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# THE **IOWA** ORTHOPEDIC JOURNAL

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**20  
23**

Published by the residents and faculty of the  
University of Iowa Department of Orthopedics  
and Rehabilitation

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We will consider any original article relevant to orthopedic surgery, orthopedic science or the teaching of either for publication in *The Iowa Orthopedic Journal*. The manuscript submitted will be considered for print or an e-publication. The printed Iowa Orthopedic Journal is released in June and the e-publication is released in December. The deadline to submit to *The Iowa Orthopedic Journal* is January 31 of that year to be considered for either issue. Submissions are not limited to University of Iowa affiliates – all authors are welcome to submit.

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, where it receives 57,000 “hits” per month. Articles previously published will not be accepted unless their content has been significantly changed.

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# THE IOWA ORTHOPEDIC JOURNAL

2023 • Volume 43 • Issue 1

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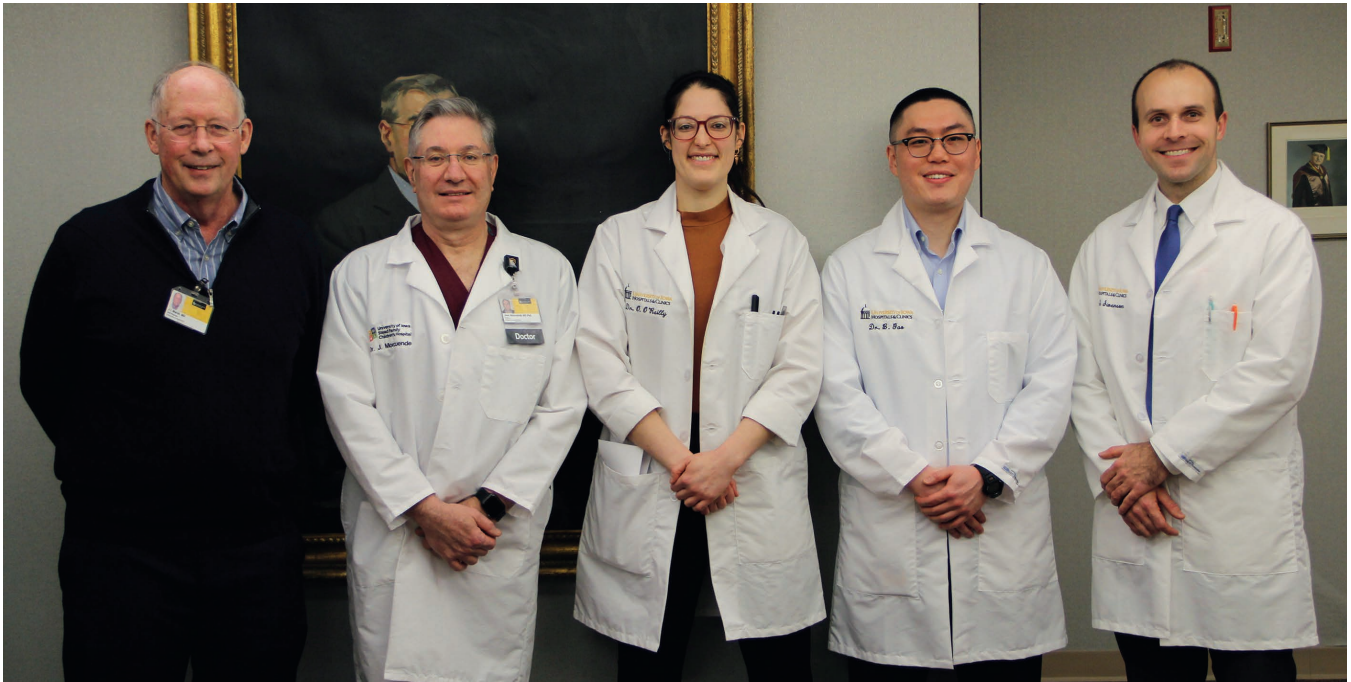
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## 2023 IOJ EDITORS' NOTE



From left to right: Drs. J. Lawrence Marsh (Staff Advisor), Jose Morcuende (Staff Advisor), Olivia O'Reilly (2023 Resident Editor), Burke Gao (2023 Resident Editor), and Samuel Swenson (2023 Resident Business Manager and Editor).

We are pleased to present the 43rd edition of the Iowa Orthopedic Journal (IOJ). We continue to receive submissions from institutions across the United States and world in high numbers, representing all subspecialties in the field, a true breadth and depth of knowledge. Due to the continued success of the IOJ, we are fortunate to continue the tradition of publishing a Fall electronic issue for a fifth consecutive year.

We would like to recognize our graduating class of senior residents: Drs. Joshua Eisenberg, James Kohler, Scott Muffly, Michael Russell, and Malynda Wynn. They set a standard for patient care, education, and departmental culture that we can only hope to continue after their departure. We wish them all the best as they complete their training, move onto fellowship, and start their careers. We will miss their teamwork, leadership, and friendship.

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 Angie Poulsen, who was instrumental in the organization and preparation of this year's IOJ. We thank Dr. Samuel Swenson for his efforts to coordinate corporate sponsors. We also extend thanks to our sponsors for their generous support of the IOJ, as publication would not be possible without their contributions. We thank Dr. Jose Morcuende and Dr.

John Lawrence Marsh for their continued guidance as faculty advisors to the journal. Finally, we would like to recognize Dr. Jacob Henrichsen as Resident Reviewer of the Year for the exceptional quality and quantity of his reviews this year.

It has been a great privilege to serve as this year's editors. The University of Iowa Orthopedics Department provides remarkable training, and we are appreciative of our opportunity to be part of its history and legacy. We are excited for the continued innovation and forward progress in the department, and hope that the readership enjoys this year's publication.

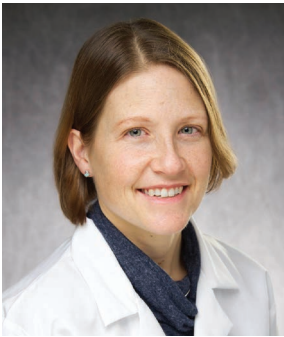
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# 2023 DEDICATION OF THE IOWA ORTHOPEDIC JOURNAL

## ERICKA LAWLER, MD

*Olivia C. O'Reilly, MD, Malynda S. Wynn, MD, Heather R. Kowalski, MD, Katherine M. Staniforth, ARNP*



**Ericka Lawler, MD**

The 2023 edition of the Iowa Orthopedic Journal is dedicated to Dr. Ericka Lawler. We are honored to have experienced Dr. Lawler's teachings, leadership, and mentorship during her time here at The University of Iowa and can think of no one more deserving of this honor.

Dr. Ericka (Andrusiak)

Lawler was born and raised in Woodhaven, Michigan to Karen and Gary Andrusiak. She grew up camping with her family in the great outdoors of Michigan. Her family describes her as "all-everything" in high school, busy with multiple activities including volleyball and soccer. She set a standard for future achievements, as she was the class president, valedictorian, and homecoming queen. For those that have the fortune of knowing Dr. Lawler, this is no surprise.

After a successful high school academic career, Dr. Lawler attended the prestigious Yale University, where she earned a Bachelor of Science in Molecular Biophysics and Biochemistry. She also met her then-future husband Judd in New Haven when they were both undergraduate students. Her academic triumphs continued, and she attended medical school at the George Washington School of Medicine and Health Sciences in Washington, D.C. She graduated in the top percentile of her class, receiving invitation into Alpha

Omega Alpha in 2000. She also received the Robert J. Neviasser Award in Orthopaedic Surgery, the beginning of a lifetime of orthopaedic achievements. She completed her residency training at New York University Hospital for Joint Disease in New York City, where she was treating patients during the terrorist attacks on September 11, 2001. Dr. Lawler developed a passion for hand and upper extremity surgery during her time in New York. She transplanted her talents from the East Coast to Iowa City for her hand and upper extremity fellowship in 2005, where she continued to excel. After fielding many offers, she accepted the position to join the orthopedic faculty at the University of Iowa Hospitals and Clinics in 2006.

Dr. Lawler is a well-respected teacher, role-model, and leader in the Carver College of Medicine. She serves as a mentor to medical students, sharing knowledge through curated lectures at the medical school, as well as inviting medical students into her clinics and operating rooms for one-of-a-kind orthopedic experiences. In 2012, she received the University of Iowa Medical Student Teaching Award for her efforts in medical education and was again recognized in 2021 with the Dr. Ernest O. Theilen Clinical Teaching and Service Award. Her reach extends outside the minds of Iowa medical students, as she served as mentor for visiting orthopaedic sub-interns from across the country participating in the Ruth Jackson-Steindler Orthopaedic Clerkship. Dr. Lawler's influence on young learners is uniquely exemplified in that many of her Ruth Jackson mentees chose to uproot their lives and move across the country to Iowa City to join the orthopaedic residency.



**Dr. Lawler camping in Michigan 1980.**



**Dr. Lawler's residency graduation with her husband Judd and mother Karen.**



Sharing Resources Worldwide Orthopedic Hand Team Fall, 2018.

Dr. Lawler's contributions to orthopaedic training at the University of Iowa are immeasurable. From her daily instruction in both the clinic setting and the operating room, to her dedication to the education of residents, she is an invaluable advocate for training the next generation of orthopaedic surgeons. Her efforts in the development of intern skills month as well as a surgical skills curriculum for junior residents have prepared junior residents for the next steps in their training. Residents and fellows over the years are eager to learn at her feet and relish the opportunity to spend time in her operating room. Her enthusiasm for teaching was revered by leaders in the department, as she was named the Adrian Flatt Hand and Upper Extremity Fellowship Director in 2014, taking over the very fellowship that she graduated from in 2006. She was also appointed Vice Chair of Diversity in 2018, and Associate Program Director of the orthopaedic surgery residency in 2021. In recognition of her tireless dedication to the residency, the residents chose her as the Faculty Teacher of the Year in 2021.



The Annual Women in Ortho Welcome Brunch.



Dr. Caldwell, Dr. Lawler, Dr. Seiler, and Dr. Fowler.

Dr. Lawler is well regarded in the world of academia and research. She has published numerous peer-reviewed articles in high impact journals, book chapters, and textbooks. She has received multiple grants for her work in the field of hand surgery and resident education. Dr. Lawler is a reviewer for multiple journals, including Clinical Orthopaedics and Related Research, the Journal of Bone and Joint Surgery, and the Journal of Hand Surgery. She is repeatedly invited to give lectures at multiple national meetings, including the National Association of Orthopaedic Nurses, American Society for Surgery of the Hand, and the American Orthopaedic Association. She is a nationally-recognized leader in the world of hand surgery and resident education.

Dr. Lawler's philanthropic efforts do not go unnoticed. She volunteered her time year after year with Kids Go STEM and Girls Go STEM, outreach programs dedicated to inspiring youth to join the fields of medicine and engineering. She helped organize the Iowa Perry Initiative outreach program to encourage young women to pursue



Dr. Lawler, Dr. Caldwell, Dr. Kowalski, and Dr. Olinger taking a stand against discrimination and bullying in orthopedics.





An orthopedic gathering.



Orthopedic Halloween party with Claire and Henry in 2010.



Dr. Lawler with her children Claire and Henry.

orthopaedic surgery and engineering as future careers, both disciplines in which women are underrepresented. Her works span geographical borders. She serves as an organizer of Sharing Resources Worldwide, a medical missions group bringing surgical care to underserved populations. Dr. Lawler helps plan mission trips to Siguatepeque, Honduras and travels with the group, performing surgery on children with congenital hand deformities. She looks forward to resuming the mission in the upcoming year after being on hiatus during the COVID pandemic.

Outside of the operating room, Dr. Lawler spends what free time she has staying busy. Reading, making photo albums, cooking, playing board games – she will do it all. She enjoys traveling on vacations with her family, hiking and camping across the country. She once backpacked through the Grand Canyon while six months pregnant. Nothing can stop her. She has a passion for

animals, and is currently hatching chicks and raising them to lay their own eggs while chasing around the family dog. She keeps her family nearby, as her parents are her neighbors. She continues to be a supermom to her children Henry and Claire, and has found a new educational pursuit – teaching Henry to drive.

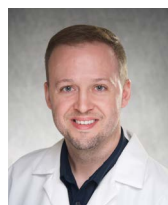
Her accomplishments are many, but do not even begin to describe the reach of Ericka Lawler. She is truly “hands-on” in everything she does, bad puns notwithstanding. She is a fierce advocate for her residents and colleagues, a dedicated surgeon to her patients, supportive mentor, and exceptional mother, wife, and friend. Her light has only begun to shine in the world of orthopaedics, and the University of Iowa is fortunate to have been a part of her journey. We are grateful for her contributions and are honored to have been a part of her story. We dedicate this journal to her in recognition of her excellence, and only hope to live up to her legacy.



## DEPARTMENT OF ORTHOPEDICS AND REHABILITATION FACULTY 2022-2023



Dr. Donald Anderson



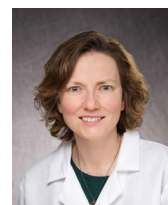
Dr. Adam Arendt



Dr. Eric Aschenbrenner



Dr. Rahul Bijlani



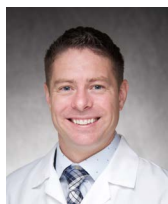
Dr. Heather Bingham



Dr. Matthew Bollier



Dr. Joseph Buckwalter IV



Dr. Joseph Buckwalter V



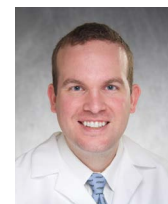
Dr. Lindsey Caldwell



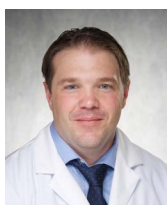
Dr. Philip Chen



Dr. Cesar de Cesar Netto



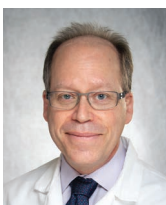
Dr. Kyle Duchman



Dr. Jacob Elkins



Dr. Ashlee Enzinger



Dr. John Femino



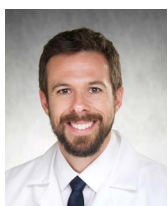
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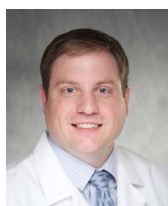
Dr. Kara Gange



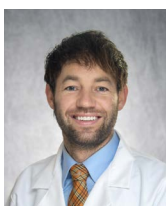
Dr. Jessica Goetz



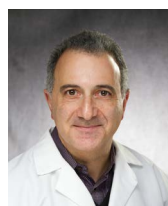
Dr. Mederic Hall



Dr. Matthew Hogue



Dr. Joshua Holt



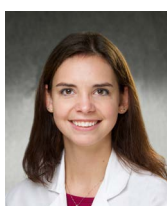
Dr. Cassim Igram



Dr. Matthew Karam



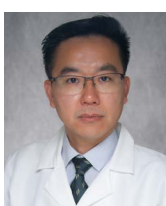
Dr. Valerie Keffala



Dr. Heather Kowalski



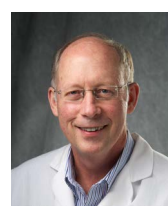
Dr. Ryan Kruse



Dr. Hongshuai Li



Dr. Megan Lundstrom



Dr. J. Lawrence Marsh



Dr. James Martin



Dr. Benjamin Miller



Dr. Jose Morcuende



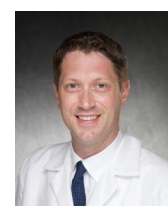
Dr. James Nepola



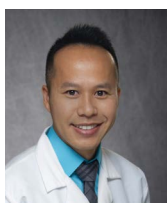
Dr. Nicolas O. Noiseux



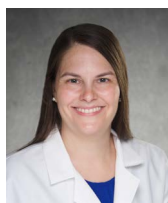
Dr. Catherine Olinger



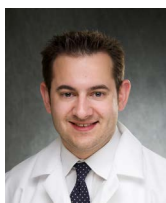
Dr. Brendan Patterson



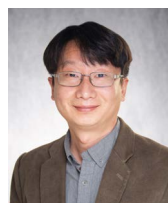
Dr. Than Pham



Dr. Sarah Polk



Dr. Andrew Pugely



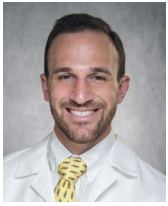
Dr. Dong Rim Seol



Dr. Jennifer Rogers



Dr. Brett Rosauer



Dr. Andrew Schwartz



Dr. Kathleen Vonderhaar



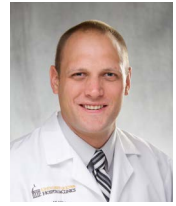
Dr. Ling Wang



Dr. Stuart Weinstein



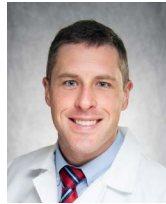
Dr. Robert Westermann



Dr. Michael Willey



Dr. Brian Wolf



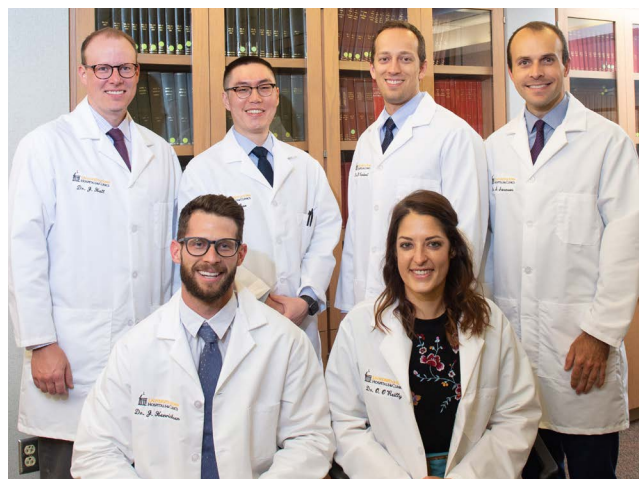
Dr. Steven Zehring



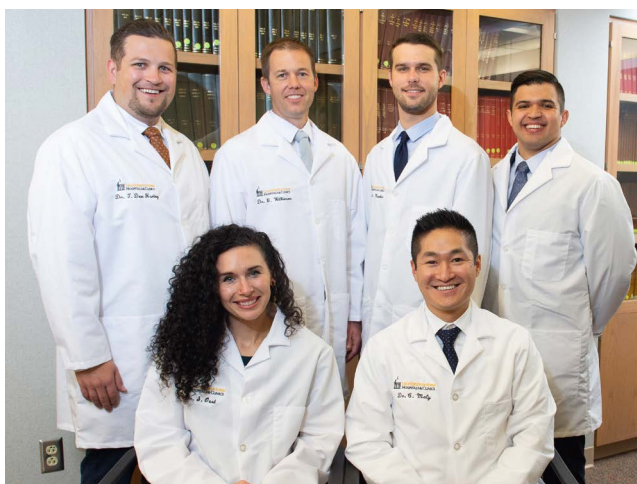
## DEPARTMENT OF ORTHOPEDICS AND REHABILITATION RESIDENTS 2022-2023



**PGY5-Class of 2023.** Back row (left to right): Drs. Michael Russell, Malynnda Wynn, and Scott Muffly. Front row (left to right): Drs. James Kohler and Joshua Eisenberg.



**PGY4-Class of 2024.** Back row (left to right): Drs. James Hall, Burke Gao, James Cardinal, and Samuel Swenson. Front row (left to right): Drs. Jacob Henrichsen and Olivia O'Reilly.



**PGY3-Class of 2025.** Back row (left to right): Drs. Taylor Den Hartog, Brady Wilkinson, Daniel Meeker, Edward Rojas. Front row (left to right): Drs. Sarah Ryan and Connor Maly.



**PGY2-Class of 2026.** Back row (left to right): Drs. Brandon Marshall, Michael Orness, Garrett Christensen. Front row (left to right): Drs. Joseph Rund, Mary Kate Skaltitzky, and Kyle Geiger.



**PGY1-Class of 2027.** Back row (left to right): Drs. Steven Leary, Austin Benson, Arianna Dalamaggas. Front row (left to right): Drs. Hannah Korrell, Alex Demers, and Ryan Guzek.

## 2023 GRADUATING ORTHOPEDIC RESIDENTS



***Joshua Eisenberg, MD***

Joshua was born in Spring Grove, IL to Mark and Brenda Eisenberg. Growing up in a small blue-collar town between Chicago and Milwaukee, his parents taught Josh and younger sister Jordan the early importance of work ethic and dedication.

Josh graduated from Richmond-Burton High School in 2010. He was a three-sport athlete competing in Football, Wrestling and Track. During

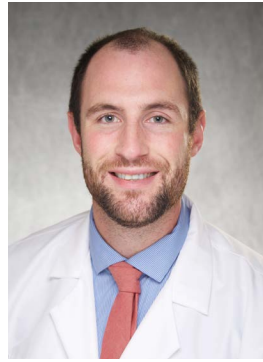
the winters he also raced snowmobiles where he rose to the semi-pro level in snocross. Early on Josh wanted to follow in his father's footsteps as an aircraft mechanic, however developed a love for science in high school, and decided to pursue medicine. Josh chose to attend Augustana College in Rock Island, IL, mostly because of the nice trees on campus. During his years in college, he competed in the Decathlon earning All-American recognition and he still holds the indoor Heptathlon school record to this day.

Josh attended Loyola Stritch School of Medicine in Chicago, IL. He got involved with research early on in Dr. John Callaci's lab looking at the effects of binge alcohol consumption on fracture healing. Already a connoisseur of adult beverages, he developed an interest in orthopedics. Josh came to the University of Iowa during his last year of medical school as a rotating student, and after the first day realized this was the best orthopedic residency in the country.

While at Iowa, Josh developed an interest in large database studies particularly in the spine population. Under the guidance of Dr. Andrew Pugely, they were able to identify modifiable risk factors that affect outcomes in spine surgery. Iowa has been known for its long-term patient outcomes studies which gave Josh the idea for his current senior project, Long Term Outcomes Following Tibial Plafond Fractures. Like many Iowans, he also has not ventured very far from home.

Following graduation Josh will pursue a fellowship in spine surgery at Emory University in Atlanta, Georgia. He has come to terms that he will be more than 200 miles from home. Josh and his fiancée Taylor will plan to return to the Midwest following fellowship

Josh would like to thank his parents for their continued support throughout this journey. His wife Taylor for keeping him level-headed. Dr. Igram for believing in him while he was a medical student along with Drs. Pugely and Weinstein for their continued mentorship and support. Finally, he would like to thank his co-residents and all the staff that have joined him for happy hour or a day out on the lake.



***James Kohler, MD***

James was born and raised in Ames, IA where he spent the first 18 years of his life. Growing up in central Iowa, he enjoyed all things outdoors. He participated in sports year-round and was always out fishing on the local rivers whenever there was down time. His father was a research scientist for the USDA and his mother was a social worker. He chose to attend The University of Evansville in Indiana for college,

where he competed four years for the baseball team. Following undergraduate education, he was fortunate to return to Iowa for medical school.

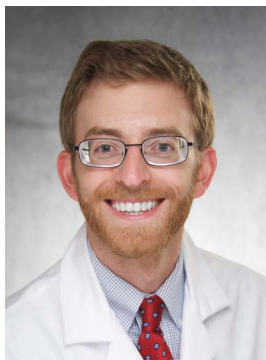
James' initial interest in medicine and the field of orthopedics is hard to pin down. Perhaps it was the combination of a science background from his father and humanitarian background from his mother. Perhaps it was his interest in manual labor and dexterous work. Or perhaps it was his love for engaging in sports or outdoor hobbies, and the ability to connect with patients by seeing them succeed in similar endeavors. Regardless of how or when it occurred, James ultimately found a deep interest in caring for patients and the field of orthopedics. He was fortunate to match into the Iowa Orthopedic residency upon completing medical school to continue his training.

James found interest in clinically based projects, with the goal of answering clinically relevant questions that may be directly applied to patient care. Several of his projects dealt with dental hygiene and pre-procedural dental screening for arthroplasty patients. During his time in residency, he was able to develop several great mentors within the arthroplasty department during his early years of residency. He would like to acknowledge the tremendous guidance and education he received from Drs. Timothy Brown and Jacob Elkins.

The path has not been an easy one and would not have been possible without the unwavering love and support of his parents, his sister, and his wife Kelsie with their beautiful daughters, Brynnlie and Rylie. His love and excitement for orthopedics comes in 2nd compared to the joy his growing family has brought him over the past 4 years. Whenever he is not in the hospital, he is often dragging his kids along on whatever outdoor adventures the season affords, from ice fishing in the winter to forest hikes in the fall. James would also like to thank his co-residents and faculty for supporting him throughout residency. The endeared "Turkey Camp" corner of the resident room was one of frequent laughter, storytelling, and hard work, all of which afforded tremendous comradery and friendships that will last far beyond residency.

Following residency, James will be attending The University of Wisconsin Adult Reconstruction Fellowship. He is excited to further his training in complex adult reconstruction and gain the tools necessary for a successful arthroplasty career.





### ***Scott Muffly, MD***

Scott was born and raised in Corbin, KY, the youngest of three. As the son of a physician, the idea of becoming a doctor intrigued him from an early age. His passion for an active lifestyle and his love for science and math lead him to study biomedical engineering at the University of Virginia, where his musculoskeletal education solidified his decision to become an orthopedist. He subsequently completed his medical degree at

Virginia Commonwealth University, then moved to Iowa City for his orthopedic surgery residency training. When not at work, Scott enjoys running, cycling, hiking, reading, and spending time with his family.

Scott's research pursuits during residency have centered around his interest in adult hip and knee reconstruction, particularly perioperative patient optimization. Specifically, he has published on early emergency department visits following primary total joint arthroplasty, as well as considerations for presurgical BMI thresholds in total knee arthroplasty candidates. His senior research project investigating at-home total knee arthroplasty telerehabilitation seeks to further understand the perioperative patient experience, particularly given the rapid integration of telemedicine and personal smart technology driven by the COVID-19 pandemic.

Following residency graduation, Scott will attend an adult reconstruction fellowship at the Carilion Clinic in Roanoke, VA.

Scott would like to thank his wife, Alexandra, and son, Eli, for their unwavering love and support during his medical training. He would also like to thank his parents, David and Cara Muffly, for a lifetime of encouragement. He is excited to continue working with his co-residents and staff during his chief resident year.



### ***Michael Russell, MD, MPH, MBA***

While Mike may like to claim Texas as his home state, he was actually born and raised in rural Pennsylvania. Born to Family Medicine doctors, Gary and Susan Russell, he was exposed to healthcare from an early age. As part of his upbringing, he was also exposed to global health on a regular basis and would routinely spend part of his year in either Honduras or Kenya on medical missions trips.

Despite this early draw into healthcare, Mike elected to forgo the "family craft" and pursue a career in automotive engineering at Kettering University in Flint, MI. Here he majored in Chemical Engineering and concomitantly worked for General Motors throughout undergraduate working on alternative energy technology for automotive purposes. It was during his junior year of undergraduate during a medical mission trip to Haiti with his father that he realized that his true passion was healthcare.

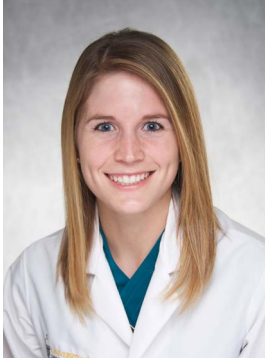
Mike attended medical school at Texas Tech in Lubbock, TX where he was able to also pursue combined programs in public health and business administration. Most importantly, it was in Lubbock that Mike met his future wife and lifelong adventure partner, Rebekah. They were married during his 4th year in medical school and were elated to match at the University of Iowa for residency.

While in Iowa City, Mike and Rebekah have been actively involved in their church, Veritas, and have been blessed with two daughters, Everest Mikah (3) and Adelaide Rebekah (1). They have loved the Iowa City community, Hawkeye athletics, beer league hockey, and archery hunting (Last one may be mostly for Mike....)

From a research perspective, Mike's focus has been centered on global health and he spent the majority of both his 3rd and 4th year research blocks doing international rotations in Ethiopia, Kenya, Honduras, and Malawi. These research blocks were extremely pivotal in helping to shape and affirm Mike and Rebekah's career plans which are focused on global health.

Upon the completion of residency, Mike and Rebekah will be pursuing a sarcoma fellowship at UCLA. When that is completed, they plan on moving to East Africa to help establish a sarcoma program in conjunction with CURE International and Pan African Council of Christian Surgeons (PACCS). Mike would love to focus on pediatric sarcoma care and resident education and medical training.

Mike would like to thank his parents Gary and Susan Russell for their constant positive influences both spiritually and professionally in his life. He would also like to thank his wife for her constant love and support. Her incredible joy and selflessness has been such a blessing and support to Mike throughout residency.



### ***Malynda Wynn, MD***

Malynda grew up in small town Ohio as an only child, raised as a joint effort of her grandparents and aunt. Their encouragement of ongoing education fostered an interest in pursuing college, and Malynda was the first in her family to graduate from college, and eventually she graduated from medical school at the University of Cincinnati.

During medical school, Malynda stumbled into the field of orthopedics after being paired for a shadowing experience with a pediatric orthopedic surgeon. It only took one day in the operating room to know that she wanted to become a surgeon. It was the patient population, quality of life improvement provided, and like-minded people in the field that drew Malynda to orthopedic surgery.

Malynda's main research interests involve how to improve orthopedic residency as well as promote diversity within the field. Pipeline programs including The Perry Initiative, and the Ruth Jackson Orthopaedic Society Mentorship have been important experiences for Malynda and will continue to be part of her career. More recently, she developed an interest in healthcare cost and clinical outcomes related to her chosen subspecialty field of orthopedic trauma as she continues to be amazed by the unique and creative ways people find to injure themselves.

Malynda is excited to pursue a fellowship in orthopedic trauma surgery after graduation. She recently has matched into a fellowship position at Indiana University Methodist Hospital in Indianapolis, Indiana. She feels fortunate to have the opportunity to learn from well-rounded and highly respected surgeons in Indiana after graduation. She is most interested in upper extremity trauma including shoulder arthroplasty in the setting of fracture.

Malynda has several people to thank, as her achievements would not have been possible without the support of her family and friends. Her husband, John, deserves the most thanks for his unconditional love, sacrifice and encouragement through both medical school and residency. Her two cats, Tonks and Albus (both Harry Potter namesakes), also deserve thanks for being wonderful emotional support animals and a reason to keep coming to work so they can live their best life. She would also like to thank the support of her grandmother and aunt. Finally, she would like to thank her amazing faculty mentors who have been instrumental in helping to shape her training as an orthopedic surgeon, including Dr. Weinstein, Dr. Marsh, Dr. Fowler, and Dr. Hogue. She feels grateful to continue training with some of the remarkable leaders in the field of orthopedics.

## 2023 GRADUATING FELLOWS



***Ryan Bailey, MD***

Ryan is the current and inaugural Adult Reconstruction fellow at the University of Iowa. Originally from Eden Prairie, Minnesota, he completed his undergraduate and graduate degrees in Electrical Engineering at the University of Notre Dame in Indiana, and medical degree at the Medical College of Wisconsin. He completed his orthopaedic residency at

St. Louis University prior to coming to the University of Iowa. He is joined by his wife, Brittany, and son, Ben. He will be moving back to Minnesota after fellowship to start practice in the St. Cloud area.

Ryan would like to extend his thanks to Drs. Elkins, Noiseux, and Schwartz for their mentorship and support during this year of training. He would also like to thank the department faculty, staff, and residents for a welcoming and enriching experience. He is grateful to have been a part of the continued outstanding legacy of excellence in arthroplasty at the University of Iowa.



***Shah Fahad, MD***

Shah is the current fellow in Musculoskeletal Oncology. He graduated of Ayub Medical College, Pakistan and completed residency at Agha Khan University, Pakistan. Before joining this current fellowship, Shah worked as an assistant professor of Orthopedic Surgery at Lady Reading Hospital in Pakistan.

Shah would like to express his gratitude to Dr. Miller, Jill Kain, and his other colleagues for providing valuable guidance and support during his fellowship. He feels honored to have learned from such experienced and skilled professionals.

As Shah moves on to the next phase of his career, he will carry with me the knowledge and skills gained during this fellowship. He is excited to continue to work towards improving outcomes for patients with musculoskeletal tumors and is confident that his experiences during this fellowship has prepared him for the challenges that lie ahead.



***Aly Fayed, MD***

Aly is the current foot and ankle fellow at UIHC this academic year. He was born and raised in Egypt and graduated from medical school as well as orthopaedic surgery residency in Egypt. In 2019, Aly received additional training under the supervision of the late Dr. Freddie Fu at the University of Pittsburgh.

He is very thankful and forever indebted to Dr. Femino and Dr. de Cesar Netto for their mentorship, patience, and support; it was really an amazing experience.

Aly is also deeply grateful for everybody on the foot and ankle team, as well as the orthopedic surgery department. They made everything run very smoothly and were all very welcoming, and supportive from day one. After graduation, Aly will be going to the University of Mississippi for a pediatric orthopedic fellowship but will always remember the Iowa experience as one of a kind. He will always be proud to be part of this amazing family.



***Brittany Homcha, MD***

Brittany is the current hand surgery fellow. She received her undergraduate degree in Biochemistry from Washington and Jefferson College. She then went on to medical school at Penn State College of Medicine and remained there to complete her Orthopaedic surgery residency. Brittany, her husband Trevin, and their three dogs plan to move to Alabama this fall where

she will be joining a private group. She feels fortunate to have been part of the Orthopaedic department at the University of Iowa. Drs. Buckwalter, Caldwell, Fowler, and Lawler have been incredible mentors throughout this year. She would like to thank them for their time, dedication, and support.





***Benjamin Packard, MD***

Ben is the current Orthopedic Sports Medicine fellow at the University of Iowa. He received his undergraduate degree in Biology at the University of Northern Colorado where he also played baseball and earned a Master of Science. He went on to medical school at Creighton University. He then moved to the southwest where he completed his Orthopedic residency at the University of New Mexico prior to coming to the University of Iowa. He is joined by his wife, JJ, son, Titus, and child (we are having a child in 2 weeks, do not know the name or gender). He is continuing to Auckland, New Zealand where he will do a second fellowship in Sports Medicine before settling down in Anchorage, Alaska where he took a job.

Ben would like to 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 and cannot imagine getting any better surgical training. He would also like to thank the whole Orthopedic department for welcoming him with open arms. The University of Iowa is truly a unique place providing the unsurpassed training, environment, and people.

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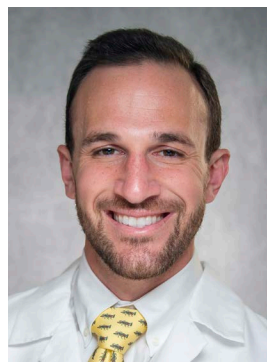
## NEW ORTHOPEDIC FACULTY



***Brett Rosauer, MD***

Dr. Brett Rosauer is a Clinical Assistant Professor in the Department of Orthopedics and Rehabilitation at the University of Iowa. He grew up in Urbandale, IA and completed undergraduate training at Iowa State University, where he majored in Kinesiology. He then completed his medical school education at the University of Iowa Carver College Of Medicine. Follow-

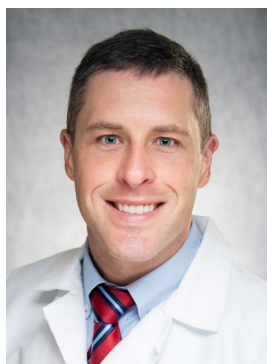
ing medical school, he completed his Physical Medicine and Rehabilitation residency training at the University of Nebraska Medical Center. He returned to Iowa City after residency and joined the University of Iowa Orthopedics and Rehabilitation department in September of 2022. Dr. Rosauer enjoys caring for patients with a multitude of neurologic injuries. Outside of medicine, he enjoys running as well as spending time w/ his wife, Hannah, and their dog, Fergie.



***Andrew Schwartz, MD***

Dr. Andy Schwartz is a Clinical Assistant Professor in the Department of Orthopedics and Rehabilitation and joined the faculty in August of 2022 as a hip and knee adult reconstruction surgeon. He grew up outside of Cincinnati, OH and completed his undergraduate degree in biology at Kenyon College in Ohio. He then went to medical school at Albert Einstein College

of Medicine in Bronx, NY, followed by an orthopaedic residency at Emory University in Atlanta, GA. His final year of subspecialty arthroplasty training was at Duke University in Durham, NC. He currently lives in Coralville, IA with his wife Quinn and two Labrador retrievers, Buck and Maple. Dr. Schwartz enjoys treating routine and complex arthritis and degenerative conditions of the hip and knee, as well as failed joint replacements. His research interests include arthroplasty implant-related outcomes, infection prevention and treatment, and enhanced revision component accuracy.



***Steven Zehring, DO***

Dr. Steven Zehring is an assistant-professor in the Department of Orthopedics and Rehabilitation at the University of Iowa. He specializes in Physical Medicine and Rehabilitation and completed his residency training at The Ohio State University. Prior to joining UI, Dr. Zehring was the medial director of an inpatient rehabilitation unit in Ohio. He also served in the Army Reserve

as both an enlisted soldier and officer in the medical corps. He currently treats patients at the University of Iowa Rehabilitation Hospital and primarily works in the inpatient setting.

## **The 2023 Michael Bonfiglio Award for Student Research in Orthopaedic Surgery**

## **The 2023 Iowa Orthopaedic Society Medical Student Research Award for Musculoskeletal Research**



**Chris Halbur, MS4**  
**Michael Bonfiglio Recipient**



**Jace Lapierre, MS3**  
**IOS Recipient**

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

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

The Iowa Orthopaedic Society Medical Research Award for Musculoskeletal Research is an award for a student in the Carver College of Medicine who completes a research project involving orthopedic surgery during one of his or her first three years of medical school. The award consists of a \$2000 stipend, \$500 of which is designated as a direct award to the student and \$1500 of which is designated to help defray continuing costs of the project and publication. The student must provide an abstract and a progress report on the ongoing research. The aim is to stimulate research in the field of orthopedic

surgery and musculoskeletal problems. This award is also presented at a medical convocation. In addition, the student presents his or her work at the spring meeting of the Iowa Orthopaedic Society and at a conference in the Department of Orthopedics and Rehabilitation. This award is supported through the generosity of the Iowa Orthopaedic Society.

This year the selection committee consisted of Drs. Charles R. Clark and Joseph A. Buckwalter IV. They recommended that Christopher Halbur, MS4, receive the 2023 Michael Bonfiglio Student Research Award. Christopher's award was based on his project, "Weight-Based Aspirin Dosing May Further Reduce the Incidence of Venous Thromboembolism Following Primary Total Joint Arthroplasty" His advisor was Dr. Nicolas Noiseux.

The selection committee recommended that the 2023 Iowa Orthopaedic Society Medical Student Research Award be given to Jace Lapierre, MS3, for his research titled "Examining Long-Term Outcomes Following High Tibial Osteotomy or Distal Femoral Osteotomy." His advisors were Drs. Kyle Duchman and Robert Westermann.

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

-Benjamin J. Miller, MD, MS  
Director of Orthopedic Medical Student Education

# PATIENT INITIATED DISCRIMINATION AND HARASSMENT—A DESCRIPTIVE SURVEY OF EXPERIENCES WITHIN A SINGLE ACADEMIC DEPARTMENT

Sarah Ryan, MD<sup>1</sup>; Maria Bozoghlian, MD<sup>1</sup>; Ericka Lawler, MD<sup>1</sup>; Brendan Patterson, MD, MPH<sup>1</sup>

## ABSTRACT

**Background:** Diversity in orthopedics is lacking despite ongoing efforts to create a more inclusive workforce. Increasing diversity necessitates recruitment and retainment of underrepresented providers, which involves representation among leadership, mentorship initiatives, and development of a safe work environment. Discrimination and harassment behaviors are prevalent within orthopedics. Current initiatives aim to address these behaviors among peers and supervising physicians, but patients are an additional underrecognized source of these negative workplace behaviors. This report aims to establish the prevalence of patient-initiated discrimination and harassment within a single academic orthopedic department and establish methods to reduce these behaviors in the workplace.

**Methods:** An internet-based survey was designed using the Qualtrics platform. The survey was distributed to all employees of a single academic orthopedic department including nursing staff, clerks, advanced practice providers, research staff, residents/fellows, and staff physicians. Survey was distributed on two occasions between May and June of 2021. The survey collected information on respondent demographics, experience with patient-initiated discrimination/harassment, and opinions regarding possible intervention methods. Fisher exact test was used for statistical analysis.

**Results:** Over one half of survey respondents report observing or personally experiencing patient-initiated discrimination within our orthopedics department (57%, n=110). Nearly half of respondents report observing or personally experiencing patient-initiated harassment within our department (46%, n=80). Encounters with these behaviors were more commonly reported from resident and staff female

physicians. The most frequently reported negative patient-initiated behaviors include gender discrimination and sexual harassment. Discordance exists regarding optimal methods to address these behaviors, but one third of respondents indicate potential benefit from visual aids throughout the department.

**Conclusion:** Discrimination and harassment behaviors is common within orthopedics, and patients are a significant source of this negative workplace behavior. Identification of this subset of negative behaviors will allow us to provide patient education and provider response tools for the protection of orthopedic staff members. Ideally, minimizing discrimination/harassment behaviors within our field will help create a more inclusive workplace environment and allow continued recruitment of diverse candidates into our field.

**Level of Evidence:** V

**Keywords:** diversity

## INTRODUCTION

Diversity is imperative in healthcare as increased gender, ethnic, and cultural representation among providers affords benefits to patient care, minimizes healthcare disparities, and enhances the educational value of training programs.<sup>1-4</sup> Despite ongoing efforts to create a more diverse workforce, orthopedic surgery remains the least gender diverse of the surgical subspecialties (females represent only 15% of current trainees—lower than both neurosurgery at 17.5% and urology at 25%).<sup>5</sup> Orthopedics also lacks minority representation, in view of the fact that Black/African American and Hispanic providers represent only 4.0% and 5.6% of the orthopedic workforce, respectively.<sup>6</sup> Perhaps unsurprisingly, these trends are reflected in that the first Black/African American and female presidents of the American Academy of Orthopedic Surgeons (AAOS) were only appointed in 2008 and 2019. Increasing diversity necessitates recruitment and retainment of providers from underrepresented backgrounds, and orthopedic initiatives including the Ruth Jackson Orthopedic Society (RJOS), The Perry Initiative, and J. Robert Gladden Orthopaedic Society (JRGOS) aim to address these disparities. Establishing diversity among physicians both in mentorship and leadership positions is

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critical, and lack of female and ethnic underrepresented minority (URM) mentors are potential deterrents to choosing orthopedics as a specialty.<sup>7,8</sup>

In addition to mentorship resources, work environment can largely factor into specialty choice and an unwelcoming workplace creates an additional barrier to successful recruitment of diverse applicants. Discrimination, which involves differential treatment of an individual based on characteristics such as gender, race, religion, or sexual orientation; and harassment, which involves unwelcome conduct toward an individual based on these same factors, can both contribute to a negative workplace environment. Ongoing efforts exist to reduce discrimination and harassment within orthopedics. However, while much of the current discussion involves addressing negative behaviors from peers and supervising physicians, 43% of respondents in a survey by Whicker et al. noted patients as a source of workplace harassment.<sup>9</sup> Raising awareness and implementing procedures to address patient-initiated discrimination and harassment behaviors should be included in efforts to address workplace safety and inclusivity. This study aims to establish and analyze the prevalence of patient-initiated discrimination and harassment within a single academic orthopedic department and explore methods to reduce these behaviors in the workplace.

METHODS

This study does not meet the regulatory definition of human subject research under institutional IRB and therefore did not require IRB review. An internet-based survey was constructed using Qualtrics XM. Demographic data including age, department role, gender, and race was collected. Survey contents include questions addressing situations of discrimination and harassment, questions regarding training and techniques for responding to discrimination and harassment, and a narrative section to share examples of personal experience. A definition of “harassment” and “discrimination” was provided at the beginning of the survey. In this survey, discrimination was defined as ‘differential treatment of an individual or group of people based on their race, color, national origin, religion, sex, age, disability, sexual orientation, or genetic information’, and harassment was defined as ‘unwanted conduct toward an individual based on these characteristics’. Responses to survey questions include “yes/no” (binary), “Likert scale”, multiple choice, matrix questions and free-response questions.

The survey was distributed via email to all 359 orthopedic staff members at a single institution between May and June of 2021. Staff members of the orthopedics department include Clerks, Nurses, Advanced Practice Providers, Residents, Fellows, Researchers and Attend-

ing Physicians. The survey was sent in two instances separated by 10 days for non-respondents. Response collection and data analysis was performed using Qualtrics XM. Descriptive statistics (means, medians, percentages, standard deviations, and inter-quartile ranges) were computed for all variables. Categorical variables were compared using Fisher’s exact test. Statistical significance was set at  $p<0.05$ .

RESULTS

A total of 173 survey responses were submitted representing a 48% response rate. Resident and staff physicians comprised 35% of respondents (n=49), in addition to advanced practice providers, nurses, medical assistants, administrative staff, athletic training, and research staff. Respondents were 65% female (n=89), and 93% of respondents self-identify as White (n=128). Overall, over half of survey respondents reported observing or personally experiencing patient-initiated discrimination within our orthopedics department (57%, n=110). The most frequent types of patient-initiated discrimination encountered include gender/identity based (37%, n=43) and race/ethnicity-based behaviors (33.6%, n=39). 46% (n=80) of respondents reported observing or personally experiencing patient-initiated harassment within our department. The most frequent types of harassment encountered were gender/identity based (n=22, 25.6%), sexual harassment (n=19, 22.1%), and race/ethnicity based (n=10, 11.63%). Among clinical respondents (resident/staff physicians,

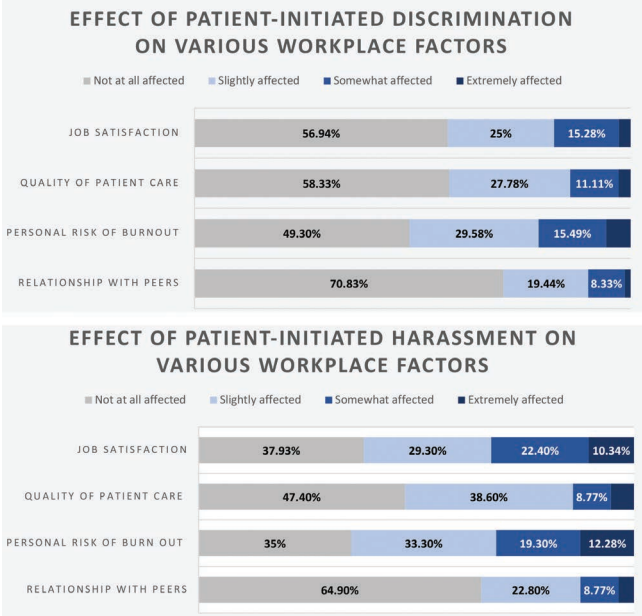
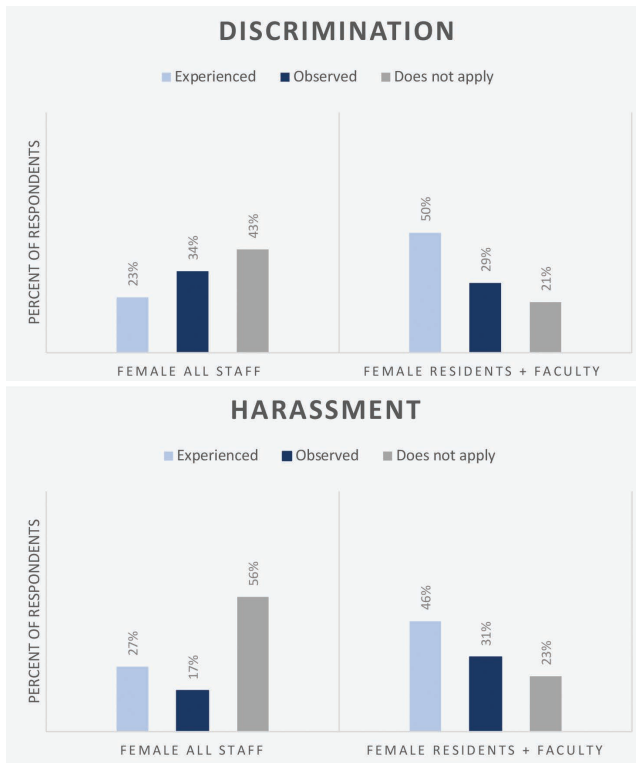


Figure 1A to 1B. Effect of Patient-Initiated Discrimination (1A) and Harassment (1B) on job satisfaction, quality of patient care, personal risk of burnout, and relationship with peers. Unlabeled portions of bar graph represent <5% of responses.

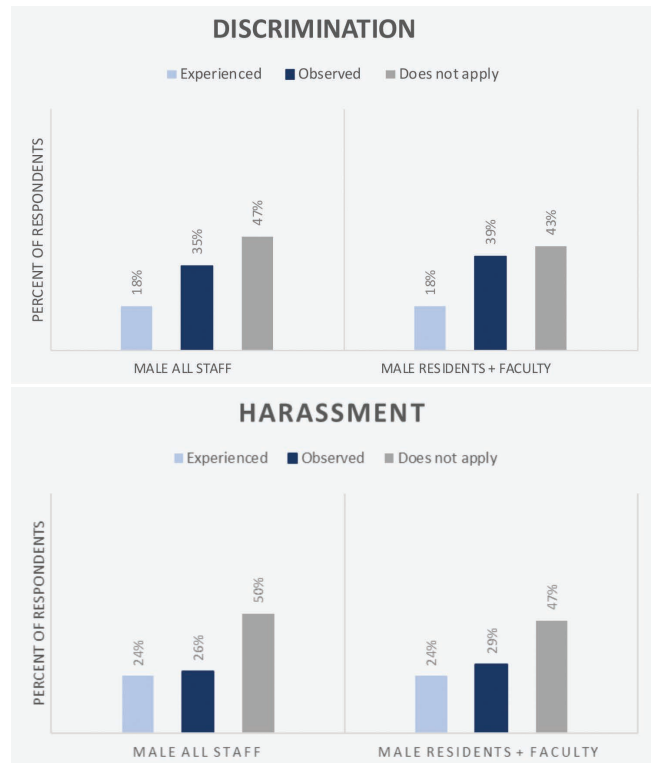


**Figure 2A.** Percentage of female staff and female residents/faculty that report personally experiencing or observing patient-initiated discrimination (A) and harassment (B) behaviors within our department.

advanced practice providers, nursing staff, medical assistants), 25% (n=25) and 39% (n=39) report experiencing or observing patient-initiated discrimination, and 33% (n=32) and 26% (n=25) report experiencing or observing patient-initiated harassment. Comparatively, approximately 2/3 of non-clinical staff respondents (administrative/clerical, research), have never encountered these behaviors in the workplace (62%, n=36 and 75%, n=43).

Over half of survey respondents indicate patient-initiated discrimination and harassment has contributed to personal burnout, and between 40-60% of participants cite negative effects on job satisfaction and patient care (Figure 1, A and B). Among respondents that chose not to report these events (91%, n=40) reasons for not reporting include not knowing whether the incident was severe enough to report (24%), assumptions that nothing would be done in response to the report (19%), fear of negative professional consequence (15%), and not knowing how to report the event (13%).

When analyzed by gender and job classification of respondents, results showed that of all female orthopedic staff, 34% (n=36) report having observed patient-initiated discrimination, and 23% (n=24) report having experienced this type of behavior. In an analysis of a



**Figure 2B.** Percentage of male staff and male residents/faculty that report personally experiencing or observing patient-initiated discrimination (A) and harassment (B) behaviors within our department.

subgroup of female staff including only female residents and faculty, 29% and 50% (n=7, n=4) of respondents report having observed or experienced patient-initiated discrimination respectively. Similarly, 17% (n=17) and 27% (n=27) of female all staff respondents report having observed or experienced patient-initiated harassment, compared to 31% and 46% (n=10, n=13) of female resident/staff respondents (Figure 2a). Of all male orthopedic staff, 35% report having observed patient-initiated discrimination (n=17), and 18% (n=9) report having experienced this type of behavior, while 26% (n=13) and 24% (n=12) report having observed and experienced patient-initiated harassment. Subgroup analysis of male staff including only male residents and faculty demonstrated similar results to the all-staff group (Figure 2b).

