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</tr>
<tr>
<td>24341</td>
<td>Tendon/muscle repair upper arm/elbow</td>
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<td>73 (54-97)</td>
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<tr>
<td>24359</td>
<td>Epicondyle debridement with tendon repair</td>
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<tr>
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<td>Proximal ulna ORIF</td>
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<td>60</td>
<td>252</td>
<td>9,065</td>
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<td>2233</td>
</tr>
<tr>
<td>25215</td>
<td>Proximal row carpectomy</td>
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<td>$626.75</td>
<td>86</td>
<td>269</td>
<td>1,751</td>
<td>80 (58-106)</td>
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<td>26531</td>
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<td>62</td>
<td>215</td>
<td>2,838</td>
<td>94 (61-141)</td>
<td>266</td>
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<td>Tendon transplant/transfer, forearm/wrist</td>
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<td>11,830</td>
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<tr>
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<td>1,153</td>
<td>71 (46-109)</td>
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<tr>
<td>25545</td>
<td>Ulna shaft ORIF</td>
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<td>$480.60</td>
<td>60</td>
<td>286</td>
<td>1,802</td>
<td>58 (44-84)</td>
<td>464</td>
</tr>
<tr>
<td>26910</td>
<td>Amp ray</td>
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<td>$637.05</td>
<td>88</td>
<td>251</td>
<td>1,409</td>
<td>50 (30-80)</td>
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<tr>
<td>24305</td>
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<td>$532.12</td>
<td>63</td>
<td>209</td>
<td>1,079</td>
<td>66 (46-90)</td>
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<td>25116</td>
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<td>1,391</td>
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<td>26735</td>
<td>Phalanx shaft (proximal or middle) ORIF</td>
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<td>$592.56</td>
<td>60</td>
<td>237</td>
<td>1,932</td>
<td>60 (40-83)</td>
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<tr>
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<td>Lengthening/shortening tendon, forearm/wrist</td>
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<td>$398.36</td>
<td>53</td>
<td>195</td>
<td>1,678</td>
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<td>Metacarpal ORIF</td>
<td>7.07</td>
<td>$824.64</td>
<td>45</td>
<td>217</td>
<td>2,548</td>
<td>55 (38-77)</td>
<td>2637</td>
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<tr>
<td>26480</td>
<td>Tendon transfer, CMC area or dorsal hand</td>
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<td>$478.64</td>
<td>60</td>
<td>222</td>
<td>13,601</td>
<td>65 (45-94)</td>
<td>249</td>
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<td>29846</td>
<td>Arthroscopy, wrist, TFCC repair/excision</td>
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<td>$565.72</td>
<td>72</td>
<td>179</td>
<td>2,181</td>
<td>56 (39-81)</td>
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<tr>
<td>CPT Code</td>
<td>ACGME Description</td>
<td>wRVUs</td>
<td>Mean CMS-allowed Amount, $</td>
<td>CMS Operative Time, min</td>
<td>CMS Perioperative Time, min</td>
<td>Total Procedures</td>
<td>Operative Time, min^c</td>
<td>Total Procedures</td>
</tr>
<tr>
<td>-----------</td>
<td>----------------------------------------------------</td>
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<td>------------------</td>
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<td>------------------</td>
</tr>
<tr>
<td>25295</td>
<td>Tenolysis, forearm/wrist</td>
<td>6.72</td>
<td>$384.28</td>
<td>48</td>
<td>191</td>
<td>2,295</td>
<td>33 (20-62)</td>
<td>266</td>
</tr>
<tr>
<td>26540</td>
<td>Collateral ligament repair MCPJ or IPJ</td>
<td>6.60</td>
<td>$333.19</td>
<td>54</td>
<td>204</td>
<td>1,731</td>
<td>44 (32-61)</td>
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<tr>
<td>26536</td>
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<td>$806.22</td>
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<td>1,763</td>
<td>76 (50-62)</td>
<td>266</td>
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<tr>
<td>26952</td>
<td>Amp thumb/finger phalanx, w/ local flap</td>
<td>6.48</td>
<td>$548.28</td>
<td>43</td>
<td>173</td>
<td>2,086</td>
<td>32 (23-52)</td>
<td>475</td>
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<tr>
<td>64702</td>
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<td>6.26</td>
<td>$369.10</td>
<td>50</td>
<td>212</td>
<td>1,247</td>
<td>37 (23-62)</td>
<td>257</td>
</tr>
<tr>
<td>25210</td>
<td>Carpectomy, single bone</td>
<td>6.12</td>
<td>$400.82</td>
<td>53</td>
<td>194</td>
<td>3,093</td>
<td>55 (40-87)</td>
<td>301</td>
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<tr>
<td>25020</td>
<td>Decompression fasciotomy forearm/wrist</td>
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<td>$730.36</td>
<td>54</td>
<td>204</td>
<td>1,408</td>
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<td>146</td>
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<tr>
<td>26951</td>
<td>Amp thumb/finger phalanx, direct closure</td>
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<td>$479.96</td>
<td>30</td>
<td>203</td>
<td>8,011</td>
<td>30 (21-45)</td>
<td>988</td>
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<tr>
<td>26437</td>
<td>Realignment of extensor tendon, hand</td>
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<td>$444.13</td>
<td>51</td>
<td>183</td>
<td>2,447</td>
<td>45 (31-70)</td>
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<tr>
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<td>$511.19</td>
<td>45</td>
<td>217</td>
<td>1,506</td>
<td>40 (26-61)</td>
<td>505</td>
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<tr>
<td>26593</td>
<td>Release, intrinsic muscles</td>
<td>5.50</td>
<td>$349.85</td>
<td>68</td>
<td>233</td>
<td>1,234</td>
<td>50 (25-99)</td>
<td>25</td>
</tr>
<tr>
<td>26525</td>
<td>Capsulectomy/capsulotomy IPJ</td>
<td>5.50</td>
<td>$479.07</td>
<td>44</td>
<td>175</td>
<td>2,044</td>
<td>50 (32-83)</td>
<td>251</td>
</tr>
<tr>
<td>26520</td>
<td>Capsulectomy/capsulotomy MCPJ</td>
<td>5.47</td>
<td>$431.69</td>
<td>45</td>
<td>176</td>
<td>1,033</td>
<td>59 (29-86)</td>
<td>133</td>
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<tr>
<td>25290</td>
<td>Tenotomy, forearm/wrist</td>
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<td>$337.44</td>
<td>35</td>
<td>164</td>
<td>2,994</td>
<td>41 (26-61)</td>
<td>83</td>
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<tr>
<td>26277</td>
<td>Phalnax percutaneous pinning</td>
<td>5.42</td>
<td>$541.91</td>
<td>47</td>
<td>174</td>
<td>2,896</td>
<td>27 (19-41)</td>
<td>1115</td>
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<tr>
<td>25240</td>
<td>Excision distal ulna (Darrach)</td>
<td>5.31</td>
<td>$434.73</td>
<td>46</td>
<td>176</td>
<td>1,655</td>
<td>66 (45-109)</td>
<td>169</td>
</tr>
<tr>
<td>26440</td>
<td>Tenolysis, flexor tendon, palm/finger</td>
<td>5.16</td>
<td>$453.35</td>
<td>43</td>
<td>162</td>
<td>2,988</td>
<td>39 (19-68)</td>
<td>576</td>
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<tr>
<td>26410</td>
<td>Extensor tendon hand repair</td>
<td>4.77</td>
<td>$413.17</td>
<td>43</td>
<td>162</td>
<td>1,629</td>
<td>40 (28-60)</td>
<td>570</td>
</tr>
<tr>
<td>25118</td>
<td>Synovectomy, extensor, wrist</td>
<td>4.51</td>
<td>$527.53</td>
<td>40</td>
<td>158</td>
<td>2,627</td>
<td>30 (19-52)</td>
<td>220</td>
</tr>
<tr>
<td>26418</td>
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<td>$436.57</td>
<td>39</td>
<td>153</td>
<td>2,804</td>
<td>35 (24-50)</td>
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</tr>
<tr>
<td>26445</td>
<td>Tenolysis extensor tendon, hand or finger</td>
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<td>$382.51</td>
<td>37</td>
<td>137</td>
<td>2,038</td>
<td>38 (23-62)</td>
<td>457</td>
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<tr>
<td>24105</td>
<td>Excision of olecranon bursa</td>
<td>3.78</td>
<td>$431.00</td>
<td>35</td>
<td>143</td>
<td>5,708</td>
<td>31 (21-44)</td>
<td>1075</td>
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<tr>
<td>25000</td>
<td>Incision extensor tendon (deQuervain’s)</td>
<td>3.55</td>
<td>$431.99</td>
<td>33</td>
<td>135</td>
<td>12,383</td>
<td>19 (13-27)</td>
<td>1888</td>
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<tr>
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<td>$431.68</td>
<td>41</td>
<td>140</td>
<td>8,498</td>
<td>28 (20-39)</td>
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</tr>
<tr>
<td>23030</td>
<td>Abscess drainage shoulder</td>
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<td>$238.03</td>
<td>36</td>
<td>152</td>
<td>1,139</td>
<td>27 (17-48)</td>
<td>303</td>
</tr>
</tbody>
</table>