Participants were surveyed regarding potential learning tools to reduce the frequency of patient-initiated discrimination and harassment in our department. While discordance exists regarding optimal methods to address discrimination/harassment behaviors, 33% of respondents indicate potential benefit from implementing visual aids (posters/signs) throughout the department, 32% feel that online trainings might be beneficial, and 22% of respondents answered that didactic materials, such as

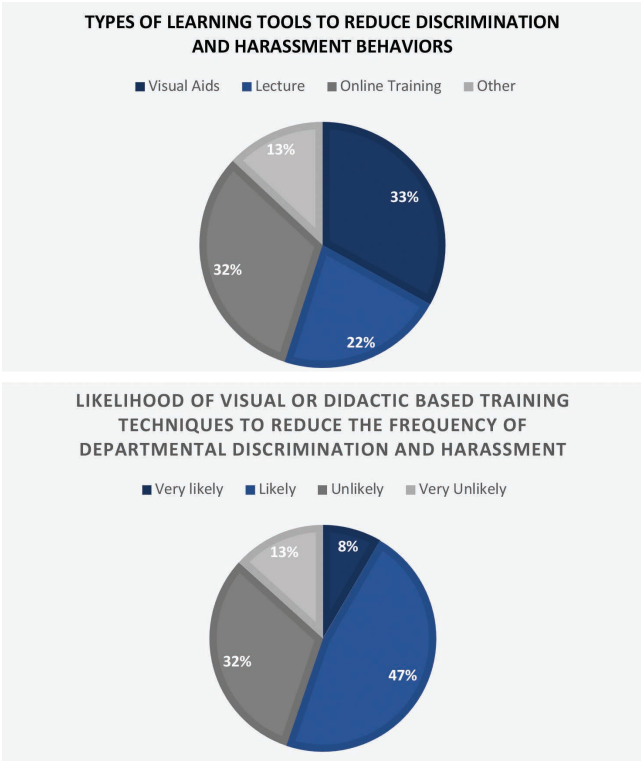


Figure 3A to 3B. (3A) Percent of survey responses indicating which types of learning tools are likely to aid in reducing discrimination and harassment behaviors, (3B). Percent of survey responses indicating likelihood that visual or didactic based training can aid in reducing discrimination and harassment behaviors.

lectures, would help address this issue. Regarding the utility of visual aids throughout the department, 55% of participants feel this intervention would “likely” or “very likely” reduce the frequency of patient-initiated negative workplace behaviors (Figure 3).

DISCUSSION

Lack of existing gender, racial, and cultural diversity among practicing orthopedists is both a detriment to patient care and a barrier to successful recruitment of diverse orthopedic providers. Promoting diversity in orthopedics involves creating an inclusive work environment, but a 2020 survey by Samora et al. highlights the ubiquity of negative workplace behaviors such as discrimination, sexual harassment, and bullying in Orthopaedics. Nearly 4 of 5 female and Black/African American AAOS member respondents report having personally experienced these behaviors in the workplace, while a separate survey notes a staggering 68% of female trainees report experiencing episodes of sexual harassment during their residency training.<sup>9,10</sup>

Despite slow progress, representation in orthopedics is increasing. The current 15% of female trainees represents a significant improvement and nearly a 30% increase from only 11.6% female trainees a decade prior,<sup>8</sup> likely due to both increased recruitment efforts and improvements in overall workplace culture. As an unwelcoming workplace can deter underrepresented candidates from pursuing orthopedics, current initiatives such as #SpeakUpOrtho help prompt discussion that drives necessary change to minimize these behaviors from fellow resident and staff surgeons.<sup>11,12</sup>

Current literature seldom discusses other sources of these behaviors, but as demonstrated by the results of this survey, patients are a common and underrecognized source of workplace discrimination and harassment in orthopedics. Gender discrimination and sexual harassment were the most frequently reported behaviors in this study. Survey respondents in this study cite behaviors including verbal attacks, insulting comments, and un-

Table 1. Narrative Responses of Personal Examples with Patient Initiated Discrimination and Harassment within our Department

Frequently harassment happens on phone triage when a patient or family member is pushing for something and we can't do it.
Patients screaming and swearing at our staff over the telephone.
Because I'm female, some patients lessen my value as a part of the care team compared to my male coworkers.
Patients are sometimes ignorant when it comes to the diversity of our staff.
Patients questioning my competency as a female provider, making comments about my appearance.
Gender discrimination with or without sexual harassment - unwanted sexual advances or crude jokes.
Discrimination or harassment based on national origin, "I want a doctor I can understand, not this (pejorative ethnic or racial slur)"
Female trainees and staff are not treated with the same respect.
I have had multiple adult patients assume that I am the medical student/nurse/trainee and not the staff surgeon due to my gender
Patient phone calls are a frequent source of patient-initiated harassment.
On several occasions I witnessed patients treat an african american resident much differently than his caucasian colleagues.
Patients being very sexually inappropriate in their comments/gestures with our female APP and MD staff.



wanted sexual advances, among others (Table 1). Over half of respondents in this survey have encountered these behaviors from patients, and female resident/staff providers are twice as likely to report personal harassment from patients in comparison with the remainder of this cohort. While male providers report lower rates of patient-initiated discrimination and harassment than their female counterparts, they are not exempt from this behavior—nearly ¼ of male respondents in this survey also reported personal experience with discrimination and harassment. Unfortunately, assessment of race/ethnicity related patient-initiated discrimination/harassment was limited in this study given lack of non-White survey respondents. Additionally, demographic information of non-respondents in this survey was not available and unrecognized response bias may therefore limit this report. Nonetheless, this report demonstrates the ubiquity of patient-initiated discrimination and harassment behaviors in the orthopedic workplace.

Similar to prior literature demonstrating the ill effects of negative workplace behaviors on providers' health and well-being,<sup>13</sup> respondents of this survey indicate patient-initiated discrimination and harassment negatively affects workplace environment, particularly relating to burn out and job satisfaction. If unaddressed, repeated occurrences of these negative workplace behaviors can contribute to an unsustainable work environment.

Attempts should be made to minimize these behaviors in the workplace given implications on provider wellbeing and patient care, but limited solutions have been proposed. In this survey, discordance exists among respondents regarding optimal methods to address discrimination/harassment behaviors, although over half of respondents believe visual and/or didactic training techniques would reduce the amount of these behaviors experienced in our department. Visual aids such as posters or pamphlets throughout the department would be a simple intervention to ideally help elucidate the problem, deter inappropriate patient behavior, and provide potential response tools and accessible reporting mechanisms when these behaviors are encountered.

Overall, this survey demonstrates that patient-initiated discrimination and harassment behaviors is a frequent occurrence in our department, particularly among female resident and staff physicians. Identification of this subset of negative behaviors will allow us to develop patient education and provider response tools to minimize these behaviors, protect orthopedic staff members, and build a more inclusive orthopedic environment.

#### ACKNOWLEDGEMENTS

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# PUBLICATION AND CAREER TRENDS OF RUTH JACKSON ORTHOPAEDIC SOCIETY GRANT WINNERS OVER THE PAST DECADE

Natalia Czerwonka, BA<sup>1</sup>; Christen M. Russo, MD<sup>1</sup>; Lisa K. Cannada, MD<sup>2</sup>

## ABSTRACT

**Background:** The Ruth Jackson Orthopaedic Society awards the Jacquelin Perry, MD Resident Research Grant and RJOS/Zimmer Biomet Clinical/Basic Science Research Grant to female orthopedic surgeons, intending to aid women in the progression and completion of their orthopedic research and bolster their pursuit or current career in academic orthopedic surgery. The impact of these grants has not yet been studied. The purpose of this study is to determine the percentage of scholarship/grant-winners who went on to publish the findings of their research, pursue academic positions, and currently hold positions of leadership in the field of orthopedic surgery.

**Methods:** The titles of the winning research projects were searched in PubMed, Embase, and/or Web of Science to ascertain publication status. For each award recipient, the number of publications prior to the award year, number of publications after the award year, total number of publications, and H-index were calculated. Each award recipient was searched online through the websites of their employment and social media pages to determine their residency institution, whether they pursued a fellowship, the number of fellowships they pursued, their subspecialty within orthopedics, their current job, and whether they are in academic or private practice.

**Results:** Of the fifteen Jacquelin Perry, MD Resident Research Grant winners, 73.3% of awarded research projects have since been published. 76.9% of award winners currently work in an academic setting and are affiliated with a residency program, and 0% currently hold leadership positions in orthopedic surgery. Of the eight winners of the RJOS/Zimmer Biomet Clinical/Basic Science Research Grant, 25% have published the findings of their awarded grant. 87.5% of award winners currently work in academics, and 75% hold leadership positions in orthopedic surgery.

**Conclusion:** Our results show that many of the winners of the Jacquelin Perry, MD Resident Research Grant and RJOS/Zimmer Biomet Clinical/Basic Science Research Grant have published their research findings, continued research within the field of orthopedic surgery, and pursued academic careers and leadership positions. Many of the barriers to career progression and entry into orthopedic surgery that women and underrepresented groups face could be overcome through more grant opportunities and mentorship.

**Level of Evidence:** V

**Keywords:** diversity, equity, inclusion, orthopedic surgery

## INTRODUCTION

The number of female residents in surgical specialties has been increasing concurrently with the number of female medical students.<sup>1</sup> As of 2020 in the United States, women constitute 53.7% of medical students and 36.3% of the physician workforce.<sup>2</sup> While American medical schools have come to achieve balance in the proportion of male and female graduates, orthopedic surgery has shown less progress and is the least diverse surgical specialty.<sup>2,3</sup> In orthopedic surgery, 15% of residents as of 2019 and 7% of practicing surgeons as of 2022 are women, respectively.<sup>4,5</sup> This is much lower than general surgery (38.4-43.1% of female residents, 22% of female staff).<sup>6,7</sup> Further, these numbers have made little improvement since 2016, when 14% of women were orthopedic surgery residents.<sup>8</sup> In academic medicine, the number of women in academic positions across all medical specialties was found to be 40.8% in 2020, while the percentage of fe-

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Disclosures: LKC: Leadership or fiduciary role in board or society (Orthopedic Trauma Association, Mid-America Orthopedic Association, Association of Women's Surgeons, Speak Up Ortho, Ruth Jackson Orthopedic Society, and Southeast Fracture Consortium); Editorial or Governing Board (Journal of Bone and Joint Surgery, Journal of Orthopedic Experience and Innovation, Orthopedics, Wolters Kluwer Health: Lippincott Williams and Wilkins) CMR: Leadership or fiduciary role in board or society (Ruth Jackson Orthopedic Society, Pediatric Orthopedic Society of North America) Ethical Review Committee Statement: This study did not require IRB approval.

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male academic orthopedic faculty is 17.8%; though this is a slight increase from 13% in 2010, the percentage of female academic orthopedic faculty remains lower than any other medical specialty.<sup>2,8,9,10</sup> In an effort to level the playing field and support the growth and leadership of current and prospective women in orthopedic surgery, the Ruth Jackson Orthopaedic Society (R JOS) was founded in 1983 and the organization has been a fervent advocate and recruiter for women in orthopedic surgery. R JOS offers a variety of grants and scholarships to help boost women in academic orthopedic surgery, as well.

The Jacquelin Perry, MD Resident Research Grant is open to any resident currently enrolled in an accredited orthopedic surgery residency program who is the primary investigator of a clinical or basic science research project. Any current R JOS member in any year of residency is eligible to receive the award. The R JOS/Zimmer Biomet Clinical/Basic Science Research Grant is a \$30,000 grant awarded to any active R JOS member in good standing who is Board Certified or Board eligible, who is the primary investigator of a clinical or basic science research project in the field of orthopedic surgery. Furthermore, recipients of both awards receive reimbursement to attend the annual R JOS meeting.

The primary purpose of this study is to determine the percentage of grant-winners who went on to publish the findings of their research. Secondly, our purpose was to determine the percentage of women who continued to publish after receiving these awards, the percentage who pursued academic positions, and the percentage who are currently in positions of leadership in the field of orthopedic surgery.

## METHODS

The recipients of the Jacquelin Perry, MD Resident Research Grant and R JOS/Zimmer Biomet Clinical/Basic Science Research Grant award winners from 2013 to the present were extracted from the R JOS database. The Jacquelin Perry, MD Research Grant was first awarded in 2013; the R JOS/Zimmer Biomet Grant was first awarded in 2014. Neither the Jacquelin Perry nor R JOS/Zimmer Biomet Grants were awarded during 2021 due to the COVID-19 pandemic. Both grants are advertised through the R JOS website and newsletter, and more recently through social media outlets such as Instagram and Twitter.

The titles of the winning research projects were searched in PubMed, Embase, and/or Web of Science to ascertain publication status. If neither of these searches provided sufficient information to determine the publication status of the research project, a Google search was performed to identify the publication status from sources such as university websites, press releases, social media

pages, and online CVs. If insufficient data was unable to be extracted from these additional searches, the publication status was marked as not published. For projects that were found to be published, the journal(s) of publication was/were noted. For each award recipient, the number of publications prior to the award year, number of publications after the award year, total number of publications, and H-index were calculated.

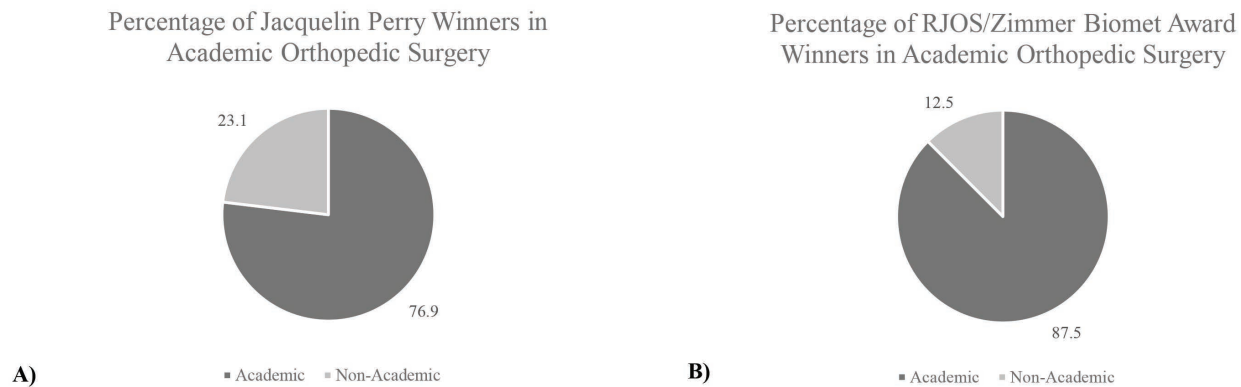
Each award recipient was searched through the R JOS website to determine their status of membership. They were then searched online through the websites of their place of employment, as well as via social media to determine their residency institution, whether they pursued a fellowship, the number of fellowships they pursued, their subspecialty within orthopedics, their current job, and whether they are in academic or private practice. Those who currently hold positions of leadership were noted. In this study, we define leadership positions as any role in which an individual is in charge of a residency program (such as a chair, program director, or associate program director) or in charge of an orthopedic team (such as the division chief of their orthopedic subspecialty division, director of the department of research, or director of the department of education).

## RESULTS

### Jacquelin Perry, MD Resident Research Grant

There were fifteen recipients of the Jacquelin Perry, MD Resident Research Grant since its inception in 2013. Of the fifteen award winners, 73.3% of awarded research projects have since been published. Clinical Orthopaedics and Related Research and Journal of Orthopedic Research were the most common journals of publication. The average number of publications prior to the year of a resident's award was 13.6 (range: 1 to 81). The average number of publications after the year of the award was 32.5 (range: 0 to 191). The sole recipient who had 0 publications after the year of their award was the most recent award recipient from the year 2022. Of the fifteen recipients, nine had more publications after their award than before. The average number of total publications was 46.1 (range: 2 to 252). The highest H-index was 31, and the average H-index was 8.6. The percentage of women who are current members of R JOS was 50%.

From the available information, 100% of women went on to complete a fellowship in a subspecialty of orthopedics, excluding the most recent grant winner who is a current resident. The percentage of women who completed two fellowships was 11.8%. The most common fellowship/subspecialty among award winners was Sports Medicine (43.8%), while no award winner pursued an Arthroplasty, Foot and Ankle, or Spine Fellowship. Excluding two award recipients who are



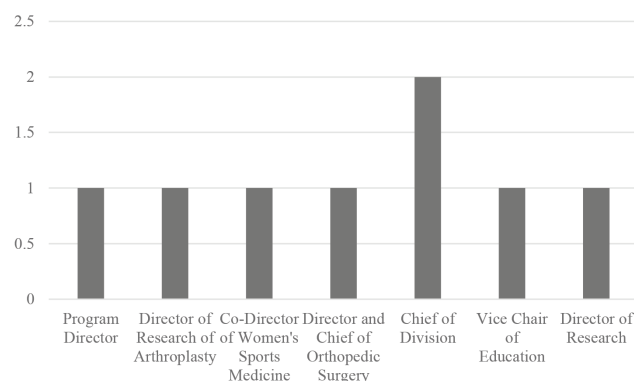
**Figure 1A to 1B. The percentage of (1A) Jacquelin Perry, MD Resident Research Grant Winners and (1B) RJOS/Zimmer Biomet Clinical/Basic Science Research Grant Winners in academic orthopedic surgery.**

currently in their residency and fellowship, 76.9% of award winners currently work in an academic setting and are affiliated with a residency program (Figure 1A). Three are associate professors of orthopedic surgery, and seven are assistant professors. Four of the fifteen award winners hold academic positions at one of the top five orthopedic residency programs in the country, as determined by Doximity 2021 rankings.

### RJOS/Zimmer Biomet Clinical/Basic Science Research Grant

There were eight recipients of the RJOS/Zimmer Biomet Clinical/Basic Science Research Grant since its inception in 2014. Of the eight winners, 25% have published the findings of their awarded grant. The average number of publications prior to the award year was 47.4 (range: 0 to 198). The average number of publications after the award year was 30.6 (range: 4 to 97). The average total number of publications was 78 (range: 5 to 295). The average H-index was 15.1, and the highest H-index was 35. The percentage of women who are current RJOS members is 87.5%.

All of the included women completed a fellowship in a subspecialty of orthopedics. None completed two fellowships. The most common subspecialty was Hand (37.5%), followed by Pediatrics (25%) and Sports Medicine (25%). Eighty seven and a half percent of award winners currently work in academics (Figure 1B). One is the current program director of an orthopedic surgery residency program; one is the current Vice-Chair of Education; three are directors of their respective subspecialty research departments; one is the Director and Chief of Orthopedic Surgery at their affiliated hospital; and two are the chiefs of their respective orthopedic subspecialty divisions at their respective hospitals. Four are associate professors, and three are professors (Figure 2). The majority of the award winners currently practice in the northeast (37.5%), followed by the midwest (25%) and south (25%). Three of the award recipients are current faculty members at one of the top five orthopedic surgery residency programs in the country. Furthermore, all award recipients graduated from an orthopedic surgery residency program that is in the top 25 in the United States.



**Figure 2. The number of RJOS/Zimmer Biomet Clinical/Basic Science Research Grant Winners in leadership positions in orthopedic surgery.**

## DISCUSSION

Top-performing businesses and teams value diversity, as it enables individuals of different backgrounds, experiences, and training environments to bring forth new ideas, creative problem-solving methods, or out-of-the-box thinking to the team environment.<sup>11,12</sup> In the traditionally male-dominated fields of technology and computer science, Microsoft, Google, Intel and IBM have all created professional platforms geared towards increasing diversity within their workforce and community-based programs designed to introduce tech as a career option to young women from middle school to college.<sup>13</sup> Moreover, women make up 25-30% of all employees at these companies, which is the same percentage as women in the technology and computer



science fields overall.<sup>14,15,16</sup> Medicine as a whole has also progressed in creating a more diverse community of physicians, with more women than men now matriculated into medical school. Yet, the number of women in orthopedic surgery has increased at a glacial pace and is on track to continue to do so. Chambers et al. found that not only does orthopedic surgery have the lowest proportion of female residents, but it also has seen the least growth in female representation.<sup>8</sup> This is despite the proven data that women do no worse than men in orthopedic surgery: female residents have been found to perform well and comparably to their male counterparts on exams such as the Orthopedic In-training Exam (OITE) and American Board of Orthopedic Surgery (ABOS) Credentialing Exams, Part 1 and Part 2.<sup>17</sup> Thus, while other medical specialties and fields within science, technology, engineering, and mathematics (STEM) have recognized and responded to the value of diversity and have taken measurable action to increase it within their workforces, orthopedic surgery has fallen behind.

The advantages of having a diverse healthcare team are not novel and are in fact well-documented. Doctors who identify as underrepresented minorities or hail from a disadvantaged background are more likely to practice in underserved locations.<sup>18,19</sup> Further, patients themselves may be more willing to trust physicians who look, speak, and even behave like them.<sup>19</sup> Additionally, Wallis et al. found that patients treated by female surgeons are less likely to die or experience complications within 30 days of surgery, compared to those patients treated by male surgeons.<sup>20</sup> A more recent study has demonstrated that additionally, worse outcomes are experienced by female patients who are treated by male surgeons, than female patients treated by female surgeons.<sup>21</sup> Altogether, a more diverse workplace in orthopedic surgery may lead to greater trust between patient and doctor, reduction in disparities in patient care, and therefore improved patient care as a result.<sup>22</sup> Recruiting physicians of diverse gender, race, ethnicity, religion, and sexual orientation is therefore a logical next step that the field of orthopedic surgery is late to take.

The Jacquelin Perry, MD Resident Research Grant and the RJOS/Zimmer Biomet Clinical/Basic Science Research Grant are awarded each year by RJOS to promote the growth and development of research and leadership in women in the field of orthopedic surgery. Within the past ten years, 73.3% of the research projects that were awarded the Jacquelin Perry, MD Resident Research Grant and 25% of the research projects awarded the RJOS/Zimmer Biomet Clinical/Basic Science Research Grant have been published. Of the resident winners, 60% published more papers after winning their award than prior; nearly 77% went on to work in academic orthopedic

surgery; and 26.7% are currently on faculty at a top 5 orthopedic surgery residency. Of the attending winners, 37.5% published more papers after winning their award than prior; 87% work in academic orthopedic surgery; and 37.5% are on faculty at a top 5 orthopedic surgery residency. Further, 62.5% hold leadership positions at their current place of employment.

The paucity of women in positions of leadership is not unique to orthopedic surgery or medicine: globally, less than 5% of Fortune 500 CEOs are women and only 34% hold managerial positions.<sup>10</sup> The lack of balance of women in leadership is a significant cultural, societal, and organizational problem. Aiding women in the funding of their orthopedic research is the primary and obvious aim of these grants; however, a by-product of these research grants is the increase of women in positions of leadership in orthopedic surgery residencies and medical schools. Currently, 3% of orthopedic surgery chairs, 11% of program directors, 27% of assistant program directors, and 9% of division chiefs are women.<sup>23</sup> The percentage of female program directors and assistant program directors can be viewed as promising: though these percentages are still quite low, they imply a growth in junior female leadership, which can create a pipeline of women who are well-qualified and prepared to take on more senior leadership roles. However, these percentages are a snapshot in time. It is important to analyze these percentages in the coming years: the goal is for the percentages of women in both junior and senior leadership roles to increase over time. It is not enough if only the percentage of female junior leaders increases over time without a corresponding increase in female senior leaders.

In medicine, research may be an effective means of ascending the leadership ladder: physicians who conduct research are by default more likely to hold faculty positions at residency programs and medical schools, where they can teach and mentor residents and medical students. Mentorship is fundamental in many trade professions: taking on an apprentice is how one teaches the next generation useful tips and tricks. A mentor can help their apprentice recognize and overcome the obstacles that they themselves once faced. Orthopedic surgery is no different: having a variety of mentors willing to offer different perspectives, recommendations, and advocacy is transformational for one's career. Okike et al. found that female medical students whose medical schools are affiliated with a gender-diverse orthopedic surgery residency program were more likely to apply for a position in orthopedic surgery residency.<sup>24</sup> Further, it has been shown that having mentors of the same sex and race can positively influence one's decision to enter a particular field of medicine. A 2013 survey

study showed that women are more likely than men to indicate that having a mentor of the same sex or race would positively influence their decision to pursue orthopedic surgery as a career.<sup>25</sup> Thus, teaching institutions with available research opportunities are an important means of promoting global increases in gender representation in orthopedic surgery. Having more women in academic orthopedics, where they are easily visible by medical students and undergraduates alike, may be an important way to attract more women into orthopedic surgery. Our data demonstrate that within the last ten years, slightly more than three-quarters of resident award winners and nearly 90% of RJOS/Zimmer Biomet award-winning attendings went on to or continued to work at teaching institutions. Further, the majority of attending grant winners hold important leadership positions such as program directors of a residency program or vice-chairs of education. These achievements are due to these women's own efforts and prowess. Perhaps by providing them with a means to advance their research and connections within the field of orthopedic surgery, RJOS may have played a small role in moving them up the research and leadership ladders.

Just as research may help women achieve leadership positions in orthopedic surgery, so too may involvement in professional societies. Subspecialty societies can play a pivotal role in improving diversity and providing leadership opportunities in all areas of orthopedics. Many surgeons who are in leadership positions in societies such as the Orthopedic Trauma Association (OTA) and American Academy of Hip and Knee Surgeons (AAHKS) are likewise leaders in education and research; thus, they have access and the ability to advise residents and junior faculty.

In a survey study of 304 women in orthopedics, Bratescu et al. found that meaningful mentorship within a subspecialty of orthopedics was the greatest factor that influenced a female resident to pursue a particular orthopedic subspecialty.<sup>26</sup> Specialties such as Hand and Pediatrics have historically been composed of higher percentages of women, while other specialties such as Spine and Arthroplasty lag behind.<sup>27,28</sup> One potential logical method to increase gender diversity within the least diverse subspecialties would be to engage women leaders within said fields in mentoring, education, and training events for junior trainees. For example, RJOS has partnered with the Arthroscopy Association of North America (AANA) and the OTA for Specialty Day at the last two American Academy of Orthopedic Surgeons (AAOS) Annual Meetings. Having more women on the podium representing specialties with less gender diversity is a step toward more exposure on an esteemed level at a national meeting. The networking that often follows

at such a meeting can be a natural segue to mentorship and advocacy moving forward.

Another means of actively recruiting women to a subspecialty is to recruit women as board and committee members of subspecialty societies. In 2020, Saxena et al. found a strong correlation between the percentage of women in a specialty society and the percentage of women on that society's board of directors.<sup>29</sup> The American Society for Surgery of the Hand (ASSH) was composed of 14% of women at the time of the study, and had a board of directors made up of 31% of women. ASSH has had two female Presidents despite the high number of female members. In contrast, AAHKS was composed of 5% of women, and had no women on the board of directors at the time of study publication.<sup>29</sup> To date, there has been one female president of the OTA, one female president of the American Shoulder and Elbow Society (ASES), and currently one woman in the presidential line of AAHKS. Though there have been no studies that have investigated whether the percentage of women in an orthopedic society predicts the percentage of women in future leadership positions in that society, it is worth considering this as a potential avenue to both increase diversity within orthopedic subspecialties and increase the percentage of women in leadership roles. Because the majority of each subspecialty society's board of directors is composed of men,<sup>29</sup> women cannot be alone in this endeavor to increase the percentage of women in leadership positions. Men have played a pivotal role in increasing diversity in orthopedics when acting as allies and sponsors, and must continue to do so.

Lastly, in addition to research opportunities and professional societies, cultural changes are needed to support the advancement of female faculty within orthopedic surgery. One important method is to address factors that have been acknowledged as critical to women's well-being and career in medicine. In a survey study of 163 female faculty at Stanford University School of Medicine, McGuire et al. found that a flexible work environment without negative consequences for women with young children, departmental mentoring for academic career development, and support for grant and manuscript preparation were indicated as specific interventions that would advance female faculty member's careers in academic medicine and would improve their wellbeing.<sup>30</sup> For pregnant orthopedic surgeons, provision of appropriate shielding from radiation during cases involving fluoroscopy, designated lactation rooms in the hospital, and facilities to store breast milk, have been identified as specific supportive measures during residency and in practice and supported with ACGME Common Program Requirements.<sup>31,32,33</sup> Finally, civility is also paramount – in a survey study of 190 US orthopedic surgery residents,



Mulcahey et al. found that about 1 in 5 women delayed becoming pregnant in residency due to the fear of negative perception by male faculty or residents; nearly 60% of those who became pregnant in residency received biased and unsupportive comments from their co-residents and attendings regarding pregnancy during training; and nearly 50% of pregnant residents felt unsupported by their residency's culture during their pregnancy.<sup>34</sup>

The culture of a program is set by its leadership. An environment that is free of discrimination, bullying, and harassment is crucial. Currently, the literature does not demonstrate that. In general, female orthopedic surgeons in the US are twice as likely than men to experience discrimination, bullying, and harassment as attendings, fellows, and residents.<sup>35</sup> Workplace leadership must define the parameters of appropriate workplace behaviors, strictly define which behaviors qualify as discrimination, harassment, and bullying, and encourage professionalism and a zero-tolerance policy for such actions.<sup>36</sup> Further, leadership must make it obvious to employees that there are methods available to report such behaviors within the workplace, and how to take such steps, ensuring that reporting is conducted in a genuinely confidential and safe manner. When untoward events occur, the leadership can set the tone for zero tolerance and resources to support those involved.

There are some limitations to our study. Foremost, some of our data were collected from online sources such as departmental websites and social media pages. Not all award winners had available online information or easily accessible social media pages, nor did all departmental websites frequently update their pages. Therefore, the data collected from these websites and social media pages may not be entirely complete.

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# RURAL COMMUNITIES IN THE UNITED STATES FACE PERSISTENT DISPARITIES IN ACCESS TO ORTHOPAEDIC SURGICAL CARE

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## ABSTRACT

**Background:** Access to orthopaedic care across the United States (U.S.) remains an important issue, however, no recent study has examined disparities in rural access to orthopaedic care. The goals of the present study were to (1) investigate trends in the proportion of rural orthopaedic surgeons from 2013 to 2018 as well as the proportion of rural U.S. counties with access to such surgeons and (2) analyze characteristics associated with choice of a rural practice setting.

**Methods:** The study analyzed the Centers for Medicare and Medicaid Services (CMS) Physician Compare National Downloadable File (PC-NDF) for all active orthopaedic surgeons from 2013 to 2018. Rural practice settings were defined using Rural-Urban Commuting Area (RUCA) codes. Linear regression analysis investigated trends in rural orthopaedic surgeon volume. Multivariable logistic regression evaluated the association of surgeon characteristics with rural practice setting.

**Results:** The total number of orthopaedic surgeons increased 1.9%, from 21,045 (2013) to 21,456 (2018). Meanwhile, the proportion of rural orthopaedic surgeons decreased by roughly 0.9%, from 578 (2013) to 559 (2018). From a per capita perspective, the number of orthopaedic surgeons practicing in a rural setting per 100,000 population ranged from 4.55 orthopaedic surgeons per 100,000 in 2013 and 4.47 per 100,000 in 2018. Meanwhile, the number of orthopaedic surgeons practicing in an urban setting ranged from 6.63 per 100,000 in 2013 and 6.35 per 100,000 in 2018. The surgeon characteristics most associated with decreased odds of practicing orthopaedic surgery in a rural setting included earlier career-

stage (OR: 0.80, 95% CI: [0.70-0.91];  $p < 0.001$ ) and sub-specialization status (OR: 0.40, 95% CI: [0.36-0.45];  $p < 0.001$ ).

**Conclusion:** Existing rural-urban disparities in musculoskeletal healthcare access have persisted over the past decade and could worsen. Future research should investigate the effects of orthopaedic workforce shortages on travel times, patient cost burden, and disease specific outcomes.

**Level of Evidence:** IV

**Keywords:** rural disparities, health disparities, health equity, orthopaedic care, access

## INTRODUCTION

Recent estimates from the United States (U.S.) Census Bureau suggest the number of Americans older than 65 will increase from 15% in 2018 to nearly 25% in 2060.<sup>1</sup> Many common health problems faced by older populations are musculoskeletal in nature, including fractures of the hip, spine, or forearm, as well as degenerative joint diseases of the hip or knee.<sup>2,3</sup> Studies have projected the demand for orthopaedic surgical care to grow rapidly over the next several decades, with potential for substantial workforce shortages across the nation.<sup>4,6</sup> It has also been estimated that more than 1 in 5 older Americans live in rural areas and that these communities face major health inequities and poorer outcomes compared to their urban and suburban counterparts.<sup>7-11</sup>

Prior research has demonstrated that the supply of orthopaedic surgical services is not spread evenly throughout the United States.<sup>5,6,14</sup> Specifically, one study surveying 145 hospital administrators similarly found that only 30% of rural hospitals had a full-time orthopaedic surgeon on staff.<sup>12</sup> Furthermore, 71% stated the need for additional orthopaedic surgical services within their community.<sup>12</sup> In order to ensure equity in musculoskeletal health and healthcare access, it is necessary to pursue an effective geographic distribution of the US orthopaedic workforce. Although previous research has demonstrated discrepancies in the workforce between rural and urban areas, there has yet to be an examination of rural-urban disparities in orthopaedic access over the past decade.<sup>11</sup>

Therefore, the goals of the present study were to (1) identify trends in rural access to orthopaedic surgeons

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in the United States between 2013 and 2018 and (2) determine the surgeon characteristics associated with practice in a rural area.

## METHODS

### Data Source

The present study retrospectively queried the Centers for Medicare and Medicaid Services (CMS) Physician Compare National Downloadable File (PC-NDF) for all orthopaedic surgeons with an active National Physician Identifier from January 1st, 2013, to December 31st, 2018.<sup>13</sup> Following the initial data extraction, the dataset was linked with the Medicare Part B Provider and Other Supplier Payment and Utilization File (POSPUF) dataset to obtain additional surgeon level characteristics.<sup>14</sup> For each orthopaedic surgeon, we compiled self-reported gender, year of medical school graduation, geographic practice location, number of annual Medicare beneficiaries, group practice size, and sub-specialization status. The number of years in practice was estimated by taking the difference between the reported medical school graduation year and year of data reporting, followed by subtracting five years for generalists and six years for subspecialists. These data were then categorized as early ( $\leq 14$  years), mid (15-24 years), and late ( $\geq 25$  years) career stages, in concordance with previously published methodology.<sup>15</sup>

### Rural and Urban Classification

Within the CMS POSPUF dataset, each physician entry was assigned a Rural-Urban Commuting Area (RUCA) code based on their reported primary practice location. RUCAs are a classification system developed by the Economic Research Service of the United States Department of Agriculture (USDA) using 2010 US census tracts as well as the 2006-2010 American Community Survey. The RUCA classification utilizes whole numbers (1-10) and is utilized to distinguish zip code level geographic regions based on differences in population density, degree of urbanization, and daily commuting patterns.<sup>16</sup> In concordance with previous literature, we grouped RUCA codes 1 through 3 as urban and RUCA codes 4 through 10 as rural.<sup>17,18</sup> These categories are defined by primary commuting flow to census tracts of size 50,000 or more (Urban, RUCA 1-3), 10,000 to 49,999 (large rural, RUCA 4-6), 2,500 to 9,999 (small rural, RUCA 7-9), and 2,499 or less (isolated rural, RUCA 10).<sup>19,20</sup> Zip code to county geographic crosswalk files were obtained from the Office of Policy Development and Research at the U.S. Department of Housing and Urban Development (HUD) and utilized to determine surgeon practice region and county level access trends.<sup>21</sup>

### Statistical Analysis

Descriptive statistics analysis was conducted based on the surgeon characteristics, such as self-reported gender, number of years in practice, sub-specialization status, U.S. census region, Medicare patient volume, and group practice size. A bivariate analysis was conducted using Pearson's chi-squared test. County population estimates were extracted from the U.S. Census Bureau website and used to calculate the population density of orthopaedic surgeons per 100,000 individuals in each U.S. counties.<sup>22</sup> The above data sets were imported into Quantum Geographic Information System (QGIS) geospatial analysis software (version 3.12.1; open-source license GNU GPLv2), along with county boundary files from the U.S. Census Bureau website.<sup>22</sup> Heatmaps were then constructed to visualize changes in the geographic distribution and relative population density of U.S. orthopaedic surgeons between 2013 and 2018. Linear regression analysis was utilized to determine the significance of trends in the number and proportion of rural orthopaedic surgeons.

A multivariable logistic regression was used to evaluate the impact of various surgeon characteristics, as well as practice setting characteristics, on rurality of practice setting. The constructed regression model also included gender, number of years in practice, sub-specialization status, census region, practice group size, and number of Medicare beneficiaries treated annually. Odds ratios (ORs) and their respective 95% confidence interval (95% CI) were determined to quantify the effects of the included variables on the rurality of practice setting. All statistical tests were two-sided and utilized a pre-determined significance threshold of  $p < 0.05$ . All statistical analyses were performed via RStudio R version 4.1.1 (R, Foundations for Computational Statistics, Vienna, Austria) using the dplyr, DescTools, gtsummary, and ggplot2 packages.

This study was considered exempt from review by the Cleveland Clinic Foundation ethical review board due to the public nature of all data included and lack of protected health information as defined by 45 CFR 46.102 of the Department of Health and Human Services' Code of Federal Regulations.

## RESULTS

### Trends in Rural Access to Orthopaedic Surgeons

Throughout the study period the total number of practicing orthopaedic surgeons in the dataset increased by approximately 1.9%, from 21,045 in 2013 to 21,456 in 2018. The proportion of these surgeons working in rural areas decreased significantly over the same timeframe, from 11.9% to 11.0% ( $p = 0.002$ ) (Figure 1). This trend was driven primarily by a decrease in orthopaedic surgeons

working in large rural areas (9.1% in 2013 to 8.4% in 2018,  $p = 0.001$ ). Over the same period, no significant changes were seen in the proportion of surgeons working in small rural areas ( $p = 0.097$ ) and isolated rural areas ( $p = 0.772$ ) (Figure 1). Among rural U.S. counties specifically, roughly 66.6% (1,316 of 1,976) did not have access to a local orthopaedic surgeon in 2013 (Figure 2A). In 2018, only 33.5% of rural counties (664 of 1,976) possessed access to a local orthopaedic surgeon, compared to 67.8% (791 of 1,167) of urban counties (Figure 2B).

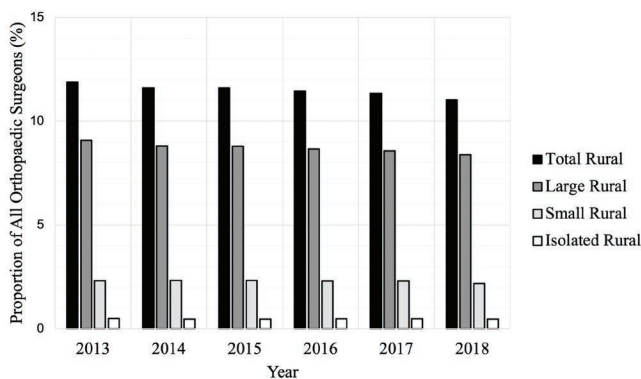


Figure 1. Trends (2013-2018) in the Proportion of Total Orthopaedic Surgeons Practicing in Rural Areas, stratified by Rural Urban Commuting Area (RUCA) categories.\*

\*Urban (RUCA 1-3, Primary commuting flow to metropolitan area of size 50,000 or more); Large Rural (RUCA 4-6, Primary commuting flow to micropolitan area of size 10,000 to 49,999); Small Rural (RUCA 7-9, Primary commuting flow to town of size 2,500 to 9,999); Isolated Rural (RUCA 10, Primary commuting flow to an area of 2,499 or less).

## Surgeon Characteristics Associated with Rural Practice Setting

In 2018, we analyzed a national cross-section of 21,456 practicing orthopaedic surgeons, of which 89.0% (19,088 of 21,456) were determined to practice in an urban setting and 11.0% (2,368 of 21,456) were determined to practice in a rural setting (Table 1). Following multivariable logistic regression analysis, sub-specialization in any given orthopaedic sub-field was shown to be significantly associated with decreased odds of rural practice setting (OR: 0.40, 95% CI: [0.36-0.45];  $p < 0.001$ ) (Table 2). With respect to geography, U.S. orthopaedic surgeons were significantly more likely to practice in a rural setting if located in the Midwest (OR: 1.92, 95% CI: [1.64-2.25];  $p < 0.001$ ), South (OR: 1.23, 95% CI: [1.05-1.44];  $p = 0.010$ ), or West (OR: 1.39, 95% CI: [1.17-1.65];  $p < 0.001$ ) compared to the Northeast. Furthermore, the present data show that earlier career orthopaedic surgeons, defined as those who have practiced 14 years or less, are less likely to practice in a rural setting, compared to later-career orthopaedic surgeons (OR: 0.80, 95% CI: [0.70-0.91];  $p < 0.001$ ) (Table 2).

## DISCUSSION

In response to the growing demand for musculoskeletal care across the U.S., it is essential to understand access to orthopaedic services across a variety of marginalized communities. It has been well demonstrated that patients residing in rural areas face higher rates of chronic disease, poorer access to social and psychological support services, and lower life expectancies.<sup>23,24</sup> Although prior research has raised concerns regarding the uneven distribution of the orthopaedic workforce, there has been insufficient evidence to assess trends in rural access over the past decade. The present study determined that, as of 2018, approximately two thirds of

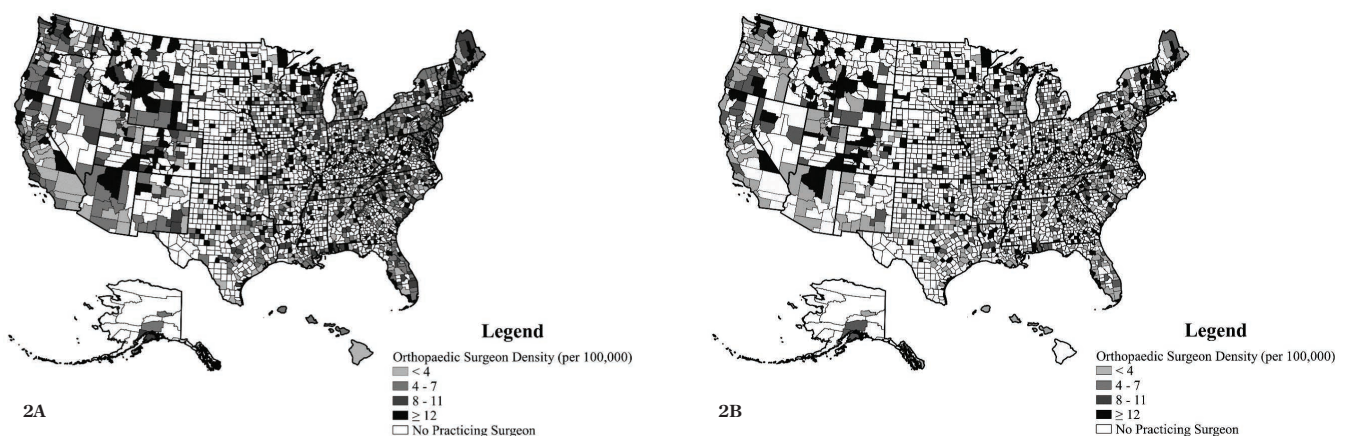


Figure 2A to 2B. Density of Practicing Orthopaedic Surgeons per 100,000 Population, across United States Counties in (2A) 2013 and (2B) 2018.

**Table 1. Orthopaedic Surgeon Characteristics, Stratified by Urban vs. Rural Practice Setting, 2018**

	Rural (n = 2368) <sup>a</sup>	Urban (n = 19088) <sup>a</sup>	p-value <sup>b</sup>
<b>Gender</b>			0.3
Male	2247 (95)	18,007 (94)	
Female	121 (5.1)	1081 (5.7)	
<b>Region</b>			<0.001
Northeast	338 (14)	3190 (20)	
Midwest	729 (31)	4135 (22)	
South	819 (35)	6968 (37)	
West	482 (20)	4075 (21)	
<b>Number of Years Practiced</b>			<0.001
25 and more	605 (31)	4468 (27)	
15-24	596 (31)	4375 (27)	
≤ 14	747 (38)	7644 (46)	
<b>Patient Volume</b>			0.072
500 and more	526 (22)	4055 (21)	
201-499	1095 (46)	8564 (45)	
11-200	747 (32)	6469 (34)	
<b>Practice Group Size</b>			<0.001
200 and more	438 (24)	6147 (41)	
50-199	499 (28)	3286 (22)	
1-49	857 (48)	5600 (37)	
<b>Sub-specialization</b>			<0.001
General	1777 (79)	10707 (59)	
Sub-specialist	480 (21)	7447 (41)	

<sup>a</sup> n (%)

<sup>b</sup> Pearson's Chi-squared Test

**Table 2. Multivariable Logistic Regression for Orthopaedic Surgeon Characteristics Associated with Rural Practice Setting**

	Odds Ratio	95% CI	p-value
<b>Gender</b>			
Male	Reference		
Female	1.13	0.89, 1.41	0.3
<b>Region</b>			
Northeast	Reference		
Midwest	1.92	1.64, 2.25	<0.001
South	1.23	1.05, 1.44	0.010
West	1.39	1.17, 1.65	<0.001
<b>Number of Years Practiced</b>			
25 and more	Reference		
15-24	1.07	0.94, 1.23	0.3
≤ 14	0.80	0.70, 0.91	<0.001
<b>Patient Volume</b>			
500 and more	Reference		
201-499	1.09	0.96, 1.24	0.2
11-200	0.98	0.85, 1.14	0.8
<b>Practice Group Size</b>			
200 and more	Reference		
50-199	2.10	1.83, 2.41	<0.001
1-49	2.20	1.94, 2.49	<0.001
<b>Sub-specialization</b>			
General	Reference		
Sub-specialist	0.40	0.36, 0.45	<0.001

rural counties did not have access to a local orthopaedic surgeon. Furthermore, the proportion of rural orthopaedic surgeons was shown to gradually decrease from 2013 to 2018. Residence in the Midwest, later career-stage, smaller practice size, and lack of sub-specialization were associated with greater odds of rural practice setting. Despite increased attention and discussion surrounding the musculoskeletal needs of rural communities in the U.S., these data suggest there have been no definitive improvements in rural-urban access disparities. Considering the aging current workforce and propensity for younger surgeons to practice near metropolitan areas, recruitment and retention of the rural orthopaedic surgeons remains an urgent policy priority.<sup>6,25,26</sup>

## Limitations

The above findings have several limitations. The data utilized for this study were confined to orthopaedic surgeons certified by the CMS and caring for at least 11 Medicare patients annually. It should be noted that surgeons and those in cash-based practices are not represented within the datasets used for the present study. However, recent survey estimates have shown that those not certified by the CMS and those not accepting Medicare patients to be a small minority of the overall orthopaedic workforce.<sup>27</sup> Additionally, more specific information describing employment characteristics, such as compensation models, part-time work, or locum tenens contracts, were not accessible for this study.<sup>15,28,29</sup> Such

data may be helpful to understand the motivating forces behind workforce fluctuations in terms of geography and practice setting. Trends such as declining procedural reimbursements, alternative payment models, and health system consolidation have been well described, although their effects on the rural orthopaedic workforce remain unclear.<sup>30</sup> Finally, the current analysis was limited to be between 2013 to 2018 and was unable to account for the large workforce disruptions in the year 2020 related to the COVID-19 pandemic.<sup>31</sup> It is possible the disparities highlighted above have been recently exacerbated by the closure of rural hospitals or safety hazards faced by older surgeons still in practice.<sup>25,32</sup> Further research on this subject is warranted as more recent workforce data becomes available.

### **Trends in Rural Access to Orthopaedic Surgeons**

While the total number of practicing orthopaedic surgeons rose over the study period, the proportion of these surgeons in rural practice settings demonstrated a modest decrease. Furthermore, as of 2018, roughly two of every three rural counties did not have access to a local orthopaedic surgeon. These data support prior research suggesting disparities in rural access to a wide variety of surgical services.<sup>26,33</sup> A 2005 policy report from the University of Washington Rural Health Research Center showed rural orthopaedic surgeons to comprise 13.5% of the overall workforce. Additionally, the report determined that 10.2%, 2.7%, and 1.6% of orthopaedic surgeons practiced in large rural, small rural, and isolated rural areas, respectively. The present study findings for the year 2018, using the same categorization scheme, suggest a 2.5% decrease the proportion of orthopaedic surgeons in any rural practice setting. For those practicing in large rural, small rural, and isolated rural settings, the present study findings show decreases of 1.8%, 0.5%, and 1.1%, respectively. These data should raise concerns for impending exacerbations of existing rural-urban disparities. Prior research has indicated the rate of financial distress among rural hospital to be rapidly increasing, with more than 100 confirmed closures distributed throughout the U.S. between the years 2010 and 2018.<sup>34</sup> These closures have contributed to worsening access to essential medical, surgical, and emergency services in the surrounding communities.<sup>35</sup> A variety of interventions have been attempted to address workforce disparities including, but not limited to, telehealth expansions, visiting consultant clinics, and public service loan forgiveness programs.<sup>36</sup> However, the implementation of these programs has often lacked coordination beyond the local level.<sup>37</sup> Future research should investigate the impact of workforce changes on delays to orthopaedic care, travel times, and cost-burden on patients.<sup>38</sup>

### **Surgeon Characteristics Associated with Rural Practice Setting**

The surgeon characteristics most associated with increased odds of practicing orthopaedic in a rural setting included later career-stage, residence in the Midwest, smaller practice size, and generalist status. Recent evidence has shown trends towards increasing fellowship sub-specialization, health system consolidation, and difficulty of managing a sustainable solo-practice.<sup>15,39,40</sup> Considering these trends, these present study findings highlight the persisting rural-urban disparities in orthopaedic surgical care and suggest a potential for further decline in the rural orthopaedic workforce over the coming years. An aging rural physician workforce has been previously described in both the generalist and surgical subspecialty literatures. The present study underscores the continued trend of later career staged orthopaedic surgeons to be significantly associated with rural practice setting as demonstrated in previous literature. Among primary care physicians, a recent systematic review determined that rural upbringing, receipt of government scholarships, and enrollment in dedicated rural-health medical school programming to be the three most predictive factors for rural practice setting. Among orthopaedic surgeons, similar factors may be helpful to identify, recruit, and retain newly trained or earlier career surgeons in rural areas.

### **CONCLUSION**

The present study determined that, as of 2018, approximately two-thirds of rural counties did not have access to a local orthopaedic surgeon and the proportion of rural orthopaedic surgeons has gradually decreased from 2013 to 2018. Additionally, surgeons practicing general orthopaedics in the Midwest, in small groups, in later stages of their careers had greater odds of working in a rural community. These findings suggest that persisting rural-urban disparities in musculoskeletal health may worsen if newly trained orthopaedic surgeons migrate to major metropolitan areas without filling the positions of retiring orthopaedic surgeons in rural regions. Future research should investigate the effects of orthopaedic workforce shortages on travel times, patient cost burden, and disease specific outcomes.

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# EFFECTS OF THE COVID-19 PANDEMIC ON THE ORTHOPAEDIC SURGERY RESIDENCY APPLICATION MATCH PATTERNS

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## ABSTRACT

**Background:** The COVID-19 pandemic and its effects on the orthopaedic match process are yet to be fully understood and should be explored. We hypothesize that the cancellation of away rotations due to the COVID-19 pandemic would decrease the variability of where students matched into orthopaedic residency compared to pre-pandemic years.

**Methods:** Accredited orthopaedic programs were collected from the Accreditation Council for Graduate Medical Education (ACGME) database. Rosters of orthopaedic residency classes for the years 2019, 2020, and 2021 were compiled across all orthopaedic programs in the United States. Data collection for the incoming 2021 orthopaedic surgery residents was carried out by reviewing each program's website, Instagram, and Twitter.

**Results:** Data for the incoming orthopaedic surgery residents from the 2021 National Residency Match Program (NRMP) were collected. 25.7% of incoming residents matched at their home institution. Data collection for the 2020 and 2019 orthopaedic residency classes yielded 19.2% and 19.5% home institution match rates, respectively. When examining likelihood to match into an orthopaedic residency program in one's own state, we found that in the 2021 match cycle, 39.3% of applicants matched within their state, while 34.3% and 33.4% of incoming residents matched in 2020 and 2019, respectively.

**Conclusion:** To keep our patients and staff safe, visiting externship rotations were suspended in the 2021 Match cycle. As we continue to navigate the shifting waters of the COVID-19 pandemic, it is

important to understand how our choices affect the dynamics of applying into residency training and beyond. This study demonstrates that a higher percentage of applicants that matched into orthopaedic residency remained at their home program compared to the previous two years before the pandemic. This indicates that programs tended to rank their home applicants, and that applicants tended to rank their home programs, higher than those that were less familiar.

**Level of Evidence:** IV

**Keywords:** orthopaedic match, COVID-19, orthopaedic surgery, education, orthopaedic residency

## INTRODUCTION

The COVID-19 pandemic has impacted nearly all facets of modern life. In March of 2020, medical schools largely ceased in person curriculums and began to strategize novel methods to continue delivering adequate medical training to its students. Some critical features of a standard medical school curriculum were put on hold indefinitely; home clinical and visiting sub internship/externship rotations being a few examples.<sup>1-6</sup> This decision was made in attempts to flatten the pandemic curve because medical students were not considered to be essential to the management of COVID-19 patients.<sup>7</sup> In addition to the change in curriculum, the National Residency Match Program (NRMP) residency interview process was converted into an all-online virtual format. Both residency applicants and the Orthopaedic Surgery residency programs interviewing prospective residents had to adjust to all-virtual remote interviews for the first time.

Inevitably, these changes added another layer of complexity to the existing challenges of medical school and introduced questions on how the traditional path to residency training would be affected.<sup>2</sup> In many cases, medical students have reported decreased clinical exposure and a reduced ability to experience hospital programs outside of where they are enrolled. Many students considered taking extra time to complete medical school to strengthen their candidacies and up to 20% of medical students reported that they considered changing the specialty of interest due to COVID-19.<sup>2</sup> Further, Byrne et al. discussed the effects that the restrictions on

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travel and socialization had on the Match program by impacting the geographical relocation of matriculating postgraduate year 1 (PGY-1) residents.<sup>8</sup> Lastly, various specialties including Orthopaedic Surgery have considered specialty-specific factors that may have been impacted by the COVID-19 pandemic.<sup>9-11</sup> For example, given that Orthopaedic surgery applicants have traditionally completed an average of 2.4 away rotations per applicant prior to the COVID-19 pandemic, these changes have likely impacted the Orthopaedic field more drastically than other specialties that do not strongly encourage away externships.<sup>12</sup>

Fortunately, studies have offered promising solutions to overcome the new challenges residency applicants face in the COVID-19 era.<sup>13,14</sup> Some suggest that because of the changes to the residency application process, mentors have an increased duty to represent residency applicants throughout the process, especially during the interview and pre-application period.<sup>13,14</sup>

Our study sought to analyze how the COVID-19 pandemic impacted the rate at which residency applicants matched into the Orthopaedic Surgery residency program at the same institution or program that was affiliated with where they attended medical school ("home" institution), compared to an Orthopaedic Residency program outside of their home institution ("external" institution). Given the lack of in-person exposure, both for the applicant to external institutions and the residency program to external applicants via visiting rotations, as well as the first-time virtual interview process, we hypothesize that a higher percentage of applicants matched into their home institution compared to years prior to the COVID-19 pandemic. Further, we hypothesize that because programs were inevitably more familiar with their home applicants, applicants matching at one's home institution exacerbated the critical role that visiting externship rotations have for applicants applying to Orthopaedic Surgery residency programs.

To our knowledge, there are no other studies that have identified the recent changes in the Orthopaedic Surgery residency application process during the COVID-19 pandemic. Our goal is this study will highlight the significance of in-person clinical rotations at external residency programs and the possible impact that the all-virtual interview process has on a residency applicant's ability to instill confidence as a prospective resident to external institutions and ultimately Match.

## METHODS

### Data Collection

All accredited Orthopaedic Surgery residency programs were collected from the Accreditation Council for Graduate Medical Education (ACGME) database. Orthopaedic Surgery programs that have been ongoing

for less than two years were excluded due to lack of data for comparison between residency Match lists. The first round of data collection was performed on 4/1/2021 and was reviewed on a weekly basis until we obtained at least 80% of the completed dataset of individuals that matched into orthopaedics.

The primary method of data collection for incoming 2021 Orthopaedic Surgery residents was through investigation of institutional-specific Orthopaedic Surgery residency websites. Often, orthopaedic residency programs post profiles on their institutional webpages about their current residents. Instagram™ and Twitter™ searches for each residency program were conducted if information on the orthopaedic residency program webpages were inconsistent or missing, as many programs have dedicated social media accounts and posts about their incoming residents. Data of interest for each incoming resident included each resident's medical school, their home institution, the state, and region where they attended medical school, and where they matched for residency. A regional Match was defined as an incoming orthopaedic surgery resident who attended medical school in the following 4 regions: Northeast, South, Midwest, West, and matched within the same region. The US Census Bureau has 4 regional designations in the United States: Northeast, South, Midwest, and West. The North region included states: PA, NY, VT, NH, ME, MA, RI, CT, NJ. South region included TX, OK, AR, LA, MA, AL, TN, KY, WV, VA, MD, DE, NC, SC, GA, FL. Midwest region included ND, SD, NE, KS, MN, IA, MO, WI, IL, IN, MI, OH. West region included MT, WY, CO, NM, AZ, UT, ID, CA, NV, OR, WA.

If the residency program posted online about their incoming residents, each incoming resident was searched for on Instagram, Twitter, a 163 nd on Google to look for information mentioned in the previous paragraph. The resident classes entering in 2020 and 2019 databases were generated in a more directed search of residency program websites, as most programs had updated their lists of current residents up to the class of 2020.

If information was still unavailable, emails were sent out to unaccounted residency program directors regarding the study being conducted and their willingness to provide our group with their incoming 2021 orthopaedic surgery resident class. A total of two emails were sent with the latter being a follow up to those programs who had not initially responded. Phone calls to remaining programs were made regarding willingness to share incoming orthopaedic surgery resident demographics.

### Statistical Analysis

The names of orthopaedic surgery residents accounted for in classes entering during 2021, 2020, and 2019 were reported along with the percentage of each class

matching into their home institution. SPSS Premium Statistics V28 was used to determine significance between home institution likelihood for Match 2021 against Match 2020 and Match 2019. Incoming orthopaedic surgery residents matching at their home institution were assigned a value of 1 while those who did not were assigned a 0. The same was done for orthopaedic surgery residents in 2020 and 2019. Two t-tests of 2 samples assuming equal variances were assessed with 95% confidence intervals (2021 vs. 2020, 2021 vs. 2019). One-tail and two-tail p-values were recorded and included. P-values <0.05 were statistically significant.

### RESULTS

690 of the total 800 (86.25%) matriculating orthopaedic surgery residents from the 2021 NRMP Data Report and their medical schools were collected. Review of the 2020 and 2019 NRMP Data Reports was done to compare the matriculating orthopaedic surgery residents of 2021 with the previous two years. Full data points for 766 out of 850 (90.12%) and 760 of 824 (92.23%) of all incoming orthopaedic surgery residents and their home institutions was collected for the 2020 and 2019 Match cycles respectively. Of the 690 incoming residents, 177 (25.7%) matched at their home institution during the 2021 orthopaedic Match cycle, (Table 1). This demonstrates a statistically significant increase from the 19.2% and 19.5% home institution Match rate from the 2020 and 2019 cycles, respectively, and indicates a percent change of over 30% from each of the previous two years. Visual comparison

**Table 1. Incoming Orthopaedic Residents Matching at Home vs. Non-Home Institutions**

Graduation Year	Residents not Matching at Home Institution	Residents Matching at Home Institution	Total	% Matching at Home Institution
2021	513	177	690	25.7
2020	619	147	766	19.2
2019	612	148	760	19.0

**Table 2. T-test Comparing 2021 vs. 2020 and 2021 vs. 2019 Orthopaedic Surgery Residency Match**

	2021	2020		2021	2019
Mean	0.257	0.192	Mean	0.257	0.195
P (T<=t) one-tail	0.0016		P (T<=t) one-tail	0.0025	
P(T<=t) two-tail	0.0032		P(T<=t) two-tail	0.0050	

depicted in Figures 1 and 2 show the increase in home institution match rates compared to previous years for incoming orthopaedic surgery residents.

One and two-tail t-tests were conducted to compare the 2021 incoming orthopaedic surgery residents to the 2020 and 2019 groups to determine significance in home institution match rate. Table 2 shows relevant p-values for each comparison. 417 total 209 incoming orthopaedic surgery residents of the 690 total residents in 2021 had a known medical school, matching within their region roughly 60.4% of the time. Known medical schools were also collected from the 2020 and 2019 orthopaedic surgery residency Match, where 59.4% and 59.3% of incoming residents matched within their home region, respectively (Table 3).

Of the 690 matched applicants in the 2021 cycle, 271 matched at an orthopaedic residency program within the state to which they attended medical school (39.3%). This is a statistically significant change from the previous two years, where 34.3% and 33.4% of residents from the 2020

**Table 3. Incoming Orthopaedic Residents Matching with Known Medical School Matching in Region (p<0.05)**

	Known Medical School	Matched Within Region	% Within Region
2021	690	417	60.4%
2020	766	455	59.4%
2019	760	451	59.3%

**Table 4. Incoming Orthopaedic Residents Matching with Known Medical School Matching in State**

	Known Medical School	Matched Within Region	% Within Region
2021	690	217	39.3%
2020	766	263	34.3%
2019	760	451	59.3%

**Table 5. T-test Comparing 2021 vs. 2020 and 2021 vs. 2019 Orthopaedic Surgery Residency Match Within State**

	2021	2020		2021	2019
Mean	0.3942	0.34	Mean	0.3942	0.3342
P (T<=t) one-tail	0.0224		P (T<=t) one-tail	0.0089	
P(T<=t) two-tail	0.0448		P(T<=t) two-tail	0.0178	

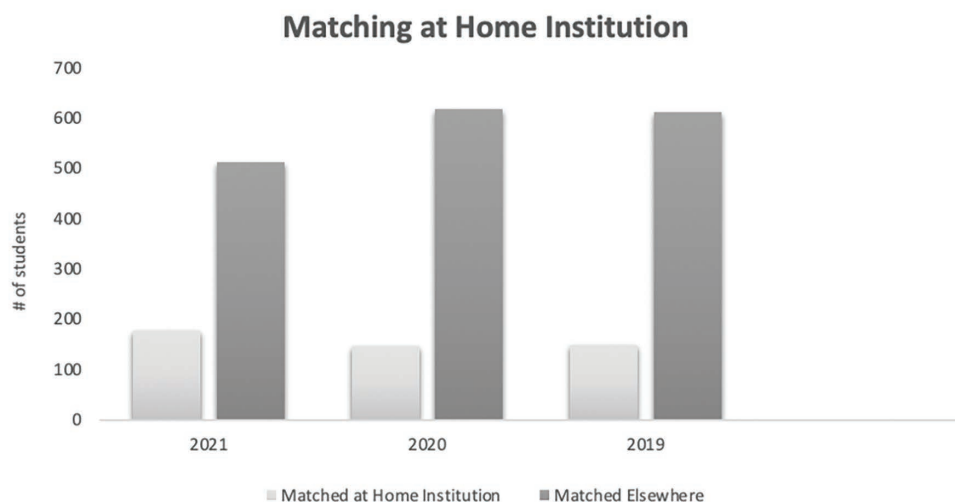


Figure 1. Number of residents matching at their home program vs. an external program from 2019-2021.

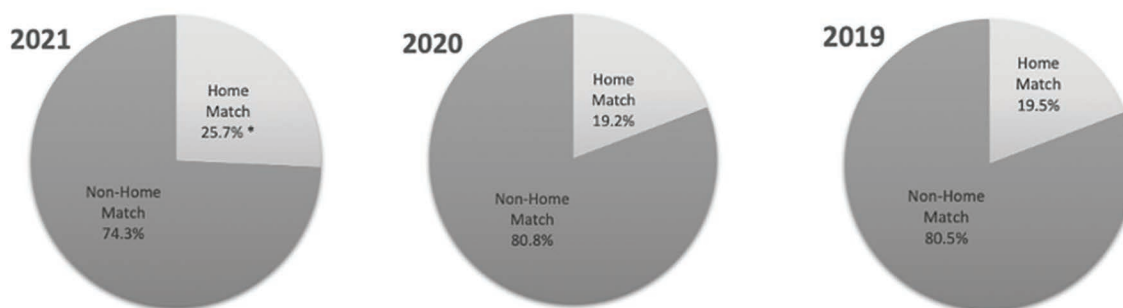


Figure 2. Percentages of incoming orthopaedic surgery residents that matched at their home program vs. external program from 2019-2021.

and 2019 cycles matched within their state, respectively. This indicates that the 2021 Match demonstrated a 14.9-17.7% increase in percent change from previous years of in-state residency matching (Table 4). Table 5 shows one and two-tail T test comparing the 2021 incoming orthopaedic surgery residents that matched within their state to 2020 and 2019 rates along with relevant p-values.

## DISCUSSION

The orthopaedic surgery residency application process is a rigorous one. The Match rate has remained stable for over a decade at a mean Match rate of 76.9% and a standard deviation of 2.3%.<sup>15</sup> The applicant pool is filled with extremely competitive prospective applicants, and many of those that go unmatched are likely also qualified to become 232 orthopaedic surgeons. Previous studies have shown no differences in Step 1 scores, Step 2 clinical knowledge scores, or the number of publications between applicants who matched or did not match.<sup>16</sup> To add to the complexity of matching into an

Orthopedic Surgery residency, the COVID-19 pandemic created an unprecedented change to the way resident applicants are evaluated, theoretically altering Match outcomes. In fact, our study shows an increase in the percent change for matching at one's home institution by 34.5% and a 32.5% during the first year of the COVID-19 pandemic compared to the two previous pre-pandemic Match cycles. In absolute terms, this indicates an increase from approximately 19% to 26% of successfully matched applicants remaining at their home institution during the COVID-19 pandemic. Additionally, we saw a statistically significant increase in in-state matching in the 2021 Match compared to previous years indicating that more incoming orthopaedic interns are staying close to their medical school. This may be due to positive relationships that their home program may have on neighboring institutions, and thus an easier time to make introductions to foster relationships with the applicants given the lack of away rotations. It could also be explained by those personally affected by COVID-19 preferred to stay closer to home.

There are many reasons why the percent of applicants matching at their home institution increased. First and foremost, elimination of away externship rotations in the 2020-2021 cycle likely played an important role. Visiting rotations have classically served as a vital tool for applicants to showcase themselves to residency programs outside of their home institution. The COVID-19 pandemic may have made the evaluation of prospective applicants from outside institutions more difficult by nature of not having the in-person interaction within the work environment. This time is critical for both the applicant and the residency program. For the residency program, this time allows them to evaluate an applicant's work ethic, breadth of knowledge, personality fit within the program's culture, and likeness. Similarly, this time is imperative of the applicant to gauge strengths and weaknesses of a program, their fit within the program, and desire to spend the next chapter of their life within a particular program and geographic location. It has been shown that applicants who completed at least two away rotations were 10% more likely to match than those who completed one or zero, with diminishing returns after successful completion of two.<sup>6</sup> Additionally, while externships are important for all orthopaedic residency applicants, they are likely especially vital for those that do not have a home orthopaedic residency program.

Furthermore, the COVID-19 pandemic increased the complexity of interviewee selection and ranking. As previously stated, the transition to completely virtual interviews was another divergence away from the traditional in-person experience programs were accustomed to. While much more subjective in comparison to the importance of in-person clinical rotations, lack of in-person interview also eliminates the value of face-to-face interaction. Further, from an applicant's standpoint, they lose the opportunity to visit a program, its hospital(s), and city. This complicates the decision process for both parties. The applicant may lack confidence going to a program and city they have not physically been to or experienced. The residency program may also lack confidence in selecting an applicant from a different region of the country, questioning the applicant's commitment to move without ever visiting.

The implications that may arise from this new implementation of interviewee selection in the Match process are numerous. Typically, an interviewee attending an in-person interview was one of the strongest showings of interest in a program. Recent studies also correlate the significant changes regarding the pre-COVID vs. COVID Match.<sup>17,18</sup> If these changes made by residency programs remain implemented, there will be emphasis on other aspects of the application process that will be augmented to show interest, such as the recent adaptation of signaling in orthopaedic surgery.

Along with these direct effects that the pandemic had on the Match process, other areas played an indirect role, for example, medical school training. Some of these changes include less opportunity for clinical exposure during medical school at one's home institution in a global effort to "flatten the curve".<sup>7</sup> In addition to a decrease in in-person clinical exposure, a survey of 1463 incoming PGY-1's reported that the pandemic adversely affected their connection with their medical school communities, and 58% of said interns reported that the pandemic impeded their preparation for intern year.<sup>19</sup> Even more, some studies have indicated statistically significant decreases in predictors of emotional wellbeing including coping, personal resilience and other health behaviors (sleep changes, poor exercise).<sup>20</sup> Residency admissions staffs are doing their best to evaluate each applicant fairly, however with less in-person exposure to each applicant and a changing landscape of standardized examinations, the emphasis on certain attributes and interview approach is, and will continue to be, affected. Those involved in the residency application process have anecdotally experienced an improvement to a single visiting rotation in the 2021-2022 cycle, but a continued limitation in the process, nonetheless.

The residency programs are working to implement changes to improve the altered residency application process. Some proposed improvements include working to create stronger pathways for advising during the preapplication process, creating and implementing a more holistic approach to application screening, and emphasizing intentional mentorship on clinical and research rotations for candidates.<sup>9,10</sup> As guidelines change and new variants of the COVID-19 pandemic continue to emerge, these improvements will likely need to be flexible and revisited.

Our study is not without limitations. We were able to collect 86% of the Match data from the 2021 cycle, as some programs had not updated their websites/social media and did not respond to repeated attempts of contact. Furthermore, we cannot be certain the lack of visiting rotations was the driving force behind the increased home institution match rate. It is not entirely clear if the increase in home institution matching was due to the removal of visiting rotations, the replacement of in-person interviews with virtual interviews, a combination of the two, or additional factors not considered in this study. Furthermore, there may be alternatives to in-person visiting rotations such as virtual away externships that may be improved and more widely implemented over the next few years to help reduce the volatility seen in 2021. However, given that over 50% of applicants on average match at either their home institution or where they complete their visiting externship, the suspension



of visiting rotations during the 2020-2021 likely played a major role in any changes seen in the Match statistics.<sup>12</sup>

To keep our patients, medical staff, and students safe, visiting externship rotations were suspended in the 2021 Match cycle and were limited to one externship during 2022 Match cycle. As we continue to navigate the shifting waters of the COVID-19 pandemic, it is important to understand how our choices affect the dynamics of applying into residency training and beyond. This study highlights how the removal of in-person visiting externships correlated with an increase in the percent of applicants that matched at both the affiliated program and within the state of their medical school. It will be important to see how the reimplementation of one single visiting rotation during the 2021-2022 orthopaedic Match cycle changes these statistics. If a decrease in percent home or state Match for the 2022 cycle is experienced, then there will be even stronger evidence for the importance of visiting rotations for promoting a more geographically diverse residency class and will help guide future consideration for away externships as we continue to face the threat of the COVID-19 pandemic.

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# ESTABLISHING CONSTRUCT VALIDITY OF A NOVEL SIMULATOR FOR GUIDE WIRE NAVIGATION IN ANTEGRADE FEMORAL INTRAMEDULLARY NAILING

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## ABSTRACT

**Background:** Antegrade femoral intramedullary nailing (IMN) is a common orthopedic procedure that residents are exposed to early in their training. A key component to this procedure is placing the initial guide wire with fluoroscopic guidance. A simulator was developed to train residents on this key skill, building off an existing simulation platform originally developed for wire navigation during a compression hip screw placement. The objective of this study was to assess the construct validity of the IMN simulator.

**Methods:** Thirty orthopedic surgeons participated in the study: 12 had participated in fewer than 10 hip fracture or IMN related procedures and were categorized as novices; 18 were faculty, categorized as experts. Both cohorts were instructed on the goal of the task, placing a guide wire for an IM nail, and the ideal wire position reference that their wire placement would be graded against. Participants completed 2 assessments with the simulator. Performance was graded on the distance from the ideal starting point, distance from the ideal end point, wire trajectory, duration, fluoroscopy image count, and other elements of surgical decision making. A two-way ANOVA analysis was used to analyze the data looking at experience level and trial number.

**Results:** The expert cohort performed significantly better than the novice cohort on all metrics but one (overuse of fluoroscopy). The expert cohort had a more accurate starting point and completed the task while using fewer images and less overall time.

**Conclusion:** This initial study shows that the IMN application of a wire navigation simulator demonstrates good construct validity. With such a large cohort of expert participants, we can be confident that this study captures the performance of active surgeons today. Implementing a training curriculum on this simulator has the potential to increase the performance of the novice level residents prior to their operating on a vulnerable patient.

**Level of Evidence:** III

**Keywords:** simulation, trauma, guide wire navigation, medical education

## INTRODUCTION

Simulation of surgical procedures has become a cornerstone in modern post-graduate training and has been extensively explored the last few decades.<sup>1</sup> Advantages gained by simulation-based training include decreased cognitive load<sup>2</sup> and increased confidence,<sup>3</sup> but the major advantage of simulation-based surgical skill training is that it allows the acquisition of skills in a safe environment and without compromising patient safety.<sup>4,5</sup>

This is particularly true in high stakes procedures, such as hip fracture surgery, where up to 25% of the patients die within the first postoperative year.<sup>6</sup> Here, optimal reduction and placement of implants is needed to allow early weightbearing as tolerated and thus the ability for the patient to restore the preoperative quality of life and function, i.e., daily activities.<sup>7,8</sup>

A wire navigation simulation platform (Iowa Simulation Solutions, LLC) has been developed that supports a variety of orthopedic procedures. Several of its training modules have been shown to have construct validity, specifically simulator performance scores differentiate between experts and novices.<sup>9,12</sup> The ability of a simulator to distinguish between these levels of expertise is required before the simulator can be more thoroughly validated according to either Kane's<sup>13</sup> or Messick's<sup>14</sup>

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framework. These frameworks have been extensively interpreted as seen by Cook and Hatala.<sup>15-17</sup>

Previous work has established the construct validity of both the dynamic hip screw (DHS) simulator<sup>11</sup> and a simulator for pediatric supracondylar humeral (SCH) fractures.<sup>18</sup> The present study tests the construct validity of a new antegrade femoral intramedullary nailing (IMN) simulator module by comparing the performance scores of novices and experts.

## METHODS

This study prospectively evaluates the construct validity of the current scoring criteria of the IMN simulator (Figure 1).

Novices (medical students and physicians with less than 10 hip fracture or IMN-related surgical procedures) and experts (faculty) were verbally introduced to the simulator and the designated task. The task required each participant to complete two cases by placing a Kirschner-(K-)wire to the best of their abilities. The optimal entry point of an IMN depends on the type of fracture, the type of nail, and the femoral curvature. To avoid confusion, we predefined and communicated an “ideal” position in both the anteroposterior and lateral plane for each case (Figure 2). A foot pedal was connected to the simulator, so that depressing the left pedal requested a fluoroscopic anteroposterior (AP) image, depressing the right pedal requested a lateral image.

The measured scoring criteria were: Start Point Distance [mm] from the predefined entry point, End Point Distance [mm], Trajectory of the K-wire compared with the predefined entry wire, Number of AP and Lateral

fluoroscopic images as well as procedural efficiency measures. Some of the efficiency measures included the numbers of incorrect adjustments, found by counting the number of times the pin was angled away from the ideal pin placement, or improper/premature switch between fluoroscopic planes, which occurs when a subject switches from AP to lateral or vice versa without being on target in the initial plane. Additionally, taking unnecessary radiographs without adjusting the position of the K-wire was counted as an overuse of fluoroscopy and finally out of plane movement of the K-wire occurred when the participant moved the K-wire in the opposite plane to the plane that the images were acquired in. Some of these behaviors were initially defined in a study by Long et al. and were adapted for this new application.<sup>9</sup> At the current state of developing the simulator, external validation of these parameters is needed before the simulator scoring criteria can be further adjusted and a global score can be constructed.

Statistical analysis: All data were analyzed using two-way ANOVA with case 1 – case 2 and level of experience as factors. The contribution to the total variance of these factors and the inter-person variation were evaluated and tested for statistical significance, i.e.,  $p\text{-value} \leq 0.05$ . Data are given as median (minimum-maximum) or absolute numbers in Table 1 and mean (95% confidence interval) in Table 2.

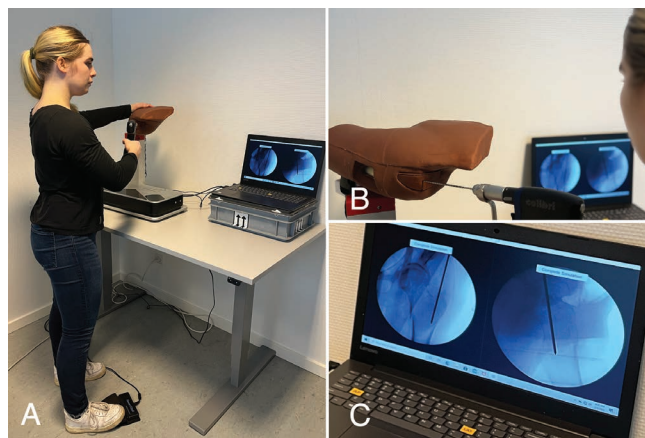


Figure 1A to 1C. Participant using the intramedullary nailing simulator (1A) placing a Kirschner-wire for the IMN entry point with a power tool into the sawbone within the soft tissue envelope (1B). The foot pedals (1A) were used to obtain simulated fluoroscopic images (left = anteroposterior and right = lateral plane) of the proximal femur and guidewire (1C).

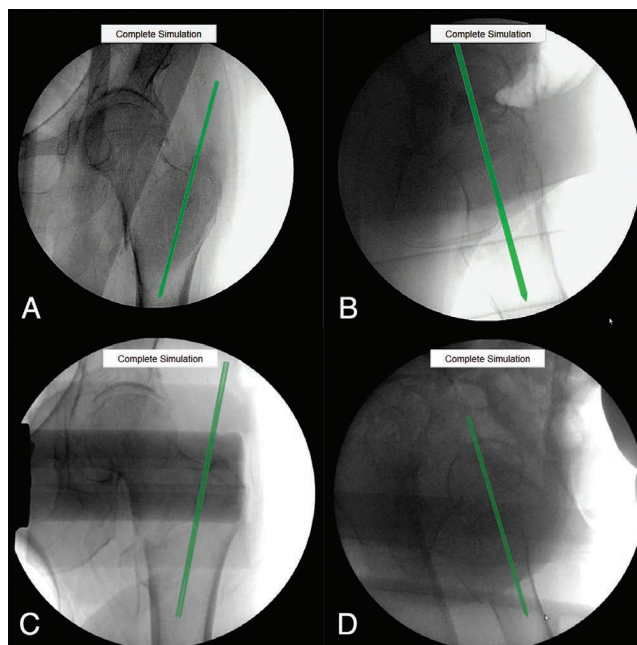


Figure 2A to 2D. Illustration of the anteroposterior and lateral fluoroscopic images and the position of the guide wire (green), which the participants were asked to replicate. The upper panels (2A+2B) represent the first case and the lower panels (2C+2D) depict the second case.

## RESULTS

In total, 12 novices and 18 experts were enrolled in the present study. Experts were 12 orthopedic consultants and 6 orthopedic physicians, all of whom had considerable experience in treating hip fractures. Among the orthopedic consultants, 7 were full-time trauma surgeons, 5 were consultants with a daily practice in other subspecialties, but with primary responsibility for

trauma shifts at a level 1 trauma center several times per month, and post-graduate year 3-5 residents, who had performed more than 60 hip fracture osteosyntheses as primary surgeon (intramedullary nail, dynamic hip screw, cannulated screws). The basic demographics of the participants are given in Table 1.

A two-way ANOVA indicated high between-person variability accounting for 38-61% of the observed total variation of the various simulator-measured outcomes (Table 2). All participants improved their scores from case 1 to case 2. However, depending on the outcome measure, the between-case variation only accounted for 2-18% of the total variation.

The level of surgical experience, i.e., being a novice or an expert, accounted for 9-25% of the total variation and these results were statistically significant for the majority of the measured outcomes (Table 2). Overuse of fluoroscopy was the only outcome that did not achieve statistical significance ( $p=0.36$ ).

## DISCUSSION

In total, 12 novices and 18 experts participated in this investigation of the construct validity of a new antegrade femoral intramedullary nailing (IMN) simulator module. All participants improved their performance, meaning that even experts get acquainted with the simulator. Statistically significant differences between the expert

**Table 1. Demographics**

	Novices (n = 12)	Experts (n = 18)
Age [years]	27 (25-31)	40 (31-61)
Male / female / other	6 / 6 / 0	14 / 4 / 0
Righthanded / lefthanded / ambidextrous	11 / 1 / 0	17 / 1 / 0
Board certified [years]	NA	5.9 (1.9-22.0)
Hip fracture osteosyntheses (no.)	0 (0-4)	98 (67-148)
Previous simulation-based training [n/N]	4 / 12 (33%)	11 / 18 (61%)
Self-reported hip fracture knowledge (5 point scale)	1 (1-3)	4.5 (4-5)

Median (minimum-maximum) or absolute numbers are given.  
NA = not applicable.

**Table 2. Results of Novices and Experts Presented as Mean (95% Confidence Interval) and P-Value of 2-Way Anova with Focus on the Experience Level**

	Novices (n = 12)		Experts (n = 6+12 = 18)		ANOVA analysis p (experience level)
	case 1	case 2	case 1	case 2	
Procedure time [min.]	7.1 (5.1-9.0)	4.3 (2.1-6.4)	3.3 (2.6-4.0)	2.2 (1.5-3.0)	<0.001
Starting point distance [mm]	11.5 (7.5-15.5)	8.3 (6.4-10.3)	6.2 (5.1-7.4)	7.1 (6.3-7.8)	0.005
End point distance [mm]	10.6 (5.5-15.6)	8.2 (6.7-9.7)	6.9 (5.1-8.6)	5.7 (4.6-6.8)	0.016
Trajectory offset [mm <sup>2</sup> ]	7.5 (5.3-9.7)	5.7 (4.0-7.5)	5.2 (4.2-6.2)	4.0 (3.0-5.0)	0.010
X-ray: AP+LAT [no.]	50 (33-68)	30 (14-45)	27 (20-33)	20 (15-24)	0.012
Improper plane switch [no.]	9 (6-11)	5 (3-7)	5 (4-6)	2 (1-4)	<0.001
Overuse of fluoro [no.]	7 (3-12)	2 (1-6)	4 (2-7)	3 (1-5)	0.367
Incorrect adjustments [no.]	8 (3-13)	2 (0-4)	3 (2-4)	2 (1-3)	0.033
Out of plane adjustments [no.]	38.8 (9.4-68.1)	10.1 (2.3-17.9)	12.5 (8.7-16.2)	5.3 (1.7-9.0)	0.018

and novice cohorts were observed in eight performance metrics with two K-wire navigation tasks using the IMN simulator. This finding strongly supports the construct validity of the simulator. Evidence of construct validity is very encouraging for the further development of the simulator.

The overlapping confidence intervals and minor differences between means of novices (case 2) compared with experts (case 2) highlight a steep learning curve for novices from case 1 and 2. This rapid improvement in scores suggests that a combined score of the outcome measures, one combining elements with the lowest p-value and highest contribution to the total variation, may strengthen the discriminatory capability of the simulator. The novices' improvement in performance from case 1 to 2 may partially be explained by an increased visuospatial awareness as well as adaption to the simulator and the power tool. Experts on the other hand were familiar with the power tool as well as acquisition of fluoroscopic images by using foot pedals beforehand. Even though the simulated fluoroscopic images depend on infrared measurements of the marked guide wire, the procedure closely resembles clinical practice. The improved performance in case 2 may therefore be routed in adapting to the rules of the study, i.e., replicating the depicted guide wire placement rather than choosing their preferred entry point and guide wire trajectory for themselves.

The results of the present study and further validation of the simulator in the light of Messick's and Kane's framework are warranted before the simulator can be fully recommended as a valuable and validated asset in the education of future orthopedic surgeons. In accordance with Messick's validity framework, five sources of evidence should be examined: content, response process, internal structure, relations to other variables, and consequences.<sup>19</sup> The content of the assessment was evaluated by an expert panel (JDR, BV, DA). To ensure validity in the response process, all information given to the participants of this study were provided by one author (LBS), who also supervised all assessments on the simulator.

Kane's framework is based on four inferences in the validity argument: 1) Scoring, 2) Generalisation 3) Extrapolation, and 4) Implications.<sup>15</sup> In the present study the simulator made automated observations of behaviours, which were translated into scores and generalized by showing differences of novices and experts. Extrapolation and implication were not performed in the present study as this would require clinical data from where participants perform the procedure on patients.

In conclusion, our study showed compelling preclinical data and encourages the further development and application of the IMN simulator for basic simulation-

based training in orthopedic surgery. The present IMN simulator may become an adjunct in training of guide wire navigation skills, visuospatial skills, and safe use of power tools.

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# RETRIEVAL OF A LANE PLATE 82 YEARS AFTER IMPLANTATION: CASE REPORT, METALLURGICAL ANALYSIS, AND HISTORICAL REVIEW

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## ABSTRACT

**Background:** The Lane plate was one of the first widely used bone plates, utilized in the first decades of the twentieth century. Here we present the results of a retrieval analysis on a Lane plate, and a review of the history of these plates. Our patient underwent plating of her femur with a Lane plate in 1938. She developed a sciatic nerve palsy, managed surgically later that year by Dr. Arthur Steindler at the University of Iowa. Her femur healed, her nerve recovered, and she did well until 2020, at age 94, when she presented to the University of Iowa with a draining sinus that appeared to communicate with the plate. She underwent irrigation and debridement with hardware removal. The plate was sectioned, and its composition and structure characterized.

**Methods:** We retrieved hard copies of the patient's archived medical records from 1938, which document in detail the treatments performed by Dr. Steindler. The plate was analyzed using scanning electron microscopy (SEM) to characterize the surface of the plate. A cross section was taken from the plate, and the composition of the alloy was determined using energy dispersive x-ray spectroscopy (EDS). A review of the literature surrounding early plating techniques was conducted.

**Results:** Our patient recovered from her surgery and soon returned to her baseline state of health. Intraoperative cultures grew *C. acnes*. Analysis of the surface of the plate demonstrated significant corrosion, and the crystal structure seen on SEM suggested a strong alloy that is prone to corrosion. Analysis of the cross section with EDS demonstrated an alloy containing 94.9% iron, 1.7% aluminum, 1.2% chromium, and 1.1% manganese.

**Conclusion:** The Lane plate was introduced around 1907 by Sir William Arbuthnot Lane, a British surgeon, and was one of the first widely used devices for the plating of fractures. Given that this patient was likely one of the last to be treated with a Lane plate, this may be the final opportunity for such a retrieval analysis.

**Level of Evidence:** IV

**Keywords:** lane plate, retrieval analysis, metallurgy

## INTRODUCTION

The Lane plate was one of the first metallic implants used for open reduction and internal fixation (ORIF), utilized in the early 20th century. Here we present a case report of a 94 year-old woman, from whom a Lane plate was removed from the left femur 84 years after implantation. In addition to the clinical case, we review the historical literature surrounding the Lane plate, and present the results of metallurgical analysis that was performed on the retrieved plate.

In June of 1938, at 12 years of age, the patient was riding a horse when she was struck by a motorized vehicle, resulting in a fracture of the left femur, which was reported in the local newspaper (Figure 1). She was initially treated with ORIF in Des Moines, Iowa, subsequently developing a sciatic nerve palsy. She was then transferred to the State University of Iowa in Iowa City for continued management. Medical records obtained from our archives confirm patient's recollection of the event. Documentation from initial presentation and treatment were not available, however, a clinic note from September 1938 states the following:

"Was horseback riding when horse was struck by an automobile. Sustained a fractured left femur. 1 week after accident an open reduction was done and Lane plate inserted—cast applied. Has been in original cast since. In hospital 1 week; at this time is noticed that patient was unable to move toes of left foot. Has had no complaints referable to foot. Left ankle was injured at time of accident, sprain. Has had no return of use of toes or foot. Patient is in a cast so not examined today. X-rays taken through cast showed perfect adaptation with considerable callus formation. Wait 1 more month for callus formation and then repair the nerve."

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The patient was indicated for sciatic neurolysis at the level of the thigh. An operative note from the procedure, performed by Dr. Arthur Steindler (1878-1959), dated November 1938 states the following:

“Clinical diagnosis: Sciatic nerve palsy following fracture of lower one third of the right femur.

Description of operation: A long posterior incision was made on the right thigh in the line of the sciatic nerve. The sciatic nerve was exposed and found to be bound down in the region of the fracture by very dense fibrous adhesions. These adhesions extended for an area of approximately 6 to 7 inches. The nerve was entirely free and a neurolysis was done. There was found considerable fibrosis in the nerve itself extending for approximately the same length as did the adhesions. The nerve was encased in fat. With the faradic current some impulse would go through. The tendo-Achillis was found to be exceedingly short and this was lengthened by a plastic procedure. The tendon was cut in the frontal plane and resutured in its lengthened state by silk. Both wounds were closed in layers in a posterior splint applied holding the knee in slight flexion and the ankle at right angles.”

The patient reported that she had good return of function in her foot and went on to have a fulfilling career as a nurse, married, and raised several children.

She presented to the University of Iowa Emergency Department in 2020 about a week after developing a red,

fluctuant, painful area, just proximal to the knee (Figure 2). This was lanced by the emergency department prior to orthopedic consult. Radiographs obtained at that point demonstrated the Lane plate over the anterolateral femur with loosening and posterior migration of the most distal screw. X-rays of the left knee had been obtained a month previously due to an episode of knee pain, and at that point the most distal screw was still present in the plate (Figure 3). Removal of the plate was recommended due to concern for infected hardware with draining sinus tract. At surgery, the plate was loose and surrounded by purulent fluid. The plate was easily pried from the bone



Figure 2. A clinical photograph of the patient's thigh upon presentation to the emergency department showing purulent sinus tract.



Figure 1. A newspaper clipping describing the mechanism of injury.

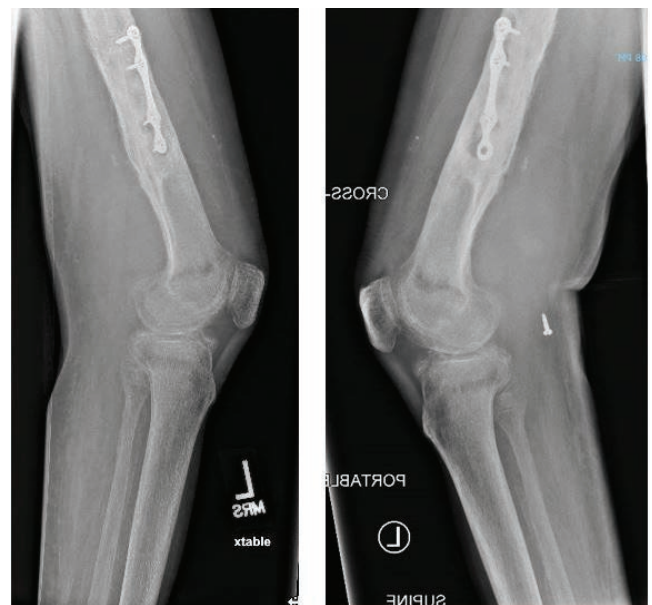


Figure 3. Radiographs of the patient's left leg 1 month apart, showing interval migration of the distal-most screw.



without the use of a screwdriver, but this did result in a portion of the plate chipping away at one of the screw holes (Figure 4). Tissue surrounding the plate was darkened. An attempt was made to remove the screw located behind the knee through the lateral incision using a hemostat, however this was unsuccessful. The benefits of a separate approach to the posterior knee were thought to not outweigh the risks, so the effort to remove the screw was abandoned. Deep tissue cultures obtained intraoperatively grew *Cutibacterium acnes*. The patient subsequently recovered from surgery and experienced uneventful healing of the wound with apparent resolution of infection.

## METHODS

Following removal of the plate, it was placed in formalin to preserve any adherent tissue. No cleaning was performed. The plate was then photographed. Scanning electron microscopy (SEM) was used to assess the surface structure of the plate. A portion of the plate was sectioned, and SEM images were obtained of the cross section. Energy dispersive x-ray spectroscopy (EDS) was then conducted within the SEM to characterize the chemical composition of the alloy as well as the corrosion products. Electron backscatter diffraction (EBSD) was performed to determine grain size of the alloy as well as of a contemporary stainless-steel bone plate for reference. A screw was also examined with scanning electron



Figure 4. Intraoperative appearance of the femur immediately following plate removal.

## RESULTS

SEM demonstrated heterogeneous appearance of the plate surface (Figure 5) with the majority being covered with corrosion products (Figure 6). On the surface, EDS analysis confirmed the presence of a prominent oxygen peak along with iron indicative of an iron oxide. Some other surface organic deposits were also present indicative of denatured proteins and lipids. In some areas of the plate surface, the underlying crystalline structure of the alloy was exposed (Figure 7). EBSD confirmed a very fine grain size of the Lane Plate alloy (Figure 8). The intact core of the plate is composed of approximately 95% iron, with less than 2% each of aluminum, chromium, and manganese, with trace amounts of additional elements (Figure 8). The grain size of the alloy as measured by



Figure 5A to 5B. Photographs of the Lane plate's (5A) front and (5B) back side. Both surfaces have a mostly rusted appearance. The second screw hole from the left exhibited severe material breakout that occurred during the surgical removal of the Lane Plate.

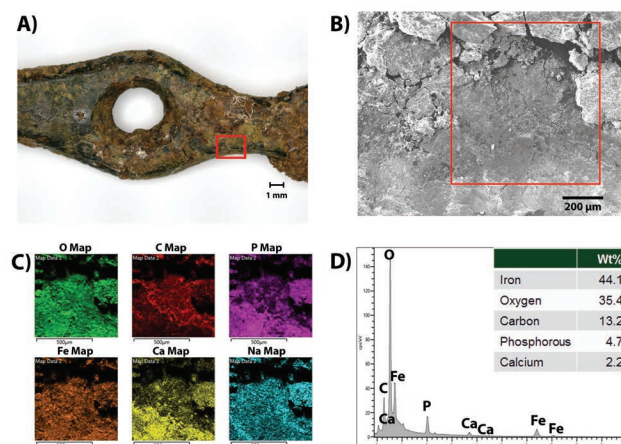


Figure 6A to 6D. (6A) Location of SEM analysis, (6B) SEM micrograph of an area on the Lane plate covered with corrosion products, (6C) EDS mapping and the location indicated in (6B). The surface consists of iron, oxygen, carbon, calcium, phosphorous and sodium. (6D) The quantification of present materials indicated that most of the surface consists of iron oxides along with some other organic deposits (note that oxygen and carbon are light elements that cannot be reliably quantified with EDS, high peaks do indicate however a strong presence of these elements).



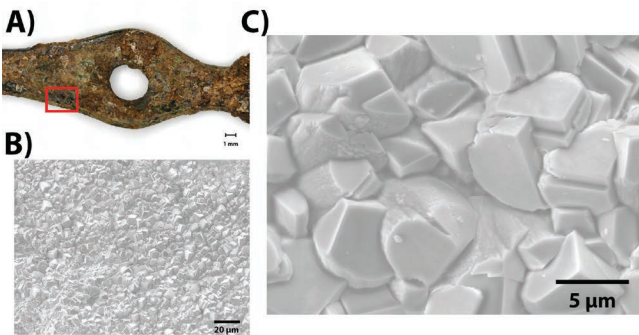


Figure 7A to 7C. (7A) Location of SEM analysis, (7B) SEM micrograph of an area on the Lane plate that was not covered with corrosion products, (7C) High magnification SEM image of the same area illustrating the fine crystalline structure of the implant alloy.

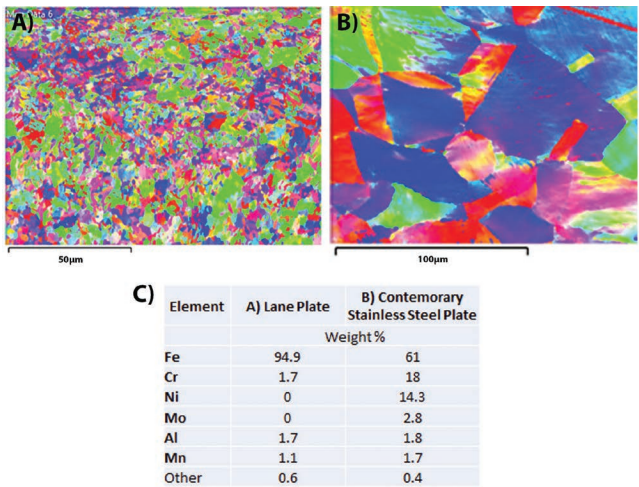


Figure 8A to 8C. EBSD grain maps of the bulk alloy microstructure of (8A) the lane plate and (8B) a contemporary stainless-steel plate. The alloys have a mean grain size of 0.66 and 5.28  $\mu\text{m}$ , respectively. (8C) the EDS quantification of the alloy microstructure shows that the Lane Plate exhibited hardly any other alloying metals indicative of a high carbon steel, whereas the stainless steel exhibited characteristic alloying metal such as chromium, nickel and molybdenum that provide corrosion resistance and strength.

the equivalent circle diameter (ECD) was  $0.66 \pm 0.5\mu\text{m}$ . By comparison, the contemporary bone plate had a mean grain size of  $5.28 \pm 7.6\mu\text{m}$ , but also featured prominently other alloying elements such as chromium, nickel, molybdenum and manganese that are typical for stainless steels (Figure 8). Cross-section SEM images revealed that the oxide layer varied between 20-80  $\mu\text{m}$  in thickness (Figure 9). Cracks within the oxide layer explained the eventual fracture at one screw hole resulting in the detachment of one screw (Figure 3). The screw had the same rusted appearance as the Lane Plate (Figure 10).

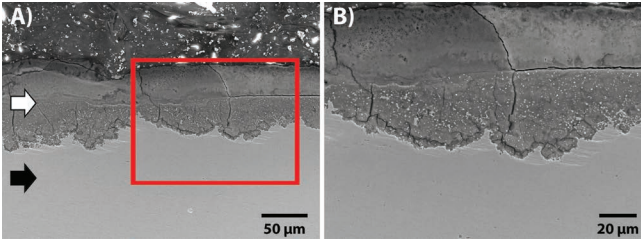
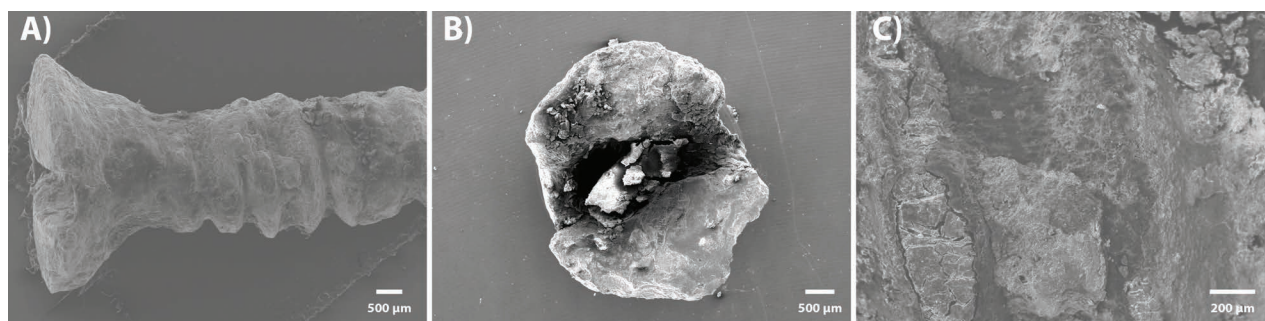


Figure 9A to 9B. (9A) Cross section SEM micrograph of the bulk alloy (black arrow) and the oxide layer (white arrow). (9B) Higher magnification SEM image showing cracks within the iron oxide (rust) layer.

### DISCUSSION

This is an interesting case on several levels. Dr. Steindler, the surgeon who treated our patient for her sciatic nerve palsy, was the founder of the Orthopedic Department at what was then the State University of Iowa. He was an innovative surgeon and made many enduring contributions to the field of orthopedics,<sup>1</sup> although not necessarily on the management of pediatric femur fractures or management of sciatic nerve palsies. On a broad historical level, this case is a snapshot of early techniques in open reduction and internal fixation. Although the identity of the original treating surgeon in Des Moines is unknown, it is possible that the treating surgeon was a general surgeon without specific orthopedic training. The Lane plate was one of the earliest widely used orthopedic implants for fracture, and the reports in the literature surrounding its implementation in the early 20th century highlight some of the differences and similarities with modern techniques. This plate also represents perhaps the longest implanted retrieved orthopedic implant reported in the literature at 82 years.

The Lane plate was developed by Sir William Arbuthnot Lane (1856-1938), and is the first widely used example of a relatively modern appearing plate and screw construct for open reduction and internal fixation. Lane's work built upon that of Joseph Lister (1827-1912), who developed and published an effective antiseptic technique beginning with a series of successful ORIF of patella fractures with silver wire in 1883. Lane's plate also succeeded the plate developed by Carl Hansmann (1852-1917), introduced in 1886, which consisted of a nickel plated steel sheet, implanted with one end of the plate protruding through the skin at a right angle to the bone, with pegs attached to screws protruding through the skin to allow for percutaneous removal of the plate. Lane was a proponent of what he called the "no touch" technique, which entailed using powerful long-handled instruments to perform surgeries, including reduction and plating of bones, without introducing the surgeon's hand into the wound (Figure 11).



**Figure 10A to 10C.** (10A, 10B) SEM images of a bone screw associated with the Lane plate. Progressive oxidation has severely deformed the screw. (10C) The surface of the screw exhibits the same appearance as the bone plate itself.

The handle of the instrument was also considered contaminated, and was kept isolated from the surgical field. Prior to incision, skin was disinfected, and after incision, subcutaneous skin edges, which were thought to pose a risk of infection, were protected from contaminating the wound by lining them with sterile gauze. Lane began plating fractures around 1905, and introduced the “Lane Plate” around 1907.<sup>2</sup> The plate and screws were made of high-carbon steel, an alloy that was soon found to be highly susceptible to corrosion when implanted *in vivo*.<sup>3</sup> Lane’s techniques and implants were described in a case series published in 1913 from Dr. Willard Bartlett (1868-1950), a St. Louis surgeon who described treating a series of 76 patients with a variety of fractures with Lane plates. He found that his results were generally favorable in short term, with most fractures uniting and providing good function.<sup>4</sup>

Our analysis of the bone plate alloy microstructure and chemical composition was consistent with a low-alloyed high carbon-steel. It exhibited a very fine grain size that provided the needed strength for the alloy.



**Figure 11.** Lane bone holding forceps are still utilized in modern orthopedic surgery.

Grain size has an inverse relationship with strength. In the absence of any meaningful content of other metal alloying elements to provide strength through solid solution, the fine grain size is necessary compared to contemporary stainless steels (Figure 8). However, the main difference to contemporary stainless steels is the absence of alloying elements that provide corrosion resistance such as chromium, nickel and molybdenum. Generally, a steel is considered stainless when it exhibits a chromium content of at least 12-13%. Under such conditions, the alloy is protected by a thin but stable passive film predominantly containing chromium oxide that prevents further corrosion. It is remarkable that the present Lane plate remained functional for 82 years despite obvious large-scale corrosion. While not stable, the thick iron-oxide formed on the bone plate’s surface did not compromise the mechanical behavior of the plate and must have formed slowly over time (Figure 9). However, the oxide layer did exhibit cracks which likely led to material breakout and eventual detachment of a bone screw (Figure 3). This would mean that the implant environment was likely not too corrosive as, for example, the periprosthetic environment of a total joint replacement can be in some cases. Furthermore, despite the finding of metallosis, there were likely no adverse local tissue responses known from cobalt containing alloys or hypersensitivity reactions often associated with nickel containing alloys. The accumulation of iron-oxides within the tissue leaves a dark staining but did not cause a severe inflammatory response, at least initially.