ACGME, Accreditation Council for Graduate Medical Education; CMS, Centers for Medicare & Medicaid Services; CPT, Current Procedural Terminology; NSQIP, National Surgical Quality Improvement Program; wRVU, work relative value unit; IA, intra-articular; EA, extra-articular; MC, metacarpal; ORIF, open reduction internal fixation; amp, amputation; MCPJ, metacarpophalangeal joint; IPJ, interphalangeal joint; CMC, carpometacarpal joint; TFCC, triangular fibrocartilage complex; IC, intercarpal. CMS data for CPT 64708 (release of nerve of arm): CMS data, 6.36 wRVU; allowed payment $348.65; intraservice time: 60 min; perioperative service time: 220 min; total procedures: 34.

^NSQIP Both NSQIP and CMS measure operative time from skin incision to closure. Data presented as median (interquartile range).

^CMS perioperative time includes pre-evaluation, positioning, scrubbing, intra-service, and immediate post-service time.

^Median operative time
APPENDIX 2. Payments and wRVUs per minute of operative time according to CMS and NSQIP data for 53 common hand and upper extremity procedures.

Procedures sorted by decreasing payment/minute per CMS operative time. Note that payment and wRVU rates may value substantially when using NSQIP operative time.

<table>
<thead>
<tr>
<th>CPT Code</th>
<th>ACGME Description</th>
<th>CMS Payment/minute, $</th>
<th>CMS wRVUs/minute</th>
<th>NSQIP Payment/minute, $</th>
<th>NSQIP wRVUs/minute</th>
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<tbody>
<tr>
<td>26615</td>
<td>Metacarpal ORIF</td>
<td>$18.33</td>
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<td>$14.99</td>
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<td>26951</td>
<td>Amp thumb/finger phalanx, direct closure</td>
<td>$18.27</td>
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<td>25607</td>
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<tr>
<td>26356</td>
<td>Repair flexor tendon (Zone 2)</td>
<td>$14.85</td>
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<td>Epicondyle debridement with tendon repair</td>
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<td>25020</td>
<td>Decompression fasciectomy forearm/wrist</td>
<td>$13.53</td>
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<td>25118</td>
<td>Synovectomy, extensor, wrist</td>
<td>$13.19</td>
<td>0.11</td>
<td>$17.58</td>
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<tr>
<td>25000</td>
<td>Incision extensor tendon (deQuervain’s)</td>
<td>$13.09</td>
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<tr>
<td>25608</td>
<td>Distal radius IA (2 fragments) ORIF</td>
<td>$12.83</td>
<td>0.12</td>
<td>$17.23</td>
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<tr>
<td>26952</td>
<td>Amp thumb/finger phalanx, w/ local flap</td>
<td>$12.75</td>
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<tr>
<td>26536</td>
<td>Arthroplasty IPJ</td>
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<tr>
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<td>26727</td>
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<tr>
<td>26765</td>
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<tr>
<td>26418</td>
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<td>26525</td>
<td>Capsulectomy/capsulotomy IPJ</td>
<td>$10.89</td>
<td>0.13</td>
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</tr>
<tr>
<td>25609</td>
<td>Distal radius IA (&gt;3 fragments) ORIF</td>
<td>$10.72</td>
<td>0.12</td>
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<tr>
<td>25076</td>
<td>Excision tumor, forearm/wrist</td>
<td>$10.71</td>
<td>0.15</td>
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<tr>
<td>26440</td>
<td>Tenolysis, flexor tendon, palm/finger</td>
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<tr>
<td>25111</td>
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<tr>
<td>26445</td>
<td>Tenolysis extensor tendon, hand or finger</td>
<td>$10.34</td>
<td>0.12</td>
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<tr>
<td>25447</td>
<td>Arthroplasty, interposition, IC or CMC</td>
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<td>0.11</td>
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<tr>
<td>26735</td>
<td>Phalanx shaft (proximal or middle) ORIF</td>
<td>$9.88</td>
<td>0.12</td>
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<tr>
<td>26540</td>
<td>Collateral ligament repair MCPJ or IPJ</td>
<td>$9.87</td>
<td>0.12</td>
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<td>24685</td>
<td>Proximal ulna ORIF</td>
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<td>0.14</td>
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<td>25290</td>
<td>Tenotomy, forearm/wrist</td>
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<td>0.13</td>
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<tr>
<td>26410</td>
<td>Extensor tendon hand repair</td>
<td>$9.61</td>
<td>0.11</td>
<td>$10.33</td>
<td>0.12</td>
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<tr>
<td>26520</td>
<td>Capsulectomy/capsulotomy MCPJ</td>
<td>$9.59</td>
<td>0.12</td>
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<tr>
<td>25240</td>
<td>Excision distal ulna (Darrach)</td>
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<td>0.12</td>
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<tr>
<td>25116</td>
<td>Excision of bursa, wrist/forearm</td>
<td>$9.35</td>
<td>0.13</td>
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<td>25260</td>
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<td>0.16</td>
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<td>0.11</td>
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<td>26745</td>
<td>MCPJ or IPJ ORIF</td>
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<td>25575</td>
<td>Radial and ulnar shaft ORIF</td>
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<td>26437</td>
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<td>CPT Code</td>
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<tr>
<td></td>
<td></td>
<td>Payment/minute, $</td>
<td>wRVUs/minute</td>
<td>Payment/minute, $</td>
<td>wRVUs/minute</td>
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<td>24305</td>
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<td>0.12</td>
<td>$8.06</td>
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<td>25320</td>
<td>Carpal stabilization</td>
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<td>$10.98</td>
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<tr>
<td>25115</td>
<td>Excision of bursa, flexor tendons, wrist</td>
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<td>0.11</td>
<td>$27.10</td>
<td>0.37</td>
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<tr>
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<td>0.11</td>
<td>$10.01</td>
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<td>26531</td>
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<td>25545</td>
<td>Ulna shaft ORIF</td>
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<td>0.13</td>
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<td>0.14</td>
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<tr>
<td>25295</td>
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<td>0.14</td>
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<td>26480</td>
<td>Tendon transfer, CMC area or dorsal hand</td>
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<td>29846</td>
<td>Arthroscopy, wrist, TFCC repair/excision</td>
<td>$7.86</td>
<td>0.10</td>
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<td>25280</td>
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<td>64702</td>
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<td>26910</td>
<td>Amp ray</td>
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<td>Tendon transplant/transfer, forearm/wrist</td>
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<td>$5.14</td>
<td>0.08</td>
<td>$7.00</td>
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</table>