Several case reports with long term retrieval analyses involving Lane plates have been published previously. In 1983, a Lane plate was removed from a patient’s distal radius after 54 years due to rapid onset of pain, erythema, and swelling at the area of the plate.<sup>5</sup> The plate was removed, and there was no growth on cultures. EDS was performed on the surface of the plate to determine composition of the alloy. An area of the plate that appeared intact showed 43% iron, 53% nickel, while a more corroded area showed 78% iron, 11% phos-



phorus, and 5% vanadium. The plate also had the word “vanadium” stamped on it, a feature not present in the plate in the present study. The authors concluded that the plate was likely plated with nickel. In 1987, a patient whose femur fracture had been treated with a Lane plate 64 years earlier underwent above knee amputation for peripheral vascular disease.<sup>6</sup> He had not experienced any complications related to the plate. The plate and surrounding tissues were analyzed. Pathology demonstrated metallosis but no significant inflammation or evidence of infectious process.

The plate was sectioned, and atomic absorption spectrophotometry was performed (unclear whether this was on the cross section or surface), and the plate was found to contain >99% iron, with the next most prevalent element being manganese, at 0.06%. Another case report published in 1980 described the case of a patient who underwent removal of two Lane plates from his femur.<sup>7</sup> He presented with redness, swelling, and fluctuance over the scar. Screws had fallen from the plate and migrated. Cultures obtained from aspirate, as well as subsequent intraoperative cultures were negative. A metallurgical analysis was also performed. Shavings of the plate sent for chemical analysis using graphite electrodes and found a total non-ferrous alloy material of <8%, with the next most prevalent element being manganese (1.5%), and traces of additional elements.

Scales et al., a study published in 1959 contains retrieval analyses of multiple implants including 39 screws and 7 plates made from “ferrous alloys.” All were corroded. One observation pertinent to the present case report is that plates of ferrous alloys, not designed to resist corrosion, were implanted in 1946 (London), 1954 (Egypt), 1955 (Basra). This fact is lamented by the authors as “depressing that in spite of all that has been written since 1936 about corrosion of these steels,” these plates were still utilized.<sup>8</sup>

With the understanding that ferrous alloys lead to unacceptably high rates of corrosion and its associated tissue complications, future plate designs began to incorporate more inert materials. Pure gold, silver, lead, and aluminum were early recognized as completely inert, with no soft tissue reactions observed or corrosive properties.<sup>1</sup> They unfortunately were very soft materials and not suitable for internal fixation.

In the early 1930s non-corrosive materials such as cobalt with chromium, tantalum, and vitallium were utilized for internal fixation techniques in the dentistry and neurosurgical fields.<sup>3</sup> Orthopedists Venable and Stuck noted the inert properties of these materials and explored their use in orthopedic implants.<sup>3,9</sup> Out of these discoveries, stainless steel arose as the metal of choice for future plate designs. Stainless steel owes its inertness

to its high levels of chromium incorporated into its iron base composition.

The 1940s also saw the first use of titanium in orthopedic implants.<sup>9</sup> A softer material than stainless steel, it showed a lower modulus but enhanced corrosion resistance. As such, purely ferrous alloys were largely abandoned by the 1940s. Outside of fine-tuning the specific stainless steel and titanium alloys utilized, there have been no major changes in orthopedic plate composition since the late 1940s. Stainless steel and titanium remain the most widely used materials for internal fixation implant designs.<sup>9</sup>

One question of clinical significance is what led to our patient’s presentation. Review of the historical literature does shed some light on this question. We found descriptions of local tissue irritation, fluid collections, pain, and loosening and migration of implants, thought to be related to metal corrosion. We did not come across a report of long-term removal with positive cultures. One possibility is that our patient developed a local inflammatory response to metal corrosion and then became infected when lanced in the emergency department. The other possibility is that the plate was seeded with bacteria, likely from hematogenous spread given the late presentation, and then developed symptoms.

This case likely represents one of the last opportunities to retrieve and study a Lane plate. Assuming the use of these plates declined rapidly in the late 1930s, children who underwent ORIF with one of these plates would now be approaching their 90s. It is likely, as was alluded to in the study by Scales et al., that the Lane plate was used in later years in some locations. The Lane plate was the first widely utilized internal fixation device, and despite its shortcomings, surgeons were able to achieve acceptable results in many patients, including the subject of this case report.

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# OUTCOMES VARY SIGNIFICANTLY USING A TIERED APPROACH TO DEFINE SUCCESS AFTER TOTAL HIP ARTHROPLASTY

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## ABSTRACT

**Background:** Clinical outcomes following primary total hip arthroplasty (THA) are commonly assessed through patient-reported outcome measures (PROM). The purpose of this study was to use progressively more stringent definitions of success to evaluate clinical outcomes of primary THA at 1-year postoperatively and to determine if demographic variables were associated with achievement of clinical success.

**Methods:** The American Joint Replacement Registry (AJRR) was queried from 2012-2020 for primary THA. Patients that completed the following PROMs preoperatively and 1-year postoperatively were included: Western Ontario and McMaster Universities Arthritis Index (WOMAC), Hip Injury and Osteoarthritis Outcome Score (HOOS) and HOOS for Joint Replacement (HOOS, JR). Mean PROM scores were determined for each visit and between-visit changes were evaluated using paired t-tests. Rates of achievement of minimal clinically important difference (MCID) by distribution-based and anchor-based criteria, patient acceptable symptom state (PASS), and substantial clinical benefit (SCB) were calculated. Logistic regression was

used to evaluate associations between demographic variables and odds of success.

**Results:** 7,001 THAs were included. Mean improvement in PROM scores were: HOOS, JR, 37; WOMAC-Pain, 39; WOMAC-Function, 41 ( $p < 0.0001$  for all). Rates of achievement of each metric were: distribution-based MCID, 88-93%; anchor-based MCID, 68-90%; PASS, 47-84%; SCB, 68-84%. Age and sex were the most influential demographic factors on achievement of clinical success.

**Conclusion:** There is significant variability in clinical outcomes at 1 year after primary THA when using a tiered approach to define success from the patient's perspective. Tiered approaches to interpretation of PROMs should be considered for future research and clinical assessment.

**Level of Evidence:** III

**Keywords:** total hip arthroplasty, patient-reported outcome measures, PROM, minimally clinically important difference, MCID

## INTRODUCTION

Hip pain and function are often measured using patient-reported outcome measures (PROM) in the perioperative period surrounding primary total hip arthroplasty (THA).<sup>1-6</sup> Evaluating PROM scores before and after THA has allowed for further understanding of the efficacy of THA as a treatment for end-stage hip arthritis, as well as resultant changes in patient pain, function, and quality of life. Understanding these changes is fundamental for surgical indications, patient counseling and expectation management, as well as clinical research.

To date, most literature evaluating change in PROM scores before and after primary THA has focused on minimal clinically important difference (MCID), which represents the smallest improvement in a given measurement that is of value to the patient.<sup>5,7-15</sup> However, metrics with more stringent thresholds, such as substantial clinical benefit (SCB), defined as clinical differences that patients may perceive are large or considerable,<sup>5,16</sup> and patient acceptable symptom state (PASS), which is the value beyond which patients consider themselves to be in a satisfactory state of health,<sup>17,18</sup> have also been described.<sup>5,8,17,19-21</sup> While use of PASS and SCB in tandem

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with MCID to evaluate clinical outcomes after orthopedic surgery has been proposed,<sup>8</sup> the relative relationship between these three metrics in terms of gross score and achievement rates is not well known. Understanding relative relationships between different metrics for clinical success has implications for patient counseling and expectation setting, but also for care delivery and measurement of value in healthcare systems. Patient expectations may influence their overall clinical outcomes after arthroplasty surgery;<sup>22-26</sup> arthroplasty surgeons need the most representative and applicable data to counsel patients effectively. The purpose of this study was to use progressively more stringent definitions of success to examine clinical outcomes of primary THA at 1-year postoperatively and to determine which demographic variables were associated with achieving clinical success from the patient's perspective.

## METHODS

The American Joint Replacement Registry (AJRR) was queried for cases of primary THA from January 2, 2012 to December 31, 2020. As of 2019, 209 of the more than 1,400 sites that participate in the American Joint Replacement Registry (AJRR) submit PROM scores.<sup>27</sup> Cases of primary THA with linked preoperative and 1-year postoperative scores for the following PROMs were included: Western Ontario and McMaster Universities Arthritis Index (WOMAC), Hip Injury and Osteoarthritis Outcome Score (HOOS), and HOOS for Joint Replacement (HOOS, JR). Preoperative PROM scores were obtained within 90 days prior to surgery and 1-year postoperative PROM scores were obtained from 10-14 months after the index surgery. A total of 7,001 primary THA were included. All cases included had preoperative and 1-year postoperative HOOS, JR scores; 301 completed all subscales of HOOS, and 202 completed WOMAC-Pain and WOMAC-Function preoperatively and 1-year postoperatively. Demographic data collected included patient sex (female or male), age (categorical; <50 years, 51-59 years, 60-69 years, 70-79 years, 80-89 years, or 90+ years), race (American Indian, Asian, Black or African American, Native Hawaiian or Other Pacific Islander, White, or Multiracial), body mass index (BMI) (categorical; underweight, BMI <18.5 kg/m<sup>2</sup>; normal 18.5-24.9 kg/m<sup>2</sup>; pre-obese, 25.0-29.9 kg/m<sup>2</sup>; class I obesity, 30.0-34.9 kg/m<sup>2</sup>; class II obesity, 35.0-39.9 kg/m<sup>2</sup>; class III obesity, ≥40.0 kg/m<sup>2</sup>), Charlson Comorbidity Index (CCI) (categorical; CCI Score 0; CCI Score 1; CCI Score 2; CCI Score ≥3), geographic region of institution where surgery was performed (Northeast, Midwest, South, West), teaching status of institution where surgery was performed (major, minor, or non-teaching), size of hospital/institution where surgery

was performed (small, 1-99 beds; medium, 100-299 beds; large, ≥400 beds), community type of institution where surgery was performed (Rural, Small Town, Suburban, or Urban) and the Distressed Communities Index (DCI) score (categorical; DCI Score I, 0.0-11.3; DCI Score II, 11.4-23.8; DCI Score III, 23.9-40.6; DCI Score IV, 40.7-63.3; DCI score V, 63.4-100.0; higher DCI score indicates increasing socioeconomic distress). DCI is a composite measure of relative socioeconomic status by ZIP code; it has been utilized previously for risk stratification and clinical outcomes research.<sup>28</sup> Demographic data are contained in Table 1.

Changes in PROM scores from preoperative to 1-year postoperative and standard deviations (SD) were calculated. Rates of achievement of MCID by distribution-based and anchor-based criteria, PASS, and SCB were calculated. Distribution-based MCID is calculated from the unique distribution of PROM scores of a given cohort; in the present study, distribution-based MCID was calculated using one-half of the SD value in PROM score change from preoperatively to 1-year postoperatively.<sup>4,24</sup> Anchor-based MCID is based on patient responses to a specific "anchor" question asked at follow-up.<sup>5,29</sup> Anchor questions are designed such that responses to the anchor question delineate between patients that have had a significant change in their health versus those who have not;<sup>5,29</sup> examples include "How much did your hip surgery improve your quality of life?"<sup>75</sup> and "Was [hip] surgery worthwhile?"<sup>29</sup> Achievement of MCID and SCB requires an increase in postoperative PROM scores relative to preoperative scores,<sup>5,16</sup> while achievement of PASS requires a reaching a specific postoperative PROM score threshold, regardless of preoperative PROM score.<sup>18,30</sup> Distribution-based MCID was calculated using one-half of the SD value in PROM score change from preoperatively to 1-year postoperatively.<sup>5,24</sup> Values for anchor-based MCID, PASS, and SCB were abstracted from the literature.<sup>5,8,15,19</sup> PASS thresholds for HOOS, JR and values for SCB for WOMAC-Pain and WOMAC-Function were not identified in current literature and as a result, were not included in the analyses for the present study. Specific values utilized for distribution-based and anchor-based MCID, SCB, and PASS for PROMs and their respective subscales are presented in Table 2.

Mean changes in preoperative to 1-year postoperative scores were found to be normally distributed using the Shapiro-Wilk test. Paired t-tests were performed to determine if changes in PROM scores were statistically significant. Multivariate logistic regression was used to evaluate associations between achievement of distribution-based MCID, anchor-based MCID, and SCB in HOOS, JR with demographic variables. Adjusted odds ratios (OR) and 95% Wald confidence intervals (95% CI)

**Table 1. Demographics**

Variable	Cohort (n=7,001)
Sex (n, %)	
Female	3,886 (55.5%)
Male	3,115 (45.5%)
Age (years; mean $\pm$ SD)	67 $\pm$ 6
Age (years, categorical) (n, %)	
<50	1,022 (14.6%)
50-59	2,562 (36.6%)
60-69	2,352 (33.6%)
70-79	700 (10.0%)
80-89	315 (4.5%)
90+	49 (0.70%)
Race (n, %)	
American Indian	147 (2.1%)
Asian or Pacific Islander	63 (0.9%)
Black or African American	245 (3.5%)
White	6,182 (88.3%)
Multiracial	35 (0.5%)
Unknown	329 (4.7%)
Body Mass Index (kg/m <sup>2</sup> ) (n,%)	
Underweight (<18.5)	1,113 (15.9%)
Normal Weight (18.5-24.9)	1,533 (21.9%)
Overweight (25.0-29.9)	770 (11.0%)
Obesity – Class I (30.0-34.9)	343 (4.9%)
Obesity – Class II (35.0-39.9)	2,065 (29.5%)
Obesity – Class III ( $\geq$ 40)	35 (0.5%)
Unknown	1,134 (16.3%)
Charlson Comorbidity Index (n, %)	
0	5,321 (76.0%)
1	973 (13.9%)
2	413 (5.9%)
$\geq$ 3	294 (4.2%)
DCI Score (n, %)	
I (0.0-11.3)	1,151 (16.5%)
II (11.4-23.8)	1,452 (20.7%)
III (23.9-40.6)	1,465 (20.9%)
IV (40.7-63.3)	1,434 (20.4%)
V (63.4-100.0)	1,499 (21.5%)
Hospital Region (n, %)	
Northeast	2,681 (38.3%)
Midwest	1,008 (14.4%)
South	1,610 (23.0%)
West	1,701 (24.3%)

**Table 1. Demographics (continued)**

Hospital Teaching Status (n, %)	
Major	525 (7.5%)
Minor	3,444 (49.2%)
Non-teaching	2,422 (34.6%)
Unknown	609 (8.7%)
Hospital Size (n, %)	
Small (1-99 beds)	1,680 (24.0%)
Medium (100-399 beds)	1,232 (17.6%)
Large ( $\geq$ 400 beds)	3,444 (49.2%)
Unknown	651 (9.2%)
Hospital Community Type (n, %)	
Rural	1,232 (17.6%)
Small Town	1,323 (18.9%)
Suburban	3,311 (47.3%)
Urban	1,141 (16.2%)

**Table 2. Requisite Values for Achievement of MCID, SCB, and PASS, by PROM Subscale**

PROM/Subscale	SD	Distribution-based MCID	Anchor-based MCID	SCB	PASS
WOMAC-Pain	23.8	$\Delta$ 11.9	$\Delta$ 23	*	80
WOMAC-Function	23.0	$\Delta$ 11.5	$\Delta$ 22	*	69
HOOS-Pain	24.1	$\Delta$ 12.1	$\Delta$ 36	$\Delta$ 36	91
HOOS-Symptoms	22.4	$\Delta$ 11.2	$\Delta$ 20	$\Delta$ 25	*
HOOS-QOL	29.0	$\Delta$ 14.5	$\Delta$ 13	$\Delta$ 27	83
HOOS-ADL	23.2	$\Delta$ 11.6	$\Delta$ 14	$\Delta$ 24	*
HOOS, JR	19.6	$\Delta$ 9.8	$\Delta$ 18	$\Delta$ 22	*

MCID – minimally clinically important difference; SCB – substantial clinical benefit; PASS – patient acceptable symptom state; PROM – patient-reported outcome measure; SD – standard deviation; WOMAC – Western Ontario and McMaster Universities Arthritis Index; HOOS – Hip Injury and Osteoarthritis Outcome Score; QOL – quality of life; ADL – activities of daily living; JR – joint replacement. Distribution-based MCID was calculated using one-half of the SD value in PROM scores from preoperatively to 1-year postoperatively [5]. Values for anchor-based MCID, PASS, and SCB were abstracted from the literature [5, 8, 15, 19]. \*denotes value not available.



are reported. Statistical significance was set at  $p<0.05$ . Statistical analysis was completed using SAS statistical software v9.4 (SAS Institute, Inc., Cary, NC, USA).

RESULTS

Mean preoperative and preoperative to 1-year postoperative change scores are shown in Table 3. Mean scores significantly increased from preoperatively to 1-year postoperatively ( $p<0.0001$  for all; Table 3) in all PROMs.

Table 3. Mean Change in PROM Scores, Preoperative to 1-Year Postoperatively

PROM/Subscale	n	Mean Change	SD	p-value
WOMAC-Pain	202	38.7	23.8	<0.0001
WOMAC-Function	202	40.8	23.0	<0.0001
HOOS-Pain	301	45.5	24.1	<0.0001
HOOS-Symptoms	301	42.9	22.4	<0.0001
HOOS-QOL	301	51.4	29.0	<0.0001
HOOS-ADL	301	44.3	23.2	<0.0001
HOOS, JR	7,001	36.7	19.6	<0.0001

PROM – patient-reported outcome measure; SD – standard deviation; WOMAC – Western Ontario and McMaster Universities Arthritis Index; HOOS – Hip Injury and Osteoarthritis Outcome Score; QOL – quality of life; ADL – activities of daily living; JR – joint replacement.

Table 4. Rates of Outcome Achievement by PROM Subscales

PROM/Subscale	n	Distribution-based MCID	Anchor-based MCID	SCB	PASS
WOMAC-Pain (n, %)	202	178 (88%)	151 (75%)	*	151 (75%)
WOMAC-Function (n, %)	202	183 (91%)	166 (82%)	*	169 (84%)
HOOS-Pain (n, %)	301	274 (91%)	206 (68%)	206 (68%)	165 (55%)
HOOS-Symptoms (n, %)	301	281 (93%)	259 (86%)	252 (84%)	*
HOOS-QOL (n, %)	301	278 (92%)	269 (89%)	241 (80%)	141 (47%)
HOOS-ADL (n, %)	301	277 (92%)	271 (90%)	246 (92%)	*
HOOS, JR (n, %)	7,001	6,480 (93%)	5,827 (83%)	5,449 (78%)	*

MCID – minimally clinically important difference; SCB – substantial clinical benefit; PASS – patient acceptable symptom state; PROM – patient-reported outcome measure; SD – standard deviation; WOMAC – Western Ontario and McMaster Universities Arthritis Index; HOOS – Hip Injury and Osteoarthritis Outcome Score; QOL – quality of life; ADL – activities of daily living; JR – joint replacement. \*denotes value not available.

Distribution-based MCID was the most frequently achieved threshold across all PROM subscales. Rates of achievement of distribution-based MCID thresholds were: WOMAC-Pain, 88%; WOMAC-Function, 91%, HOOS-Pain, 91%; HOOS-Symptoms, 93%; HOOS-Quality of Life (QOL), 92%; HOOS-Activities of Daily Living (ADL), 92%, HOOS, JR, 93%. Comparatively, rates of achievement of anchor-based MCID were: WOMAC-Pain, 75%; WOMAC-Function, 82%; HOOS-Pain, 68%; HOOS-Symptoms, 86%; HOOS-QOL, 89%; HOOS-ADL, 90%, HOOS, JR, 83%. Rates of SCB achievement were: HOOS-Pain, 68%; HOOS-Symptoms, 84%; HOOS-QOL, 80%; HOOS-ADL, 92%, HOOS, JR, 78%. Rates of PASS achievement were: WOMAC-Pain, 75%; WOMAC-Function, 84%; HOOS-Pain, 55%, HOOS-QOL, 47% (Table 4, Figures 1-3).

Demographic factors associated with achievement of distribution-based MCID in HOOS, JR are contained in Table 5. Female sex and surgery at Southern US hospitals were associated with increased odds of achieving distribution-based MCID ( $p<0.05$  for all; Table 5). Older age, Black or African American race, higher CCI score, large hospital size, and small hospital size were associated with decreased odds of achieving distribution-based MCID ( $p<0.05$  for all; Table 5).

Demographic factors associated with achievement of anchor-based MCID in HOOS, JR are contained in Table 6. Female sex, surgery at a Southern US hospital, surgery at a major teaching hospital, and surgery at a non-teaching hospital were associated with increased

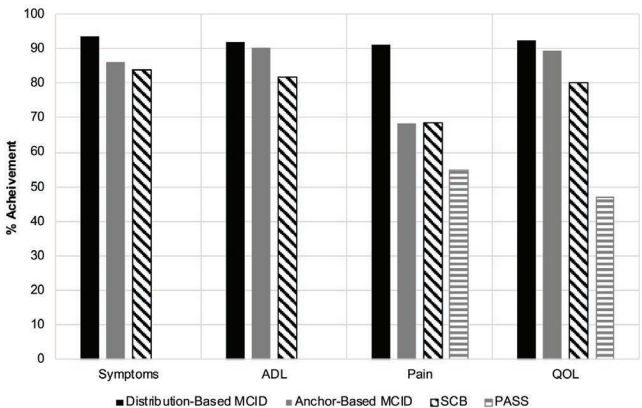


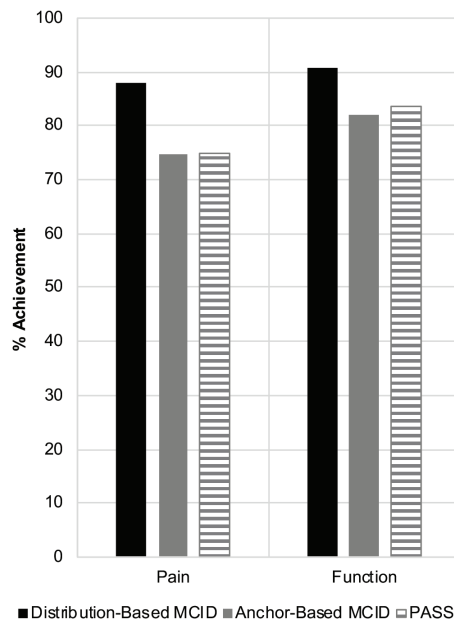
Figure 1. Rates of Outcome Achievement, HOOS Subscales. Bar chart demonstrating rates of achievement of distribution-based MCID, anchor-based MCID, SCB, and PASS by respective PROM subscales. MCID – minimally clinically important difference; SCB – substantial clinical benefit; PASS – patient acceptable symptom state; PROM – patient-reported outcome measure; HOOS – Hip Injury and Osteoarthritis Outcome Score; QOL – quality of life; ADL – activities of daily living.

odds of achieving anchor-based MCID ( $p < 0.05$  for all; Table 6). Older age and large hospital size were associated with decreased odds of achieving anchor-based MCID ( $p < 0.05$  for all; Table 6).

Demographic factors associated with achievement of SCB in HOOS, JR are contained in Table 7. Female sex and surgery at a Southern US hospital were associated with increased odds of achieving SCB ( $p < 0.05$  for all; Table 7). Older age and large hospital size were associated with decreased odds of achieving SCB ( $p < 0.05$  for all; Table 7).

## DISCUSSION

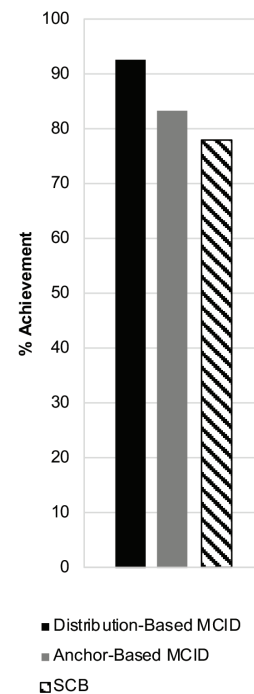
Understanding changes in health outcomes from the patient's perspective in the perioperative period surrounding primary THA is fundamental for multiple facets of arthroplasty care. Focusing on minimum score changes in PROMs (i.e., MCID) after THA may misrepresent a patient's true level of pain, function, and physical ability. Routinely evaluating additional metrics such as SCB and PASS may offer a more comprehensive understanding of clinical outcomes; in the present study, we sought to evaluate the relationship between distribution-based MCID, anchor-based MCID, SCB, and PASS at 1-year following primary THA. A secondary aim of the study was to determine which demographic variables were associated with achieving MCID or SCB.



**Figure 2. Rates of Outcome Achievement, WOMAC Scores.** Bar chart demonstrating rates of achievement of distribution-based MCID, anchor-based MCID, and PASS for WOMAC Hip Scores. MCID – minimally clinically important difference; SCB – substantial clinical benefit; PASS – patient acceptable symptom state; WOMAC – Western Ontario and McMaster Universities Arthritis Index.

Mean PROM scores significantly improved amongst all WOMAC, HOOS, and HOOS, JR scores from preoperatively to 1-year postoperatively ( $p < 0.0001$  for all, Table 3). Kuo et al.<sup>3</sup> examined HOOS and HOOS, JR scores in a cohort of 271 THA preoperatively and 1-year postoperatively. Mean improvement in HOOS, JR score was  $39.7 \pm 20.2$ , similar to the mean change of  $36.7 \pm 19.6$  observed in the present study.<sup>3</sup> The authors noted a mean change of 44-50 points in HOOS-Pain, HOOS-Symptoms, HOOS-QOL, and HOOS-ADL at 1-year postoperatively; in the present study, mean change ranged from 43-51 points. Lyman et al.<sup>5</sup> evaluated 2,323 patients undergoing primary THA preoperatively and 2 years postoperatively via HOOS and HOOS, JR. Mean changes in HOOS subscores ranged from 38-56 points of improvement; HOOS, JR scores improved by a mean of 36 points at 2 years postoperatively.<sup>5</sup> The similarities between improvements measured in the present study and cohorts of Kuo et al.<sup>3</sup> and Lyman et al.<sup>5</sup> suggest that the population of primary THA captured in the present study are representative of the primary THA population at large.

Distribution-based MCID was the most frequently achieved metric across all PROMs, with  $\geq 88\%$  of patients achieving distribution-based MCID in all PROMs and PROM subscales. Anchor-based MCID was more stringent than distribution-based MCID across all PROMs, with rates of anchor-based MCID achievement being



**Figure 3. Rates of Outcome Achievement, HOOS, JR.** Bar chart demonstrating rates of achievement of distribution-based MCID, anchor-based MCID, and SCB HOOS, JR scores. MCID – minimally clinically important difference; SCB – substantial clinical benefit; HOOS, JR – Hip Injury and Osteoarthritis Outcome for Joint Replacement.

**Table 5. Adjusted Odds Ratios for Achievement of Distribution-based MCID by HOOS, JR**

Effect	OR	95% CI		p-value
Sex: Female vs. Male	1.337	1.095	1.634	0.004*
Age†	0.984	0.974	0.995	0.003*
Race: American Indian vs. White	1.757	0.806	3.831	0.156
Race: Asian vs. White	0.527	0.243	1.143	0.105
Race: Black or African American vs. White	0.533	0.323	0.878	0.013*
Race: Multiracial vs. White	1.352	0.321	5.695	0.681
BMI: Obesity Class I vs. Normal	1.021	0.755	1.381	0.891
BMI: Obesity Class II vs. Normal	1.247	0.850	1.828	0.259
BMI: Obesity Class III vs. Normal	1.183	0.724	1.933	0.502
BMI: Overweight vs. Normal	0.960	0.725	1.272	0.778
BMI: Underweight vs. Normal	1.436	0.337	6.115	0.624
Charlson Comorbidity Index (CCI)	0.901	0.823	0.985	0.023*
DCI Score	0.999	0.995	1.003	0.673
Hospital Region: Midwest vs. Northeast	1.141	0.798	1.633	0.469
Hospital Region: South vs. Northeast	1.585	1.139	2.206	0.006*
Hospital Region: West vs. Northeast	0.832	0.635	1.090	0.182
Hospital Teaching Status: Major vs. Minor	1.434	0.964	2.135	0.076
Hospital Teaching Status: Non-teaching vs. Minor	1.180	0.932	1.493	0.168
Hospital Size: Large vs. Medium	0.659	0.498	0.871	0.003*
Hospital Size: Small vs. Medium	0.709	0.534	0.941	0.017*
Hospital Community Type: Rural vs. Suburban	0.909	0.676	1.222	0.523
Hospital Community Type: Small Town vs. Suburban	0.891	0.665	1.194	0.440
Hospital Community Type: Urban vs. Suburban	1.038	0.768	1.404	0.807

OR – adjusted odds ratio; 95% CI – 95% Wald confidence interval.  
 †Odds ratio for age represents odds of achieving given outcome with each increase in age category relative to referent group age <50 years. \*denotes statistical significance.

**Table 6. Adjusted Odds Ratios for Achievement of Anchor-based MCID by HOOS, JR**

Effect	OR	95% CI		p-value
Sex: Female vs. Male	1.360	1.184	1.561	<0.001*
Age†	0.982	0.975	0.990	<0.001*
Race: American Indian vs. White	1.347	0.852	2.130	0.203
Race: Asian vs. White	0.784	0.417	1.475	0.451
Race: Black or African American vs. White	0.713	0.484	1.049	0.086
Race: Multiracial vs. White	1.100	0.454	2.666	0.833
BMI: Obesity Class I vs. Normal	1.073	0.872	1.319	0.507
BMI: Obesity Class II vs. Normal	1.231	0.952	1.592	0.113
BMI: Obesity Class III vs. Normal	1.042	0.755	1.437	0.804
BMI: Overweight vs. Normal	1.052	0.867	1.276	0.609
BMI: Underweight vs. Normal	1.395	0.536	3.632	0.495
Charlson Comorbidity Index (CCI)	0.942	0.881	1.008	0.083
DCI Score	1.001	0.998	1.004	0.453
Hospital Region: Midwest vs. Northeast	1.123	0.881	1.432	0.349
Hospital Region: South vs. Northeast	1.506	1.208	1.878	<0.001*
Hospital Region: West vs. Northeast	0.918	0.760	1.108	0.371
Hospital Teaching Status: Major vs. Minor	1.317	1.006	1.724	0.045*
Hospital Teaching Status: Non-teaching vs. Minor	1.216	1.034	1.430	0.018*
Hospital Size: Large vs. Medium	0.752	0.620	0.912	0.004*
Hospital Size: Small vs. Medium	1.027	0.837	1.260	0.802
Hospital Community Type: Rural vs. Suburban	0.983	0.800	1.209	0.874
Hospital Community Type: Small Town vs. Suburban	0.930	0.761	1.137	0.480
Hospital Community Type: Urban vs. Suburban	1.045	0.848	1.288	0.681

OR – adjusted odds ratio; 95% CI – 95% Wald confidence interval.  
 †Odds ratio for age represents odds of achieving given outcome with each increase in age category relative to referent group age <50 years. \*denotes statistical significance.

**Table 7. Adjusted Odds Ratios for Achievement of SCB by HOOS, JR**

Effect	OR	95% CI		p-value
Sex: Female vs. Male	1.352	1.193	1.531	<0.001*
Age†	0.982	0.976	0.989	<0.001*
Race: American Indian vs. White	1.051	0.719	1.537	0.797
Race: Asian vs. White	0.789	0.444	1.403	0.420
Race: Black or African American vs. White	0.778	0.544	1.113	0.170
Race: Multiracial vs. White	1.302	0.567	2.992	0.534
BMI: Obesity Class I vs. Normal	1.079	0.896	1.300	0.423
BMI: Obesity Class II vs. Normal	1.238	0.982	1.560	0.070
BMI: Obesity Class III vs. Normal	1.071	0.800	1.433	0.647
BMI: Overweight vs. Normal	1.010	0.849	1.201	0.912
BMI: Underweight vs. Normal	1.113	0.503	2.463	0.792
Charlson Comorbidity Index (CCI)	0.964	0.906	1.026	0.248
DCI Score	1.001	0.999	1.004	0.402
Hospital Region: Midwest vs. Northeast	1.203	0.965	1.501	0.099
Hospital Region: South vs. Northeast	1.430	1.178	1.736	<0.001*
Hospital Region: West vs. Northeast	0.950	0.801	1.126	0.551
Hospital Teaching Status: Major vs. Minor	1.170	0.919	1.492	0.203
Hospital Teaching Status: Non-teaching vs. Minor	1.079	0.934	1.246	0.302
Hospital Size: Large vs. Medium	0.747	0.627	0.889	0.001*
Hospital Size: Small vs. Medium	1.011	0.843	1.213	0.903
Hospital Community Type: Rural vs. Suburban	1.056	0.878	1.271	0.562
Hospital Community Type: Small Town vs. Suburban	1.056	0.880	1.267	0.555
Hospital Community Type: Urban vs. Suburban	1.130	0.936	1.365	0.204

OR – adjusted odds ratio; 95% CI – 95% Wald confidence interval.  
 †Odds ratio for age represents odds of achieving given outcome with each increase in age category relative to referent group age <50 years. \*denotes statistical significance.

2-23% lower than rates of distribution-based MCID achievement. Requisite values for achievement of anchor-based MCID were approximately 1-2 times higher than requisite values for achievement of distribution-based MCID across all PROM subscales except for HOOS-QOL (Table 2). Lyman et al.<sup>5</sup> had similar findings, with requisite values for achievement of anchor-based MCID in HOOS being approximately 1.5 to 4 times higher than requisite values for achievement of distribution-based MCID. As a result, achievement rates of anchor-based MCID were lower across all HOOS subscales except for HOOS-QOL (achievement rates were 92% for distribution-based MCID and anchor-based MCID).<sup>5</sup> The most marked differences in achievement rates between distribution-based and achievement based MCID in the Lyman et al.<sup>5</sup> cohort and in the present study was in HOOS-Pain (67% achievement in anchor-based MCID and 94% achievement in distribution-based MCID in Lyman et al.;<sup>5</sup> 68% achievement in anchor-based MCID and 91% achievement in distribution-based MCID in the present study). Anchor-based MCID was also a more stringent metric than distribution-based MCID for WOMAC-Pain and WOMAC-Function; this is consistent with current literature.<sup>31</sup> Recognizing anchor-based MCID as a more stringent definition of success relative to distribution-based MCID when evaluating HOOS, HOOS, JR and WOMAC scores is important as methodology for calculating MCID varies significantly in THA literature.<sup>31</sup>

Achievement of SCB was consistently more stringent than distribution-based MCID across all PROM subscales except for HOOS-ADL, in which achievement rates were equal (92%). SCB tended to be of equal or greater stringency relative to anchor-based MCID; HOOS-ADL is again an exception in which anchor-based MCID was more stringent than SCB. Lyman et al.<sup>5</sup> also found SCB to be more stringent than anchor-based SCB across a majority of HOOS subscales, including HOOS, JR. PASS was the most stringent metric for HOOS-Pain and HOOS-QOL, with significantly lower rates of achievement relative to SCB, anchor-based MCID, and distribution-based MCID. PASS was of or near equal stringency to SCB for WOMAC-Pain and WOMAC-Function. Naal et al.<sup>32</sup> evaluated 193 patients after primary TKA using WOMAC and found that 85% of patients had achieved PASS by 6 months postoperatively. A relative paucity of PASS data makes it difficult to know for certain if PASS rates published in this study would remain consistent across multiple populations; additional studies utilizing PASS as a function of HOOS, HOOS, JR, and WOMAC are needed. In the interim, recognition that definitions of success and their relative stringency are necessarily not uniform across different PROMs is important. Ad-



ditionally, PROM score improvement above MCID may not imply achievement of PASS or SCB in all cases.

A second aim of this study was to evaluate if demographic variables, including socioeconomic status (via DCI score), were associated with achieving MCID and SCB for HOOS, JR following THA. Socioeconomic status was not associated with achievement of MCID or SCB in HOOS, JR at 1 year following primary THA. However, female sex was associated with increased odds of achievement of distribution-based MCID, achievement-based MCID, and SCB, while older age was associated with decreased odds of MCID and SCB achievement. Hu et al.<sup>33</sup> examined outcomes at 1-year following 46 primary THA in 38 patients in Brazil. The authors found that at 12-weeks postoperatively, women had significantly higher mean increases in HOOS, JR scores relative to men.<sup>33</sup> In a cohort of 4,114 primary THAs, Kostamo et al.<sup>34</sup> noted that female and male patients had no significant differences in clinical outcome aside from WOMAC-Pain scores, in which women scored higher than men. In a recent systematic review, Buirs et al.<sup>35</sup> reviewed data pertaining to the potential influence of gender on clinical outcomes following THA. Of 15 studies included in the systematic review, seven reported a significant association between gender and clinical outcome; 4 studies found that being male predicted a better clinical outcome, while 3 studies found that being female predicted a better clinical outcome.<sup>35</sup> The lack of consensus suggests that additional studies evaluating for potential gender differences in clinical outcomes following primary THA are needed. Older age has previously been associated with lesser clinical outcomes following THA.<sup>35,36</sup> Lalani et al.<sup>36</sup> evaluated 3,700 primary THA from 2007-2011 using HOOS, noting age-related decline in HOOS-ADL, HOOS-Symptoms, and HOOS-QOL. There was no age-related difference observed in the HOOS-Pain domain. Data from recent systematic reviews also supports a negative association between older age and clinical outcome following primary THA.<sup>35</sup>

There are several limitations to the present study. While the study utilized all available patients with preoperative and 1-year postoperative PROM data, the patients included in the present study constitute only a fraction of the total number primary THA included in the AJRR (498,050 in 2019)<sup>27</sup> which has the capacity to introduce selection bias. Similarly, capture of the HOOS and WOMAC subscales was relatively less frequent than capture of HOOS, JR. Patients that had a primary THA and then underwent a revision procedure within 1 year of their index procedure were not explicitly excluded from the results. While this theoretically has the capacity to influence study results, the rate of patients with a linked revision procedure within 1 year of the index

primary THA in the present cohort was approximately 1.5%. Further, approximately 1% of all patients with linked revision procedures included in the present study had PROM scores, making the influence of these patients on the results of the present study likely negligible.

In conclusion, rates of achievement of MCID, SCB, and PASS for HOOS, HOOS, JR, and WOMAC vary widely amongst patients 1 year postoperatively following primary THA. Distribution-based MCID was the least stringent definition of success across all PROM subscales. Generally, anchor-based MCID, SCB, and PASS were increasingly stringent in defining success in HOOS and HOOS, JR. Anchor-based MCID provided the most stringent definition of success for WOMAC subscales. Score improvement above MCID did not imply achievement of PASS or SCB. When evaluating literature regarding health outcomes following THA, particular attention should be given to what methods are used to calculate changes in PROM scores (anchor-based vs distribution-based) and what metrics are assessed (MCID, SCB, PASS). In our practice, capturing anchor and PASS questions during clinic visits has had a minimal effect on clinic visit time or staff burden, while allowing the surgeon and patient a comprehensive understanding of the patient's clinical progress. We believe that a tiered approach to implementation and interpretation of PROMs after primary THA should be considered for future research and clinical assessment as it may provide a more comprehensive understanding of the outcome after primary THA from the patient perspective.

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# PROJECTED PREVALENCE OF OBESITY IN ASEPTIC REVISION TOTAL HIP AND KNEE ARTHROPLASTY

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## ABSTRACT

**Background:** The purpose of this study was to develop projections of the prevalence of obesity in aseptic revision THA and TKA patients through the year 2029.

**Methods:** The National Surgical Quality Improvement Project (NSQIP) was queried for years 2011-2019. Current procedural terminology (CPT) codes 27134, 27137, and 27138 were used to identify revision THA and CPT codes 27486 and 27487 were used to identify revision TKA. Revision THA/TKA for infectious, traumatic, or oncologic indications were excluded. Participant data were grouped according to body mass index (BMI) categories: underweight/normal weight, <25 kg/m<sup>2</sup>; overweight, 25-29.9 kg/m<sup>2</sup>; class I obesity, 30.0-34.9 kg/m<sup>2</sup>; class II obesity, 35.0-39.9 kg/m<sup>2</sup>; morbid obesity ≥40 kg/m<sup>2</sup>. Prevalence of each BMI category was estimated from year 2020 to year 2029 through multinomial regression analyses.

**Results:** 38,325 cases were included (16,153 revision THA and 22,172 revision TKA). From 2011 to 2029, prevalence of class I obesity (24% to 25%), class II obesity (11% to 15%), and morbid obesity (7% to 9%) increased amongst aseptic revision THA patients. Similarly, prevalence of class I obesity (28% to 30%), class II obesity (17% to 29%), and morbid obesity (16% to 18%) increased in aseptic revision TKA patients.

**Conclusion:** Prevalence of class II obesity and morbid obesity demonstrated the largest increases in revision TKA and THA patients. By 2029, we estimate that approximately 49% of aseptic revision THA and 77% of aseptic revision TKA will have

obesity and/or morbid obesity. Resources aimed at mitigating complications in this patient population are needed.

**Level of Evidence:** III

**Keywords:** aseptic revision, total hip arthroplasty, total knee arthroplasty, obesity, morbid obesity

## INTRODUCTION

The prevalence of obesity and morbid obesity has increased significantly in the United States over the past 30 years;<sup>1,3</sup> these trends are projected to continue over the next 10 years.<sup>3,5</sup> Concomitantly, rates of primary total hip arthroplasty (THA) and primary total knee arthroplasty are projected to increase 75%-174% and 182%-683% by the year 2030, respectively.<sup>6,7</sup> Rates of obesity and morbid obesity amongst patients undergoing primary THA and TKA is expected to increase, such that ≥55% of all primary THA and ≥69% of all primary TKA may have obesity or morbid obesity by 2030.<sup>4,5</sup>

Patients with obesity undergoing primary THA and TKA have increased risks for aseptic and septic post-operative complications, including aseptic loosening, instability, and periprosthetic joint infection (PJI).<sup>8-13</sup> As increasing numbers of patients with obesity undergo primary THA or TKA, the subsequent burden of aseptic and septic revision THA and TKA may increase. Data from the National Inpatient Sample (NIS) suggests that relative to the year 2014, rates of revision THA and revision TKA may increase by 43%-70% and 78%-182%, respectively, by the year 2030.<sup>14</sup> Aseptic indications for revision, including aseptic loosening, instability, and implant failure are expected to account for the majority of revision surgeries over this time period.<sup>14</sup> Notably, patients with obesity demonstrate higher rates of post-operative complications and re-revision following aseptic revision TKA and THA.<sup>15-22</sup> A comprehensive understanding of the current and near-future prevalence of obesity amongst aseptic revision THA and TKA is needed to appropriately allocate resources towards clinical care and research studies aimed at improving outcomes in this patient population. The purpose of this study was to utilize American College of Surgeons National Surgical Quality Improvement Program (NSQIP) data to develop projections of the prevalence of obesity for aseptic revision THA and TKA patients through the year 2029.

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## METHODS

This study was exempt from institutional review board approval. NSQIP was queried for years 2011-2019. Current procedural terminology (CPT) codes 27134, 27137, and 27138 were used to identify revision THA and CPT codes 27486 and 27487 were used to identify revision TKA. Patients who underwent emergent or non-elective surgery, those with non-clean wound class, a history of sepsis, disseminated cancer, chemotherapy or radiation treatments were excluded. Additionally, patients undergoing revision THA or TKA for infectious, traumatic, or oncologic indications were excluded based on International Classification of Diseases (ICD) Ninth and Tenth diagnosis codes in accordance with previously published methods.<sup>23</sup>

Participant data were grouped according to World Health Organization (WHO) BMI categories: underweight/normal weight, <25 kg/m<sup>2</sup>; overweight, 25-29.9 kg/m<sup>2</sup>; class I obesity, 30.0-34.9 kg/m<sup>2</sup>; class II obesity, 35.0-39.9 kg/m<sup>2</sup>; morbid obesity ≥40 kg/m<sup>2</sup>.<sup>24</sup> Weighted frequencies and percentages of age groups and gender are reported. Prevalence of each BMI category was estimated from year 2020 to year 2029 through multinomial regression analyses. Statistical analyses were performed using SAS software (SAS Institute Inc., Cary, NC, USA. Copyright © 2021).

**Table 1. Demographics**

Category	Revision THA	Revision TKA
Sex (%)		
Male	44%	39%
Female	56%	61%
Not Reported/ Unknown	0%	0%
Age Group (%)		
18-29	0%	0%
30-34	1%	0%
35-39	1%	0%
40-44	2%	2%
45-49	4%	4%
50-54	8%	8%
55-59	12%	15%
60-64	14%	18%
65-69	15%	18%
70-74	15%	15%
74-79	12%	11%
80-84	9%	7%
85-89	5%	2%
≥90	2%	0%

THA – total hip arthroplasty; TKA – total knee arthroplasty.

## RESULTS

In total, 38,325 cases were included (16,153 revision THA and 22,172 revision TKA). Demographic data, including age and sex are contained in Table 1. In aseptic revision THA, the prevalence of normal weight patients decreased from 24% to 22% from 2011 to 2019; this is projected to decrease further to 20% by 2029. Similarly, the frequency of overweight patients decreased from 34% in 2011 to 32% in 2019, with a projected frequency of 31% in 2029. Class I obesity increased from 24% in 2011 to 25% in 2019 and is projected to remain at 25% through 2029. Class II obesity increased from 11% to 13% from 2011 to 2019; the frequency of class II obesity is projected to reach 15% in 2029. Prevalence of morbid obesity increased from 7% in 2011 to 8% in 2019, with projections estimated a prevalence of 9% in 2029. In total, projections estimate that approximately 49% of all aseptic revision THA will be obese or morbidly obese by 2029 (Figure 1, Table 2).

**Table 2. Prevalence of BMI Category in Revision THA, 2011-2029**

Year	Revision THA (n=16,153)					Morbidly Obese
	Normal Weight	Overweight	Obese			
			Class I	Class II	Total	
2011	24%	34%	24%	11%	35%	7%
2012	24%	34%	24%	11%	35%	7%
2013	24%	34%	24%	11%	35%	7%
2014	24%	33%	24%	12%	36%	7%
2015	24%	33%	24%	12%	36%	7%
2016	23%	33%	24%	13%	37%	7%
2017	23%	33%	24%	13%	37%	7%
2018	23%	33%	24%	13%	37%	7%
2019	22%	32%	25%	13%	38%	8%
2020*	22%	32%	25%	13%	38%	8%
2021*	22%	32%	25%	13%	38%	8%
2022*	21%	32%	25%	14%	39%	8%
2023*	21%	32%	25%	14%	39%	8%
2024*	21%	32%	25%	14%	39%	8%
2025*	21%	32%	25%	14%	39%	8%
2026*	21%	31%	25%	15%	40%	8%
2027*	21%	31%	25%	15%	40%	8%
2028*	21%	31%	25%	15%	40%	8%
2029*	20%	31%	25%	15%	40%	9%

THA – total hip arthroplasty. \*denotes projection data.

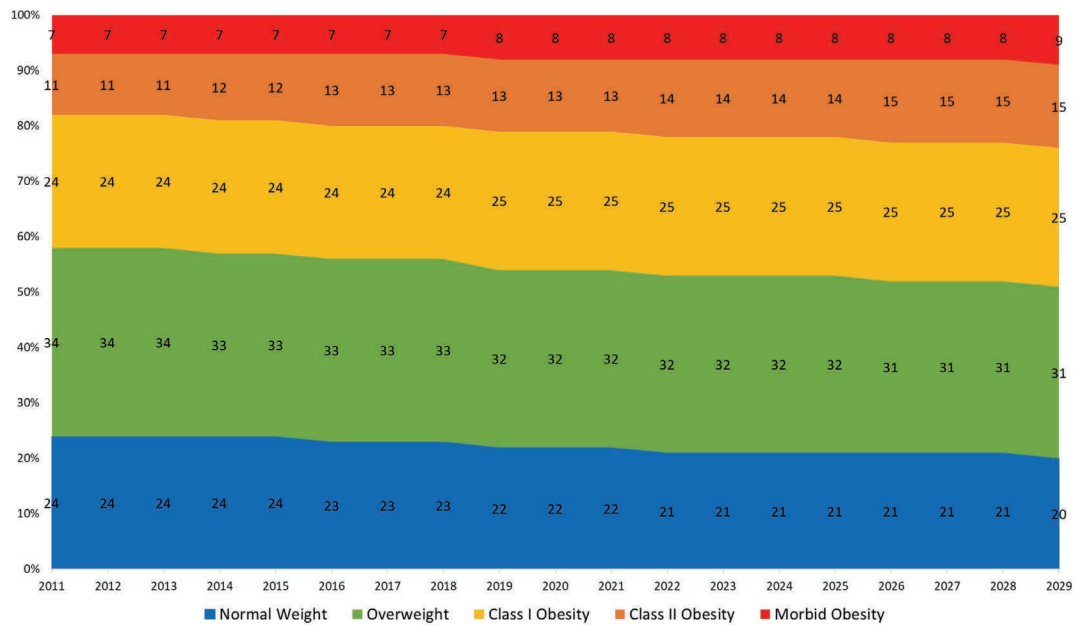


Figure 1. Stacked bar chart demonstrating trends in BMI categories for aseptic revision THA from 1999-2029. Years 2020-2029 represent projected data.

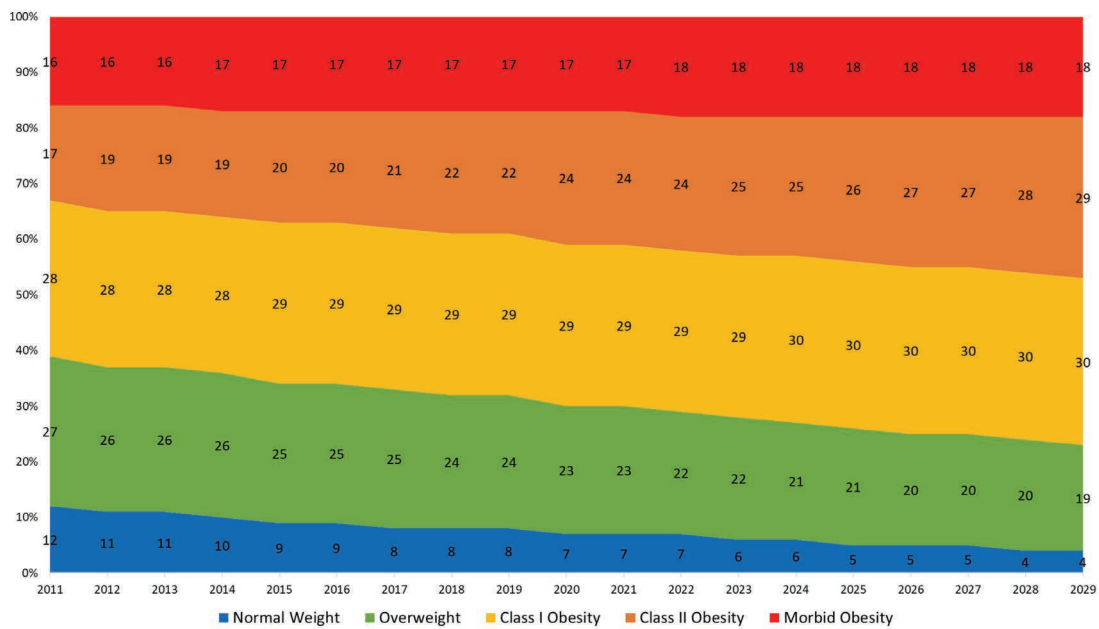


Figure 2. Stacked bar chart demonstrating trends in BMI categories for aseptic revision TKA from 1999-2029. Years 2020-2029 represent projected data.

In aseptic revision TKA, the prevalence of normal weight patients decreased from 12% to 8% from 2011 to 2019 and is projected to decrease to 4% by 2029. Frequency of overweight patients decreased from 27% in 2011 to 24% in 2019, with a projected frequency of 19% in 2029. Class I obesity increased from 28% to 29% from 2011 to 2019 and is estimated to increase to a frequency of 30% by 2029. Class II obesity increased more rapidly, with a prevalence of 17% in 2011, 22% in 2019, and projected prevalence of 29% in 2029. Prevalence of morbid obesity increased from 16% in 2011 to 17% in 2019, with projections estimated a prevalence of 18% in 2029. In total, projections estimate that approximately 77% of all aseptic revision TKA will be obese or morbidly obese by 2029 (Figure 2, Table 3).

**Table 3. Prevalence of BMI Category in Revision TKA, 2011-2029**

Year	Revision TKA (n=22,172)					
	Normal Weight	Overweight	Obese			Morbidly Obese
			Class I	Class II	Total	
2011	12%	27%	28%	17%	45%	16%
2012	11%	26%	28%	19%	47%	16%
2013	11%	26%	28%	19%	47%	16%
2014	10%	26%	28%	19%	47%	17%
2015	9%	25%	29%	20%	49%	17%
2016	9%	25%	29%	20%	49%	17%
2017	8%	25%	29%	21%	50%	17%
2018	8%	24%	29%	22%	51%	17%
2019	8%	24%	29%	22%	51%	17%
2020*	7%	23%	29%	24%	53%	17%
2021*	7%	23%	29%	24%	53%	17%
2022*	7%	22%	29%	24%	53%	18%
2023*	6%	22%	29%	25%	54%	18%
2024*	6%	21%	30%	25%	55%	18%
2025*	5%	21%	30%	26%	56%	18%
2026*	5%	20%	30%	27%	57%	18%
2027*	5%	20%	30%	27%	57%	18%
2028*	4%	20%	30%	28%	58%	18%
2029*	4%	19%	30%	29%	59%	18%

TKA – total knee arthroplasty. \*denotes projection data.

## DISCUSSION

A growing proportion of primary THA and TKA are being performed in patients with obesity and/or morbid obesity; this proportion is expected to increase such that by 2029, 55% of all primary THA and 69% of all primary TKA patients will have obesity or morbid obesity.<sup>4,5</sup> With increased rates of septic and aseptic complications occurring in patients with obesity following primary THA and TKA,<sup>8,11,25,26</sup> it follows that the prevalence of obesity and morbid obesity amongst patients undergoing aseptic revision THA and TKA may increase. We estimate that by 2029, 49% of all aseptic revision THA and 77% of all aseptic revision TKA will be obese and/or morbidly obese. Notably, class II obesity and morbid obesity were the two BMI categories with the most pronounced increases in prevalence from 2011-2029.

Prevalence of obesity within the general adult population of the United States is projected to increase significantly over the next 10-20 years.<sup>2,5</sup> Similarly, the prevalence of obesity and morbid obesity amongst patients undergoing primary THA and TKA is projected to increase from 2011-2029.<sup>4,5</sup> In 2011, prevalence of normal weight, overweight, obese, and morbidly obese patients was 23%, 35%, 25%, and 7%, respectively in primary THA and 11%, 29%, 45%, and 15%, respectively, in primary TKA. By 2029, prevalence of normal weight and overweight individuals are projected to decrease to 15% and 30%, respectively, in primary THA, and 7% and 24%, respectively, in primary TKA. Frequency of patients with class I and II obesity are projected to increase, accounting for 48% of primary THA and 57% primary TKA by 2029.<sup>4,5</sup> Prevalence of morbid obesity is projected to remain constant at 7% in primary THA, while being projected to decrease to 12% by 2029 in primary TKA. Overall, these data are like the data in the present study evaluating aseptic revision THA and TKA, with a few notable differences. We estimate a slightly higher prevalence of normal weight patients undergoing aseptic revision THA relative to primary THA. Additionally, we estimate a slightly lower prevalence of patients with obesity undergoing aseptic revision THA relative to primary THA and a slightly higher prevalence of morbid obesity in aseptic revision THA.<sup>5</sup> Prevalence of normal weight and overweight patients follow a similar decreasing trend for primary TKA and aseptic revision TKA, while the magnitude of decrease is greater in aseptic revision TKA. Projected increases in prevalence of class I and class II obesity are similar between primary and aseptic revision TKA; revision TKA is projected to have slightly more patients with class II obesity. Projected trends for the prevalence of morbid obesity are discordant between primary TKA and aseptic revision TKA: primary TKA is projected to have a decreasing prevalence of patients with morbid obe-

sity, while aseptic revision TKA is projected to have an increasing prevalence of patients with morbid obesity.<sup>4</sup>

Myriad explanations for the observed projections are possible. As these studies both examine years 2011-2029, it may be that any effect from an increased prevalence of obesity in primary THA and TKA leading to increased rates of aseptic revision THA and TKA has not yet had time to be fully “seen” in the data in the present study. However, increases in the prevalence of morbid obesity amongst aseptic revision THA and TKA cohorts relative to primary THA and TKA may be a harbinger of trends in the year 2030 and onward. Alternatively, while patients with obesity and/or morbid obesity tend to have increased rates of postoperative complications and revisions following primary THA and TKA, the vast may experience a complication-free surgery.<sup>27-30</sup> The differential in rates of postoperative complications that would necessitate an aseptic revision surgery between BMI categories may not be enough to influence projection data more than a few percentage points. Importantly, the present study is designed only to produce projections of BMI categories, not to provide explanations for said projections. Prevalence of patients with morbid obesity is projected to remain constant in primary THA and decrease in primary TKA while being projected to increase in aseptic revision THA and TKA. This finding aligns with current data suggesting that patients with morbid obesity are at increased risk for aseptic complications necessitating revision surgery following primary THA and TKA.<sup>11,31</sup> The constant or decreasing prevalence of morbid obesity in primary THA and TKA has been hypothesized to be secondary to enforcement of BMI cutoffs. At present, BMI cutoffs are employed by approximately 60% of members of the American Association of Hip and Knee Surgeons (AAHKS); the most common cutoff being BMI < 40 kg/m<sup>2</sup>.<sup>31-33</sup> Enforcing a BMI cutoff on aseptic revision surgery may be more difficult if the surgical indication is relatively urgent, which may be reflected in the increasing prevalence of morbid obesity in patients undergoing aseptic revision THA and TKA.

Volume of revision THA and TKA in the United States is projected to increase significantly over the next 10 years.<sup>14</sup> Using NIS data from 2002-2014, Schwartz et al.<sup>14</sup> estimated that the incidence of revision THA and TKA would increase 43%-70% and 78%-182%, respectively, by the year 2030. While PJI is becoming an increasingly common mode of failure of THA and TKA, aseptic indications for revision arthroplasty, such as mechanical loosening, instability, and periprosthetic fracture are projected to account for the majority of revision THA and TKA to the year 2030.<sup>14,34,35</sup> Revision arthroplasty in obese patients may incur higher up-front costs secondary to increased operative time and longer lengths of stay

as well as higher secondary costs due to increased rates of postoperative complications, hospital readmission, and re-revision surgery.<sup>15-19,21</sup> Further studies of how the growing prevalence of obesity in aseptic revision THA and TKA patients may impact costs of care and overall economic burden to the healthcare system in the United States are needed.

Contemporary data suggests that instability is one of the most common failure modes following revision THA, occurring in approximately 4-5% of cases.<sup>36,37</sup> Instability accounts for 35-52% of re-revision THA.<sup>36,37</sup> Presence of obesity and/or morbid obesity appears to exacerbate the risk for postoperative instability following revision THA.<sup>15,18</sup> Watts et al.<sup>18</sup> retrospectively examined propensity matched cohorts of morbidly obese and non-obese patients undergoing aseptic revision THA with a minimum clinical follow-up of 5 years. The authors demonstrated that aseptic revision THA patients with morbidly obese had significantly higher rates of postoperative instability relative to non-obese revision THA patients (12% vs. 4%; p=0.03).<sup>18</sup> Kim et al.<sup>15</sup> examined rates of instability following septic and aseptic revision THA, finding significantly higher rates of instability in patients with BMI > 35 relative to non-obese patients (19% vs. 2%; p=0.01). Retrospective data suggests that dual-mobility constructs may offer increased stability relative to conventional instrumentation in revision THA,<sup>38</sup> including in patients with obesity.<sup>39</sup>

Failure of contemporary revision TKA is often secondary to PJI, accounting for 20-44% of failures.<sup>40-43</sup> Morbid obesity may be a risk factor for PJI following aseptic revision TKA; however, current data is mixed.<sup>17,19,21</sup> Watts et al.<sup>17</sup> retrospectively examined propensity matched cohorts of 93 patients with morbid obesity and 93 non-obese patients undergoing aseptic revision TKA with a minimum clinical follow-up of 5 years. Patients with morbid obesity had a 6-fold increased risk for PJI relative to non-obese patients over the study period.<sup>17</sup> Sisko et al.<sup>19</sup> retrospectively studied propensity matched cohorts of 87 patients with morbid obesity and 87 non-obese patients undergoing revision TKA for septic and aseptic indications. When evaluating only aseptic revision TKA at a minimum clinical follow-up of 5 years, there were 10 PJI (15%) in patients with morbid obesity and 4 PJI (6%) in non-obese patients; this difference did not reach statistical significance.<sup>19</sup> As patients with obesity and morbid obesity comprise an increasing proportion of the total population undergoing aseptic revision THA, further understanding of the risk of postoperative complications must be elucidated to allow for comprehensive preoperative patient counseling and appropriate resource allocation.



Clinical outcomes, as measured by patient reported outcome measures (PROMs) may also be influenced by obesity following revision THA and TKA.<sup>16,17,19</sup> Lübbeke et al.<sup>44</sup> examined the influence of obesity (BMI  $\geq 30$  kg/m<sup>2</sup>) on the Harris Hip Score (HHS) following aseptic and septic revision THA at a minimum of 5 years postoperatively. Patients with obesity had significantly lower HHS scores and increased pain as measured by HHS than non-obese patients; however, there was no significant difference in patient satisfaction as measured by HHS.<sup>44</sup> Hanna et al.<sup>16</sup> examined HHS at a minimum of 5 years following aseptic or septic revision THA in patients with obesity and morbid obesity. Both patients with obesity and morbid obesity demonstrated significantly increased HHS at final follow-up relative to preoperative scores.<sup>16</sup> Final HHS were significantly higher in the obese cohort relative to the morbidly obese cohort [16]. Watts et al.<sup>17</sup> evaluated Knee Society Scores (KSS) in patients with morbid obesity and non-morbidly obese patients at a minimum of 5 years following aseptic revision TKA. At 2, 5, and 10-year follow-up intervals, non-morbidly obese patients demonstrated significantly higher KSS pain and function scores than patients with morbid obesity.<sup>17</sup> Sisko et al.<sup>19</sup> looked at Short Form-12 (SF-12), KSS, and Western Ontario and McMaster Universities Index (WOMAC) at 5 years following aseptic and septic revision TKA in patients with morbid obesity and non-morbidly obese patients. At final follow-up, the authors noted higher WOMAC scores in non-morbidly obese patients; there was no difference in KSS, SF-12 Mental, or SF-12 Physical scores between cohorts.<sup>19</sup> While arthroplasty surgeons would ideally select only patients who will “do well” postoperatively for surgical indications, this may not always be possible in the revision setting, depending on the urgency of the revision. Similarly, traditional optimization strategies such as weight loss through dietary and exercise modifications or bariatric surgery may not be possible, again depending on the indication for revision surgery.

There are several limitations to the present study. Cases captured in NSQIP may not be representative of the aseptic revision THA and TKA patient population at large. However, other large national databases may not collect BMI data that is needed to create categorical projections; use of NSQIP data to create categorical BMI projections has been utilized previously.<sup>4,5</sup> Projection data contained in the present study assumes that current practice environments, including referral patterns and surgical indications, of institutions captured in NSQIP stays relatively constant from 2011-2029. Projection data is likely to become increasingly inaccurate as projections get further into the future.

In conclusion, we estimate that by 2029, 49% of all aseptic revision THA and 77% of all aseptic revision TKA will be obese and/or morbidly obese. Overall, these projections are similar to projected prevalence of obesity and morbid obesity in primary THA and TKA. Class II obesity and morbid obesity are the two BMI categories projected to have the most pronounced increases in prevalence from 2011-2029. Increases in the prevalence of class II obesity and morbid obesity in revision THA and TKA may have implications for rates of postoperative complications, including instability, aseptic loosening, and periprosthetic joint infection, as well as clinical outcomes as measured by PROMs. Increased research efforts aimed at minimizing risk of complications and maximizing postoperative function in this patient population are needed.

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# 'TIS TIME 'TIS TIME: THE IMPORTANCE OF OPERATIVE TIME, THOROUGHNESS, AND SHAKESPEARE IN DAIR PROCEDURES IN TOTAL JOINT ARTHROPLASTY

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## ABSTRACT

**Background:** Prosthetic joint infections (PJIs), while rare, are a devastating complication of both total joint arthroplasty (TJA). With most patients undergoing surgical treatment for PJI, options vary between one-stage or two-stage (the gold standard) procedures. Debridement, antibiotics, and implant retention (DAIR) procedures are a common, less morbid alternative to two-stage revisions, but patients undergoing DAIR procedures more often experience reinfections. This is likely in part due to non-standardized irrigation and debridement (I&D) methods within these procedures. Furthermore, DAIR procedures are often desired due to their cost effectiveness and lesser operative times, but no investigations have occurred regarding operative-time-based outcomes. This study aimed to compare reinfection incidence with procedure time in DAIR procedures. In addition, this study aimed to introduce the novel Macbeth Protocol for the I&D portion of DAIR procedures and assess its efficacy.

**Methods:** Records of unilateral DAIR procedures for primary TJA PJI performed by arthroplasty surgeons from 2015-2022 were retrospectively reviewed for patient demographics, select medical history, body mass index (BMI), joint, microbiology, and follow-up data. In addition, a single surgeon's DAIR procedures (for primary and revision TJA) were reviewed and use of The Macbeth Protocol was noted.

**Results:** A total of 71 patients (mean age 64.00  $\pm$  12.81 years) who underwent unilateral DAIR were included. Patients with reinfections following their DAIR procedure had significantly ( $p = 0.034$ ) lower procedure times (93.72  $\pm$  15.01 min) compared to those without reinfections (105.87

$\pm$  21.91 min). Twenty-two patients underwent 28 DAIR procedures by the senior author, where 11 (39.3%) DAIR procedures utilized The Macbeth Protocol. The use of this protocol did not significantly affect reinfection rate ( $p = 0.364$ ).

**Conclusion:** This study concluded that increased operative time led to less reinfections for DAIR procedures treating unilateral primary TJA PJIs. Additionally, this study introduced The Macbeth Protocol, which demonstrated promising potential as an I&D technique despite not showing statistical significance. Arthroplasty surgeons should not sacrifice patient outcomes determined by reinfection rate for decreased operative time.

**Level of Evidence:** III

**Keywords:** prosthetic joint infections, total joint arthroplasty, DAIR, irrigation and debridement

## INTRODUCTION

Prosthetic joint infections (PJIs) are a well-known and dreaded complication of total joint arthroplasty (TJA).<sup>1,4</sup> Traditionally, PJIs require surgical treatment, with either a two-stage procedure or a single procedure. The gold standard, the two-stage procedure, involves an initial prosthesis explant, implantation of an antibiotic spacer, and a later revision TJA following infection eradication.<sup>5,6</sup> While this method is effective at eliminating persistent PJIs and the associated biofilms, it comes with increased cost, morbidity, and mortality.<sup>5,7-11</sup> An alternative is the single stage debridement, antibiotics, and implant retention (DAIR) procedure.<sup>2,12</sup> As DAIR procedures rely on preservation of the prostheses – aside from the polyethylene bearing – thorough irrigation and debridement (I&D) is required.

Currently, there exists no consensus on the gold-standard I&D method to utilize within DAIR or two-stage procedures.<sup>3,13,14</sup> Siddiqi et al. recently reviewed the literature surround I&D techniques; however, these authors determined that a meta-analysis was unable to be conducted as too much variation in protocols existed alongside lack of controls.<sup>3</sup> Individual studies reporting their I&D protocols commonly include copious saline lavage with debridement adjuncts (methylene blue, argon beam), antiseptics (povidone-iodine (PI), chlorhexidine gluconate (CHG), acetic acid), and detergents/surfac-

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**Table I. The Macbeth Protocol**

Full Macbeth Protocol	
<i>Following removal of previous hardware, debridement, and trialing of new hardware (if applicable):</i>	
1.	Irrigation and mechanical agitation with a 1:3 mixture of 40mL 10% povidone-iodine (PI) and 120mL 3% hydrogen peroxide (H <sub>2</sub> O <sub>2</sub> ) added to 1L normal saline (NS, 0.9% NaCl)
2.	Irrigation with 3L NS
3.	Irrigation with 3L NS - 0.05% chlorhexidine gluconate mixture (CHG)
4.	Irrigation with 3L normal saline
5.	Final irrigation with 1L 0.1% polyhexanide and 0.1% betaine (Prontosan®, B. Braun Medical Inc., Bethlehem, Pennsylvania, USA)

tants (castile soap, benzalkonium chloride).<sup>3,12,15-19</sup> Similarly, studies have also incorporated antibiotic lavages – commonly with bacitracin or vancomycin – in addition to systemic and local, post-I&D antibiotic delivery.<sup>20,21</sup> Aside from saline additives and other solutions, there have been reports investigating variable pressure saline delivery, and it has been theorized that high-pressure pulse lavage may disseminate the infection and associated biofilms, yet this has not been proven.<sup>22,23</sup> Despite these published techniques, there has yet to emerge a widespread, efficacious I&D method to utilized within DAIR procedures. However, publications beyond the medical literature have yet to be explored.

William Shakespeare (1564-1616) often had references to renaissance medicine and early surgeries in his writings. It has even been speculated that The Bard was a student of anatomy and physiology based on his plays.<sup>24</sup> When it comes to orthopaedics, he often referenced bones, joints, and sinew with occasional discussions of early orthopaedic procedures such as amputation and prosthetic fitting.<sup>25-27</sup> He describes an afflicted patient needing an amputation due to having a “festered joint” in Richard II, which likely would have likely benefited from an I&D.<sup>26</sup> Sadly, however, modern medicine is largely defunct of allusions to the playwright and his works. The extent of his modern reach in medicine is seemingly limited to titles of publications referencing popular works.<sup>28</sup>

As there is a paucity of data regarding outcomes of DAIR procedures based on operative time, this study primarily aimed to determine if operative time affected reinfection outcomes following DAIR procedures. Additionally, this study aims to introduce and assess the efficacy of the novel Macbeth Protocol within DAIR procedures. It was hypothesized that increased operative time would result in less reinfections following DAIR procedures. Furthermore, it is hypothesized that The Macbeth Protocol will facilitate higher PJI clearance.

**Table II. Inclusion and Exclusion Criteria for Retrospective Review**

Inclusion Criteria
<ul style="list-style-type: none"> <li>DAIR procedures completed between 2015-2022</li> <li>DAIR procedures with polyethylene liner (± femoral head, if applicable) exchanges</li> <li>DAIR procedures with indication of known/suspected PJI following primary TJA</li> <li>DAIR procedures performed by a fellowship-trained arthroplasty surgeon</li> </ul>
Exclusion Criteria
<ul style="list-style-type: none"> <li>DAIR procedures performed alongside other procedures (e.g. hardware removal, ORIF, etc.)</li> <li>Irrigation and debridement (I&amp;D) procedures that do not enter the deep joint space (i.e. superficial I&amp;D)</li> </ul>

## METHODS

This study received IRB approval prior to initiation. Records of DAIR were obtained through the Epic (Redwood City, California, US) add-on SlicerDicer by searching for “irrigation and debridement, knee, with polyethylene exchange” and “irrigation and debridement, hip, with polyethylene exchange”. Following this search, records were reviewed for select inclusion and exclusion criteria (Table II). Records were reviewed for demographics, select comorbidities, body mass index (BMI), procedure details (surgeon, joint, laterality, procedure time), infection microbiology, and patient follow-up details. Operative time was defined as first incision (procedure start) to wound closure (procedure end).

In addition to the primary retrospective review, DAIR procedure records from a single fellowship-trained arthroplasty surgeon were also reviewed for use of The Macbeth Protocol. This retrospective review included all DAIR procedures by this surgeon including those indicated by any PJI (primary and revision TJA).

The Macbeth Protocol, designed by the senior author (JME), is utilized during an I&D of a PJI in DAIR and two-stage procedures alike. This technique varies from those in the current literature by emphasizing thoroughness and mechanical agitation: 1:3 mixture of 40mL 10% povidone-iodine (PI) and 120mL 3% hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>) added to 1L normal saline (NS) is introduced into the joint space and mechanically agitated by handled sponges. Concurrently, a surgeon, traditionally a post-graduate year two (PGY-2) resident, recites the Three Witches’ Monologue from Act 4 Scene 1 of William Shakespeare’s Macbeth (Appendix A).<sup>29</sup> The speech, when performed, lasts approximately three to five minutes. This portion of the procedure is followed by additional lavages (Table I). The protocol is implemented after the removal of prostheses and prior to implantation of new hardware, spacers, and/or antibiotics.

**Table III. Select Patient and Procedure Factors Stratified by Reinfection Occurrence**

Variable	Reinfection	No Reinfection	p-value
Age (years)	59.64	64.80	0.245
Procedure time (min)	93.72	105.87	0.034*
BMI (kg/m <sup>2</sup> )	36.42	34.70	0.709
Sex (%)			0.424
Male	72.2	60.0	
Female	27.3	40.0	
Hypertension (%)			0.233
Yes	81.8	63.3	
No	18.2	36.7	
Diabetes (%)			0.128
Yes	45.5	23.3	
No	54.5	76.7	
Smoking (%)			0.424
Current	18.2	5.0	
Former	27.3	28.3	
Never	54.5	66.7	

\*p < 0.05 is statistically significant

Note: student t-test performed for continuous variables, and chi-squared performed for categorical variables.

Descriptive statistics, student t-test, and chi-squared analyses were completed using SPSS 28 (IBM, Armonk, New York, USA).

## RESULTS

A total of 71 patients with mean age 64.00 ( $\pm$  12.81) years were included for analysis. Forty-four (61.9%) were male. Overall mean BMI was 34.96 ( $\pm$  9.33) kg/m<sup>2</sup>. Average procedure time was 103.99 ( $\pm$  21.37) min with patients experiencing reinfections following their DAIR procedure have significantly ( $p = 0.034$ ) lower operative times (Figure 1). Reinfection rate did not significantly vary by demographics or comorbidities (Table III). Procedure time did not correlate significantly with increasing BMI with ( $p = 0.817$ ). Intraoperative cultures grew most commonly Methicillin-Susceptible *S. Aureus* (21.1%), *S. Epidermidis* (12.7%), and Methicillin-Resistant *S. Aureus* (7.0%). Additionally, 14.1% of intraoperative cultures were negative. Average follow-up time of all patients was 476.66 ( $\pm$  455.67) days. Average time to reinfection (N = 11) was 334.00 ( $\pm$  354.65) days with 5 (45.5%) occurring under 60 days and 7 (63.6%) occurring within 1 year of initial DAIR procedure.

Twenty-two patients underwent 28 DAIR procedures by the senior author, where 11 (39.3%) procedures

**Table IV. Single Surgeon's DAIR Procedure Time Stratified by the Use of The Macbeth Protocol**

PJI Type	Variable	All	Macbeth Protocol	No Macbeth Protocol
Primary TJA	Total N	11	4	7
	Reinfection N	1	0	1
	Procedure Time, min	123.36	120.75	124.86
	(SD)	(20.00)	(17.52)	(22.49)
Revision TJA	Total N	17	7	10
	Reinfection N	4	1	3
	Procedure Time, min	160.94	174.86	151.2
	(SD)	(52.28)	(40.12)	(59.42)
Total	N	28	11	17

**Table V. Single Surgeon's Dair Procedures (for Infected Primary and Revision Tja) Stratified by the Use of the Macbeth Protocol**

N = 28	Macbeth Protocol	No Macbeth Protocol	p-value
Reinfection	1 (9.1%)	4 (23.5%)	0.364
No Reinfection	10 (90.9%)	13 (76.5%)	
Total	11 (100%)	17 (100%)	

Chi-Squared Analysis Was Performed on the Included Cohorts.

were indicated by a primary TJA PJI. Of the total 28, 11 (39.3%) DAIR procedures utilized The Macbeth Protocol for the I&D portion of the surgery. DAIR procedures for an infected primary TJA and infected revision TJA took 123.36 ( $\pm$  20.00) min and 160.94 ( $\pm$  52.28) min, respectively (Table IV). There was 1 reinfection out of 11 after Macbeth (9.1%) and 4 reinfections out of 17 without Macbeth (23.5%) (Table V).

## DISCUSSION

Prosthetic joint infections are a rare but morbid complication following TJA. Patients often require surgical intervention to eradicate the infection and prevent reinfection and/or chronic infections. DAIR procedures are a common alternative to two-stage revision procedures, and this study identified that longer DAIR operative times have less likelihood of reinfections.

Operative efficiency, as determined by low operative time, is sought after due to cost effectiveness of the individual case and ability to host more cases in a single operating room.<sup>30-32</sup> Studies regarding various implants,

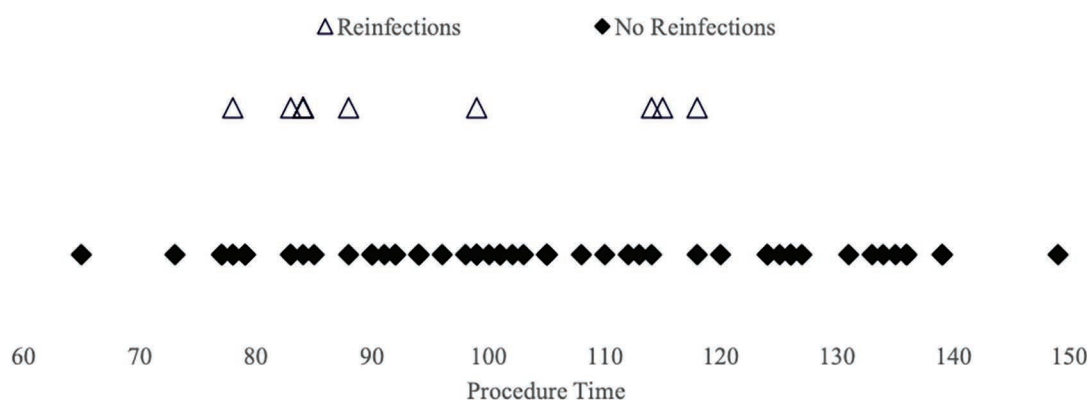


Figure 1. Patients with reinfections following their DAIR procedure had significantly ( $p=0.034$ ) lower procedure times ( $93.72 \pm 15.01$  min) compared to those without reinfections ( $105.87 \pm 21.91$  min).

surgical techniques, and patient population have varied operative times without largely sacrificing outcomes, and therefore, those with lower operative times are valued.<sup>33-36</sup> When it comes to PJI treatment, DAIR procedures are known to have lower costs and lower operative times, but they are also known to have higher reinfection rates.<sup>9-11</sup> To the authors' knowledge, there exists no studies examining the cost analysis of increased DAIR operative time compared to shorter, failed DAIR procedures.

With DAIR procedures associated with higher reinfection rates compared to two-stage procedures, attention has been brought to the eventual outcomes of these failed DAIR procedures. Poorer outcomes have been reported for two-stage procedures following a failed DAIR,<sup>37</sup> but Huffaker et al. recently demonstrated that those that failed DAIR and subsequently underwent a two-stage revision had non-inferior outcomes to the initial two stage cohort.<sup>9</sup> This study suggests that the risk of increased reinfection is not as detrimental to the patient as previously thought with eventual outcomes of the DAIR-F cohort likely equivocal. With that in mind, a thorough, initial DAIR procedure will likely posit the patient to acceptable outcomes with a likelihood of infection eradication.

Additionally, this study reviewed DAIR procedures that utilized The Macbeth Protocol. This current data showed no significant relationship between those that underwent the protocol compared to those that did not. However, this may be due to lack of power as those who lacked The Macbeth Protocol had an approximately 2.5x higher reinfection rate. This technique, which emphasizes thoroughness through increased operative time and mechanical agitation to disrupt biofilms over surgical efficiency, has promising potential as a method of I&D. Further studies are required to fully elucidate the efficacy of The Macbeth Protocol.

Several surgeons have reported their I&D technique utilized in PJI treatment procedures, but the overall volume and level of evidence lacks with most studies relying on retrospective review without a control cohort.<sup>3</sup> In addition to meticulous debridement and substantial saline irrigation, surgeons often rely on a combination of antiseptic agents, surfactants, and/or antibiotics within their irrigation along with or without mechanical scrubbing.<sup>3,12,15-19,38-41</sup> The success rates of these methods vary from 35-100%, yet the individual studies have varied endpoints and outcomes with at most Level II evidence.<sup>3</sup> Additionally, with multiple solutions involved, surgeons must proceed cautiously with mixing agents due to potential chemical reactions including gas formations and precipitation of certain solutions.<sup>3,21</sup>

Aside from DAIR procedure time and techniques, this study also observed no impact of comorbidities such as increasing BMI, diabetes mellitus, and smoking status on reinfection rate or procedure time. These findings, which are contrary to the literature, are likely secondary to low cohort sizes.<sup>42-44</sup>

Limitations of this study include that it is a single-center, retrospective review. In addition, in an attempt to control for numerous procedural variables innate to DAIR procedures, there was a small sample size. Similarly, the reports on The Macbeth Protocol were from a retrospective review of a single surgeon's practice with limited sample size. Finally, this study was limited by procedural coding variations for DAIR procedures, which may limit completeness of retrospective review.

In conclusion, this study identified that increased DAIR operative times, when treating primary TJA PJIs, led to less reinfections at an average follow-up time of approximately 16 months. Despite concerns regarding increased operative time leading to increased cost within the literature, completing a thorough I&D of the

infected joint at the cost of increased operative time likely improves patient outcomes while decreasing the overall and potential treatment cost. In addition, this study introduced a novel technique for I&D of PJIs. While this portion of the study was underpowered to demonstrate statistical significance within DAIR procedures, The Macbeth Protocol is likely a promising I&D technique as it emphasizes key, accepted methods including thoroughness, mechanical agitation, and multi-modal lavages. Overall, arthroplasty surgeons completing DAIR procedures should emphasize meticulous I&D over a desire for decreasing operative time.

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APPENDIX A. The Three Witches' Monologue from William  
Shakespeare's Macbeth – Act IV, Scene 1

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**First Witch**

Thrice the brinded cat hath mew'd.

**Second Witch**

Thrice and once the hedge-pig whined.

**Third Witch**

Harpier cries 'Tis time, 'tis time.

**First Witch**

Round about the cauldron go;  
In the poison'd entrails throw.  
Toad, that under cold stone  
Days and nights has thirty-one  
Swelter'd venom sleeping got,  
Boil thou first i' the charmed pot.

**ALL**

Double, double toil and trouble;  
Fire burn, and cauldron bubble.

**Second Witch**

Fillet of a fenny snake,  
In the cauldron boil and bake;  
Eye of newt and toe of frog,  
Wool of bat and tongue of dog,  
Adder's fork and blind-worm's sting,  
Lizard's leg and owlet's wing,  
For a charm of powerful trouble,  
Like a hell-broth boil and bubble.

**ALL**

Double, double toil and trouble;  
Fire burn and cauldron bubble.

**Third Witch**

Scale of dragon, tooth of wolf,  
Witches' mummy, maw and gulf  
Of the ravin'd salt-sea shark,  
Root of hemlock digg'd i' the dark,  
Liver of blaspheming Jew,  
Gall of goat, and slips of yew  
ilver'd in the moon's eclipse,  
Nose of Turk and Tartar's lips,  
Finger of birth-strangled babe  
Ditch-deliver'd by a drab,  
Make the gruel thick and slab:  
Add thereto a tiger's chaudron,  
For the ingredients of our cauldron.

**ALL**

Double, double toil and trouble;  
Fire burn and cauldron bubble.

**Second Witch**

Cool it with a baboon's blood,  
Then the charm is firm and good.

**HECATE**

O well done! I commend your pains;  
And every one shall share i' the gains;  
And now about the cauldron sing,  
Live elves and fairies in a ring,  
Enchanting all that you put in.

**Second Witch**

By the pricking of my thumbs,  
Something wicked this way comes.  
Open, locks,  
Whoever knocks!

# CHARACTERISTICS AND LONG-TERM OUTCOME OF SURGICALLY MANAGED HIGH-GRADE EXTREMITY CHONDROSARCOMA

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## ABSTRACT

**Background:** Dedifferentiated chondrosarcoma (DCS) is a highly malignant variant that portends a poor prognosis. Although factors such as clinicopathological characteristics, surgical margin, and adjuvant modalities likely play a role in overall survival, debate continues with varying results on the importance of these indicators. The purpose of this study is (1) To delineate the characteristics, local recurrence (LR), and survival of patients with intermediate (IGCS), high (HGCS) and dedifferentiated (DCS) chondrosarcoma of the extremity by utilizing detailed cases at one tertiary institution. (2) To assess survival between high grade chondrosarcoma and DCS utilizing a less detailed but large cohort from the Surveillance, Epidemiology, and End Results (SEER) database.

**Methods:** Twenty-six cases of high-grade (conventional FNCLCC grades 2 and 3, dedifferentiated) chondrosarcoma were identified from an ongoing prospective cohort of 630 sarcoma patients managed surgically at a tertiary referral university hospital between 9/1/2010-12/30/2019. A retrospective review of demographics, tumor characteristics, surgical procedure, treatment course, and survival data was performed to determine prognostic factors for survival. An additional 516 cases of chondrosarcoma were identified from the SEER database. Using the Kaplan-Meier method, both the large database and case series were evaluated, and estimated cause-specific survival was calculated at 1, 2, and 5 years.

**Results:** There were 12 IGCS, 5 HGCS, and 9 DCS patients in the single institution cohort. DCS had a higher stage at diagnosis ( $p=0.04$ ). Limb salvage was the most common procedure performed

in every group (11/12 IGCS, 5/5 HGCS, and 7/9 DCS;  $p=0.56$ ). Margins included 8/12 wide and 3/12 intralesional for IGCS. For HGCS, there were 3/5 wide, 1/5 marginal, and 1/5 intralesional. A majority of DCS margins were wide (8/9) with only 1 marginal. There was no difference of associated margins between the groups ( $p=0.85$ ), however there was a difference when margins were classified based on numerical measurement (IGCS: 0.125cm (0.1-0.35); HGCS: 0cm (0-0.1); DCS: 0.2cm (0.1-0.5);  $p=0.03$ ). The overall median follow-up was 26 months (IQR:16.1-70.8). The time interval from resection to death was lower in DCS (11.5 months (10.7-12.2)), followed by IGCS (30.3 months (16.2-78.2)), and HGCS (55.1 months (32.0-78.2;  $p=0.047$ ). LR occurred in 5/9 DCS, 1/5 HGCS, and 1/14 IGCS patients. Of the DCS patients only 2/6 who received systemic therapy had LR, while all 3/3 who did not receive systemic therapy had LR. Overall systemic therapy and radiation did not impact incidence of LR ( $p=0.67$ ;  $p=0.34$ ). However, patients who had LR were 17.5 times more likely to die within one year (HR=17.5, 95%CI (1.01-303.7),  $p=0.049$ ), after adjusting for the age at the surgery. There was no correlation with the utilization of systemic therapy, radiation therapy, or margin and overall survival ( $p=0.63$ ,  $p=0.52$ ,  $p=0.74$ ). In the SEER patient cohort, 149 cases (28.9%) were DCS and 367 (71.1%) were HGCS. At final follow-up, 49.6% ( $n=256$ ) of the cohort had a cause of death due to chondrosarcoma. HGCS was associated with higher chance of 1-year survival ( $p<0.001$ ), 2-year survival ( $p<0.001$ ), 5-year survival ( $p<0.001$ ), and overall survival ( $p<0.001$ ). Additionally, decreased survival was associated with metastatic disease at presentation ( $p=0.01$ ). Overall limb salvage was most utilized for both HGCS (76.5%) and DCS (74.3%). In regard to limb salvage vs. amputation, there was no difference in survival at 1 year ( $p=0.10$ ) or 2 year ( $p=0.13$ ) between the groups, however those who underwent limb salvage procedure had a significantly better chance of survival at 5 years when compared to amputation (HR=1.49 (1.11-1.99);  $p=0.002$ ).

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**Conclusion:** High-grade chondrosarcoma remains a fatal disease in many patients, particularly if associated with dedifferentiated subtype. Interestingly, all (100%) DCS patients who did not receive systemic therapy had LR. However, chemotherapy and radiation did not significantly increase survival. In this case series and large database study, HGCS had the smallest surgical margin, but with the longest time interval for both LR and death. Additionally, using the SEER database, DCS and amputation had worse prognosis at the 5-year survival time. Further studies on valuable prognostic influences as well as earlier identification of this rare disease may help in developing better management options.

**Level of Evidence:** III

**Keywords:** chondrosarcoma, tumor

## INTRODUCTION

Chondrosarcoma is the third most common primary malignancy of the bone but is relatively rare with an estimated incidence of 1 in 200,000.<sup>1</sup> For high-grade lesions, surgical resection is the main stay of treatment with limited role for adjuvant chemotherapy and radiation.<sup>2,4</sup> Conventional chondrosarcoma is the most commonly found type but there are also several subtypes of chondrosarcoma including myxoid, mesenchymal, juxtacortical, clear cell, and dedifferentiated.<sup>1,5</sup>

Dedifferentiated chondrosarcoma (DCS) is a highly malignant variant that portends a poor prognosis with survival rates reported below 25%.<sup>6,7</sup> The main treatment of DCS includes surgical excision with wide margins similar to other high-grade tumors.<sup>8,9</sup> Even with treatment, local recurrence rates are high. Although factors such as clinicopathological characteristics, surgical margin, and adjuvant modalities likely play a role in overall survival, debate continues with varying results on the importance of these indicators.

Due to the rarity of tumors like chondrosarcoma studies are typically limited to small but more detailed case series or larger but less detailed database studies. In order to capture an accurate understanding of the factors influencing outcomes for patients with high-grade and dedifferentiated chondrosarcoma, we utilized both detailed cases at one tertiary institution and a large cohort from the Surveillance, Epidemiology, and End Results (SEER) database.

The purpose of this study was to further delineate the characteristics and long-term outcomes, local recurrence (LR) and survival, of patients with intermediate-grade (IGCS), high-grade (HGCS) and dedifferentiated (DCS) chondrosarcoma of the extremity.

## METHODS

Twenty-six cases of high-grade (conventional FN-CLCC grades 2 and 3, dedifferentiated) chondrosarcoma were identified from an ongoing prospective cohort of 630 sarcoma patients managed surgically at a tertiary referral university hospital between 9/1/2010-12/30/2019. A retrospective review of demographics, tumor characteristics, surgical procedure, treatment course, and survival data was performed to determine prognostic factors for survival.

Additionally, we queried the Surveillance, Epidemiology and End Results Program Database. The SEER registries collect data from a variety of U.S. geographical areas and represents approximately 28% of the United States population. The database includes deidentified data on patient demographics, tumor characteristics, and survival. The SEER cohort included patients of all ages, race, and sex with high-grade and dedifferentiated chondrosarcoma diagnosed from 1990 to 2015. Further selection criteria included patients with a single primary tumor only, microscopic diagnostic confirmation, and tumors limited to the bones and soft tissue of the extremities. Patients were captured using ICD-O-3 (International Classification of Diseases for Oncology, Third Edition) morphology codes including: 9220/3 chondrosarcoma, NOS, 9221/3 juxtacortical chondrosarcoma, 9230/3 chondroblastoma, malignant, 9231/3 myxoid chondrosarcoma, 9240/3 mesenchymal chondrosarcoma, 9242/3 clear cell chondrosarcoma, 9243/3 dedifferentiated chondrosarcoma. We considered chondrosarcoma, NOS equivalent to conventional chondrosarcoma. Within SEER, chondrosarcoma grading is reported in a 4-tier system. We considered grades I and II to represent grade 1 and grade 2 lesions respectively, and grouped grades III and IV to represent grade 3 lesions as has been done in a previous SEER database, chondrosarcoma study.<sup>10</sup>

For our analysis high-grade chondrosarcoma and its subtypes were grouped together for comparison against dedifferentiated chondrosarcoma. Outcome variables for the SEER data analysis included presence of metastasis on presentation, surgery modality (limb salvage vs. amputation), and survival.

Using the Kaplan-Meier method, both the large database and case series were evaluated, and all-cause mortality was calculated at 1, 2, and 5 years. For the single center cohort, we compared demographics and location of the primary tumor between the three grades. We assessed the time to local recurrence and time to metastasis. We analyzed AJCC 7th/8th edition staging at presentation and analyzed the use of systemic therapy, radiation therapy and surgical margin size on overall survival. For the SEER cohort, we assessed patient's survival comparing high-grade chondrosarcomas to dedifferenti-

ated chondrosarcoma. We assessed survival based on the presence of metastasis at presentation. Finally, we compared outcomes based on surgery modality for all high-grade chondrosarcomas of the extremity.

## RESULTS

There were 26 patients: 12 IGCS, 5 HGCS, and 9 DCS patients in the single institution case series that met inclusion criteria. Of the three groups, DCS had a higher stage at diagnosis ( $p=0.04$ ). Limb salvage was the most common procedure performed in every group (11/12 IGCS, 5/5 HGCS, and 7/9 DCS;  $p=0.56$ ). Surgical margins included 8/12 wide and 3/12 intralesional for IGCS. For HGCS, there were 3/5 wide, 1/5 marginal, and 1/5 intralesional. A majority of DCS margins were wide (8/9) with only 1 marginal. There was no difference of associated margins between the groups ( $p=0.85$ ), however there was a difference when margins were classified based on numerical measurement with HGCS having the narrowest margins (IGCS: 0.125cm (0.1-0.35); HGCS: 0cm (0-0.1); DCS: 0.2cm (0.1-0.5);  $p=0.03$ ).

The overall median follow-up was 26 months (IQR:16.1-70.8). The time interval from resection to death was lower in DCS (11.5 months (10.7-12.2)), followed by IGCS (30.3 months (16.2-78.2)), and HGCS (55.1 months (32.0-78.2;  $p=0.047$ ). LR occurred in 5/9 DCS, 1/5 HGCS, and 1/14 IGCS patients. Of the DCS patients only 2/6 who received systemic therapy had LR, while all 3/3 who did not receive systemic therapy had LR. Overall systemic therapy and radiation did not impact incidence of LR ( $p=0.67$ ;  $p=0.34$ ). However, patients who had LR were 17.5 times more likely to die within one year ( $HR=17.5$ , 95%CI (1.01-303.7),  $p=0.049$ ), after adjust-

ing for the age at the surgery. There was no correlation with the utilization of systemic therapy, radiation therapy, or margin and overall survival ( $p=0.63$ ,  $p=0.52$ ,  $p=0.74$ ).

There was a total of 516 patients who met inclusion criteria in the SEER patient cohort, 149 cases (28.9%) were DCS and 367 (71.1%) were HGCS. At final follow-up, 49.6% ( $n=256$ ) of the cohort had a cause of death due to chondrosarcoma. Utilizing Kaplan Meier survival analysis, we found that HGCS was associated with higher chance of 1-year survival ( $p<0.001$ ), 2-year survival ( $p<0.001$ ), 5-year survival ( $p<0.001$ ), and overall survival ( $p<0.001$ ) compared to DCS. Additionally, decreased survival was associated with metastatic disease at presentation ( $p=0.01$ ). Unfortunately, only 459/516 (89%) patients in the cohort had information on the surgical modality utilized and we excluded those that did not from our treatment analysis. Overall limb-salvage was the most utilized surgical modality for both HGCS (76.5%) and DCS (74.3%). In regard to limb-salvage vs. amputation, there was no difference in survival at 1 year ( $p=0.10$ ) or 2 year ( $p=0.13$ ) between the groups, however those who underwent limb salvage procedure had a significantly improved survival at 5 years when compared to amputation ( $HR=1.49$  (1.11-1.99);  $p=0.002$ ). These results are shown in more detail in Table 1 and Figures 1-3.

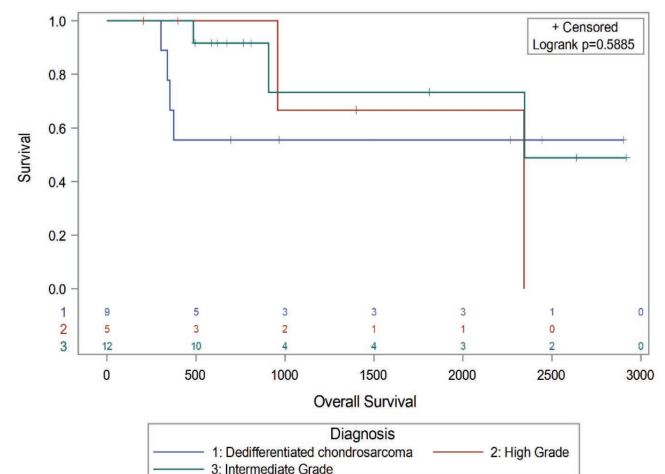
## DISCUSSION

Primary cartilaginous tumors are challenging to treat and require a multidisciplinary team comprised of radiologists, pathologists, and orthopaedic oncologists due to its varying morphology and behavior. High-grade chondrosarcoma remains a fatal disease in many patients, particularly if associated with dedifferentiated

**Table 1. Local Recurrence and Survival per Grade**

Subtype	Number	Local recurrence	Death within 1 year
Intermediate-grade	12	1	0
Wide	8	0	0
Marginal	0	0	0
Intralesional	3	1	0
High-grade	5	1	0
Wide	3	1	0
Marginal	1	0	0
Intralesional	1	0	0
Dedifferentiated	9	5	3
Wide	8	5	3
Marginal	1	0	0
Intralesional	0	0	0

Wide: R0, > 1 mm; Marginal: R0, < 1 mm; Intralesional: R2, R3.



**Figure 1. Product-Limit Survival Estimates. With Number of Subjects at Risk and 95% Hall-Wellner Bands.**

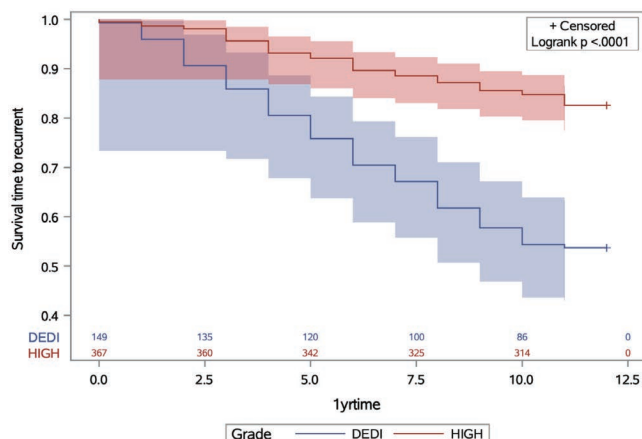


Figure 2. Product-Limit Survival Estimates. With Number of Subjects at Risk and 95% Hall-Wellner Bands.

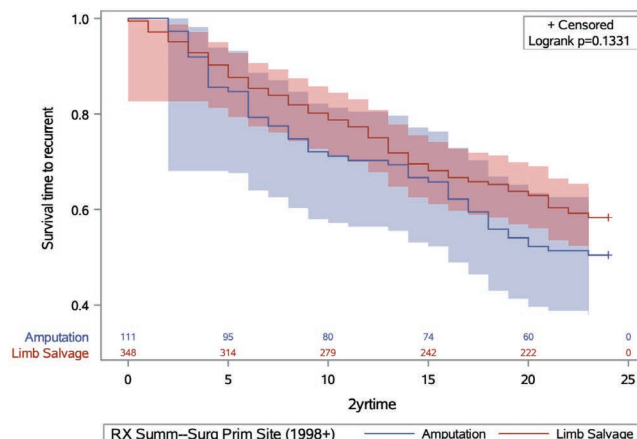


Figure 3. Product-Limit Survival Estimates. With Number of Subjects at Risk and 95% Hall-Wellner Bands.

subtype despite modern advancements in imaging, chemotherapy, and radiation treatment.<sup>1,6,7,11</sup> There is debate over the significance of prognostic indicators for high-grade chondrosarcoma and we aimed to further characterize outcomes based on some of these factors using cases from a single tertiary care center and from the SEER database. While studies have shown that both high grade chondrosarcoma and dedifferentiated chondrosarcoma have poor outcomes, we are unaware of any studies directly comparing grades 2 and 3 chondrosarcomas to dedifferentiated chondrosarcoma.<sup>1,6,12-16</sup> While ultimately the discovery of effective systemic therapy will change the treatment of high-grade chondrosarcomas, there may be factors that indicate improved outcomes. Interestingly, for the single center study 3/3 (100%) of the DCS patients who did not receive systemic therapy experienced local recurrence while only 2/6 (33%) that received systemic therapy experienced LR. Like other studies we found that local recurrence was a significant factor in mortality.<sup>16-18</sup> However, chemotherapy and radiation did not significantly increase survival.

Chemo/radiotherapy is controversial within chondrosarcoma treatment with studies showing conflicting results, but largely pointing towards no improvement in overall survival.<sup>3,13,19-22</sup> We found that chemo/radiotherapy had no effect on survival in all three groups. In this case series and large database study, HGCS had the smallest surgical margin, but with the longest time interval for both LR and death. Despite having the narrowest margins, only 1/5 HGCS patients had intralesional margins. The current literature suggests that wide margins decrease the risk for local recurrence for all grades of chondrosarcoma, which is a significant factor in mortality.<sup>7,17,23</sup> However, our case series did not find a difference in survival based solely on surgical margins.

Additionally, using the SEER database, DCS and amputation had worse prognosis at the 5-year survival time. While the data from the single center was unable to show a difference in survival between grades the larger cohort did show a significant difference between DCS and high-grade chondrosarcoma. This is likely explained by the larger cohort size providing a more powered analysis. This study confirms that high-grade chondrosarcoma is still a deadly disease and shows that DCS has decreased survival compared to other sub-types of chondrosarcoma even when high-grade which is shown to be a risk factor.<sup>4,13,14</sup>

In both the case series and SEER cohort we saw the majority of patients undergoing limb-salvage procedures with no evidence of decreased survival which confirms what other studies have found.<sup>7,24,25</sup> It is difficult to give an exact reason for the increase in survival seen at 5 years for patients undergoing limb-salvage versus amputation given the lack of information on patient demographics/comorbidities, tumor characteristics, and possible adjuvant treatment.

There are limitations to this study. The single center cohort was small and was not powered for a robust multivariate analysis of survival. We found this justified given the detail on tumor characteristics and individual treatment protocol. However, due to the lack of detail on cause of death in the chart review we analyzed all-cause mortality versus disease specific mortality. Regarding the SEER cohort, there are inherent limitations to using large databases. The SEER database does not provide detailed treatment information and is often missing data that limits statistical analysis. We were unable to assess whether patients underwent systemic treatment, and it is possible that it played a role in their outcomes. However, the lack of clear indications for the use of

systemic therapy offsets this limitation. Additionally, location of tumors is only roughly divided into small or large bones of the extremities and further details are not provided about the characteristics of the tumors or their location. Finally, the SEER database lacks information about surgical margins, local recurrence rates or patient comorbidities which could affect treatment decisions. We aimed to minimize many of these limitations by analyzing both cohorts.

### CONCLUSION

Further studies on valuable prognostic influences as well as earlier identification of this rare disease may help in developing better management options.

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# EFFECTS OF RADIOTHERAPY UPON BONE STRUCTURE-STRENGTH RELATIONSHIPS VARY WITH SEX AND FRACTIONATION OF DOSING

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## ABSTRACT

**Background:** Radiotherapy for tumor treatment in or near bones often causes osteopenia and/or osteoporosis, and the resulting increased bone fragility can lead to pathologic fractures. Bone mineral density (BMD) is often used to screen for fracture risk, but no conclusive relationship has been established between BMD and the microstructural/biomechanical changes in irradiated bone. Understanding the effects of radiation dosing regimen on the bone structure-strength relationship would improve the ability to reduce fracture-related complications resulting from cancer treatment.

**Methods:** Thirty-two C57B6J mice aged 10 – 12 weeks old were randomized to single dose (1 x 25 Gy) and fractionated dose (5 x 5 Gy) irradiation groups. Right hindlimbs were irradiated while the contralateral hindlimbs served as the non-irradiated control. Twelve weeks after irradiation, BMD and bone microstructure were assessed with micro-computed tomography, and mechanical strength/stiffness was assessed with a torsion test. The effects of radiation dosing regimen on bone microstructure and strength were assessed using ANOVA, and bone strength-structure relationships were investigated through correlation analysis of microstructural and mechanical parameters.