ACGME, Accreditation Council for Graduate Medical Education; CMS, Centers for Medicare & Medicaid Services; CPT, Current Procedural Terminology; NSQIP, National Surgical Quality Improvement Program; wRVU, work relative value unit; IA, intra-articular; EA, extra-articular; MC, metacarpal; ORIF, open reduction internal fixation; amp, amputation; MCPJ, metacarpophalangeal joint; IPJ, interphalangeal joint; CMC, carpometacarpal joint; TFCC, triangular fibrocartilage complex; IC intercarpal.
ABSTRACT

Background: Recent changes in healthcare have placed increased emphasis on price transparency, quality measures, and improving the patient experience. However, limited information is available for patient cost of obtaining a hip MRI and factors associated with cost variability. For a patient with femoroacetabular impingement (FAI), this study sought to report (1) the availability of pricing and quality information for a hip magnetic resonance imaging (MRI) in the state of Iowa, (2) the time investment required to obtain pricing and quality information, and (3) factors that influence hip MRI cost, quality and the time investment required for patients to obtain cost and quality information.

Methods: Within the state of Iowa, 126 unique hospital institutions and 30 active, private orthopaedic practices were identified. All 156 providers were contacted via telephone using a standardized script of a hypothetical 25-year-old adult male patient with FAI requesting a quote for a hip MRI. Cost of the MRI and its components, availability of payment discounts, and MRI magnet tesla (T) were requested. A final bundled cost (FBC) was calculated for each MRI provider with all available services and discounts applied. The total amount of time needed to obtain a quote from each location was recorded.

Results: One hundred and thirty-six of the 156 institutions contacted provided hip MRI services (87%). Median call duration was 9.1 minutes (Range 2.3-25.6). Median FBC was $2,114.00 (Range $484.75-4,463.00) across all providers. Hospital median FBC was $2,261.70 (Range $909.62-4,463.00) versus $1,225.13 (Range $484.75-2,218.40) for independent imaging centers (P<0.0001). No difference in median cost was observed between nine available 3.0 T machines and eighty-nine 1.5 T machines (P=0.2655).

Conclusions: MRI cost varies widely across the state of Iowa and within individual metropolitan areas. Hip MRIs cost less at independent imaging centers compared to hospital locations. The amount of time required to obtain quality and cost data for a hip MRI presents a substantial time burden for patients with FAI. Surgeons, healthcare systems, and policy makers should be cognizant of the large price differences for a hip MRI and the time burden placed on patients with FAI to obtain this information.

Level of Evidence: IV

Keywords: femoroacetabular impingement (fai), magnetic resonance imaging (mri), cost analysis, imaging quality

INTRODUCTION

Lack of transparency in cost and quality information for healthcare services causes patients confusion when attempting to understand what they are purchasing. From a patient and healthcare systems perspective, understanding price and quality information is important as healthcare spending continues to climb and projects to account for greater than 20% of the U.S. gross domestic product in the coming years. Previous authors have proposed that increasing the availability of cost and quality data to patients and hospitals would drive the price for healthcare services down due to competition. Additionally, access to pricing information helps individuals that may need to pay out of pocket for...
healthcare services due to lack of insurance or high deductibles that are attractive for individuals seeking a low monthly cost, such as younger patients.  

Femoroacetabular impingement (FAI) is an increasingly recognized clinical entity that typically affects a young patient population. 7,9 Surgical correction of FAI can alleviate symptoms and improve patient function. 8,9 The diagnostic imaging exams of choice for FAI include hip radiography and cross-sectional imaging including hip magnetic resonance imaging (MRI). 9,10 11 Hip MRI provides critical information regarding the extent of hip disease and, from an economic perspective, leads to substantial and variable out of pocket costs. 10,12

For a hypothetical patient with FAI, this investigation sought to report (1) the availability of pricing and quality information for a hip MRI in the state of Iowa, (2) the time investment required to obtain pricing and quality information, and (3) factors that influence hip MRI cost, quality and the time investment required for patients to obtain this information.

### METHODS

This study was deemed Institutional Review Board exempt. Hospitals within the state of Iowa were identified using the Iowa Hospital Associates (IHA) database that provides contact information on all hospital institutions within the state. Additionally, Iowa Orthopaedic Society (IOS) member data was utilized to identify 30 active orthopaedic practices that may have an associated imaging center.

All hospitals and orthopaedic practices were contacted via telephone using a scripted query of a hypothetical, 25-year-old male patient diagnosed with FAI (Appendix A) regarding the cash price for a non-contrast MRI of the right hip (CPT code 73721). A maximum of two phone calls were initiated with each location. Similar to previously utilized methods, a call was defined as an attempt to make initial contact via telephone with a location. 13 Transfers to different departments or referrals to call another number resulting from a call were considered part of a single call. Likewise, if a message was left at a location regarding obtaining a quote and that message was returned within three business days, this still qualified as a single call. Messages from a call not returned within three business days, calls that resulted in a location not willing to disclose a quote due to lack of patient information, and calls ending without the opportunity to leave a message were considered a complete call. Any subsequent initiated contact was classified as a second call attempt. Time elapsed to obtain cost and quality information was recorded and defined as starting with any automated or live person response to a call and ending when the call was disconnected. For locations requiring the hypothetical patient to call another number, the timer was not stopped while being connected with the new location. At locations where messages were left, the timer was stopped after disconnecting the initial call and restarted if the message was returned.

All hospital locations that were contacted were considered “hospital MRI” providers whereas all independent orthopaedic practices that were contacted were considered “independent MRI” providers. Of the 126 hospital institutions identified using IHA data, 116 facilities provided hip MRI services. Using IOS data, 20 independent orthopaedic practices offered hip MRI services. In addition to requesting pricing imaging providers were asked if a discount or other financial incentives were available if services were paid for in full using cash or debit up front. Details regarding the components of the MRI price quote, such as radiology reading fees, service charges, and facility fees were asked of locations in order to quantify the amount each component contributed to the final bundled cost (FBC) (Table 1). The FBC consisted of the full amount the hypothetical patient would be billed for all exam components provided by the location (MRI, read, discountetc.), when paying up front with cash or debit on the date of service. Locations offering pricing data were also asked about the quality of their machine in terms of Tesla (T) as machines with higher Tesla values can provide no discrete value for discount or stated no discounts are offered for up-front cash payment; Median (Range)

![Table 1. Breakdown of Cost Estimates for a MRI of the Hip by Included Components (N=114)](https://example.com/table1.png)

<table>
<thead>
<tr>
<th>Components Included</th>
<th>Sample Size</th>
<th>Median Value USD</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRI Technical Exam</td>
<td>N=27</td>
<td>$1,658.2 (484.75-4,090.50)</td>
</tr>
<tr>
<td>Radiology Fee</td>
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<td></td>
</tr>
<tr>
<td>Applicable Discount</td>
<td>N=30</td>
<td>$1,847.48 (909.62-3,803.75)</td>
</tr>
<tr>
<td>MRI Technical Exam</td>
<td>N=22</td>
<td>$2,412.50 (900.00-4,463.00)</td>
</tr>
<tr>
<td>Radiology Fee</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MRI Technical Exam</td>
<td>N=35</td>
<td>$2,392.00 (857.00-3,500.00)</td>
</tr>
</tbody>
</table>

*Table 1. Breakdown of Cost Estimates for a MRI of the Hip by Included Components (N=114)*

<table>
<thead>
<tr>
<th>Location Type</th>
<th>Sample Size</th>
<th>Median Call Time in Minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical Access Hospital</td>
<td>70</td>
<td>9.6 (3.1-25.6)</td>
</tr>
<tr>
<td>Urban Hospital</td>
<td>15</td>
<td>7.4 (2.3-25.6)</td>
</tr>
<tr>
<td>Rural Hospital</td>
<td>13</td>
<td>7.8 (2.8-16.7)</td>
</tr>
<tr>
<td>Independent Imaging Provider</td>
<td>16</td>
<td>8.8 (4.1-22.5)</td>
</tr>
</tbody>
</table>

*Table 2. Median Call Time by Location Type*
improve the detection of cartilage lesions. Attempts to obtain MRI Tesla data via internet search were made for locations where the institution could not provide the data over the phone or failed to return a message asking for MRI Tesla. Internet resources for Tesla data included institution websites listing the MRI Tesla, press releases listing MRI Tesla, and public meeting minutes reporting the approval of MRI machine purchases.

Moreover, hospitals were also classified based on the Centers for Medicare and Medicaid services (CMS) designations listed on the IHA website. The different classifications within our study were "critical access hospital," "urban," "rural," or "rural-referral center." Additionally, locations were classified as metropolitan and non-metropolitan per the United States Office of Management and Budget that can be found at https://www.iowadatacenter.org/aboutdata/statisticalareas. A total of nine metropolitan areas exist in Iowa and are as follows: Ames; Cedar Rapids; Davenport-Moline-Rock Island, IA-IL; Des Moines-West Des Moines; Dubuque; Iowa City; Omaha-Council Bluffs, NE-IA; Sioux City, IA-NE-SD; Waterloo-Cedar Falls.

Descriptive statistics were performed, and the normality of quantitative continuous variables was evaluated using the Shapiro-Wilk test and through exploratory plots (e.g. histograms and Q-Q plots). Because continuous variables were not normally distributed, they were described using median (min-max) values, and between group comparisons were made using the Wilcoxon Rank Sum Test. We constructed frequency distributions for qualitative categorical variables. Statistical significance was set at an alpha level of 0.05. SAS Statistical Software version 9.4 was utilized for all analyses (SAS Institute, Inc., Cary, NC).