**Results:** Fractionated irradiation induced significantly greater losses in BMD in the femur (23% - male mice,  $p=0.016$ ; 19% - female mice) and the tibia (18% - male mice; 6% - female mice) than the single-dose radiation. The associated reductions in trabecular bone volume (-38%) and trabecular

number (-34% to -42%), and the increase in trabecular separation (23% to 29%) were only significant in the male mice with fractionated dosing. There was a significant reduction in fracture torque in the femurs of male ( $p=0.021$ ) and female ( $p=0.0017$ ) mice within the fractionated radiation group, but not in the single dose radiation groups. There was moderate correlation between bone microstructure and mechanical strength in the single-dose radiation group ( $r = 0.54$  to  $0.73$ ), but no correlation in the fractionated dosing group ( $r=0.02$  to  $0.03$ ).

**Conclusion:** Our data indicate more detrimental changes in bone microstructure and mechanical parameters in the fractionated irradiation group compared to the single dose group. This may suggest the potential for protecting bone if a needed therapeutic radiation dose can be delivered in a single session rather than administered in fractions.

**Keywords:** micro-computed tomography, torsion, radiotherapy, bone morphometry, fractionation, osteopenia

## INTRODUCTION

Focal radiation therapy is a technique commonly employed to treat metastatic tumors to bone and soft tissue tumors adjacent to bone. Radiotherapy can be used with curative intent in definitive treatment, as a neoadjuvant to sterilize the peripheral margin or shrink a tumor before surgery, or as an adjuvant to limit local recurrence.<sup>1</sup> Radiotherapy is also used to relieve tumor-related pain that is not controlled with pain medications or pain that is localized to smaller regions, like in bone metastases. Metastases to bone are common in the spine, pelvis, humerus, and femur and cause significant morbidity due to the combination of pain and risk of pathological fracture through the metastatic lesion. Radiotherapy has been proven to significantly palliate painful bone metastases in 50-80% of patients with up to one-third of patients achieving complete pain relief at the treated site<sup>2</sup> and a 68% overall pain response rate.<sup>3</sup>

Unfortunately, confounding the positive therapeutic aspects of radiation therapy is the common development of osteopenia and/or osteoporosis, which can increase risk of fracture.<sup>4</sup> Bone fragility fractures are a common

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late-onset complication that occur in bones within or underlying the radiation field.<sup>5</sup> Despite dose-limiting strategies developed to mitigate such side effects, the incidence of normal tissue injury and its subsequent complications tend to remain and even increase with time in cancer survivors. Post-radiotherapy complication rates are approximately 18%<sup>6</sup> overall but can range up to 45% for post-radiotherapy insufficiency fractures.<sup>7</sup>

Complication rates can be related to radiation dosage, which varies based on delivery method, treatment purpose, type of cancer, stage of cancer, spread, location, patient age, and patient health history.<sup>8</sup> The large radiation doses required for treatment are often delivered on a fractionated dosing schedule, which involves dividing the total desired dose into a series of smaller doses (fractions) delivered repeatedly over a specified time. For example, a typical fractionation dosage used for radiotherapy in curative treatment is 1.8 – 2 Gy per day over 6-8 weeks.<sup>9</sup> Fractionated radiotherapy exploits the differences in the repair capacities of tumor and normal tissues to maximize the therapeutic ratio, with the intention of reducing complications and increasing the rate of killing the tumor cells.<sup>9,10</sup> Fractionation also provides the opportunity to re-irradiate any tumor cells that were resistant during previous fractions. However, despite the benefits of fractionation, pathological fractures do still occur with a 5% incidence in fractionated radiotherapy-treated patients.<sup>11</sup> This is a clinical situation difficult to treat, often requiring multiple operative procedures and occasionally resulting in limb amputation. The persistence of pathological fracture in radiotherapy-treated patients has led to continuing investigation of the differential effects of fractionated and single dose treatment regimens on bone health.<sup>5,11-13</sup>

Bone strength is well known to be highly correlated to bone mineral density (BMD), and BMD is often used to screen for fracture risk.<sup>14</sup> However, BMD and several other bone parameters that correlate with bone strength for non-irradiated femurs have been found not to correlate with bone strength for irradiated femurs.<sup>5</sup> Furthermore, clinical studies of cancer survivors treated with radiotherapy have revealed no consistent relation between changes in bone mineral density and irradiation.<sup>15,16</sup> Such studies have shown significant increases<sup>16</sup>, decreases,<sup>17</sup> or no significant effect<sup>15,18</sup> of radiotherapy on BMD. Fractionation has also shown differential effects on bone. For example, Jia et al.<sup>6</sup> reported consistent 7.3% and 7.7% losses of BMD in mouse tibias and femurs, 14 days after a single 15 Gy radiation dose to the pelvic-abdominal cavity. However, in the fractionated group which was irradiated twice a day with 3 Gy for 7.5 consecutive days, there was a smaller 5.1% BMD loss in the tibia and a larger 13.8% BMD loss in the femur, 10 days after the

last radiation dose was administered. Many such studies are limited in their clinical applicability, as whole-body or torso radiation could introduce significant systemic effects that could influence bone density, and it is not reflective of the method of treating tumors in or near bones. Nevertheless, the inconsistencies in the effects of radiation dosing on BMD suggests a highly multifactorial response of irradiated bone that is likely due to wide variations in post-radiotherapy bone remodeling.<sup>5</sup>

A better understanding of the effect of specific aspects radiation therapy on the compositional, structural, and mechanical changes of bone may assist in developing strategies to mitigate the negative effects of radiation therapy in clinical settings.<sup>19</sup> The purpose of this study was to assess the effect of localized (non-systemic) single and fractionated radiation doses on bone strength, composition, and microstructure. We hypothesized that single high doses of radiation would result in greater loss of BMD, trabecular structure, and bone strength than a fractionated dosing regimen, but there would be little relationship between BMD and bone strength in either radiation dosing group.

## METHODS

Thirty-two C57B6J mice aged 10 – 12 weeks old were randomized to two different radiation study groups. Under IACUC-approved procedures, animals were sedated with an intraperitoneal injection of ketamine/xylazine and placed in a prone position inside protective lead boxes. The right hindlimbs were extended through a hole up to the hip and secured with adhesive (Figure 1). Depending on study group, the right hind limb



Figure 1. Protective lead shielding used to ensure only the right limb was irradiated during the study protocol.

was irradiated with one of two dosing regimens using a Pantak Therapax DXT 300 X-ray machine (200 kVp with added filtration of 0.35 mm copper and 1.5 mm aluminum). Group 1 (n=9 males; n=7 females) received a total radiation dose of 25 Gy (1×25 Gy) in a single session at a rate of 1.38 Gy/min (biological effective dose (BED) of 233.33 Gy). Group 2 (n=8 males; n=8 females) received a total 25 Gy in 5 Gy fractions delivered over a five-day period (5×5 Gy) (BED of 66.67 Gy). Animals recovered from sedation in isolation prior to returning to standard laboratory group housing conditions with up to 5 mice per enclosure. During the ensuing 12-week survival time, mice were housed on shavings and had free access to water and food. Animals were monitored daily by veterinary staff for overall health and by study team members for signs of radiation damage. A small number of animals that developed skin lesions at the radiation site were treated with topical ointment.

12 weeks post-irradiation, mice were euthanized, and both the irradiated and non-irradiated hind limbs were harvested for analysis. Superficial soft tissues were removed, leaving the periosteum intact. As freezing has been shown to not have any detrimental effect on the strength of the bone,<sup>20</sup> the femur and tibia were disarticulated, wrapped in saline-soaked gauze and frozen to -20°C in left/right pairs until subsequent micro-CT imaging and mechanical testing procedures.

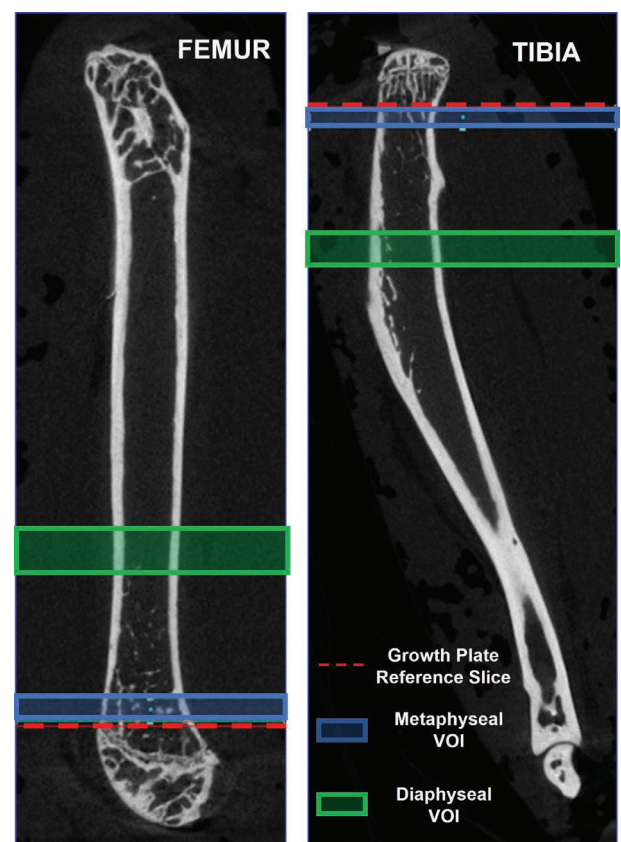
### Micro-CT Acquisition & Analysis

Changes in bone morphology associated with radiation dosing regimen were evaluated using micro-computed tomography (micro-CT). Ex vivo scans of the dissected tibias and femurs were performed using the Skyscan 1176 scanner (Bruker, Kontich, Belgium) at 8.85 µm isotropic resolution (0.3° rotation steps over 180° rotation and frame averaging on). Approximately one third of the specimens, spanning both radiation groups, were scanned using a 0.5 mm Al filter (50 kV, 500 µA, 980 ms exposure time). However, this filter was unavailable when the second group of specimens were harvested, and a 1.0 mm Al filter (65 kV, 385 µA, 1037 ms exposure time) was used for the remaining specimens. For scanning, specimens were thawed to room temperature, aligned with the vertical axis of the scanner, and scanned in airtight containers while wrapped in saline-soaked gauze. Two 2 mm-diameter phantom rods with known mass concentrations of calcium hydroxyapatite (0.25 g/cm<sup>3</sup> and 0.75 g/cm<sup>3</sup>) were included in each scan for calibrating bone mineral density (BMD) calculations. Scans were reconstructed in the associated SkyScan NRecon software (v.1.6.1.1), using a modified Feldkamp cone-beam algorithm. Image compensation settings were as follows: generalized Hamming filter ( $\alpha=0.54$ ), 20%

beam hardening correction, 6% ring artifact correction, attenuation range 0 – 0.08.

DataViewer software (v 1.5.6.2) was used to reorient the resulting image volumes in the axial, coronal, and sagittal planes into a standard orientation for analysis. A metaphyseal volume of interest was extracted for both the femur and tibia by defining a location 0.05 mm<sup>5</sup> away from the distal and proximal growth plate, respectively, and extending 0.5 mm into the metaphysis (Figure 2). A diaphyseal volume of interest was defined for each bone beginning from a location 3 mm proximal or distal to the growth plate reference and extending 1 mm into the mid-diaphysis<sup>19</sup> (Figure 2).

An automated segmentation algorithm (CTAn software, v.1.20.3.0, SkyScan, Belgium) was customized to separate the trabecular and cortical bone regions in the extracted diaphyseal and metaphyseal volumes of interest for automated densitometric, structural, and morphometric parameter quantification. A density threshold of 0.502 g/cm<sup>3</sup> was chosen to isolate bone tissue. This



**Figure 2.** Volume of interest delineation from re-oriented micro-CT images. Proximal is up in both images. The reference slice in the femur is selected as the proximal-most edge of the growth plate and that of the tibia is selected as the distal-most edge of the growth plate. The proximal-most and distal-most slices were defined as those locations within the 3D volume and did not change on each image in the volume.



threshold was based on sensitivity to our image acquisition and reconstruction parameters and fell between the  $0.35 \text{ g/cm}^3$ <sup>19</sup> and  $0.654 \text{ g/cm}^3$ <sup>5</sup> range reported in the literature for micro-CT evaluation of irradiated mouse bones. Greyscale thresholds corresponding to the density threshold value were selected using the BMD-TMD to signal relationship provided by the inclusion of the calibration phantoms at the time of scan acquisition. For specimens in which both phantoms were not visible for the generation of this relationship, we used a density/intensity relationship that was the average of those generated for all other specimens that were scanned on that same day. Despite filtering, we observed that images acquired using the 1.0 mm Al filter contained more imaging noise, which interfered with the contrast along bone edges and therefore altered the automated region of interest selection. This was addressed by reconstructing the images with a lower maximum attenuation coefficient (0 – 0.06 range) which improved contrast enough for segmentation (delineation of the boundary region of contours within the volume of interest selection). These boundary contours were then applied to the original 0.08 maximum attenuation coefficient reconstructed images for morphometric quantification. Prior to morphometric evaluation, a square kernel, 1 voxel radius Gaussian filter was applied to reduce the inherent signal noise in the reconstructed micro-CT data.<sup>21</sup>

Densitometric, structural, and morphometric analyses were performed according to standard procedures.<sup>21</sup> Bone mineral density (BMD) was quantified for the metaphyseal regions and tissue mineral density (TMD) was quantified for the diaphyseal regions. Trabecular morphological measurements calculated for this work were tissue volume (TV), bone volume (BV), percent bone volume (BV/TV), trabecular thickness (Tb.Th)/separation (Tb.Sp)/number (Tb.N) and total porosity (Tb.Po). Cortical morphological measurements included tissue volume, bone volume, bone surface (BS) area, bone surface to volume ratio (BS/BV), bone surface density (BS/TV), cross-sectional thickness (Cs.Th), cross-sectional tissue area (Cs.T.Ar), and cross-sectional bone area (Cs.B.Ar).

### Mechanical Testing

Biomechanical torsional testing was performed using an electromechanical testing machine (MTS Insight, MN, USA). To interface with the testing device, a 3-mm self-drilling k-wire was threaded through the proximal and distal end of each bone, and the ends of the bone were potted in 6 mm × 6 mm square brass tubes using polymethyl methacrylate (PMMA). Bones that broke during handling were discarded (n= 2). For testing, the potted bones were thawed to room temperature and

affixed to the mechanical testing device by sliding the proximal end of the potted bone into a mating square holder that was attached to a 23.7 mm diameter cylindrical drum. A wire connected the drum to a 10 N load cell mounted on the vertical actuator, which when moved vertically caused the drum to rotate counterclockwise and applied torsion to the bone. The other end of the bone was held stationary with a leveling system comprised of a horizontally oriented metal bar clamp. The clamping mechanism height could be adjusted with washers to account for any uneven potting and ensure rotation occurred around the central axis of the bone (Figure 3). The tests were performed beginning from a slightly slack cable condition and ran in displacement control with a rate of 0.222 mm/s. This extension rate and drum diameter corresponded to a 0.21 degrees per mm rate of twist. Testing was manually stopped after an abrupt drop in the measured load-displacement curve. The load-displacement curves were used to calculate fracture torque, rotation at fracture, torsional stiffness, energy absorption capacity prior to failure, shear modulus, and maximum shear stress.

To calculate the torsional behavior of each specimen, the bones were approximated as a bar of homogenous material with a prismatic cross-section. With this assumption, the torsional angle of twist ( $\theta$  in radians) can be described by the equation:  $\theta = TL/GJ$  where T is the applied torsional moment, L is the gauge length, J is the polar moment of inertia of the cross-section, and G is the shear modulus of the bone. The denominator GJ represents the effective torsional rigidity of the specimen and is representative of the slope of the linear region of the

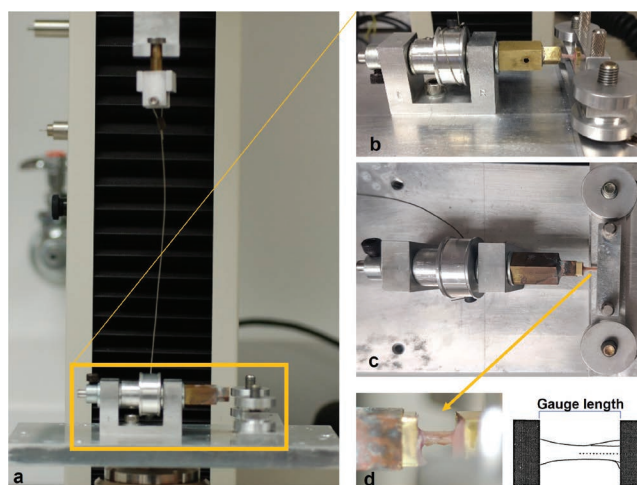


Figure 3a-d. Mechanical torsion testing setup. (3a) The cable connected to the vertical actuator to the rotating drum. (3b) Side view of a bone leveled horizontally and clamped for testing. (3c) Top-down view of a specimen positioned in the fixture for torsion testing. (3d) Zoomed-in side view of the bone positioned for testing (left) and schematic with the bone's central axis indicated (right).

torque-angle of twist curve. The polar moment of inertia,  $J$  was derived automatically by the CTAn software from a micro-CT image selected in the center of the diaphyseal region. Torsional stiffness was defined as the amount of torque per radian twist. The energy absorption capacity of the bones was defined as the area under the curve of the torque-angle of twist curve. Maximum shear stress,  $\tau$ , across the surface of the bones was calculated as  $\tau = Tr/J$ . The outer radius of the bone,  $r$ , was measured before torsional fracture tests using a digital caliper.

### Statistical Analysis

Results are presented as means  $\pm$  standard deviations. Percentage changes are reported as the difference between the irradiated and non-irradiated bones of a given animal relative to the non-irradiated value. 2-way ANOVA was used to assess the significance of differences in the bone morphometric parameters and mechanical strength data between the single and fractionated radiation dosing groups as well as between both sexes using the Graph-Pad Prism software. Significance was assumed when  $p < 0.05$ . Pearson correlation was used to determine the relationships between microstructural parameters and mechanical strength parameters independently for the single-dose and the fractionated dosing groups.

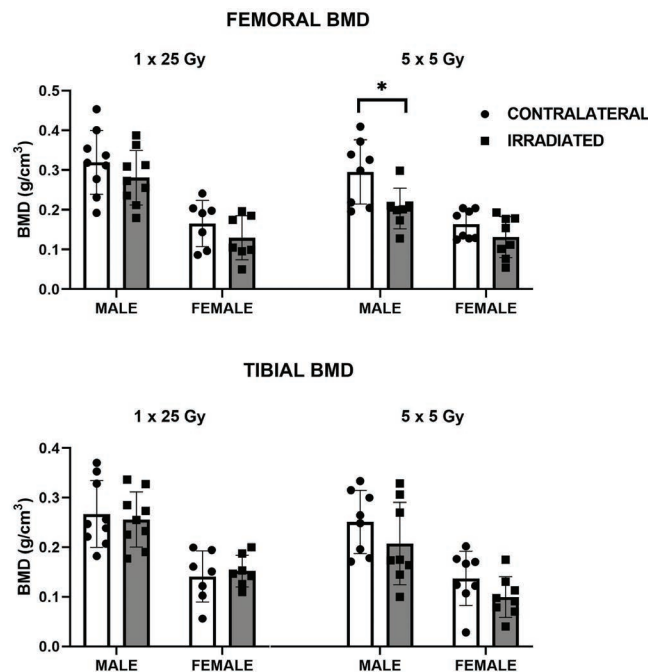


Figure 4. The differences in the effects of single dose (1  $\times$  25 Gy) and fractionated dosing (5  $\times$  5 Gy) on bone mineral density appeared to be sex related (\* $p=0.016$ ).

## RESULTS

### Bone Density

The BMD for the non-irradiated contralateral limbs in the female mice was significantly lower than that in the male mice for both the femur ( $p=0.0005$ ) and tibia ( $p=0.0004$ ). In both radiation dosing groups and in both male and female mice, the irradiated limb consistently had a lower bone mineral density (BMD) than the non-irradiated contralateral limb, however this trend only reached statistical significance ( $p=0.016$ ) in the femurs of the male mice in the fractionated dose group (Figure 4) with a 23% loss of BMD. Tissue mineral density (TMD) changes paralleled BMD changes, with a similar reduction of the TMD after radiation in all groups, but only reaching statistical significance ( $p=0.047$ ) in the femurs of the male fractionated group.

### Bone Microstructure

In both the femur/tibia of male mice, there was a significant decrease in trabecular bone volume (-38% / -39%;  $p=0.0003$  /  $0.0014$ ), significant increase in trabecular separation (+23% / +29%;  $p=0.028$  /  $0.001$ ),

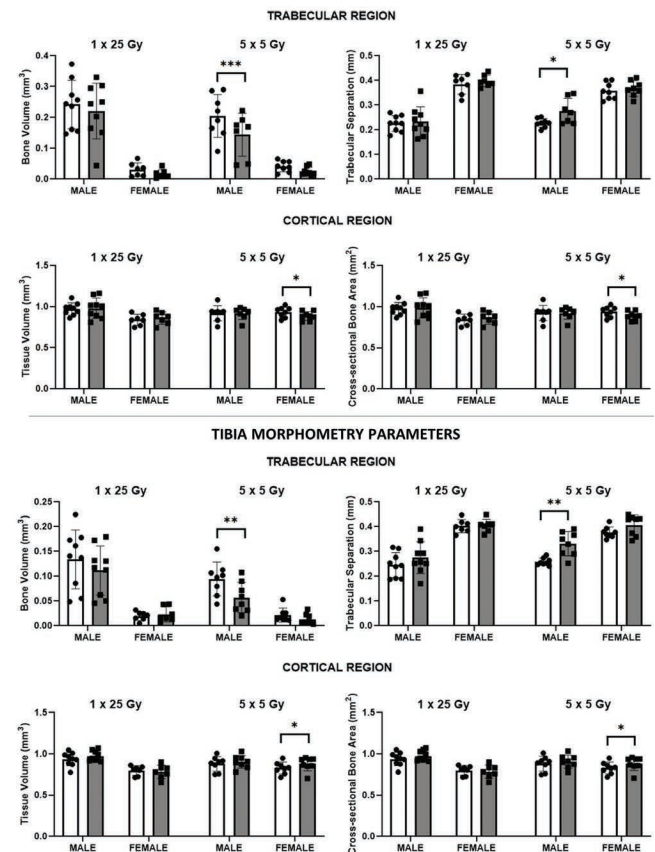


Figure 5. Femur Morphometry Parameters. Selected trabecular and cortical bone morphometric parameters demonstrated sex-related effects of single (1  $\times$  25 Gy) and fractionated (5  $\times$  5 Gy) dose on bone microstructure. \* $p < 0.05$ , \*\* $p < 0.01$ , \*\*\* $p < 0.001$ .

**Table 1. Statistical Significance of Radiation Effects on Bone Microstructure and Mechanical Parameters**

Bone Parameter		FEMUR				TIBIA			
		MALE		FEMALE		MALE		FEMALE	
		1×25Gy	5×5Gy	1×25Gy	5×5Gy	1×25Gy	5×5Gy	1×25Gy	5×5Gy
TRABECULAR REGION	BMD		↓*						
	TV								
	BV		↓***				↓**		
	BV/TV		↓**				↓**		
	Tb.Th								
	Tb.Sp		↑*				↑***		
	Tb.N		↓**				↓***		
	Tb.Po		↑***				↑***		
CORTICAL REGION MORPHOMETRY	TMD		↓*						
	TV				↓*				↑*
	BV				↓*				↑*
	BS/BV								↓**
	BS/TV								↓**
	Tb.Th			↑*					↑****
	Tb.N								↓****
	BS								
	Cs.T.Ar				↓*				↑*
	Cs.B.Ar				↓*				↑*
	Cs.Th			↑*					↑*
MECHANICAL PARAMETERS	Tq		↓*		↓**				
	EAC	↓**	↓***		↓****				
	TR								
	TS								
	SM								↑*
	MSS				↓*				↑**

For mechanical parameters: Tq= torque, EAC = energy absorption capacity, TR= torsional rigidity, TS = torsional stiffness, SM = shear modulus, MSS = maximum shear stress. Statistically significant change \*p<0.05, \*\*p<0.01, \*\*\*p<0.001, \*\*\*\*p<0.0001. ↑increase, ↓decrease.

and a significant decrease in trabecular number (-34% / -42%; p= 0.002 / 0.0001) in the irradiated limbs of the fractionated group compared to their non-irradiated contralateral limb (Figure 5). While similar trabecular microstructure changes were measured for the irradiated limbs of female mice in both radiation dosing regimens, as well as the male mice within the single radiation dose group, these changes were not statistically significant.

In the cortical regions, the most noticeable changes in bone morphometry were in the female mice that received fractionated radiation (Table 1). Interestingly, in

the cortical regions, significant decreases in quantities such as tissue volume associated with radiation paralleled those found in the trabecular bone, but only for the femur. In contrast, there were significant increases in tissue volume in the tibia of female mice with fractionated radiation (Figure 5).

### Mechanical Strength & Stiffness

As would be expected from a torsion test, specimens mostly exhibited spiral fractures at failure (Figure 6). While there were some changes in bone mechanics

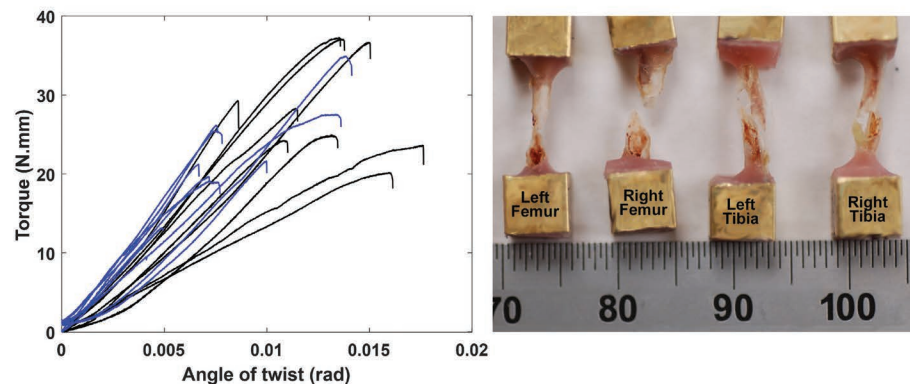


Figure 6. Torque-angle of twist curves measured for irradiated (blue) and contralateral (black) femurs from the single dose ( $1 \times 25$  Gy) irradiation group (left). This composite plot illustrates the consistency in the slopes of the linear regions of the curves, and the general stiffening that was associated with radiation. The wide range in torsional stiffness and failure torque of the non-irradiated group was decreased with radiation. Composites from tibia tests and tests of the fractionated dosing groups were similarly clustered. Typical spiral fracture patterns resulting from the torsion test are shown for the femur and for the tibia (right). The ruler is showing units of millimeters.

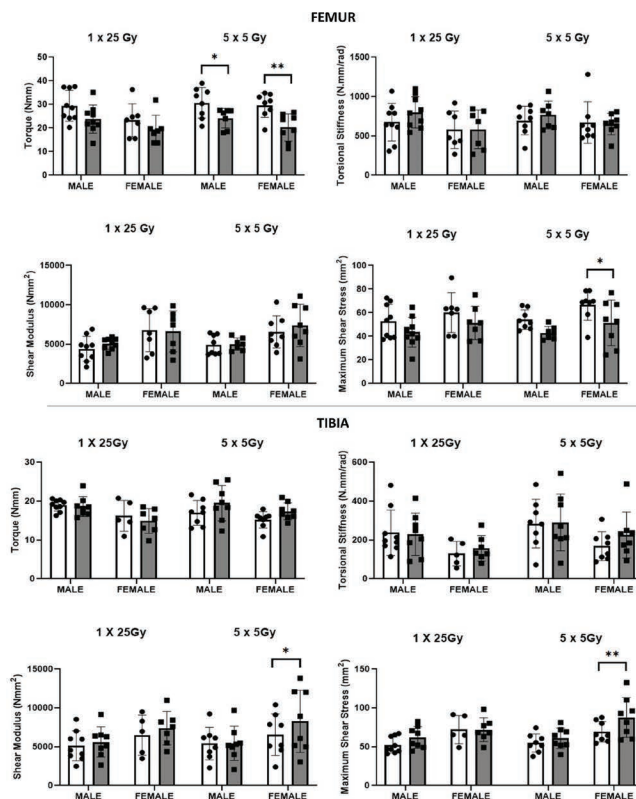


Figure 7. Selected mechanical parameters showed the effects of single ( $1 \times 25$  Gy) and fractionated ( $5 \times 5$  Gy) dose were sex-related and varied by bone. \* $p < 0.05$ , \*\* $p < 0.01$ .

among the males in the single radiation group, the vast majority of the significant differences in mechanical parameters were in the fractionated dosing group (Table 1). There was a significant reduction in the torque at fracture in the femurs of both male ( $p=0.021$ ) and female ( $p=0.002$ ) mice within the fractionated radiation group (Figure 7), however, no significant change in failure torque was measured for the tibia. Irradiated bones generally had increased torsional stiffness (were stiffer) as compared to non-irradiated bones, however, the differences were not statistically significant in either dosage groups or between the sexes (Table 1). There was a significant decrease ( $p=0.020$ ) in maximum shear stress in the femur of the female mice for the fractionated group. Like what was found in the cortical morphometry metrics for these mice, the opposite trend was found in the irradiated tibia. Specifically, there was a significant increase ( $p=0.003$ ) in the maximum shear stress of the tibia among the female mice within the fractionated dosing group.

### Bone Morphology-Strength Relationship

Overall, there were few strong relationships found between the BMD, morphological parameters, and mechanical strength of the bones. For the single dose radiation group, trabecular and cortical bone volumes of the femur were only modestly positively associated with torsional stiffness ( $r=0.57, 0.54$ ). Cortical cross-sectional bone and tissue area were also moderately positively associated with torsional stiffness in the femur ( $r=0.54, 0.54$ ). Trabecular thickness was negatively associated with maximum shear stress for both the femur ( $r=-0.61$ ) and the tibia ( $r=-0.53$ ). In contrast, in the fractionated



dosing group, even the modest associations between microstructural parameters and mechanical measures disappeared. The femurs in the fractionated group showed no association between the trabecular and cortical bone volumes with torsional stiffness ( $r=0.34$ ,  $0.27$ ), no association between the cortical cross-sectional bone and tissue area with torsional stiffness ( $r=0.27$ ,  $0.27$ ) and further, no association between trabecular thickness and maximum shear stress ( $r=-0.13$ ).

This trend was repeated for all the correlations that were explored. There was a good correlation of fracture torque with BMD ( $r=0.73$ ) in tibia of the single radiation group. However, for the fractionated group, there was no correlation ( $r=0.15$ ). Torque at fracture for the tibia within the single radiation dose group was moderately associated with bone volume ( $r=0.55$ ), trabecular separation ( $r=-0.51$ ) and total porosity ( $r=-0.53$ ). Again, the fractionated group showed no association between torque at fracture with bone volume ( $r=0.14$ ), trabecular separation ( $r=-0.02$ ) and total porosity ( $r=-0.10$ ).

## DISCUSSION

In this study, we confirmed local irradiation decreased trabecular bone mineral density and altered several components of bone microstructure. Loss of bone mineral density was pronounced in trabecular regions, with the most significant BMD decreases in the irradiated femurs of male mice. This trend did not reach statistical significance in the female mice, which could be attributed to the fact that the baseline trabecular BMD in the female mice was significantly lower than that of their male counterparts. The mechanical strength of the bones was also reduced by radiation, and the increase in torsional stiffness suggests embrittlement of the bone tissue. While the sex-related differences in irradiation effects were reversed in the cortical bone, with more detrimental effects found in the cortical regions in the female mice, the fractionated dosing consistently had a more pronounced effect than the single radiation dose.

Overall, our findings suggest that a single dose irradiation has less detrimental effects to the microstructure and mechanical strength of the bone than the fractionated dosage regimen. This may imply that reductions in the morbidity, i.e., fractures associated with radiation treatment, can be achieved with further refinement of patient radiotherapy fractionation schedules. A systematic review and meta-analysis of 25 randomized controlled trials of palliative radiotherapy,<sup>22</sup> compared single versus fractionated routines, finding overall response rates for intention-to-treat patients were 60% (from 2818 pooled randomizations) for single radiation dose treatment (8 Gy) and 61% (from 2799 pooled randomizations) for the fractionated treatment (30 Gy/10 fractions, 20 Gy/5 frac-

tions and 40 Gy/20 fractions). There was no significant difference in the overall response rate for pain between the dose fractionation schedules. Building on those findings, work by Bedard, et al.<sup>23</sup> reports equivalent pain relief outcomes between single and multiple fraction regimens and proposes adoption of single dose regimens for treatment of painful bone metastases. Single fraction treatment has also been proposed to optimize patient and caregiver convenience as well for cost-effectiveness (\$1099 vs \$2322).<sup>24</sup> As fractionation schedules become more varied for different malignancies, these results suggest that bone may be one tissue that will benefit from fewer fractions.

We elected to test our murine bones to failure using a torsion test rather than the often reported three-point bending and four-point bending tests. This approach was selected because the 15.3 to 16.7 mm lengths of our mouse bones were substantially shorter than the majority of reported rodent bone studies, which are performed in rat bones with lengths ranging from 34 to 46 mm.<sup>25</sup> Within those published studies, the fixed span and orientation of the bone within the testing setup influenced fracture pattern, stress distribution, and force-displacement relationships.<sup>25,26</sup> As the achievable fixed gauge length possible with the shorter mouse bones is significantly smaller than the 15 mm minimum used in rat studies,<sup>25</sup> a torsion test was utilized. The torque moment exerted in a torsional loading is the same in every section of the specimen along its entire length, and therefore, the result from the torsional test is less sensitive to experimental errors associated with directional alignment of the bones. Furthermore, torsion is a highly clinically relevant form of fracture failure.<sup>27</sup>

This study had several limitations that may have impacted the findings. First, the micro-CT images of the bones were scanned with two different scanner settings due to one of the filters being non-operational at the necessary post-euthanasia timepoint. While we were able to carefully adjust our analysis protocol to achieve equivalent segmentation edges and bone mineral density information, we cannot rule out systematically different bone morphometry data between batches that would slightly modify the relationship between morphometric measures and mechanical strength. Secondly, we did not perform limb loading analysis on these animals, which means that we cannot evaluate to what extent some of the osteoporosis identified was a result of changes in loading of the irradiated limb. However, during regular observation, no lameness was noted, and activity levels remained the same between groups. Another limitation of this work is the large difference in biological effective dose (BEDs) between groups. This was a result of choosing easily scalable fractions for delivery, rather than

hitting any specific therapeutic target. Nevertheless, the single dose BED (233.33 Gy) was higher than the fractionated dosing scheme (66.67 Gy) but resulted in fewer changes to the bone. Inclusion of a dosing scheme using the equivalent dose in 2 Gy fractions (EQD<sub>2</sub>) of the 5 x 5 Gy scheme (EQD<sub>2</sub>: 20 x 2 Gy) and direct comparison between the two could also shed light on the effect of increased fractionation on bone tissue. Finally, the very short gauge length available for testing after potting was further reduced for a few specimens which broke at the ends during k-wires drilling. Rather than discarding the specimen, when possible, the fractured end was disposed of, and the remainder potted, which in effect reduced the gauge length. Specimens that fractured during handling had to be discarded, effectively reducing our already relatively small sample size.

One other factor that cannot be ignored is the potential of a systemic reaction of the mice to the irradiation, which could cause changes to the bone in the non-irradiated contralateral limb. This is particularly important as results were assessed as left-to-right changes in microstructural and mechanical parameters. In a previous study,<sup>28</sup> it was found that in addition to the local effects at a localized site of irradiation (2 Gy), there was a 17% decrease in bone volume of the contralateral tibia relative to that of the tibia of non-irradiated control mice. These changes in the contralateral limb were accompanied by changes in associated microstructural parameters including increased trabecular separation and reduced trabecular thickness.<sup>28</sup> Similar work has found<sup>5</sup> significant loss of bending strength in the contralateral femurs of locally irradiated mice. This consideration of the systemic effects of irradiation is relevant as clinical studies have also reported systemic osteopenia in radiation-treated cancer patients.<sup>29,30</sup> This systemic effect would suggest that reporting our results relative to the non-irradiated contralateral would underestimate the impact of the radiation treatment on the irradiated limb. Nevertheless, changes in irradiated bone in this study parallel previously reported values in the range of 22% and 14% reductions in trabecular bone volume in the irradiated tibia and femur or decreases in trabecular number and increase in trabecular spacing/separation in the irradiated tibia (-16%/+20%) and femur (-13%/+16%).<sup>28</sup>

Recent advances to improve therapeutic ratio have introduced modified fractionation strategies including hyperfractionation and hypofractionation.<sup>10</sup> Hyperfractionation involves prolongation of treatment through delivery of radiation in small-dose fractions (2-3 times per day) with the advantage of avoiding acute reactions and allowing adequate reoxygenation in tumors. However, this approach does not spare late injury and may in fact allow the repopulation of tumor cells during treatment.<sup>31</sup>

In contrast hypofractionation involves the acceleration of treatment through delivery of smaller number of radiation fractions but with an increased dose per fraction. For example, breast cancers can be treated in three weeks (40 Gy in 15 fractions) as compared to the standard five weeks (50 Gy in 25 fractions).<sup>32</sup> In a systematic review,<sup>33</sup> it was shown that patients undergoing hypofractionation had a significantly reduced incidence of skin toxicity and no significant differences in the survival rates and tumor reoccurrences compared to standard fractionation. Our results also seem to support the concept of hypofractionation, as a single high dose of radiation resulted in less detrimental effects to the bone compared to a similar total dose delivered in smaller fractions. Optimal methods for delivering therapeutic radiation will continue to evolve, however, our findings would suggest that all other considerations being equal, the approach that utilizes the smallest number of fractions could be more protective of long-term bone strength.

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# INCREASED NUMBER OF MEDICAL COMORBIDITIES ASSOCIATED WITH INCREASED RISK OF PRESENTING WITH PATHOLOGICAL FEMUR FRACTURE IN METASTATIC BONE DISEASE

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## ABSTRACT

**Background:** Many cancers metastasize to bone and may lead to pathologic fracture or impending pathologic fracture. Prophylactically stabilizing bones before fracture has been shown to be more cost-effective with improved outcomes. Many studies have examined risk factors for pathological fracture, with radiographic and functional pain data serving as predominant indicators for surgery. Conditions associated with poor bone health and increased risk of fracture in the non-oncologic population, including diabetes mellitus, chronic obstructive pulmonary disease (COPD), cardiovascular disease, renal disease, smoking, corticosteroid use, and osteoporosis, have not been studied in the context of metastatic disease. Characterization of these factors could help providers identify candidates for prophylactic stabilization thereby reducing the number of completed pathological fractures.

**Methods:** 298 patients over the age of 40 with metastatic bone disease of the femur treated between 2010-2021 were retrospectively identified. Patients without complete medical documentation or with non-metastatic diagnoses were excluded. 186 patients met inclusion and exclusion criteria, including 74 patients who presented with pathological femur fracture and 112 patients who presented for prophylactic stabilization. Patient demographics and comorbidities including diabetes mellitus, COPD, cardiovascular disease, renal disease, osteoporosis, active tobacco or corticosteroid use, and use of anti-resorptive therapy were collected. Descriptive statistics were compiled, with univariable analysis by Mann-Whitney or chi-squared testing. Multiple logistic regression was then performed to identify the most significant

patient variables for presenting with completed fracture.

**Results:** On univariable analysis, patients with COPD were more likely to present with pathologic fracture (19/32 [59%] compared to 55/154 [36%],  $p = 0.02$ ). A trend emerged for patients with an increasing number of comorbidities (28/55 [51%] for 2+ comorbidities compared to 18/61 [29%] with zero comorbidities,  $p = 0.06$ ). On multivariable analysis, patients with two or more comorbidities (OR: 2.49;  $p=0.02$ ) were more likely to present with a femur fracture.

**Conclusion:** This analysis suggests that those with an increasing number of comorbidities may be at increased risk for pathologic fracture. This study raises the possibility that patient factors and/or comorbidities alter bone strength and/or pain experiences and may guide orthopaedic oncologists weighing prophylactic stabilization of femur lesions.

**Level of Evidence:** III

**Keywords:** pathologic fracture, metastatic bone disease, impending fracture

## INTRODUCTION

Many cancers metastasize to bone and lead to completed pathologic fracture or impending pathologic fracture. Determining whether to prophylactically surgically stabilize cancer patients with metastatic bone lesions or treat them conservatively through radiation, chemotherapy, or lifestyle modification therapy has been extensively studied.<sup>1</sup> Completed pathological fracture is associated with increased mortality in cancer patients, with estimated one year survival rates as low as 22-40% following a hospitalization due to fracture.<sup>2</sup> Prophylactically stabilizing bones before fracture has been shown to be more cost-effective with improved patient outcomes.<sup>3,4</sup> Given the recognition of improved patient outcomes and cost effectiveness of prophylactic stabilization, the identification of cancer patients who are likely to fracture has become increasingly important.

Many studies have examined risk factors for pathologic fracture and identified radiographic findings and patient perception of functional pain as predominant indicators for surgery.<sup>5</sup> These indicators are not all-encompassing nor are they associated with a strong

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**Table 1. Preoperative Characteristics and Comorbidities in Patients Presenting for Prophylactic Stabilization of Impending Pathologic Fractures, Compared to Those Presenting with Completed Pathologic Fracture**

	Prophylactic Stabilization (N=116)	Completed Fracture (N=77)	p value
Age (years)			
Mean (SD)	64.9 (10.7)	65.7 (12.0)	0.566
Sex			
Male	60 (53.6%)	32 (43.2%)	0.219
Female	52 (46.4%)	42 (56.8%)	
Body mass index (BMI)			
Mean (SD)	30.3 (15.7)	30.3 (8.99)	0.468
Chronic obstructive pulmonary disease (COPD)			
No	99 (88.4%)	55 (74.3%)	0.0220
Yes	13 (11.6%)	19 (25.7%)	
Smoker			
No	87 (77.7%)	60 (81.1%)	0.708
Yes	25 (22.3%)	14 (18.9%)	
Cardiovascular disease			
No	92 (82.1%)	55 (74.3%)	0.272
Yes	20 (17.9%)	19 (25.7%)	
Diabetes			
No	88 (78.6%)	52 (70.3%)	0.266
Yes	24 (21.4%)	22 (29.7%)	

	Prophylactic Stabilization (N=116)	Completed Fracture (N=77)	p value
End stage renal disease (ESRD)			
No	110 (98.2%)	70 (94.6%)	0.217
Yes	2 (1.8%)	4 (5.4%)	
Osteoporosis			
No	110 (98.2%)	71 (95.9%)	0.388
Yes	2 (1.8%)	3 (4.1%)	
Steroid use			
No	90 (80.4%)	56 (75.7%)	0.563
Yes	22 (19.6%)	18 (24.3%)	
Number of comorbidities			
0	43 (38.4%)	18 (24.3%)	0.062
1	42 (37.5%)	28 (37.8%)	
2+	27 (24.1%)	28 (37.8%)	
Bisphosphonate use			
No	104 (92.9%)	73 (98.6%)	0.0889
Yes	8 (7.1%)	1 (1.4%)	
Denosumab use			
No	111 (99.1%)	74 (100%)	1.00
Yes	1 (0.9%)	0 (0%)	

p-value less than 0.05 is significant.

predictive value. Furthermore, much of the identification and characterization of these risk factors are subjective data points such as the patient's perceived pain or degree of cortical bone involvement rather than reproducible and objective measures. Given the relative subjectiveness and limited scope of these fracture risk indicators, identification of more objective risk factors could supplement the surgeon's clinical decision making. Common medical comorbidities that impact bone health have been extensively characterized in the context of the non-oncological population but have not been assessed in cancer patients with metastatic bone disease.

Common conditions that have been associated with poor bone health and increased risk of fracture in the non-oncologic population include gender, diabetes mellitus, chronic obstructive pulmonary disease (COPD), cardiovascular disease, renal disease, smoking, corticosteroid use, and osteoporosis.<sup>6-12</sup> However, these factors have not been studied in the context of metastatic bone disease. Thorough investigation of these risk factors could help providers identify candidates for prophylac-

tic stabilization thereby reducing the number of completed pathological fractures and ultimate cancer related morbidity. Therefore, the objective of this study is to characterize the risk of fracture in cancer patients with identifiable comorbid conditions and disease.

## METHODS

### Study Design

This is a retrospective cohort study using an institutional electronic medical record data source. Given the lack of direct patient interaction and minimal risk, this study was deemed to be exempt by an institutional review board.

### Study Population

298 patients over the age of 40 with confirmed metastatic bone disease involving the femur and treated at an urban academic institution between 2010-2021 were retrospectively identified by CPT codes (27187, 27235, 27236, 27244, 27245, 27495, 27506, 27507, 27511). The presence of metastatic disease of the femur was then

**Table 2. Biopsy Confirmed Metastatic Disease Cancer Histology of Patients who Presented with Completed Pathological Fracture vs. Prophylactic Fixation**

Histology	Completed Fracture	Prophylactic Fixation	Total
B-Cell Lymphoma	5(6.7%)	3(2.7%)	8(4.3%)
Breast Carcinoma	18(24.3%)	15(13.4%)	33(17.7%)
Breast Spindle Cell Sarcoma	1(1.4%)	1(0.9%)	2(1.1%)
Breast Phyllodes Fibrosarcoma	0(0%)	1(0.9%)	1(0.5%)
Colonic Adenocarcinoma	0(0%)	3(2.7%)	2(1.1%)
Esophageal Carcinoma	2(2.7%)	2(1.8%)	4(2.2%)
Gastric Carcinoma	0(0%)	1(0.9%)	1(0.5%)
Lung Carcinoma	10(13.4%)	23(20.4%)	33(17.7%)
Melanoma	3(4.0%)	5(4.4%)	8 (4.3%)
Multiple Myeloma	15(20.2%)	25(22.3%)	40(21.5%)
Pancreatic Adenocarcinoma	0(0%)	2(1.8%)	2(1.1%)
Pheochromocytoma	0(0%)	1(0.9%)	1(0.5%)
Neuroendocrine- Poorly Differentiated	1(1.4%)	1(0.9%)	2(1.1%)
Carcinoma- Poorly Differentiated	1(1.4%)	3(2.7%)	3(1.6%)
Prostate Adenocarcinoma	5(6.8%)	4(3.5%)	8 (4.3%)
Renal Cell Carcinoma	11(14.9%)	14(12.5%)	25(13.4%)
Thyroid Carcinoma	1(1.4%)	4(3.5%)	4(2.2%)
Unknown Histology	0(0%)	1(0.9%)	1(0.5%)
Urothelial Carcinoma	1(1.4%)	4(3.5%)	5(2.7%)
TOTAL	74	112	186

Percentages rounded to nearest tenth.

confirmed. Patients were then assigned one of two cohorts; those who presented with completed pathological fracture (fracture cohort) and those who were prophylactically stabilized (prophylactic cohort). Patients without complete medical documentation or with non-metastatic diagnoses were excluded. Given this study analyzes the risk factors prior to presentation, no minimum post-operative follow-up was required. 186 patients met our inclusion and exclusion criteria, including 74 patients who presented with completed pathological femur fractures and 112 patients who presented for prophylactic stabilization. Decision for prophylactic fixation due to high risk of fracture was judged by the treating surgeon primarily based on presence or absence of functional pain, but also considered factors such as location, size, and internal characteristics of the lesions, as well as patient preference.

#### Data Collected

Patient factors extracted from the medical record included: age at surgery, gender, date of surgery, cancer histology, and clinical diagnoses of particular interest, in-

cluding diabetes mellitus, COPD, cardiovascular disease (including diagnoses of either coronary artery disease or peripheral arterial/vascular disease), osteoporosis, active tobacco or corticosteroid use (use within the preceding 3 months to fracture or fixation), and end-stage renal disease (ESRD; CKD Stage IV, GFR< 15ml/min, or use of hemodialysis). All diagnoses that were documented within three months pre-operatively were considered comorbidities and recorded. Use of bone-modifying agents such as Bisphosphonates or RANK-L inhibitor use within three months preoperatively were also recorded. Using anesthesia records from the date of service, patient weight and height were also collected to calculate body mass index (BMI).

#### Statistical Analysis

Descriptive statistics were compiled and univariable analysis performed by Mann-Whitney or chi-squared testing. A multivariable logistic regression analysis was performed after stepwise backward selection to identify the most significant patient variables for presenting with completed fracture. Statistical analyses were performed

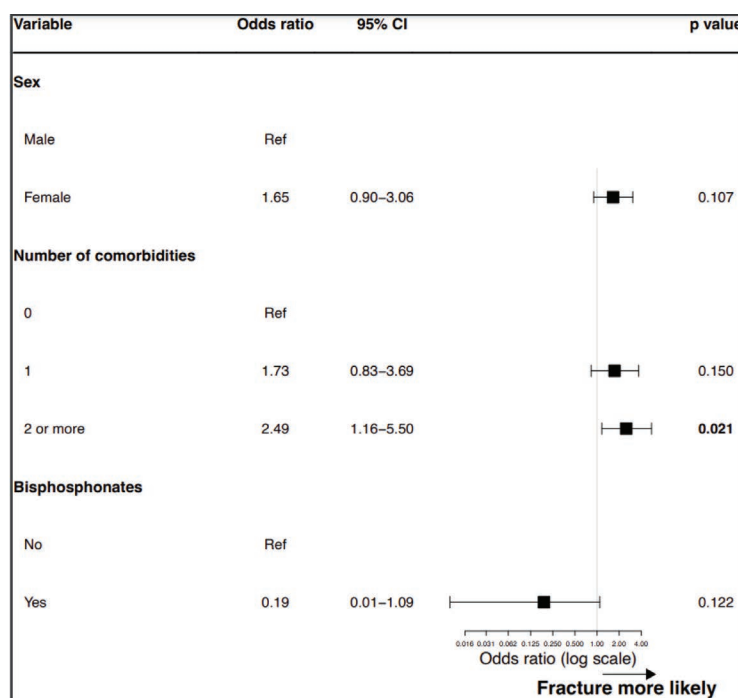


Figure 1. Logistic regression analysis after stepwise backward selection of factors associated with fracture on presentation. Unstandardized odds ratios are displayed on a logarithmic scale with 95% confidence intervals. CI indicates confidence interval. p-value less than 0.05 is significant.

with the package DescTools in R (R Foundation; <https://www.r-project.org/>). Data were visualized in R with packages ggplot2 and forestplot. All statistical testing was two-sided, with a p value less than 0.05 considered significant.

## RESULTS

Out of 298 patients, 186 met our study criteria. The mean age was  $64.9 \pm 10.6$  years for the prophylactic fixation, and  $65.7 \pm 12.0$  years for the completed pathological fracture cohort. 94 female patients were included, of which 55.3% were prophylactically stabilized and 44.7% presented with a fracture. 92 male patients were included of which 65.2% were prophylactically stabilized, with 34.8% completing a pathological fracture. The most common histologies include multiple myeloma (40 patients), breast carcinoma (33), lung carcinoma (33), and renal cell carcinoma (25). Descriptive statistics on comorbidity and medication use between groups is shown in Table 1. Patient cancer histology is shown in Table 2.

On univariable analysis, patients with COPD were more likely to present with pathologic fracture (19/32 [59%] compared to 55/154 [36%],  $p = 0.02$ ). There was also a trend for patients with an increasing number of comorbidities overall to present with pathological fracture 28/55 [51%] for 2+ comorbidities compared to 18/61 [29%] with 0 comorbidities, ( $p=0.06$ ). On multivariable lo-

gistic regression analysis (Figure 1), patients with female sex (odds ratio [OR]: 1.65; 95% confidence interval [CI]: 0.9-3.06;  $p=0.106$ ) trended towards increased fracture risk while those patients with or two or more comorbidities (OR: 2.49; 95% CI: 1.16-5.50;  $p=0.02$ ) were more likely to present with a completed femur fracture. Bisphosphonate use trended towards a lower likelihood of presenting with a pathological fracture but did not reach statistical significance (OR: 0.19; 95% CI: 0.01-1.09;  $p=0.122$ ).

## DISCUSSION

The goal of this study was to assess comorbidities commonly associated fracture in cancer patients with completed or impending pathologic fracture. Comorbidities associated with increased fracture risk in the non-oncologic population were studied. Female patients trended towards increased fracture risk while patients with at least two comorbidities were associated with increased fracture risk at presentation in this study.

The presence of metastatic bone disease is a negative prognostic marker for cancer patients, with the completion of a pathological fracture also being associated with worse survival.<sup>13-17</sup> Prophylactic fixation may prevent a patient from completing a pathological fracture, therapy reducing morbidity and costs. Still, it is essential to identify the patients that are most at risk of fracturing in order to avoid unnecessary surgical interventions in low fracture

risk patients.<sup>18,19</sup> Identification of prophylactic fixation candidates has traditionally relied on radiographic indices and subjective patient pain.<sup>20</sup> Mirel's risk stratification system, first developed in 1980's, relies upon cortical bone involvement, lesion location, and perceived pain by the patient. These criteria, however, have been shown to exhibit low sensitivity and specificity in predicting pathologic fracture occurrence.<sup>21</sup> Furthermore, these criteria fail to incorporate more comprehensive medical data, such as medical co-morbidities that are commonly associated with increased fracture risks and worsening bone health.

Our study identified common medical conditions that have previously been implicated in poor bone health. We found that COPD was the only medical comorbidity independently associated with fracture. Kulak et. al.<sup>22</sup> previously suggested this could be due in part to a decrease in trabecular bone density resulting from decreased collagen cross-linking that is observed in females with COPD. Although corticosteroid use was not noted to be a significant risk factor for fracture, it is important to note that use was only assessed within the preceding 3 months prior to fixation or fracture. Patients with COPD are more likely to undergo repeated oral steroid courses in addition to potential long term inhaled corticosteroid usage. This may suggest that the increased fracture risk seen in the COPD cohort may be compounded by the prevalence of corticosteroid treatments. Kulak et. al also implicated diabetes as a contributor to decreased collagen cross-linking in female patients at higher risk for bone fragility. Notably, in our study, diabetes was not associated with completed fracture by itself with the numbers available, though diabetes was more prevalent in the fractured group. A multivariable logistic regression analysis showed that increasing number of comorbidities were associated with increased risk of presenting with a completed pathologic fracture of the femur. This suggests that the presence of multiple conditions known to alter bone quality may be a risk factor for completing a pathological fracture. Additionally, the incidence of completed fracture in the female cohort approached significance. Interestingly, breast carcinoma was the only histological cohort with more than 10 patients that exhibited more fractures than prophylactic stabilizations (54.5% vs. 45.4%). Given the association between females who have undergone menopause and increased fracture risk, further characterization of the role of hormonal therapies and fracture incidence may yield further insight into this observed trend.

Several trends were noted with specific comorbidities and antiresorptive therapies, but this analysis was likely underpowered to evaluate this comprehensively. Although not statistically significant, antiresorptive

therapies likely would show decreased fracture rates in a higher-powered sample. This study did not account for socioeconomic differences that may predispose to both comorbidities and access to care before fracture. To aid in the feasibility and economy of this study, the metastatic disease characterized was limited to the femur. However, the axial skeleton and upper extremity are also common sites of metastatic disease and fracture. These anatomical sites necessitate further study to improve the generalizability of these findings. Future studies are needed, using larger patient cohorts and additional sites of metastatic bone disease to adequately address the question raised by and determine the potential role of estrogen deprivation in contributing to fracture risk in cancer patients.

Despite these limitations, this study raises the possibility that patient factors and/or comorbidities alter bone strength and/or pain experiences that may mislead orthopaedic oncologists weighing prophylactic stabilization of femur lesions in the setting of metastatic bone disease. The risk factors we assessed such as diabetes, tobacco use, corticosteroid use, and ESRD,<sup>23-27</sup> are associated with increased fracture risk in the non-oncologic population. However, none of these comorbidities were significant sole risk factors for fracture in our sample. This suggests that the presence of 2 or more of these comorbid conditions may increase the risk of fracture in metastatic bone disease of the femur. Mirel's criteria and similar risk strata such as Harrington's criteria do not account for the impact of non-oncologic factors on bone health. Together, the findings of this study may supplement existing prophylactic stabilization criteria to guide decision making in metastatic bone disease of the femur. Future studies examining the risk of pathologic fracture should include such patient factors and/or comorbidities in their analyses.

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# ORTHOPEDIC MANIFESTATIONS OF HEREDITARY SENSORY AND AUTONOMIC NEUROPATHY IV IN A 10-YEAR-OLD PATIENT

James Kohler, MD<sup>1</sup>; Rory Metcalf, MD<sup>1</sup>; Heather Kowalski, MD<sup>1</sup>

## ABSTRACT

**Hereditary sensory and autonomic neuropathy type IV (HSAN) is a rare and debilitating disorder highlighted by congenital absence of pain and anhidrosis. Orthopedic sequelae include physeal fractures, Charcot joint development, excessive joint laxity, soft tissue infections and recurrent painless dislocations, all of which often present in a delayed fashion. While there is no accepted guideline on management of these patients, several case studies have highlighted the importance of early diagnosis and cautioned against surgical intervention in these patients due to their inability to perceive pain and comply with post-operative restriction. The purpose of this case report is to present the clinical course of a patient with HSAN IV and the unique orthopedic challenges it presented. While some of her orthopedic injuries healed appropriately following treatment, others have gone on to have devastating complications and progressive joint destruction.**

**Level of Evidence: IV**

**Keywords: pediatric, neuropathy, charcot, HSAN**

## INTRODUCTION

Hereditary sensory and autonomic neuropathy type IV (HSAN), also known as congenital indifference to pain with anhidrosis (CIPA), is a rare and incompletely understood diagnosis.<sup>1,4</sup> At the molecular level, HSAN is caused by mutations in the nerve growth factor receptor tyrosine kinase 1 (NTRK1) which leads to abnormal peripheral nerve formation and function.<sup>5</sup> At the clinical level, HSAN IV is associated with complete absence of pain response to noxious stimuli and inability to thermoregulate, which is the etiology of its wide spectrum of clinical manifestations.<sup>6,7</sup> Precise incidence of this condition is not well known, with existing literature limited to small case series and case reports only.

Diagnosis of HSAN IV is difficult in the early years of life, as these patients can be otherwise developmentally normal without other congenital anomalies.<sup>1,4</sup> Early signs of HSAN IV may include oral/buccal trauma from repetitive biting or onychophagia with resultant self-mutilation.<sup>1,8</sup> Secondary to anhidrosis and impaired thermoregulation, patients may also present with recurrent hyperthermia or febrile seizures at a young age.<sup>9,11</sup>

As HSAN IV patients age and increase their activity level with ambulation, orthopedic manifestations become apparent.<sup>12-18</sup> Painless limb swelling may reveal diaphyseal fractures and painless joint swelling may reveal significant physeal injuries or early Charcot changes. Early recognition of orthopedic injuries in HSAN IV patients is paramount to prevent further damage to the extremity.

We report a case here of a 10-year-old child with HSAN IV whose orthopedic manifestations included recurrent hip dislocations, proximal patellar sleeve fracture, proximal humerus physeal fracture, distal radius physeal injury, and bilateral Charcot ankle. Her treatment remains exceedingly difficult and has presented unique complications.

## CASE REPORT

The patient, a Caucasian female, was initially diagnosed at 18 months with HSAN IV after presenting with febrile seizures and painless recurrent left hip dislocations. Genetic and neurologic evaluation at that time confirmed the diagnosis, with heterozygosity for L213P mutation and partial deletion of the NTRK1 gene. For her hip dislocations, she underwent a period of intermittent hip abduction bracing over the course of two years and then was not seen again by our pediatric orthopedic team until she was 6 years old.

At age 6 the patient returned to our orthopedic clinic for evaluation of a left proximal patellar sleeve fracture, having already undergone attempted ORIF at an outside hospital which was complicated by hardware failure and wound healing issues with underlying deep infection. She developed recurrent knee effusions and an incompetent extensor mechanism. Ultimately, she underwent proximal pole of the patella excision and primary repair of her quadriceps tendon with prolonged non-weightbearing and immobilization. Once allowed to mobilize, it was noted that her patella tracked in a laterally dislocated

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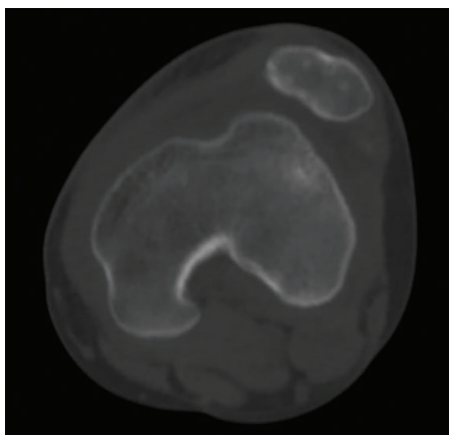


Figure 1. Axial CT scan demonstrating a laterally subluxated patella following quad tendon repair.

position throughout range of motion (Figure 1), albeit without any pain or functional limitation to the patient. Family preference was to avoid further surgery to this knee and defer patellar stabilization surgery given she had returned to functional ambulation. She eventually underwent lateral retinacular release and medial imbrication approximately 3 years later in efforts to improve her patellar tracking.

At age 7, painless effusions were noted of the patient's bilateral ankles. Radiographs and MRI demonstrated evidence of early degenerative changes and chronic ligamentous injuries, suggestive of excessive joint laxity and early Charcot changes (Figure 2). Joint aspirates in clinic were performed to ensure no underlying infection which all returned negative. Patient was fitted with solid ankle bilateral AFOs with attempts to maintain joint alignment to prevent further collapse and degeneration of her foot and ankle.

Patient was seen again at age 8, when she presented to our emergency department with 2-week history of left shoulder redness, swelling and difficulty with range of motion. Radiographs demonstrated a displaced Salter

Harris 1 proximal humerus fracture. There was no reported preceding trauma and patient was in no pain. Given her young age and concern about potential complications with pin fixation with her HSAN IV diagnosis, decision was made to pursue non-operative management with sling immobilization. She was followed closely over the next 18 months. An attempt at callus formation and healing was noted at her 4 week and 8 week follow up radiographs, however by 6 months there was noted to be continued motion across her physis with progressive metaphyseal resorption noted at 20 months post initial presentation (Figure 3).

Painless right wrist swelling was noted in clinic at age 9, which correlated with a chronic appearing distal radius physeal injury and associated longitudinal growth disturbance as noted by positive ulnar variance (Figure 4). She underwent distal ulna epiphysiodesis to prevent further angular deformity of the wrist with pinning of the distal radius.

At most recent follow up examination patient was 10 years old and had severely limited use of her left arm, with active forward flexion of 30 degrees and abduction to 30 degrees. An MRI was obtained at that point to better evaluate bone stock for possible surgical fixation but there was noted to be approximately 6 cm bone defect of the proximal humerus (Figure 5). For this reason, fixation efforts were deferred and continued conservative cares were chosen. Regarding her ankles, she was ambulatory with the use of AFOs. Her left knee had good range of motion, but her patella was noted to dislocate laterally when flexed beyond 45 degrees. Her right distal radius was healing but with continued positive ulnar variance not causing functional difficulty.

## DISCUSSION

Hereditary sensory and autonomic neuropathy has subtypes, with HSAN IV representing the rarest form of HSANs. HSAN IV is an autosomal recessive disease characterized by recurrent episodic fever, anhidrosis, absence of reaction to noxious stimuli, self-mutilating

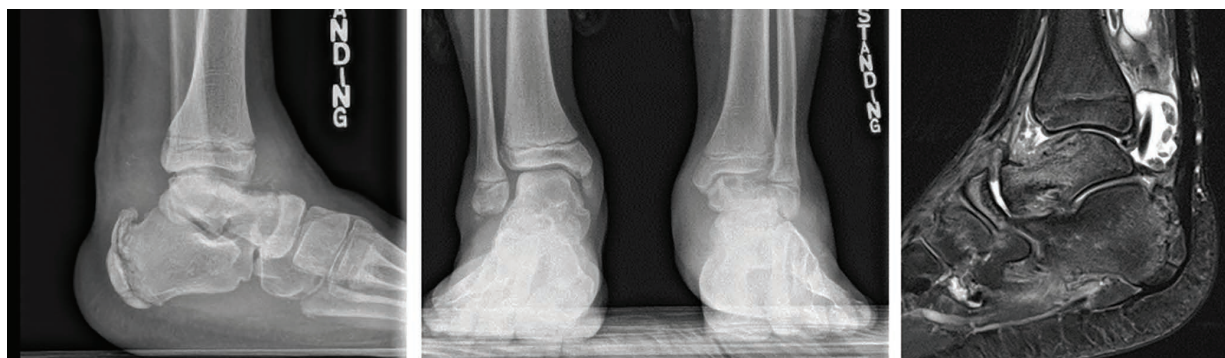
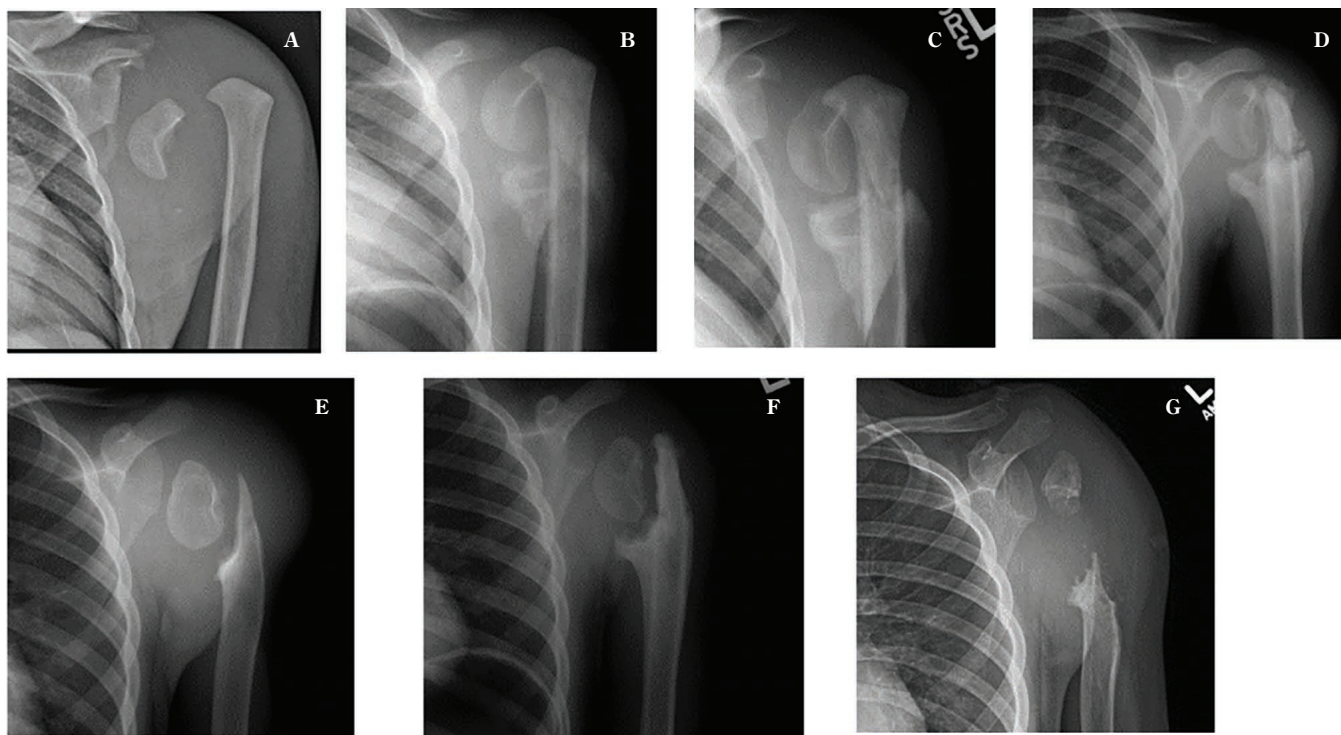
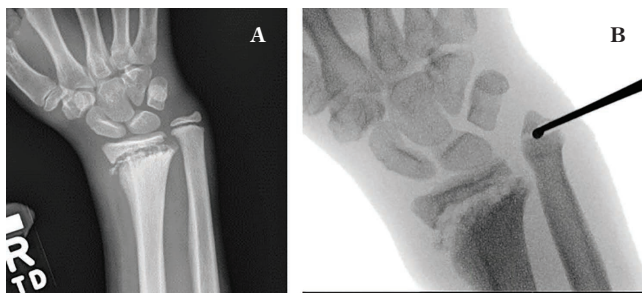


Figure 2. Ankle XRs and T2 weighted sagittal MRI highlighting talar collapse and early Charcot changes.

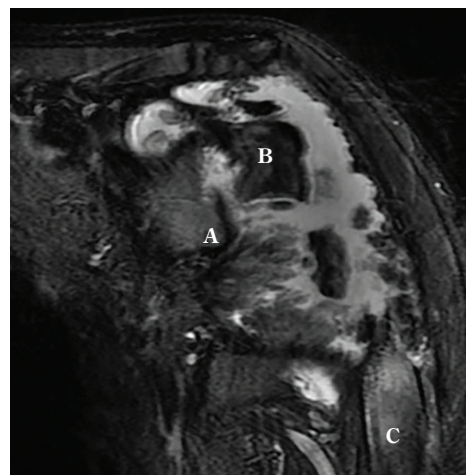


**Figure 3.** Left shoulder XRs at injury (A), 4 weeks (B), 8 weeks (C), 3 months (D), 6 months (E), 1 year (F) and 18 months (G), demonstrating attempted healing but ultimate nonunion with significant bone loss after proximal humerus physeal injury.



**Figure 4.** Wrist XRs (A) showing distal radius physeal injury with significant ulnar positivity that underwent distal ulna epiphysiodesis (B).

behavior, and often cognitive delay.<sup>14</sup> At the genetic level, the etiology of HSAN IV is a loss of function mutation in the NTRK1 gene located on chromosome 1 (1q21-q22).<sup>5</sup> Defects in this signaling pathway lead to apoptosis of various NGF dependent neurons during development. On the molecular level, electron microscopic studies of the radial and sural nerves of HSAN IV patients have shown a reduction in number or complete absence of small myelinated and unmyelinated fibers with very few Schwann cells present.<sup>19</sup> Examination of the skin of these patients reveals a lack of sympathetic innervation of the eccrine sweat glands, which manifests as anhidrosis. Immunohistochemistry studies of the skin reveals



**Figure 5.** Coronal T2 weighted left shoulder MRI showing large area of metaphyseal bone loss between residual epiphysis (B) and diaphysis (C). Glenoid (A).

absent C and A-delta fibers in the skin, which parallels the findings of electron microscopy.

Here we present a patient with HSAN IV, with both confirmatory genetic and molecular studies. Her orthopedic manifestations included painless dislocations, physeal injuries and Charcot joint development, all of which are known orthopedic sequela of HSAN.<sup>12-18</sup> Her



orthopedic care was exceedingly difficult and presented unique challenges secondary to her insensitivity to pain.

As with our patient, some HSAN IV patients have limited neurocognitive involvement with an otherwise normal intelligence and healthy appearing child.<sup>3,4</sup> Special scrutiny needs to be made to rule out non-accidental injury in these cases, as patients may have relatively unexplained injuries due to their absence of pain and recollection of the injury timing.

Repetitive microtrauma to insensate articular surfaces is known to cause progressive articular collapse and deformity as first described by Charcot.<sup>4,20</sup> This same principle applies to our patient and others with HSAN. The inability to respond to pain is compounded by the child's young age and inability to modify activities once an injury is identified on imaging. This makes Charcot joint prevention exceedingly difficult in HSAN patients and relies heavily upon vigilant parents and close monitoring. There must also be high suspicion for concomitant pyogenic arthritis, with sterile aspirates needed to rule out infection. Treatment of Charcot joints in HSAN IV patients is much like adult Charcot treatment: stabilization, and prevention of additional joint deterioration.<sup>21,22</sup> Conservative treatment using air cast boots, wheelers, and custom-walking boots is recommended to achieve this. Casts must be adequately padded, and skin integrity must be diligently monitored to prevent skin ulcers.

HSAN IV patients are also known to have abnormal gait kinematics which is thought to lead to abnormal joint laxity and contact stresses,<sup>4</sup> which certainly contributed to our patient's chronic patella dislocation and Charcot joint progression. Behavioral monitoring with gait and postural training can be helpful in preventing undue stress on the developing limbs and spine.

Surgical treatment for orthopedic injuries in HSAN patients must be approached with caution, as post-operative immobilization and activity restrictions can be exceedingly difficult in these children. Further, an increased incidence of infection, non-union, hardware complications, wound healing complications, and avascular necrosis following surgery has been reported.<sup>12-18</sup> Previous studies suggest K-wire fixation may not be sufficient in this cohort,<sup>14</sup> as patients lack the pain reflex that aids in immobilization. Rigid external or intermedullary fixation is recommended if fracture non-union persists. When surgery is indicated, close post-operative wound monitoring and radiographic follow up is essential. Furthermore, general anesthesia can lead to increased risk of autonomic dysfunction in this cohort so special monitoring may be required.<sup>23</sup>

HSAN IV presents difficult and unique challenges for treating orthopedic surgeons. This case highlights the variety of orthopedic presentations seen in HSAN IV,

including physeal injuries, wound healing complications, and Charcot joint. Parent education and fracture prevention techniques are paramount when treating these patients. Operative treatment remains difficult given the congenital absence of pain and ability to comply with post-operative immobilization.

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# INCREASED INCIDENCE OF UPPER EXTREMITY SOFT TISSUE INJURIES AND ORTHOPAEDIC SURGERIES IN PATIENTS WITH EATING DISORDERS

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## ABSTRACT

**Background:** Despite an established increased fracture risk in eating disorder patients, no studies, to our knowledge, have investigated the association between eating disorders and upper extremity soft tissue injury or surgery incidence. Given the association of eating disorders with nutritional deficiency and musculoskeletal sequelae, we hypothesized that patients with eating disorders would have an increased risk of soft tissue injury and surgery. The aim of this study was to elucidate this link and investigate if these incidences are increased in patients with eating disorders.

**Methods:** Cohorts of patients with anorexia nervosa or bulimia nervosa, identified using International Classification of Diseases (ICD) -9 and -10 codes, were identified in a large national claims database over 2010-2021. Control groups without these respective diagnoses were constructed, matched by age, sex, Charlson Comorbidity Index, record date, and geographical region. Upper extremity soft tissue injuries were identified using ICD-9 and -10 codes and surgeries using Current Procedural Terminology codes. Differences in incidence were analyzed using chi-square tests.

**Results:** Patients with anorexia and bulimia were significantly more likely to sustain a shoulder sprain (RR=1.77; RR=2.01, respectively), rotator cuff tear (RR=1.39; RR=1.62), elbow sprain (RR=1.85; RR=1.95), hand/wrist sprain (RR=1.73; RR=16.0), hand/wrist ligament rupture (RR=3.33; RR=1.85), any upper extremity sprain (RR=1.72; RR=1.85), or any upper extremity tendon rupture (RR=1.41; RR=1.65). Patients with bulimia were also more likely to sustain any upper extremity ligament rupture (RR=2.88). Patients with anorexia

and bulimia were significantly more likely to undergo SLAP repair (RR=2.37; RR=2.03, respectively), rotator cuff repair (RR=1.77; RR=2.10), biceps tenodesis (RR=2.73; RR=2.58), any shoulder surgery (RR=2.02; RR=2.25), hand tendon repair (RR=2.09; RR=2.12), any hand surgery (RR=2.14; RR=2.22), or any hand/wrist surgery (RR=1.87; RR=2.06).

**Conclusion:** Eating disorders are associated with an increased incidence of numerous upper extremity soft tissue injuries and orthopaedic surgeries. Further work should be undertaken to elucidate the drivers of this increased risk.

**Level of Evidence:** III

**Keywords:** eating disorder, female athlete, shoulder, elbow, hand

## INTRODUCTION

Eating disorders are a group of psychological conditions defined by disturbances in eating behaviors and body image. Anorexia nervosa and bulimia nervosa affect an estimated 0.6% and 2.0% of the United States population, respectively.<sup>1,2</sup> These conditions are particularly prevalent in young female athletes, with studies estimating prevalence rates of anywhere from 13% to 62% depending on factors such as the sport's emphasis on aesthetics.<sup>3,5</sup> Although often associated with young females, eating disorders also impact men, and in particular male athletes. However, studies have proposed that these symptoms are often not recognized in men.<sup>6,8</sup> As these conditions are highly prevalent in athletes, patients with bulimia and anorexia frequently sustain sports injuries. Consequently, it is crucial to understand the sequelae of eating disorder diagnoses in the context of sports injuries and orthopaedic surgeries.

Studies have shown that patients with psychological comorbidities experience poorer outcomes after various orthopaedic surgeries.<sup>9,16</sup> However, these studies have not focused on or even included eating disorders. It is established that anorexia nervosa increases fracture risk, most commonly attributed to reduced bone mineral density in this population.<sup>17-25</sup> This increased fracture risk is not seen in patients with bulimia nervosa. The discrepancy is thought to be because bulimia patients do not experience the same reduction in bone mineral density

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as patients with anorexia nervosa.<sup>26-28</sup> Additionally, eating disorders are frequently associated with electrolyte imbalance and nutritional deficiency,<sup>29,30</sup> and this state of malnutrition may contribute to reduced joint integrity, increasing the risk for injury.<sup>31</sup> Some studies have also shown that risk of injury broadly, including fractures, is increased in individuals with eating disorders.<sup>4,32-36</sup> However, it is unclear if the increased injury risk was driven primarily by fractures, soft tissue injuries, or a combination.

No studies, to our knowledge, have investigated the association between eating disorders and risk of soft tissue injuries or surgeries. Therefore, the purpose of this study is to assess the association between incidence of upper extremity soft tissue injuries and orthopaedic surgeries in patients with eating disorders. Based on the established increased risk for fractures and poor outcomes after orthopaedic surgeries, we hypothesized that individuals with eating disorders would have a greater incidence of soft tissue injuries and subsequent surgeries than matched controls.

## METHODS

### Data Source

The data used in this study were retrieved from the PearlDiver Mariner Patient Claims Database (PearlDiver Technologies, Colorado Springs, CO, USA), a large national insurance claims database which contains Health Insurance Portability and Accountability Act (HIPAA) compliant medical and prescription data. The Mariner subset of the PearlDiver database contains a total volume of over 151 million patients, with records dating from January 1, 2010 to April 30, 2021. The diagnostic and procedural information within this database is derived from International Classification of Diseases Ninth Revision (ICD-9), Tenth Revision (ICD-10), and Current Procedural Terminology (CPT) codes. The database uses unique patient identifiers which allows longitudinal tracking of data.

### Patient Population

Patients with a diagnosis of anorexia nervosa (ICD-9-D-3071, ICD-10-D-F5000, ICD-10-D-F5001, ICD-10-D-F5002) or bulimia nervosa (ICD-9-D-30751, ICD-10-D-F502) were identified using ICD-9 and -10 codes. Using these patients, two experimental cohorts were created: 1) patients diagnosed with anorexia nervosa, and 2) patients diagnosed with bulimia nervosa. Respective control groups were created which contained patients without a diagnosis of anorexia nervosa or bulimia nervosa, respectively, which were matched to the anorexia nervosa and bulimia nervosa cohorts, respectively, by age, sex, Charlson Comorbidity Index (CCI), record dates,

and geographical region. All ages were included in the analysis, including children and adolescents. States are defined as belonging to one of four geographic locations in the PearlDiver database: Northeast, South, Midwest, and West. While we included this variable so that our cohorts were as closely matched as possible, we have not been able to find any studies showing that geographic location affects eating disorders and orthopaedic injuries.

### Outcomes of Interest

Instances of upper extremity soft tissue injuries were identified through ICD-9 and ICD-10 codes within the time period of 2010-2021. Injuries investigated included shoulder sprain, shoulder strain, rotator cuff tear, shoulder tendon rupture, upper arm tendon rupture, forearm tendon rupture, elbow sprain, elbow ligament rupture, hand tendon rupture, hand/wrist sprain, and hand/wrist ligament rupture. Instances of upper extremity soft tissue orthopaedic surgery procedures in these patients were identified through Current Procedural Terminology (CPT) codes within the time period of 2010-2021. Procedures investigated included superior labrum anterior to posterior (SLAP) repair, rotator cuff repair, biceps tenodesis, elbow tendon repair, elbow ligament repair, wrist tendon repair, hand tendon repair, and hand ligament repair. The specific ICD and CPT codes used to define these outcomes of interest are reported in Supplementary Table 1.

### Statistical Analysis

The rates of upper extremity soft tissue injuries and orthopaedic surgeries among all cohorts were retrieved. Univariate chi-squared analysis was used to analyze differences between matched cohorts using a p-value of <0.05 as the threshold of significance. The anorexia nervosa and bulimia nervosa experimental cohorts were exclusively compared to their respective matched control groups. The raw data on these rates was organized and presented with corresponding risk ratios and 95% confidence intervals for each outcome of interest.

## RESULTS

### Patient Characteristics

The anorexia nervosa cohort and its matched control group contained a total of 46,422 patients each (83.3% female). The bulimia nervosa cohort and its matched control group contained a total of 37,242 patients each (89.8% female). There was an equal distribution of patient age, sex, CCI, geographical region, and record dates in each matched pair. A breakdown of patient characteristics within the matched cohorts is presented in Table 1.

**Supplementary Table 1. ICD and CPT Codes Used to Define Upper Extremity Soft Tissue Injuries and Surgeries**

Outcome	ICD or CPT Code(s)
Shoulder Sprain	ICD-9-D-8400, ICD-9-D-8401, ICD-9-D-8402, ICD-9-D-8403, ICD-9-D-8404, ICD-9-D-8405, ICD-9-D-8406, ICD-9-D-8407, ICD-9-D-8408, ICD-9-D-8409, ICD-10-D-S43401A, ICD-10-D-S43402A, ICD-10-D-S43409A, ICD-10-D-S43411A, ICD-10-D-S43412A, ICD-10-D-S43419A, ICD-10-D-S43421A, ICD-10-D-S43422A, ICD-10-D-S43429A, ICD-10-D-S43431A, ICD-10-D-S43432A, ICD-10-D-S43439A, ICD-10-D-S43491A, ICD-10-D-S43492A, ICD-10-D-S43499A, ICD-10-D-S4350XA, ICD-10-D-S4351XA, ICD-10-D-S4352XA, ICD-10-D-S4360XA, ICD-10-D-S4361XA, ICD-10-D-S4362XA, ICD-10-D-S4380XA, ICD-10-D-S4381XA, ICD-10-D-S4382XA, ICD-10-D-S4390XA, ICD-10-D-S4391XA, ICD-10-D-S4392XA
Shoulder Strain	ICD-10-D-S46011A, ICD-10-D-S46012A, ICD-10-D-S46019A, ICD-10-D-S46111A, ICD-10-D-S46112A, ICD-10-D-S46119A, ICD-10-D-S46211A, ICD-10-D-S46212A, ICD-10-D-S46219A, ICD-10-D-S46311A, ICD-10-D-S46312A, ICD-10-D-S46319A, ICD-10-D-S46811A, ICD-10-D-S46812A, ICD-10-D-S46819A, ICD-10-D-S46911A, ICD-10-D-S46912A, ICD-10-D-S46919A
Rotator Cuff Tear	ICD-9-D-72761, ICD-9-D-72613, ICD-10-D-M75100, ICD-10-D-M75101, ICD-10-D-M75102, ICD-10-D-M75110, ICD-10-D-M75111, ICD-10-D-M75112, ICD-10-D-M75120, ICD-10-D-M75121, ICD-10-D-M75122
Shoulder Tendon Rupture	ICD-10-D-M66211, ICD-10-D-M66212, ICD-10-D-M66219, ICD-10-D-M66311, ICD-10-D-M66312, ICD-10-D-M66319, ICD-10-D-M66811, ICD-10-D-M66812, ICD-10-D-M66819
Upper Arm Tendon Rupture	ICD-10-D-M66221, ICD-10-D-M66222, ICD-10-D-M66229, ICD-10-D-M66321, ICD-10-D-M66322, ICD-10-D-M66329, ICD-10-D-M66821, ICD-10-D-M66822, ICD-10-D-M66829
Forearm Tendon Rupture	ICD-10-D-M66231, ICD-10-D-M66232, ICD-10-D-M66239, ICD-10-D-M66331, ICD-10-D-M66332, ICD-10-D-M66339, ICD-10-D-M66831, ICD-10-D-M66832, ICD-10-D-M66839
Elbow Sprain	ICD-9-D-8410, ICD-9-D-8411, ICD-9-D-8412, ICD-9-D-8413, ICD-9-D-8148, ICD-9-D-8419, ICD-10-D-S53401A, ICD-10-D-S53402A, ICD-10-D-S53409A, ICD-10-D-S53411A, ICD-10-D-S53412A, ICD-10-D-S53419A, ICD-10-D-S53421A, ICD-10-D-S53422A, ICD-10-D-S53429A, ICD-10-D-S53431A, ICD-10-D-S53432A, ICD-10-D-S53439A, ICD-10-D-S53441A, ICD-10-D-S53442A, ICD-10-D-S53449A, ICD-10-D-S53491A, ICD-10-D-S53492A, ICD-10-D-S53499A
Elbow Ligament Rupture	ICD-10-D-S5320XA, ICD-10-D-S5321XA, ICD-10-D-S5322XA, ICD-10-D-S5330XA, ICD-10-D-S5331XA, ICD-10-D-S5332XA
Hand Tendon Rupture	ICD-10-D-M66241, ICD-10-D-M66242, ICD-10-D-M66249, ICD-10-D-M66341, ICD-10-D-M66342, ICD-10-D-M66349, ICD-10-D-M66841, ICD-10-D-M66842, ICD-10-D-M66849
Hand/Wrist Sprain	ICD-9-D-84210, ICD-9-D-84211, ICD-9-D-84212, ICD-9-D-84213, ICD-9-D-84219, ICD-9-D-84200, ICD-9-D-84201, ICD-9-D-84202, ICD-9-D-84209, ICD-10-D-S63501A, ICD-10-D-S63502A, ICD-10-D-S63509A, ICD-10-D-S63511A, ICD-10-D-S63512A, ICD-10-D-S63519A, ICD-10-D-S63521A, ICD-10-D-S63522A, ICD-10-D-S63529A, ICD-10-D-S63591A, ICD-10-D-S63592A, ICD-10-D-S63599A, ICD-10-D-S63601A, ICD-10-D-S63602A, ICD-10-D-S63609A, ICD-10-D-S63610A, ICD-10-D-S63611A, ICD-10-D-S63612A, ICD-10-D-S63613A, ICD-10-D-S63614A, ICD-10-D-S63615A, ICD-10-D-S63616A, ICD-10-D-S63617A, ICD-10-D-S63618A, ICD-10-D-S63619A, ICD-10-D-S63621A, ICD-10-D-S63622A, ICD-10-D-S63629A, ICD-10-D-S63630A, ICD-10-D-S63631A, ICD-10-D-S63632A, ICD-10-D-S63633A, ICD-10-D-S63634A, ICD-10-D-S63635A, ICD-10-D-S63636A, ICD-10-D-S63637A, ICD-10-D-S63638A, ICD-10-D-S63639A, ICD-10-D-S63641A, ICD-10-D-S63642A, ICD-10-D-S63649A, ICD-10-D-S63650A, ICD-10-D-S63651A, ICD-10-D-S63652A, ICD-10-D-S63653A, ICD-10-D-S63654A, ICD-10-D-S63655A, ICD-10-D-S63656A, ICD-10-D-S63657A, ICD-10-D-S63658A, ICD-10-D-S63659A, ICD-10-D-S63681A, ICD-10-D-S63682A, ICD-10-D-S63689A, ICD-10-D-S63690A, ICD-10-D-S63691A, ICD-10-D-S63692A, ICD-10-D-S63693A, ICD-10-D-S63694A, ICD-10-D-S63695A, ICD-10-D-S63696A, ICD-10-D-S63697A, ICD-10-D-S63698A, ICD-10-D-S63699A, ICD-10-D-S638X1A, ICD-10-D-S638X2A, ICD-10-D-S638X9A, ICD-10-D-S6390XA, ICD-10-D-S6391XA, ICD-10-D-S6392XA
Hand/Wrist Ligament Sprain	ICD-10-D-S63301A, ICD-10-D-S63302A, ICD-10-D-S63309A, ICD-10-D-S63311A, ICD-10-D-S63312A, ICD-10-D-S63319A, ICD-10-D-S63321A, ICD-10-D-S63322A, ICD-10-D-S63329A, ICD-10-D-S63331A, ICD-10-D-S63332A, ICD-10-D-S63339A, ICD-10-D-S63391A, ICD-10-D-S63392A, ICD-10-D-S63399A, ICD-10-D-S63400A, ICD-10-D-S63401A, ICD-10-D-S63402A, ICD-10-D-S63403A, ICD-10-D-S63404A, ICD-10-D-S63405A, ICD-10-D-S63406A, ICD-10-D-S63407A, ICD-10-D-S63408A, ICD-10-D-S63409A, ICD-10-D-S63410A, ICD-10-D-S63411A, ICD-10-D-S63412A, ICD-10-D-S63413A, ICD-10-D-S63414A, ICD-10-D-S63415A, ICD-10-D-S63416A, ICD-10-D-S63417A, ICD-10-D-S63418A, ICD-10-D-S63419A, ICD-10-D-S63420A, ICD-10-D-S63421A, ICD-10-D-S63422A, ICD-10-D-S63423A, ICD-10-D-S63424A, ICD-10-D-S62425A, ICD-10-D-S63426A, ICD-10-D-S63427A, ICD-10-D-S63428A, ICD-10-D-S63429A, ICD-10-D-S63430A, ICD-10-D-S63431A, ICD-10-D-S63432A, ICD-10-D-S63433A, ICD-10-D-S63434A, ICD-10-D-S63435A, ICD-10-D-S63436A, ICD-10-D-S63437A, ICD-10-D-S63438A, ICD-10-D-S63439A, ICD-10-D-S63490A, ICD-10-D-S63491A, ICD-10-D-S63492A, ICD-10-D-S63493A, ICD-10-D-S63494A, ICD-10-D-S63495A, ICD-10-D-S63496A, ICD-10-D-S63497A, ICD-10-D-S63498A, ICD-10-D-S63499A
SLAP Repair	CPT-29807
Rotator Cuff Repair	CPT-29827, CPT-23410, CPT-23412, CPT-23420
Biceps Tenodesis	CPT-29828, CPT-23430, CPT-24340
Elbow Tendon Repair	CPT-24341, CPT-24342
Elbow Ligament Repair	CPT-24343, CPT-24344, CPT-24345, CPT-24346
Wrist Tendon Repair	CPT-25260, CPT-25263, CPT-25265, CPT-25270, CPT-25272, CPT-25274, CPT-25275, CPT-25337
Hand Tendon Repair	CPT-26340, CPT-26350, CPT-26352, CPT-26356, CPT-26357, CPT-26358, CPT-26370, CPT-26372, CPT-26390, CPT-26410, CPT-26412, CPT-26415, CPT-26416, CPT-26418, CPT-26420, CPT-26426, CPT-26428, CPT-26433
Hand Ligament Repair	CPT-26541, CPT-26542, CPT-26545



**Table 1. Descriptive Statistics of Anorexia Nervosa and Bulimia Nervosa Matched Cohort Demographics**

Parameter	Anorexia Nervosa Experimental & Control Cohort	Bulimia Nervosa Experimental & Control Cohort
Total Number of Patients	46,422	37,242
Age (SD)	36.5 ± 19.6	33.7 ± 14.6
Sex (%)		
Male	7,763 (16.7%)	3,798 (10.2%)
Female	38,659 (83.3%)	33,444 (89.8%)
Charlson Comorbidity Index (SD)	0.27 ± 0.69	0.17 ± 0.50
Region (%)*		
Midwest	10,428 (22.5%)	9,061 (24.3%)
Northeast	11,660 (25.1%)	9,434 (25.3%)
South	16,230 (35.0%)	11,845 (31.8%)
Other*	8,104 (17.4%)	6,902 (18.5%)

## Upper Extremity Soft Tissue Injuries

### *Anorexia Nervosa*

Patients with a diagnosis of anorexia nervosa were significantly more likely than matched controls to sustain a shoulder sprain, rotator cuff tear, elbow sprain, hand or wrist sprain, hand or wrist ligament rupture, any upper extremity sprain, or any upper extremity tendon rupture ( $p < 0.05$  for all). Increased likelihood of hand tendon rupture and any upper extremity rupture trended toward significance ( $p < 0.1$ ). The full data on relative risks of upper extremity soft tissue injuries in the anorexia cohort are presented in Table 2.

### *Bulimia Nervosa*

Patients with a diagnosis of bulimia nervosa were significantly more likely than matched controls to sustain a shoulder sprain, rotator cuff tear, elbow sprain, hand or wrist sprain, hand or wrist ligament rupture, any upper extremity sprain, any upper extremity tendon rupture, or any upper extremity ligament rupture ( $p < 0.05$  for all). Increased likelihood of a forearm tendon rupture trended toward significance ( $p < 0.1$ ). The full data on relative risks of upper extremity soft tissue injuries in the bulimia cohort are presented in Table 2.

## Upper Extremity Soft Tissue Orthopaedic Surgeries

### *Anorexia Nervosa*

Patients with a diagnosis of anorexia nervosa were significantly more likely to undergo SLAP repair, rotator cuff repair, biceps tenodesis, any shoulder surgery, hand tendon repair, any hand surgery, or any hand or wrist

surgery ( $p < 0.05$  for all). The full data on relative risks of upper extremity soft tissue surgeries in the anorexia cohort are presented in Table 3.

### *Bulimia Nervosa*

Patients with a diagnosis of bulimia nervosa were significantly more likely to undergo SLAP repair, rotator cuff repair, biceps tenodesis, any shoulder surgery, hand tendon repair, any hand surgery, or any hand or wrist surgery ( $p < 0.05$  for all). Increased likelihood of elbow tendon repair or any elbow surgery trended toward significance ( $p < 0.1$ ). The full data on relative risks of upper extremity soft tissue surgeries in the bulimia cohort are presented in Table 3.

## DISCUSSION

Although the link between eating disorders and fracture risk has been well documented, this is the first study, to our knowledge, to examine the incidence of upper extremity soft tissue injuries and subsequent surgeries in patients with eating disorders. The results showed that anorexia nervosa and bulimia nervosa are associated with increased incidence of numerous upper extremity soft tissue injuries and surgeries. Orthopaedic surgeons should consider this increased risk when faced with suspicion of an eating disorder in patients, and endeavor to identify eating disorders in order to provide optimal care through a multidisciplinary approach.

The literature has highlighted several potential drivers of the increased incidence of soft tissue injuries and surgeries in patients with eating disorders. Notably, none of these factors were able to be examined in this study, as our analysis was limited to those variables available in a claims database. However, we propose several nutritional, behavioral, and psychological mechanisms to guide further investigation and highlight potential factors that may contribute to clinical decision-making. First, eating disorders are typically associated with states of malnutrition or electrolyte imbalance, including hypokalemia, hypochloremia, and elevated bicarbonate levels.<sup>29,30</sup> McLoughlin et al. additionally highlighted protein-energy malnutrition as a key contributor to muscle dysfunction in patients with anorexia nervosa, referring to this effect as metabolic myopathy.<sup>37</sup> Patients may therefore be at greater risk of soft tissue injury due to the impacts of poor nutritional states on the musculoskeletal system. Eating disorders are also often associated with compulsive exercise.<sup>38,39</sup> Therefore, patients with eating disorders may be at increased risk of injury, as injury risk has been shown to correlate directly with hours per week of sport participation.<sup>40,41</sup> Finally, eating disorders are frequently associated with self-harm, defined as non-suicidal self-injury (NSSI), or intentional destruction to

**Table 2. Incidence and Relative Risk of Upper Extremity Soft Tissue Injuries in Anorexia Nervosa And Bulimia Nervosa Cohorts vs. Controls Over 2010-2021**

Soft Tissue Injury Diagnosis	Incidence %	Incidence %	Relative Risk	95% CI	p-value
	Anorexia Nervosa	Control			
Shoulder sprain	4.37%	2.47%	1.77	1.65-1.90	<0.001
Shoulder strain	1.37%	1.45%	0.95	0.85-1.05	0.317
Rotator cuff tear	1.57%	1.13%	1.39	1.24-1.55	<0.001
Shoulder tendon rupture	0.02%	0.01%	1.17	0.39-3.47	1
Upper arm tendon rupture	0.03%	0.02%	1.63	0.67-3.92	0.383
Forearm tendon rupture	0.01%	0.01%	0.75	0.17-3.35	1
Elbow sprain	0.68%	0.37%	1.85	1.54-2.23	<0.001
Elbow ligament rupture	0.03%	0.03%	1.00	0.45-2.23	1
Hand tendon rupture	0.03%	0.01%	2.67	1.04-6.81	0.055
Hand/wrist sprain	5.13%	2.96%	1.73	1.62-1.85	<0.001
Hand/wrist ligament rupture	0.04%	0.01%	3.33	1.34-8.30	0.011
Any upper extremity sprain	9.36%	5.44%	1.72	1.64-1.81	<0.001
Any upper extremity tendon rupture	1.63%	1.16%	1.41	1.26-1.57	<0.001
Any upper extremity ligament rupture	0.07%	0.04%	1.72	0.96-3.08	0.086
	Bulimia Nervosa	Control			
Shoulder sprain	5.16%	2.57%	2.01	1.86-2.17	<0.001
Shoulder strain	1.55%	1.49%	1.04	0.92-1.16	0.5693
Rotator cuff tear	1.73%	1.07%	1.62	1.43-1.84	<0.001
Shoulder tendon rupture	0.02%	0.02%	1.29	0.48-3.45	0.803
Upper arm tendon rupture	0.03%	0.01%	2.60	0.93-7.29	0.099
Forearm tendon rupture	0.02%	0.00%	7.00	0.86-56.89	0.077
Elbow sprain	0.69%	0.35%	1.95	1.58-2.41	<0.001
Elbow ligament rupture	0.02%	0.02%	1.14	0.41-3.15	1
Hand tendon rupture	0.01%	0.01%	1.33	0.30-5.96	1
Hand/wrist sprain	5.46%	3.04%	1.80	1.68-1.93	<0.001
Hand/wrist ligament rupture	0.04%	0.00%	16.0	2.12-120.65	<0.001
Any upper extremity sprain	10.36%	5.60%	1.85	1.76-1.95	<0.001
Any upper extremity tendon rupture	1.79%	1.08%	1.65	1.46-1.87	<0.001
Any upper extremity ligament rupture	0.06%	0.02%	2.88	1.29-6.43	0.012

\*Cohorts were matched by age, gender, cci, region, and dates of care and significance was determined by chi-square test. P-values were adjusted with Yates' continuity correction.

one's own body without suicidal intent that does not occur in a socially acceptable context.<sup>42,43</sup> Eating disorders have themselves been considered a form of self-harm, as behaviors such as caloric restriction or self-induced vomiting would be considered self-injurious, similar neural circuits are involved in eating disorders and NSSI, and eating disorders and NSSI often share a common psychopathology as maladaptive coping mechanisms for emotional trauma.<sup>44,45</sup> Self-harm has been shown to be associated with increased pain tolerance and decreased pain sensitivity.<sup>46-49</sup> Consequently, patients with eating

disorders may experience less pain or choose to ignore musculoskeletal pain, thus not only increasing their risk for baseline injury, but also increasing their likelihood of progressing to injuries severe enough to necessitate surgical intervention. Future work should endeavor to elucidate the link between eating disorders and soft tissue injuries in order to identify areas of intervention.

The increased incidence of soft tissue injuries and surgeries in patients with eating disorders may have significant impacts on patient quality of life. Studies have shown that return to previous work level can take

**Table 3. Incidence and Relative Risk of Upper Extremity Soft Tissue Orthopaedic Surgeries in Anorexia Nervosa and Bulimia Nervosa Cohorts vs. Controls Over 2010-2021**

Orthopaedic Surgery Type	Incidence %	Incidence %	Relative Risk	95% CI	p-value
	Anorexia Nervosa	Control			
SLAP repair	0.14%	0.06%	2.37	1.51-3.72	<0.001
Rotator cuff repair	0.43%	0.24%	1.77	1.41-2.23	<0.001
Biceps tenodesis	0.26%	0.10%	2.73	1.94-3.84	<0.001
Any shoulder surgery	0.67%	0.33%	2.02	1.66-2.45	<0.001
Elbow tendon repair	0.03%	0.02%	2.00	0.81-4.95	0.190
Elbow ligament repair	0.02%	0.02%	0.70	0.27-0.84	0.628
Any elbow surgery	0.05%	0.04%	1.24	0.65-2.34	0.626
Wrist tendon repair	0.02%	0.02%	1.00	0.43-2.31	1
Hand tendon repair	0.14%	0.07%	2.09	1.37-3.19	<0.001
Hand ligament repair	0.02%	0.01%	2.50	0.78-7.97	0.181
Any hand surgery	0.17%	0.08%	2.14	1.44-3.18	<0.001
Any hand/wrist surgery	0.18%	0.10%	1.87	1.30-2.68	<0.001
	Bulimia Nervosa	Control			
SLAP repair	0.16%	0.08%	2.03	1.30-3.17	0.002
Rotator cuff repair	0.50%	0.24%	2.10	1.63-2.70	<0.001
Biceps tenodesis	0.28%	0.11%	2.58	1.79-3.71	<0.001
Any shoulder surgery	0.76%	0.34%	2.25	1.83-2.78	<0.001
Elbow tendon repair	0.03%	0.01%	2.60	0.93-7.29	0.099
Elbow ligament repair	0.02%	0.01%	2.00	0.50-8.00	0.505
Any elbow surgery	0.05%	0.02%	2.38	1.04-5.42	0.054
Wrist tendon repair	0.04%	0.02%	1.56	0.67-3.59	0.404
Hand tendon repair	0.15%	0.07%	2.12	1.33-3.37	0.002
Hand ligament repair	0.01%	0.00%	5.00	0.58-42.80	0.221
Any hand surgery	0.16%	0.07%	2.22	1.41-3.50	<0.001
Any hand/wrist surgery	0.19%	0.09%	2.06	1.37-3.08	<0.001

\*Cohorts were matched by age, gender, cci, region, and dates of care and significance was determined by chi-square test. P-values were adjusted with Yates' continuity correction.

as long as eight months after rotator cuff surgery, for example, with as many as one-third never returning to previous work level,<sup>50,51</sup> thus creating significant financial consequences for patients at increased risk for such surgeries. Additionally, in a recent narrative review, Daley et al. highlighted various studies showing the potential for emergence or exacerbation of underlying psychological disorders after injuries.<sup>52</sup> Consequently, if eating disorders put patients at risk of soft tissue injuries and surgeries, and injuries may exacerbate underlying disorders, this has the potential to become a self-perpetuating cycle with significant adverse impact on patients' lives. Furthermore, outcomes of the surgeries examined in this study have been shown to be impacted by mental health status.<sup>53-55</sup> Thus, not only is the incidence of these

surgeries higher in patients with eating disorders, but these patients may also be at risk for worse outcomes.

The results of this study beg the question of how orthopaedic surgeons can utilize the knowledge that patients with eating disorders have increased incidence of soft tissue injuries and surgeries in their practice. Ciao et al. noted that barriers to identification of eating disorders in adolescents include parental hesitancy to act on suspicions and the mixed reaction of patients.<sup>56</sup> Liu et al. further highlighted barriers to seeking treatment for individuals with eating disorders, which included fear, poor health literacy, and feeling undeserving of treatment.<sup>57</sup> Given these barriers, orthopaedic surgeons may be in a position of being the first physician to see a patient with a suspected eating disorder, and thus may

have the opportunity to educate patients and parents and provide appropriate referrals before disease progression. Furthermore, psychosocial interventions such as counseling have been shown to promote rehabilitation adherence after injury,<sup>58</sup> thus potentially diminishing the risk of subsequent injuries. This raises the potential for future investigation into the impact of various interventions on subsequent injury and surgery risk. For example, studies should be undertaken to examine if post-injury or post-operative nutritional or psychological counseling may promote eating disorder recovery, and if this recovery in turn is associated with reduced injury risk. Additionally, investigations into the impact on subsequent injury risk of operative management compared to nonoperative management in patients with eating disorders should be undertaken. Until such research has been conducted to provide definitive practice recommendations, appropriate awareness, preparedness, and comfort on the part of orthopaedic surgeons is paramount.