RESULTS

One hundred and thirty-six (87.2%) of the 156 hospitals and independent orthopaedic practices contacted provided hip MRI services. One-hundred and fourteen of the 136 (83.8%) hip MRI providers were willing to provide pricing information. Ninety-eight of the 114 locations providing pricing data were hospitals with their own MRI capabilities, while 16 quotes were obtained through independent orthopaedic practices. One hundred and twelve locations provided a discrete price for the actual MRI, 49 were able to comment on radiology reading fees, and MRI Tesla data was collected for 98 of the 114 locations (86%). Ninety-seven of the locations (85%) providing a quote required one patient-initiated call, with 17 (15%) requiring two calls. Median call duration was 9.1 minutes (Range 2.3-25.6 minutes) with no differences in call duration by location type or CMS designation (Table 2). Comparison of call duration for hospital locations versus independent orthopaedic practices demonstrated no difference (Table 3). Classifying locations according to metropolitan status yielded no differences in call time needed to obtain a quote (Table 4).

Median FBC for MRI among all locations was $2,114 (Range $484.75-4,463.00), while median price for only the MRI component was $2,376.77 (Range $685.62-4,475.00). Median FBC stratified by CMS criteria was $2,234.50 (Range $987.00-4,090.50) for Critical Access Hospitals (CAHs), $2,600.00 (Range $909.62-3,500.00) for Urban, $2,871.60 (Range $1,379.40-3,803.75) for Rural-Referral, and $2,148.00 (Range $295.44-4,463.00) for Rural. Significant differences were observed between CAHs and Rural-Referral locations for both FBC (P=0.0472) and MRI technical exam price (P=0.0442). Hospital based MRI providers had a median FBC of $2,261.70 (Range $909.62-4,463.00) versus $1,225.13 (Range $484.75-2,218.40) for quotes obtained through independent orthopaedic practices (P<0.0001). Likewise, a significant difference

| Table 3. IHA location versus Independent Center Call Times |
|------------------|------------|------------------|
| Location Type    | Sample Size | Median Call Time in Seconds |
| IHA Member       | 98         | 9.3 (2.3-25.6) |
| Independent Imaging Provider | 16 | 8.8 (4.1-22.5) |
| Reported as: Median (Range) |

| Table 4. Median Call Time by Metropolitan Status |
|------------------|------------|------------------|
| Metropolitan Status | Sample Size | Median Call Time in Seconds |
| Yes               | 37         | 8.7 (2.3-25.6) |
| No                | 77         | 9.6 (2.7-25.6) |
| Reported as: Median (Range) |

| Table 5. Final Bundled Cost of Hip MRI by Metropolitan Status |
|------------------|------------|------------------|
| Metropolitan Status | Sample Size | Median Cost |
| Yes               | 37         | $2,080.00 (484.75-4,047.00) |
| No                | 77         | $2,148.00 (925.44-4,463.00) |
| Reported as: Median (Range) |

| Table 6. Final Bundled Cost of Hip MRI by Machine Tesla Rating |
|------------------|------------|------------------|
| Tesla Rating     | Sample Size | Median Cost |
| 1.5T             | 89         | $2,148.00 (484.75-4,463.00) |
| 3.0T             | 9          | $1,800.00 (1,047.20-2,910.38) |
| Reported as: Median (Range) |

Prior authors have reported substantial variability in the price of MRI imaging services. These studies have highlighted the importance of transparency in healthcare pricing and quality, as well as the challenges patients face in obtaining this information. In an effort to understand the variability in hip MRI pricing and quality across a specific geographic location and the factors that may affect pricing and quality, we sought to collect and analyze data for these services in the state of Iowa. The objective of this investigation was to provide a comprehensive analysis of pricing and quality for hip MRI services in the state, with a focus on the potential impact of geographic location, provider type, and patient demographics.

**Methods**

For this study, we collected pricing and quality data from various sources, including hospital-based and independent orthopedic practices, imaging centers, and other healthcare providers. Pricing information was obtained through direct quotes from these providers, while MRI quality was assessed based on factors such as the availability of advanced imaging equipment (e.g., Tesla magnets). The data collection process involved contacting providers within a metropolitan area and in non-metropolitan areas, with the goal of obtaining information from at least 20% of all locations that provide adult hip MRI services in the state.

**Results**

Our findings indicate that there is considerable variability in the price of MRI services across Iowa. For example, the median MRI technical exam price for hospital-based locations was $2,472.50, while independent orthopedic practices charged $1,391.00. This difference is statistically significant (P<0.0001). The variability in MRI quality was also observed, with some locations providing advanced imaging equipment (Tesla) and others utilizing less expensive options.

**Discussion**

Price and quality transparency are crucial in the modern healthcare environment, particularly in the context of rising costs and the need for patient-centered care. Our study highlights the importance of understanding the factors that contribute to the variability in MRI pricing and quality. These factors include the type of provider, geographic location, and patient demographics. Further, the data collected suggest that transparency programs focused on a single item, such as MRI, may not provide a comprehensive view of healthcare pricing.

**Conclusion**

Our findings suggest that there is a need for improved transparency in healthcare pricing and quality information. Patients and healthcare providers alike would benefit from having access to real-time, accurate, and up-to-date information about MRI costs and quality options. This information could help patients make informed decisions about their healthcare and provide healthcare providers with insights into areas where they may need to improve pricing or quality.

Figure 1. Schematic representation showing proximity of hip Magnetic Resonance Imaging providers, associated price, and available Tesla data in a metropolitan area.
surrounding area to find the best price for their financial situation. Providers of hip MRI services should be ready to make detailed information regarding their pricing structures and options available to inquiring patients. Additionally, patients and those ordering hip MRIs should be aware of other hip MRI services in close proximity that could offer a potentially higher or comparable quality service at a similar or lower price (Figure 1). Future investigations should consider factors such as travel costs and lost time at work when considering how to determine the best and most economical location to obtain imaging studies in the setting of FAI.

We report that the median disclosed FBC of a hip MRI was 46% less ($1,225.13 vs $2,261.70) at independent imaging centers, and the median technical exam portion cost was 44% less ($1,391.00 vs $2,472.50). Higher efficiency due to specialization, in addition to lower facility associated costs, may help further explain this observed difference. In addition, access to imaging services varies based on geographical location, and differences in operational costs among locations has been noted in other studies, both of these factors may influence costs. Using metropolitan and CMS criteria (Urban, CAH, Rural, Rural-Referral) the only significant difference observed was between CAHs and Rural-Referral locations for both MRI technical component price and FBC. When comparing locations with 3.0T MRIs to those with only 1.5T machines, no difference in price or FBC was observed. This lack of difference between 3.0T and 1.5T machines presents an interesting concept, in that the attributed cost for an MRI did not vary based on scan quality, as 3.0T MRIs have been reported to be superior for detecting joint pathology. As evident by significantly higher costs seemingly unrelated to quality, healthcare consumers paying out of pocket for imaging services should be aware of the factors contributing to the price they are charged for these services and consider non-hospital associated imaging alternatives for hip MRI studies.

This study has several limitations. First, the data collected was confined to only the state of Iowa, meaning it may not be generalizable to the entire U.S. or any other state. However, Iowa resident’s personal health care spending per capita was $8,200 in 2014, only $155 more than the national average of $8,045, and ranked 27th out of 51 locations (States and District of Columbia), which makes it more appropriate for national extrapolation than high or low spending locations. Next, to maintain uniformity we utilized a young patient paying out of pocket in cash who best represents Iowa residents that are uninsured, underinsured, or have high-deductible health plans, all of which are increasingly common in the current healthcare environment. Thus, these results may be less applicable to the majority of insured Iowans and other alternatively insured populations, but still help highlight the complexity of payment for medical services. Further, although we requested discrete values for all associated fees in this study, not all locations were able to provide complete information. Moreover, this study only evaluated pricing information for non-contrast MRIs, but other procedures such as magnetic resonance arthrography may be routinely utilized by orthopaedic surgeons evaluating patients for FAI. In addition, the data collected to identify independent imaging providers was restricted to locations associated with physicians that are members of the Iowa Orthopaedic Society, which may have limited the number of locations we identified and contacted, possibly excluding some independent imaging providers. Finally, using MRI tesla as a proxy for exam quality is an unavoidable limitation as the quality of an exam is dependent on many factors such as scanning technique and reader reliability, which this study could not evaluate.

Overall, there is high variability in the cost for a hip MRI in the state of Iowa. We report the cost of a hip MRI is less when obtained through independent orthopaedic practices than hospital locations. We also find the amount of time spent obtaining price and quality information presents a significant time burden for patients with FAI. Patients, surgeons and healthcare systems should be cognizant of the potential large price differences between hip MRI service providers in their geographic area.

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MASKS FOR THE REDUCTION OF METHYL METHACRYLATE VAPOR INHALATION

Jocelyn Compton, MSc, MD; Jayson Clinger, MS; Ericka Lawler, MD; Jesse Otero, PhD, MD; Patrick O'Shaughnessy, PhD

INTRODUCTION

Poly-methyl methacrylate bone cements contain methyl methacrylate (MMA), a substance known for its sensitizing and toxic properties. MMA is a volatile organic compound utilized for the production of co-polymer methacrylate-butadiene-styrene in a variety of total joint reconstruction procedures.

Due to its potentially hazardous properties, the US Occupational Safety and Health Administration (OSHA) permissible exposure limit for MMA is 100 parts per million (ppm) over an 8 hour work day. The concentrations of MMA in immediate breathing zones can vary widely in the operative suite. MMA is known to irritate the respiratory system mucosa. The developmental effects such as skeletal abnormalities and low birth weight have been documented in animal studies. However these results are controversial and have not been repeated to examine birth defects at the occupational exposure limit. Nonetheless, it is common practice for pregnant members of the operative team, including nursing staff, anesthesia providers, and surgeons or surgical trainees to leave the operative room during cementing procedures to avoid inhaling MMA.

Although other industries routinely utilize face masks for the reduction of organic vapor inhalation, this method has not been introduced in orthopedic surgery. The purpose of this study was to identify a disposable face mask to reduce MMA organic vapor inhalation in the operative suite in order to reduce occupational exposure to a potentially hazardous substance. With this intervention, we anticipate effecting an improved working environment for surgical personnel and minimizing interruptions in patient care.

METHODS

Determination of MMA Vapor Breakthrough:
The testing system included a cement curing chamber and an exposure chamber. MMA bone cement (Depuy Synthes Companies, Raynham, MA) was mixed as directed in a mixing bowl and placed into the curing chamber. Carrier air flowed through the cement mixing chamber into the exposure chamber at 0.1 liter per minute (LPM) to maintain steady state conditions of approximately 150 MMA ppm in the exposure chamber. A ToxiRae Pro (Rae Systems, San Jose, CA) was utilized...
to measure MMA levels in the exposure chamber, which is sensitive to within 5% of the indicated measurement (8ppm). A representative section of the activated carbon impregnated filtering face mask (Model 8514, 3M Inc., Maplewood, MN) was placed in a pass-through column; the mask section was sealed between two cylinders with an inner diameter of 2.7 cm. This allowed for sampling of air after it passed through the mask and thus was filtered. This system was designed to mimic the air velocity entering an entire face mask while breathing with a mean inspiratory airflow rate of 30 LPM. This air flow rate was based on breathing rates for occupations with high metabolic rate and moderate intensity.6 Trials were conducted until a detectable amount of MMA was achieved in the filtered air. A PPB Rae 3000 (Rae Systems, San Jose, Calif) was used to measure MMA levels of filtered air to within 1 part per billion (ppb). Four trials were performed (Figure 1).

Field Test in the Operating Room During Primary Total Knee Arthroplasty:

The effectiveness of the face mask was evaluated in the operative suite during cement mixing. The face mask was worn as directed by manufacturer instructions on the face under a standard personal protection hood and Flyte surgical helmet system (Stryker, Kalamazoo, MI) by a surgical trainee who aided in both mixing with a mixing bowl and application of the bone cement. The TSI Fit Tester probe kit (Gerson, Olathe, KS) was utilized to allow for sampling of filtered air “behind the mask” by securing a push nut through the mask and securing the tubing to a PPB Rae 3000 detection device. Experiments were performed in laminar airflow operating rooms. As a control, the MMA ppm under the hood was measured with a ToxiRae Pro affixed to the test subject’s scrub neckline near the jaw line to measure MMA ppm in air that would be otherwise inhaled. Three trials were performed (Figure 2).

RESULTS

Determination of MMA Vapor Breakthrough: The testing system included a cement curing chamber and an exposure chamber. MMA bone cement (Depuy Synthes Companies, Raynham, MA) was mixed as directed in a mixing bowl and placed into the curing chamber. Carrier air flowed through the cement mixing chamber into the exposure chamber at 0.1 liter per minute (LPM) to maintain steady state conditions of approximately 150 MMA ppm in the exposure chamber. A ToxiRae Pro (Rae Systems, San Jose, CA) was utilized to measure MMA levels in the exposure chamber, which is sensitive to within 5% of the indicated measurement (8ppm). A representative section of the activated carbon impregnated filtering face mask (Model 8514, 3M Inc., Maplewood, MN) was placed in a pass-through column; the mask section was sealed between two cylinders with an inner diameter of 2.7 cm. This allowed for sampling of air after it passed through the mask and thus was filtered. This system was designed to mimic the air velocity entering an entire face mask while breathing with a mean inspiratory airflow rate of 30 LPM. This air flow rate was based on breathing rates for occupations with high metabolic rate and moderate intensity.6 Trials were conducted until a detectable amount of MMA was achieved in the filtered air. A PPB Rae 3000 (Rae Systems, San Jose, Calif) was used to measure MMA levels of filtered air to within 1 part per billion (ppb). Four trials were performed (Figure 1).

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Masks for the Reduction of Methyl Methacrylate Vapor Inhalation

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DISCUSSION

MMA presents an occupational hazard to the orthopedic surgeon; due to its toxic properties OSHA limits its exposure. Although the effects of MMA fumes on the developing human fetus are unknown, pregnant personnel are commonly encouraged to leave the operating room during the mixing and application of poly-MMA bone cement. Currently, there are no comparable studies in the scientific literature that identify and evaluate personal protective equipment for MMA vapor exposure in the operative setting.

The tested activated carbon impregnated face mask effectively reduced inhalation of MMA vapors from 150 ppm to <1.0 ppm for greater than 40 minutes in the laboratory. In the operating room, filtered air behind the face mask did not show detectable MMA vapor levels throughout the mixing and curing of cement. Thus, the 3M Model 3514 face mask offers a solution for the orthopedic surgeon and supporting personnel who wish to limit their exposure to MMA vapors due to health concerns.

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