Studies have shown that orthopaedic surgeons' difficulty in addressing psychosocial factors with patients may result from experiential avoidance, blame toward patients, perceptions of their own skills with navigating these conversations, and knowledge of resources available to their patients.<sup>59,60</sup> Consequently, it is important to promote awareness of and confidence in addressing eating disorders among orthopaedic surgeons. Work currently being done in the field includes implementation of women's sports medicine programs and other forms of psychosocial educational training.<sup>61-63</sup> Furthermore, this increased education may alleviate discomfort around the management of these patients that may result from the abundance of literature linking mental illness with poor outcomes.

This study represents a novel addition to the literature surrounding soft tissue injuries and surgeries in patients with comorbid eating disorder diagnoses, but we recognize that limitations exist. First, this study's retrospective nature makes it difficult to establish causality rather than association. Second, the cohorts were matched on a variety of variables, but other variables not available in the database may have been mediators of the observed effects, including BMI, race/ethnicity, socioeconomic status, and the patients' level of participation in sport. Third, given the low incidence of various injuries in both cohorts, it is possible that these incidences may have been over- or under-stated. Similarly, the lack of representation of patients from the West region may limit the generalizability of our results. Finally, many studies have shown that the incidence of eating disorders is underestimated due to both low reporting in medical records and low recognition of these disorders in patients. Consequently, it is possible that patients within

our control cohorts may have had eating disorders, skewing the results.

## CONCLUSION

In summary, the results of this study demonstrate that diagnosis of an eating disorder is associated with an increased incidence of upper extremity soft tissue injuries and surgeries. Orthopaedic surgeons should be aware of this risk factor and endeavor to identify patients with eating disorders. Further work should be undertaken to elucidate the drivers of increased risk for injury and surgery. This may direct orthopaedic surgeons toward interventions such as referrals for nutritional or psychological counseling or discussions with patients and their families around the musculoskeletal sequelae of anorexia and bulimia nervosa.

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# PRE-EMPTIVE OPIOID-SPARING MEDICATION PROTOCOL DECREASES PAIN AND LENGTH OF HOSPITAL STAY IN CHILDREN UNDERGOING POSTERIOR SPINAL INSTRUMENTED FUSION FOR SCOLIOSIS

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## ABSTRACT

**Background:** Poorly controlled post-operative pain following Posterior Spinal Instrumented Fusion (PSIF) for scoliosis may be associated with delayed ambulation and longer hospital stays. Multimodal analgesia use has been shown to provide superior analgesia with improved recovery and reduction of post-operative morbidity in other orthopedic subspecialties, but has not been described with pediatric patients undergoing spinal surgery.

**Objective:** We describe a novel, pre-emptive, opioid-sparing pediatric pain medication protocol that is started two days prior to surgery, in accordance with first-order pharmacokinetics, and continued post-operatively until discharge with the goal of decreasing post-operative pain, improving early mobilization, and ultimately decreasing the patient's length of hospital stay.

**Methods:** We retrospectively reviewed 116 PSIF cases from March 2014 to November 2017. Fifty-two patients received standard analgesia before August 2016, and 64 patients after August 2016 received the pre-emptive protocol consisting of a standardized combination of acetaminophen, celecoxib, and gabapentin two days prior to surgery and continued during their inpatient stay. Scheduled oxycodone and intravenous hydromorphone via patient controlled analgesia (PCA) were given to both groups equally during the post-operative hospital stay. We analyzed length of stay, total opioid consumption, and maximum pain scores per day from surgical to discharge date.

**Results:** 116 patients were included: 64 patients in the pre-emptive group and 52 patients in the standard group. Length of hospital stay significantly

differed, with means of 3.9 days in the pre-emptive group and 4.5 days in the standard analgesia group ( $p < 0.05$ ). Patients in the pre-emptive group recorded significantly lower maximal pain levels than those in the standard analgesia group on post-operative days #1 (4.9 vs. 5.8,  $p = 0.0196$ ), #3 (4.4 vs. 6.1,  $p = 0.0006$ ), and #4 (4.2 vs. 5.4,  $p = 0.0393$ ). Total post-operative morphine equivalents taken did not significantly differ between the two groups.

**Conclusion:** This is a preliminary report demonstrating a significant decrease in maximal pain score and length of stay following PSIF on a cohort of patients receiving a novel pre-emptive opioid-sparing pain medication protocol based on first order pharmacokinetics. Future studies should investigate degree of mobilization and opioid consumption and maximal pain level after discharge from the hospital.

**Level of Evidence:** III

**Keywords:** scoliosis, spine fusion, length of stay, analgesics, opioid, pain, postoperative, child, ERAS

## INTRODUCTION

Poorly controlled post-operative pain may be associated with delays in ambulation, longer inpatient hospital stays, decreased patient satisfaction, higher hospital cost, and higher opioid use.<sup>1</sup> In addition, post-operative pain in children can cause behavioral problems lasting beyond the duration of the pain itself.<sup>2</sup>

All opioids, intravenous and oral, can have side effects and can cause significant morbidity in patients after surgical procedures.<sup>3</sup> In an effort to decrease post-operative pain while limiting opioid induced adverse effects, there has been an increased use of multimodal analgesia by combining analgesics with different mechanisms of action.<sup>4</sup> This has been shown to provide superior analgesia, with improved recovery and reduction in post-operative morbidity and overall cost.<sup>5,9</sup>

Non-opioid agents such as acetaminophen, celecoxib, and gabapentin are effective at providing analgesia via three distinct pharmacodynamics mechanisms.<sup>1,4,10-16</sup> Their use is FDA-approved and relatively safe in the pediatric population. In order to be effective and safe,

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plasma concentrations of these drugs must be maintained above the minimum effective concentration but below the minimum toxic concentration.

The purpose of this study is to evaluate the success of a novel, non-opioid, multimodal pain management protocol, based on first order pharmacokinetics, in the reduction of post-operative pain, length of hospital stay, and opioid consumption in the post-operative period for patients who have undergone posterior spinal instrumentation and fusion (PSIF) for scoliosis. We hypothesize that by having adequate blood concentrations of non-opioid analgesia in place before surgery; we will be able to decrease the total amount and duration of opioid used post-operatively, while continuing to provide excellent pain control.

METHODS

This is a retrospective case-control study for patients who underwent PSIF in our institution between March 2014 and November 2017. The pre-emptive pain protocol was instituted in August of 2016.

Patients who were in the standard opioid-based protocol (prior to August 2016) received no pre-operative medication prior to their surgery. Patients who were in the pre-emptive group (after August 2016) received weight-based pre-operative medications of acetaminophen, celecoxib, and gabapentin as per our protocol, starting two days pre-operatively and continuing until discharge from the hospital. Drug dosages were calculated as follows: acetaminophen 15 mg/kg QID, celecoxib 3.5 mg/kg BID, and gabapentin 7.5 mg/kg BID. The calculated dose was prescribed to the patient in our anesthesia pre-operative clinic. The prescribed dose was rounded down to the nearest commercially available dosage form. According to the principles of pharmacokinetics, when dosed at regular intervals, minimal effective steady state concentrations are achieved after 4-5 half-lives.<sup>17</sup> The half-life of acetaminophen is 1.5-3 hours, that of celecoxib is 11 hours, and that of gabapentin is 4.6 hours.<sup>18,20</sup> Therefore, it is necessary to start the pre-emptive non-opioid medication 48 hours prior to surgical incision to achieve effective plasma levels for pain control. Our pain protocol is innovative in abiding by the first order pharmacokinetics of oral medication and achieving a steady state of adequate plasma concentration of the non-opioid medication prior to incision.

Post-operatively, all patients in both groups received intravenous hydromorphone via patient controlled analgesia (PCA) during their pediatric intensive care unit (PICU) stay and were converted to scheduled and as-needed oral oxycodone according to body weight and pain level after transitioning to the floor on POD #1.

The total opioid consumption was recorded and

converted to morphine milligram equivalents (MME) from the day of surgery through the day of discharge. Pain scores were subjectively evaluated on a 10-point analog scale (with 1 being minimal discomfort and 10 being the worst discomfort imaginable) by the patient. A severity of 1-3 was classified as “mild,” 4-7 as “moderate,” and 8-10 as “severe.” The pain scores were collected from the nurse’s reports and the maximal pain score was used for each day post-surgery according to the Wong-baker FACES pain score.<sup>21</sup> The length of stay was recorded from the hospital medical record.

Statistical analysis

The pre-emptive and the standard cohort were compared in terms of age, gender, and pain levels as well as surgical data which includes the length of surgical fusion, use of pelvic fusion, and vertebral resection. The chi-squared test (for categorical variables) and the Student’s t-test (for continuous variables) were used to determine whether differences were significant across the categories.

RESULTS

Demographic data

116 patients were included in this study. Fifty-two patients were in the standard group and 64 patients were in the pre-emptive group. All 64 patients were able to complete their pre-emptive medication as prescribed prior to surgery.

There was no significant difference in the demographic data and the operative details between the standard and the pre-emptive group (Table 1).

Table 1. Demographic Data of Both Groups

	Standard group		Pre-emptive group		
	Mean	STD	Mean	STD	
Female	78%		72%		P=N/S
Age (years)	14.07	2.39	13.75	3.06	P=N/S
Weight (kg)	47.99	16.73	49.84	16.9	P=N/S
BMI	19.83	4.84	21.46	5.52	P=N/S
PSIF	100%		100%		P=N/S
Length of fusion (vertebrae)	11.27	2.27	11.03	2.74	P=N/S
Pelvic fusion	8%		12%		P=N/S

STD-standard deviation, N/S-non significant, BMI-Body mass index, PSIF-posterior spinal instrumentation and fusion.

### Length of stay

There was a significant difference in the length of stay between the two groups. The average length of stay in the pre-emptive group was  $3.9 \pm 0.9$  days compared to  $4.5 \pm 1.1$  days in the (p<0.05) in the standard group (Figure 1).

### Maximal pain levels

There was a significant difference in recorded maximal pain levels between the two groups during POD #1 (4.94 vs. 5.82, p=0.0196), #3 (4.42 vs. 6.06, p=0.0006), and #4 (4.16 vs. 5.43, p=0.0393) with improved pain scores in the pre-emptive group. Maximal pain level on the day of surgery not significantly different (4.28 vs. 4.84, P=N/S). Maximal pain level on POD #2 approached, but did not reach, statistical significance (4.89 vs. 5.76, P=0.058) (Figure 2).

### Amount of opioids taken during hospitalization

There was no significant difference in the total MME taken between the two groups post operatively ( $122.07 \pm 56.57$  vs.  $124.35 \pm 63.76$ , P=N/S).

Using multi-variate analysis we found significant correlation between the amount of MME taken and the patient's pain level (p=0.009,  $R^2=0.092$ ). There was also

a significant correlation between the patient's weight (p=0.012,  $R^2=0.1827$ ) and the amount of MME taken.

It is important to note that although the dosage of intraoperative intrathecal morphine was significantly higher among the standard group (0.27 vs 0.23, P=0.046), no significant difference was found in the pain scores during the day of surgery.

### DISCUSSION

The goal of this study was to determine the effects of a new, pre-emptive, non-opioid pain regimen on post-operative opioid consumption, maximal post-operative pain scores and length of stay for pediatric spinal fusion patients. Our results showed an improved pain profile through most of the first four days post-surgery without increased opioid consumption, as well as a shorter length of stay for patients in the pre-emptive group.

Pain intensity measures by patients are one of the most reliable estimates of treatment efficacy.<sup>22-30</sup> Our data show the pre-emptive cohort has significantly lower maximal pain scores throughout most of their hospital stay without an increase in the amount of opioids taken. An opioid sparing effect was likely not seen due to our standard practice of prescribing scheduled oxycodone regimens immediately post-surgery. With the success of our protocol, transitioning from a scheduled oxycodone regimen to as needed dosing would likely reflect a decrease in the amount of opioids taken. Overall, our pre-emptive pain protocol is able to provide superior acute pain control for post-surgical pediatric patients undergoing spinal fusion. Our finding is consistent with the literature wherein perioperative use of multimodal pain medication is effective for post-operative pain control.<sup>4,31,32</sup>

Inadequate post-operative analgesia hinders the effective participation of patients in early physical therapy and therefore their immediate functional recovery.<sup>33-35</sup> We speculate that the superior pain control seen in our pain protocol cohort in the immediate post-operative period may have allowed these patients to better participate in physical therapy. In addition, earlier mobilization have been shown to decrease risks of DVT, atelectasis, constipation and abdominal pain.<sup>5,6,36,37</sup> The patients who received the pre-emptive protocol may have achieved therapy discharge criteria at an earlier time, resulting in a shorter length of stay. The resulting reduction in the length of stay for our post-operative patients translates into cost savings, significant financial benefits and increased efficiency for the resources used by the hospital.

In addition, adequate treatment of post-operative pain has been shown to influence patient satisfaction.<sup>38-40</sup> Our results showed that there was a significantly lower maximal pain score in the pre-emptive group compared to the standard group without relying on increased opi-

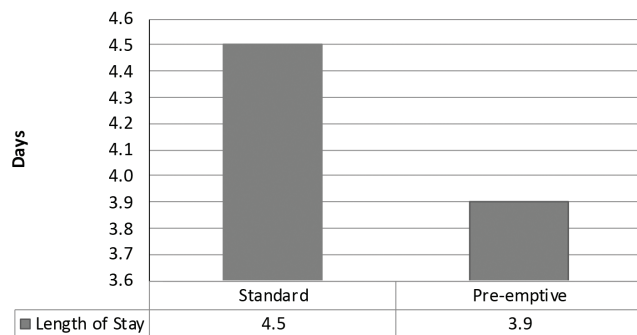


Figure 1. Mean Length of Stay. Length of hospital stay was significantly shorter for the Pre-emptive group.

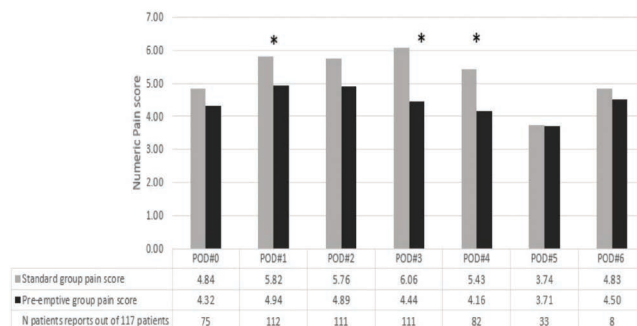


Figure 2. Maximal Daily Pain Level. Pain scores for the length of the hospital stay. Significantly improved pain scores were noted in the pre-emptive group for POD #1, POD #3, and POD #4 (asterisk).

oid consumption. Although the study did not directly measure this, the patients likely benefited from improved pain control and may be more satisfied with their surgical experience.

Our study is limited by its retrospective nature. All data is based on what is recorded in the hospital electronic medical records. Another limitation of this study is our comparison of two historical cohorts of patients undergoing PSIF. There may be undocumented differences in the hospital's pain management practices during the two different time periods. Although we have started collecting opioid consumption and maximal pain level after discharge from the hospital since the analysis of this study, the data are inadequate. Therefore, we cannot comment on whether the new protocol allowed for decreased opioid consumption at home.

In conclusion, starting oral non-opioid analgesic pain medication pre-emptively, based on first order pharmacokinetics, has shown improved pain control in PSIF patients compared to the standard opioid-based pain management protocol that is started post-operatively. The improved overall pain experience may have led to a shorter overall length of stay for patients undergoing PSIF for scoliosis.

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# DELAYED POST-OPERATIVE NEUROLOGICAL DEFICIT AFTER POSTERIOR SPINAL FUSION FOR ADOLESCENT IDIOPATHIC SCOLIOSIS: POSSIBLE ASSOCIATION WITH POST-OPERATIVE ANEMIA

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## ABSTRACT

**Background:** To present a patient with adolescent idiopathic scoliosis who developed a significant neurological deficit after posterior spinal fusion, in association with anemia on postoperative day two.

**Case Report:** A 14-year-old otherwise healthy female underwent a T3-L3 instrumented posterior spinal fusion for idiopathic scoliosis which was uneventful. Immediate post-operative clinical examination was unremarkable but at postoperative day three the patient developed generalized lower extremity weakness with inability to stand and an urinary retention needing continuous intermittent catheterization program. Her hemoglobin (Hg) dropped from 10 g/dL on postoperative day one to 6.2 g/dL at day two, despite no significant bleeding was noticed. Compressive etiology was ruled out by postoperative myelogram-CT. The patient started to improve significantly after transfusion support. At three months follow-up the patient was neurologically normal.

**Conclusion:** Close clinical neurological evaluation over 48 to 72 hours is needed in order to detect unexpected delayed paralysis following scoliosis surgery.

**Level of Evidence:** IV

**Keywords:** idiopathic scoliosis, spinal fusion, neurological deficit, delayed

## INTRODUCTION

Neurological injury following spinal deformity surgery although rare remains a devastating complication.<sup>1,3</sup> Most of neurological insults occur during surgery secondary to vascular injury during the correction or direct cord

trauma during exposure or instrumentation. Spinal cord ischemic injury is considered to be multifactorial in its etiology with causes as vessel ligation, traction and embolization that can threaten tissue perfusion and can be exacerbated by hypotension, local postoperative edema and oxygen tension.<sup>4,5</sup> Pathophysiology of intraoperative spinal cord injury during deformity correction was studied by Turner et al. combining spinal cord perfusion (SCP) with intrathecal pressure and neurological monitoring (MEP). The authors depicted a direct relation between SCP fluctuation and MEPs reduction.<sup>6</sup> As we know hypotension correction is one of the most widely performed general measure, following an intra-operative alert, since there is good evidence that even a mild drop in systemic systolic blood pressure can affect the motor potentials profile.<sup>7-9</sup> Deletis and Sala resumes corrective measures to the acronym "TIP" that stands for Time, Irrigation and Pressure as the important steps preserving or regaining spinal cord potentials during spinal tumor surgery. Pharmaceutically induced normo- or hypertensive blood pressure as well as local papaverine infusion assume also a particular role.<sup>10</sup>

Delayed postoperative neurological deficits (DPND) have been reported mostly due to ischemic and compression events.<sup>11</sup> Taylor et al., published a clinical case of a 46 years old female patient undergoing deformity revision surgery where the patient developed a flaccid paralysis at the recovery room two hour after surgery that reversed completely after hypotension and anemia correction.<sup>9</sup> We present a clinical case of a delayed post-operative neurological deficit despite an uneventful surgery with stable intraoperative monitoring profile, normal wake up test and perfectly normal neurological exam during the first 48 h post-operatively. The neurological impairment detected at the end of the second post-operative day was concurrent with a progressive and relevant drop in hemoglobin and hematocrit values associated with a transient hemodynamic instability.

## CASE STUDY

A 14 year old otherwise healthy female, underwent a T3-L3 instrumented posterior spinal fusion for a right major 50 degrees thoracic curve and a left 42 degree lumbar curve (Fig 1 – a,b). Surgery under controlled hypotensive anesthesia went uneventfully. Well-defined

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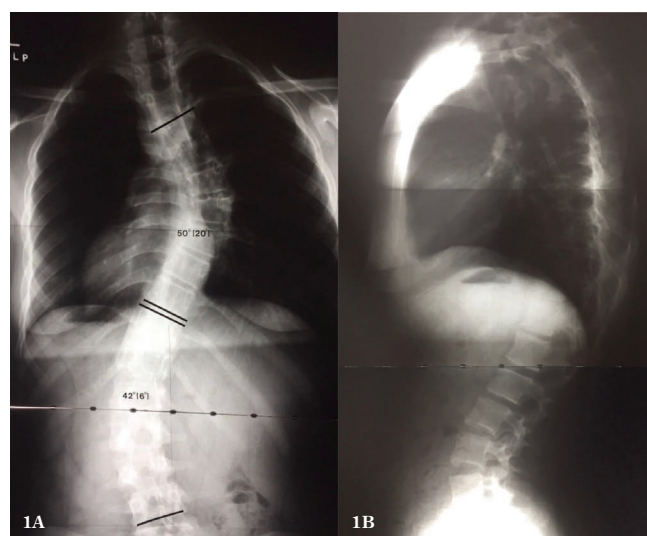


Figure 1A to 1B. AP and lateral pre-operative long standing X-rays. A Lenke type I 50° curve with a thoracolumbar kyphosis of 22° and a lumbar modifier C.

somatosensory evoked potentials (SEPS) were recorded with P31 latency being 25.6 MSEC bilaterally and remained unchanged. There was amplitude decline before the start of MEP recording, but this was not considered significant. MEPS from left and right quadriceps and tibialis anterior muscle following stimulation of thoracic cord via epidural electrodes showed well defined responses. This remained unchanged and amplitude became larger before the wake-up test, which was normal with patient being able to move both lower extremities. Wound was closed with running sutures and drains were left superficially. Estimated blood loss was 400cc and postoperative hemoglobin and hematocrit were 9.7g/dL and 31% respectively, compared to pre-operative values of 15.1g/dL and 41% respectively. A well-balanced spine was achieved with 63% correction of the major curve and 71% correction of the lower curve (Fig 2 – a,b). The patient was taken to the pediatric intensive care unit in excellent hemodynamic conditions and neurological examination was normal, remaining so on the multiple evaluation done during first postoperative day, and at the beginning of the second postoperative day two. Towards the end of postoperative day two, the patient started to feel as if both lower extremities were "heavy" and hypersensitive to touch. This has persisted with no significant change and on the third day she was unable to support herself standing. On neurological exam, patient was unable to raise both lower extremities from bed with good knee and ankle flexion/extension. Rectal tone was normal as well as sensation to light touch and pin-prick. A withdrawal plantar response was present and her deep

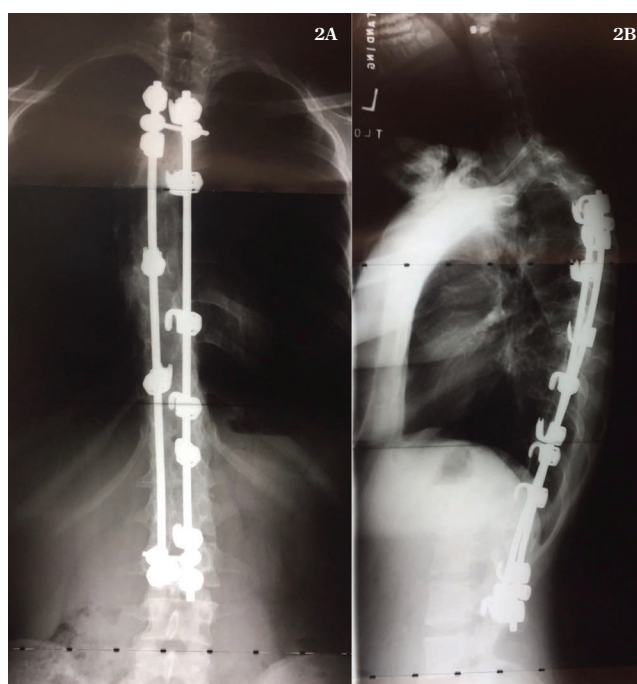


Figure 2A to 2B. Post-operative long standing AP and lateral X-ray where a all hooks contract enabled a good overall deformity correction and a well balanced spine.

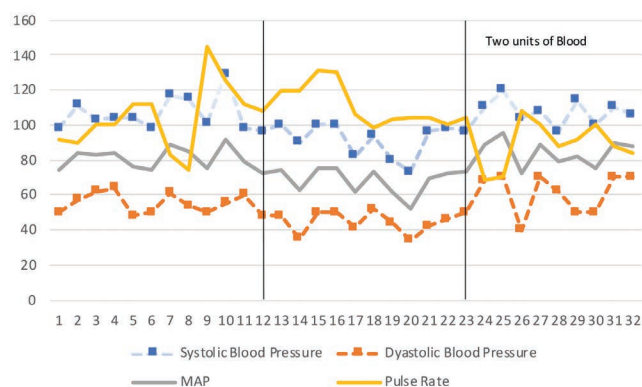
tendon reflexes were 2/2 at knee and ankle 1/1. After urinary catheter discontinuation she developed urinary retention that required a continuous intermittent catheterization program.

During this postoperative time her hemoglobin (Hg) had dropped from 9,7 g/dL on postoperative day one to 7.3 g/dL on the second post-operative day and continued to fall the next day, to 6.2 g/dL with a hematocrit (Htc) of 18% (Table 1). At this stage patient was complaining of light-headiness and exhibiting persistent hypotension and tachycardia with pain well controlled (Graph 1). Drains had been removed on post-operative day two with no abnormal bleeding noticed. Compressive etiology was ruled out by myelogram (Fig 3 – a,b,c,d) and two units of packed blood cells (RBC's) were then administered correcting the hemoglobin to 9,3 g/dL and hematocrit to 27%. No further treatment was undertaken with a rapid clinical improvement documented during hospital stay. Differential diagnosis raised by neurology consultation were transient spinal cord ischemia and acute inflammatory demyelinating polyneuropathy. Patient was discharged on postoperative day thirteen on a supervised physical therapy program and a continuous intermittent catheterization program. At three months follow-up she was neurologically normal and at six months follow-up a second spinal cord monitoring was performed that showed different wave form distribution compared to the pre-op SEPS although within normal limits.

**Table 1. Hemoglobin / Hematocrit And Hemodynamic Post Operative Profile and Clinical Neurological Evaluations During Same Period**

Unit Notes	RBC	Hg G /DL	Hct %	Time	Blood Pressure	MAP	Pulse rate	Neuro Checks for mobility
Post-Op Day 0				18:00	98/50	74	92	Normal
Post-Op Day 1	3,39	9.7	30	20:00	111/57	84	90	Normal
				24:00	103/62	82,5	100	Normal
				04:00	104/64	84	100	Normal
				08:00	104/48	76	112	Normal
				12:00	98/50	74	112	Normal
				16:00	117/61	89	83	Normal
				20:00	115/54	84,5	74	Normal
				24:00	101/50	75,5	145	Normal
Post-Op Day 2	2.51	7.3	22	04:00	129/55	92	125	Normal
				06:00	- / -	-	-	Normal
				08:00	98/60	79	112	Normal
				12:00	96/48	72	108	Normal
				16:00	100/48	74	120	Mod. Weak
				20:00	90/35	62,5	120	Mod. Weak
				24:00	100/50	75	131	Mod.Weak
Post-Op Day 3	2.06	6.2	18	04:00	100/50	75	130	Mod. Weak
				08:00	82/41	61,5	106	Mod. Weak
				10:00	94/52	73	98	Mod. Weak
1ºRBC				10:25	80/44	62	103	Mod. Weak
				12:30	73/34	53,5	104	Mod. Weak
				13:35	96/42	69	104	Mod. Weak
				13:50	98/46	72	100	Mod. Weak
2ºRBC				15:25	96/50	73	100	Mod. Weak
				20:00	110/68	89	120	Mod. Weak
				24:00	120/70	95	120	Mod. Weak
Post-Op Day 4		9.3	27	08:00	104/40	72	108	Mod. Weak
				12:00	108/70	89	100	Mod. Weak
				20:00	96/62	79	88	Mod. Weak
Post-Op Day 5	-	-	-	04:00	114/50	82	92	Mod. Weak
				08:00	100/50	75	100	Mod. Weak
				14:00	110/70	90	88	Mod. Weak
				16:00	106/70	88	84	Mod. Weak
Post-Op Day 6	-	10.1	30	08:00	100/70	85	80	Mod. Weak
				20:00	100/50	75	88	Mod. Weak





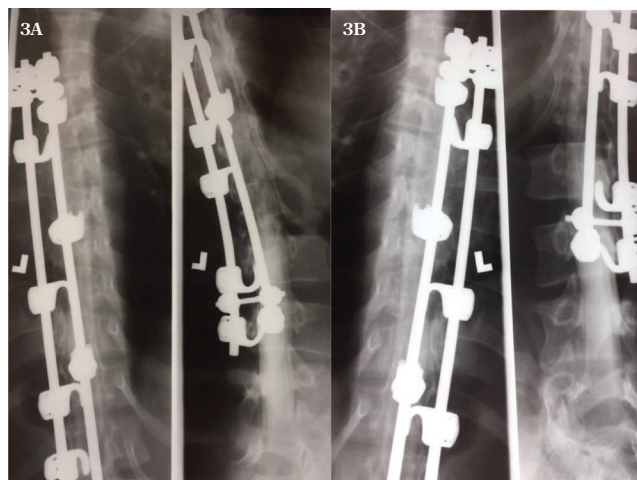
**Graph 1. Blood pressure and pulse rate profile.** Patient's blood pressure and pulse rate during the first 5 days post- op. Note the steady decline in mean arterial pressure (MAP) from measurement 10 until measurement 20 with concomitant increase in pulse rate and subsequent diagnosis of neurological deficit.

## DISCUSSION

Evidence for the benefit of proper cord perfusion comes from intraoperative monitoring data where appropriate and timely measures, like correction of hypotension, and loosening of distraction are measures that can help regaining spinal cord potentials and most likely prevent the occurrence of a permanent deficit.<sup>11</sup> Well established policies to reduce overall blood transfusion, and increased awareness of possible correlation between blood transfusion and surgical site infection, among other possible complications, has changed significantly the rate of blood transfusion in spinal surgery. A multimodal approach is now reinforced to decrease blood loss and restrict any transfusion to clinically symptomatic post-operative anemia or very low levels of hemoglobin.<sup>12</sup> Theoretically, this policy can put some patients at risk for spinal cord ischemic events.

DPND is characterized by the development of post-operative paralysis within hours or days of the surgical procedure, despite an uneventful surgery, stable intraoperative monitoring profile, and normal postoperative neurologic examination. According to Auerbach et al. it has an estimated incidence of 0,01% with ischemic events being reported in 38% of the cases, followed by a compressive etiology in 15%. Of the 92 cases reported and revised by these authors, most of the DPND occurred in the setting of scoliosis (69%) with 90% of deficits being present at 48 hours.<sup>13</sup>

Our patient expressed at the end of the second day subjective symptoms in relation to her lower limbs following a normal postoperative course. The clear diagnosis of a relevant motor deficits on the beginning of the following day leads us to consider the possible association with the progressive hypotension followed by



**Figure 3A to 3B. Myelogram ruling out epidural hematoma or mechanical compression by misplaced hook.**

an increase pulse rate registered toward the end of the second day (Graph 1 – Registries 8 to 23). This was also related to a relevant and continuous drop in hemoglobin and hematocrit values. The nature of the deficit and the absence of obvious mechanical compression on myelogram supported a conservative approach with prompt correction of anemia with a good outcome.

A previous publication of a delayed neurological deficit appearing at 24 hours after index surgery, progressed rapidly from a gradual onset of distal left lower extremity weakness to a T8 level paraplegia. In this case patient was immediately taken to the operating room and significant hematoma under tension was evacuated followed by instrumentation removal with clinical progressive recovery.<sup>14</sup> A very similar deficit and type of presentation is presented by Chang et al. where an epidural hematoma, depicted in a post-operative myelo-CT, led to a rapid decompression and partial hardware removal followed by reconstruction after neurologic improvement.<sup>15</sup> In both cases was there any abnormal pain referred by the patients in contrast with a series of cases presented by Uribe et al., where the initial presenting symptom, heralding subsequent neurological deficit was a sharp and intense pain in the majority of epidural hematomas following posterior cervical and lumbar decompression surgery.<sup>16</sup>

Literature supports the need, whenever possible, for proper imaging to rule out any mechanical compression by hematoma or misplaced screw as well as any residual translation or angulation not noticed during surgery.<sup>11</sup> Otherwise, immediate return to the operating room for implant removal and spine relaxation may not achieve the expected goal. For this purpose, CT-Scan or CT myelogram are probably the most effective imaging

modalities that can depict the most frequent causes of DPND related to mechanical compression.

Even though our neurologist raised the possibility of an acute inflammatory demyelinating polyneuropathy or Guillain-Barré Syndrome (GBS), this is a complication rarely described in the perioperative period of spinal surgery and only once following scoliosis.<sup>17-19</sup> In our case, myelogram had been done already, previously to the neurology consultation, and no decision was made to pursue this hypothesis by obtaining a cerebral spinal fluid (CSF) sample for chemical investigation. Anyway, the absence of a clear sensory impairment and a more proximal muscular weakness, rather than distal, makes this diagnosis less likely.

One of the limitations of this clinical case can be the absence of a previous MRI enabling us to rule out any spinal cord abnormality that could explain the partial neurological deficit in the post-operative period. If this was the case, we would expect to have had any somato-sensory and spinal motor potentials instability or even an equivocal wake-up test not occurring in this case. On the other hand, this doesn't refute our concern on the possible association of this DPND with hypotension and anemia reinforcing only the concept of cord at risk where a longer postoperative vigilance at the PICU or a more liberal use of blood products can be adopted for selected cases.

## CONCLUSION

Close clinical neurological evaluation over 48 to 72 hours continues to be mandatory for early detection of delayed paralysis following scoliosis surgery. Although judicious use of blood products is prudent in the face of children being able to safely tolerate low haemoglobin levels, transfusion policies may have to be revisited, especially in deformity surgery, as the cord may be transiently at risk from ischemic events after deformity correction.

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# DIFFERENCE IN BIOIMPEDANCE ACROSS THE KNEE IN UN-INJURED YOUNG ADULTS

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## ABSTRACT

**Background:** Knee injuries induce swelling and resolution of swelling may be a useful factor in identifying states of healing and time to return to sports activities. Recent work has suggested that bioimpedance can provide an objective measure of swelling following total knee arthroplasty (TKA) and therefore may also provide guidance for clinical decision-making following knee injury. This study measures knee bioimpedance in young, active people to help define baseline variability and factors that influence limb to limb differences.

**Methods:** Bioimpedance was measured via sensors placed at the foot/ankle and thigh, in positions similar to those suggested for monitoring post-TKA swelling. Initial tests were performed to verify method repeatability, then bioimpedance was measured in a convenience sample of 78 subjects (median age 21yrs). The influence of age, BMI, thigh circumference, and knee function (KOOS-JR) on the impedance measures and difference in impedance between the subject's knees were examined using a generalized multivariable linear regression.

**Results:** The repeatability study measurements were highly consistent with a COV of 1.5% for resistance and an ICC of 97.9%. Women exhibited significantly larger dominant limb impedance and larger limb to limb difference in impedance than men. Regression analysis indicated that subject sex and BMI significantly influenced bioimpedance but joint score and age did not. The limb to limb differences in impedance were small on average (<5%), with larger magnitudes of difference

associated with female sex, lower knee function scores, and larger limb to limb differences in thigh circumference.

**Conclusion:** Bioimpedance measurements across right and left knees of healthy young people were similar, supporting use of bioimpedance measures from a patient's uninjured knee as a benchmark to monitor healing of a contralateral injured knee. Future work should focus on understanding how knee function scores and bioimpedance are related, and further explore how sex and side to side anatomic differences impact the measurement.

**Level of Evidence:** IV

**Keywords:** knee, ACL injury, bioimpedance, swelling, edema, effusion

## INTRODUCTION

Swelling is the accumulation of extracellular fluid that can occur as a result of inflammation and intra-articular bleeding after trauma or surgery.<sup>1</sup> Knee swelling is common after knee arthroscopy, total knee arthroplasty, or lower limb trauma and is especially problematic because it can decrease mobility and induce gait problems.<sup>1,3</sup> It has been associated with reduced quadriceps strength.<sup>4,5</sup> Knee swelling may be an important factor in considering ACL injuries in young patients, where it is especially important to monitor recovery to avoid re-injury.<sup>6,7</sup> While there are no clear set of criteria for determining when an athlete has recovered sufficiently to return to play, there is broad consensus that joint effusion should be minimal to none.<sup>8,10</sup> Detection of post-traumatic or post-operative swelling in the lower limb is therefore important for successful patient management.<sup>3,11-13</sup> This points to a need for an objective measure of swelling to replace less sensitive measures such as circumference measurement or visual assessment.

Bioimpedance analysis has been suggested as a tool for objective measurement of swelling in the lower extremity and has been shown to have a strong correlation with lower extremity volume.<sup>1,2,13,14</sup> Recent studies have used segmental bioimpedance measurements to assess swelling of the leg. King et al. and Pichonnaz et al. demonstrated a strong relationship between bioimpedance and limb volume when studying 14 ankle fracture and 25 post-TKA patients, respectively.<sup>3,13</sup> Single frequency

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bioimpedance (SFBIA) measurement has been shown to be relatively quick and reliable due to its simplicity, and it provides measures similar to more complex multispectrum impedance.<sup>15,16</sup> Single frequency bioimpedance analysis devices provide resistance and reactance measurements by delivering a weak 50 kHz current across the body. The resulting resistance measurement is generally associated with the amount of extracellular fluid present in the sensing region, with less resistance in the case of higher levels of extracellular fluid, making it a more sensitive edema measurement tool than measurements of circumference or volume.<sup>3,13,17,18</sup> Cardoso et al. evaluated 15 patients with chronic venous ulcers and found that segmental bioimpedance measurements of the leg were sensitive enough to detect acute changes in limb swelling throughout the day.<sup>19</sup> Another small study (7 uninjured/2 injured) showed knee injury increases the difference in impedance between the injured and uninjured limb.<sup>14</sup> These studies suggest that bioimpedance may be helpful in monitoring knee healing in athletes. The reactance portion of the bioimpedance measurement refers to the delay in conduction, typically due to cell membrane and tissue interfaces acting as capacitors and storing electrical charge.<sup>16,17,20</sup> A small study followed 3 injured professional athletes and found gradual increases in impedance and reactance measured across the knee, moving toward pre-injury levels over time during healing.<sup>21</sup> The authors suggested that reactance may be useful in tracking wound healing.<sup>21</sup>

These studies suggest bioimpedance may be a useful measure to monitor healing in patients with knee injury. To this end, single frequency bioimpedance is suggested due to its relative simplicity and low cost. No standard electrode placement exists for evaluating bioimpedance following knee injury, but an earlier study proposed sites for monitoring it in total knee replacement patients.<sup>2</sup> It is proposed that these sites should also be utilized for knee injury to create a common practice for clinical measurement, as earlier studies demonstrated that impedance measurements differ based on measurement site.<sup>15,22</sup> It would be beneficial to have a set of baseline measurements for a healthy young population taken using a standard placement. Additionally, a clinical goal for impedance measurement may be to return patients to “normal” levels of bioimpedance using measurements from their uninjured limb to define recovery. It would therefore also be helpful to understand differences in bioimpedance between limbs in uninjured young people. The current study seeks to address these questions utilizing an electrode placement similar to that suggested by Loyd et al. for monitoring knee swelling after TKA.<sup>2</sup> Knee bioimpedance measurements in uninjured young adults were collected in combination with a clinical

patient reported knee function score. These data were analyzed to examine the influence of factors such as sex, BMI, age and knee function score on baseline limb to limb differences in knee bioimpedance. This information will be helpful in defining how to use this tool in monitoring knee injuries in younger patients.

## METHODS

This study involved two series of experiments. The first set aimed to examine the repeatability of the measurement method and the second set aimed to determine baseline bioimpedance measurements for healthy volunteers. The protocols for each set of experiments and the informed consent documents and method of consent were reviewed and approved by the Kettering University IRB# 00008588. All subjects gave verbal informed consent. This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

### Repeatability of Bioimpedance Measurements

The first series evaluated the short term repeatability of the measurement method. These tests involved taking repeated measures across 4 subjects. Each subject was measured 3 times on a single day by a single evaluator, taking approximately 2 to 4 minutes per measurement, then the process was repeated 2 more times with approximately 10 minutes between trials.

To measure resistance and reactance, an RJL Systems Quantum Legacy Body Composition Analyzer was used. The participants were instructed to lie supine on the non-conductive exam table with legs outstretched and separated. One set of electrode pads was placed on the foot and were separated by about 10 cm (one pad on the dorsum of the foot proximal to the second and third digits and the second on the ankle bisecting the medial malleolus). The second set of electrode pads was placed on the lateral thigh (one at the midpoint between the greater trochanter and proximal pole of the patella and the second 10 cm distal to the first). Electrodes were placed and resistance and reactance values were recorded for each leg by one researcher (P.A.).

Measures were repeated one week later, where subjects reported no change in perceived knee function or health between these time points. The repeated tests from a single day were then used to estimate the test to test coefficient of variation for each measure, with COV < 5% considered excellent. The repeatability over time was assessed using the intra-rater correlation coefficient (ICC), with values greater than 90% indicative of excellent reliability.<sup>23</sup>

### Bioimpedance Measurements of Healthy Volunteers

The second test series measured impedance in a convenience sample of volunteers recruited at an athletic facility at Kettering University. Data was collected prospectively. Subjects that meet the following inclusion criteria were considered for this study: persons who were 18 years of age or older, absence of an electronic implantable medical device such as a pacemaker, implantable cardiac defibrillators, or spinal cord stimulators (devices which were contraindicated for bioimpedance per the meter manufacturer), no knee injury or surgery within the last year, and absence of artificial joints in the leg. Subjects were also excluded if they had engaged in exercise/sporting activities prior to recruitment on that day, in order to eliminate variability due to exercise induced muscle perfusion. Upon recruitment, subjects were asked to self-report sex, age, height, weight, and limb dominance as well as complete a Knee Injury and Osteoarthritis Score (KOOS JR) survey. This survey is a standard questionnaire commonly used to evaluate knee pain and function in orthopedic patients and consists of 7 questions scored on a scale of 0-4, with a maximum score of 28 points (indicative of excellent knee function). After obtaining informed consent for eligible subjects, a total of 73 subjects (65.8% male) were studied with a mean age of 25.1 (range, 18 to 72 yr). Impedance measurements followed the same method used in the repeatability study. Each subject's thigh circumference was also measured using a measuring tape wrapped around the thigh at the location of the proximal electrode pad. This process was repeated for both legs.

Comparisons of demographic information between men and women utilized a Mann-Whitney Rank Sum test, after a Shapiro-Wilk test showed the data was non-normal. Multi-factor linear regression was utilized to examine relationships between impedance measurements,

circumference measurements, magnitude differences in measures between subject's legs, age, sex, BMI, KOOS-JR scores. All analysis was performed using SigmaStat (Systat Software, Inc. San Jose CA).

## RESULTS

### Reproducibility Trials

The pooled mean standard deviation for resistance was 3.456, with a mean COV for resistance measured in the three repeat trials on 8 limbs of 1.5%. The pooled mean standard deviation for reactance was 1.004, with a mean COV of 3.6%. The mean difference in reactance was 1.258 and for resistance was 7.025 for the first day's trials. In the repeat trial one week later on the same 4 people the pooled mean standard deviation for the reactance and resistance were 1.399 and 1.943, respectively. The COV for resistance was 0.08% and for reactance it was 5.1%. The ICC was 98.5% for reactance (week to week average right leg readings for 4 subjects) and 97.9% for resistance, indicating that the readings were highly consistent.

### Bioimpedance Measurements for Healthy Volunteers

The groups of men and women in the study sample were similar in regard to age and KOOS-JR scores and while the women had lower BMI scores this was not statistically significant (Table 1). Women exhibited significantly larger dominant limb impedance and larger limb to limb difference in impedance than men, but this difference decreased when normalized by dominant limb impedance (Table 1). While the difference in impedance between the limbs was significantly larger in women versus men, the normalized differences were relatively small, an average of 3.67% overall (Table 1). The men tended to have a higher reactance than the women for a similar resistance (Figure 1). Multi-factor linear regression showed impedance values for the limb on the subject's dominant side were influenced by subject sex

**Table 1. Demographic Information and Average Impedance Measurements for the Sample Groups**

	Male n=48 median (Q1; Q3)	Female n=25 median (Q1; Q3)	p
BMI	25.6 (22.5; 29.8)	24.0 (20.4; 27.0)	p=0.067
KOOS JR	28 (26; 28)	28 (26; 28)	p=0.655
AGE	21 (19; 23.75)	21 (20; 22)	p=0.873
Dom. Limb Imped.	189.2 (170.2; 204.8)	233. (215.9; 247.1)	p<0.001
IMP. DIFFERENCE	5.41 (1.79; 8.37)	8.04 (4.44; 16.41)	p=0.015
% IMP. Difference	2.94% (1.14; 4.66)	3.66% (1.89; 7.59)	p=0.089

**Table 2. Multi-Linear Regression Analysis to Fit Limb to Limb Difference in Impedance and Percent Difference in Impedance**

	Model: $\Delta$ Imp. coef (Std Error)	P	Model: % $\Delta$ Imp. coef*100 (Std Error)	P
Sex	3.84 (1.41)	0.008	1.23 (0.066)	0.069
Age	-0.03 (0.06)	0.645	-0.01 (0.003)	0.673
BMI	-0.20 (0.13)	0.140	-0.06 (0.006)	0.375
KOOS-JR	-0.60 (0.21)	0.005	-0.26 (0.010)	0.009
Thigh Diff.	1.67 (0.66)	0.014	0.76 (0.031)	0.018

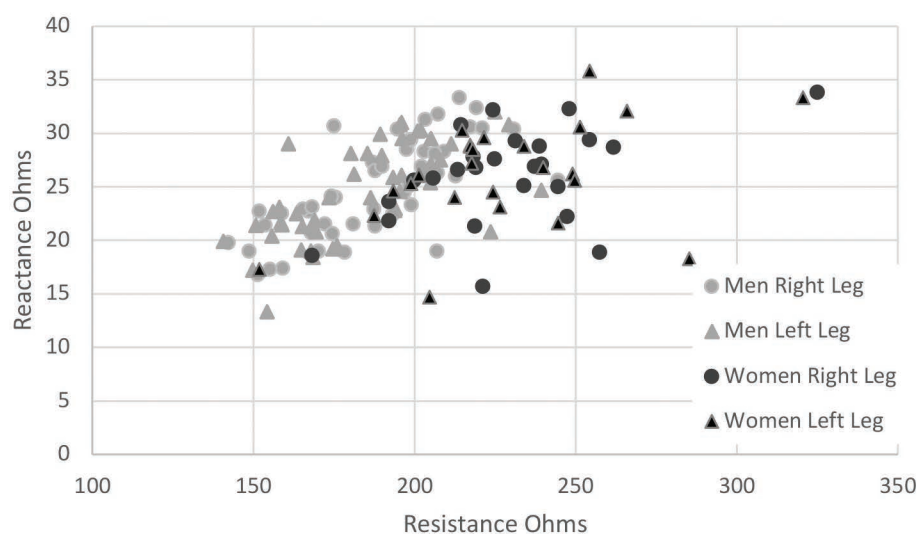


Figure 1. Resistance (R) and reactance (Z) values for subjects, impedance =  $\sqrt{(R^2 + Z^2)}$ .

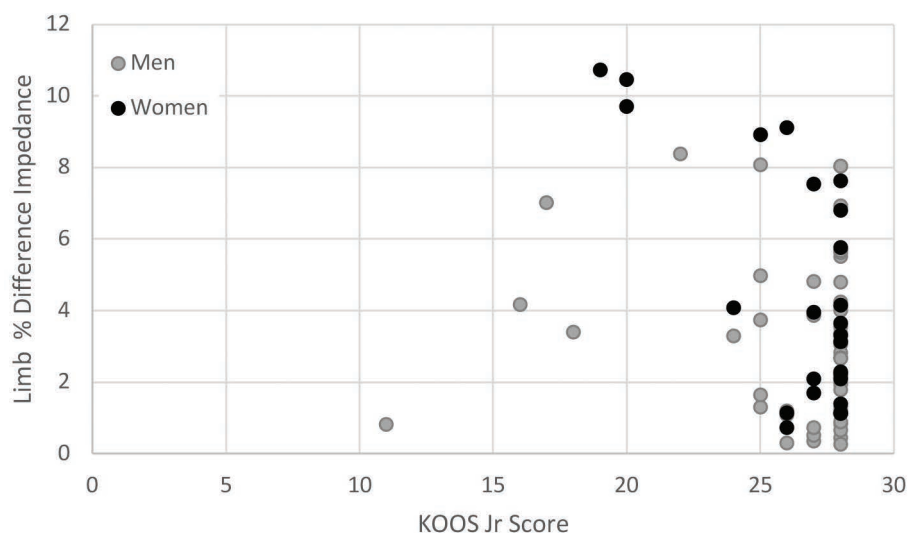


Figure 2. Relationship between joint score and difference in impedance between the subject's limbs.

and BMI ( $p < 0.001$  for both), but not age and KOOS-JR score. When regression was utilized to identify factors associated with limb to limb difference in impedance the model fit was significant (ANOVA  $p < 0.001$ ) and sex, KOOS-JR score, and difference in thigh circumference were significant factors (Table 2). Similarly, when percent difference in impedance was considered KOOS-JR and difference in thigh circumference were significant. However, when the percent difference was plotted versus the joint score, the graph showed this relationship was associated with the data from women, however this was based on influence from a relatively small number of subjects with low joint scores, and not in the data from men (Figure 2).

## DISCUSSION

Limb swelling is a common factor observed after knee injury. Resolution of swelling is commonly regarded as an indicator of recovery and readiness to return to normal activity levels. Bioimpedance measurements across the knee joint have been proposed as an objective measure of swelling and healing. The current study provides mean and average bioimpedance values measured across the knee for uninjured, young men and women. The data also shows that the difference in impedance between uninjured limbs is small, with an average percent difference of less than 5%. These values may help identify or quantify swelling in young patients. The study data also suggests that the percent difference in bioimpedance increases with decreasing KOOS-JR score, suggesting that

lower knee function is associated with larger differences between the limbs. The difference in thigh circumference had a similar association. These data help confirm that percent difference in bioimpedance has an association with functional differences.

Healthy baseline data that can be used in identifying knee swelling in young patients is limited. Ward et al. retrospectively examined lower limb impedance to develop a reference range for lymphedema in a large group of 172 females and 150 male healthy volunteers.<sup>24</sup> They found that women exhibited higher resistance than men and no difference in impedance with BMI or age, similar to the current study. Their study found that the ratio of dominant to non-dominant leg impedance averaged at 0.999 in 172 females and 0.994 in 150 male healthy volunteers, unlike the current study that showed females had larger limb to limb differences. However, the data set analyzed by Ward et al. was from an earlier study not focused on knee function, so there is no measure of knee health included. Additionally, the measurements came from electrodes placed across the body at foot and opposite side hand, rather than across the knee joint.<sup>24</sup> This is different from more recent methods proposed for monitoring knee swelling where electrodes are placed for direct measurement across the joint. York et al. found that cross body equipotential bioimpedance yielded significantly higher measures than measures made directly across the limb.<sup>15</sup> More recently Loyd proposed a standard bioimpedance curve for monitoring swelling following TKA using an ankle and thigh electrode placement.<sup>2</sup> The current study utilized a similar placement and found that this produced a highly repeatable measurement. However, Loyd et al.'s study found a smaller average difference between limbs (mean 1.01% and standard deviation 7.93 at baseline as compared to 3.67% and standard deviation 2.77 for men and women in the current study combined), which may be due to differences in knee health and activity level in this study's relatively young population as compared to a population of total knee arthroplasty patients.<sup>2</sup> In a study involving younger subjects more typical of an athletic population, Hersek et al. examined impedance across the knee in healthy volunteers (27 male and 15 female) in comparison to 7 subjects with knee injuries.<sup>14</sup> They found subjects with injured knees exhibited significantly larger differences between injured and non-injured limbs for both resistance and reactance, with limb to limb difference decreasing over time. This is similar to the finding in the current study that the difference in impedance increased in women with lower knee function scores, but this trend was not observed in the male subjects.

In the current study there was not a one to one relationship between knee function and difference in bio-

impedance, as there were persons with lower KOOS-JR scores and relatively low differences in bioimpedance as shown in Figure 2. This may be due to a ceiling effect associated with the KOOS-JR and a score more sensitive to something like ACL function may provide more clear differentiation of cases.<sup>25</sup> Additionally, the study sought healthy young volunteers so there were fewer subjects with low function scores. A sample focused on this group might provide more information on the relationship. On the other hand, the data does demonstrate that limb to limb differences are small in persons who have high function scores and who have not experienced a recent knee injury.

The current study has a number of limitations. The data presented was sampled from a non-random population using an athletic facility. However, this active population may be representative of typical active young people. While people in the study self-certified that they had no recent injury and considered themselves healthy, the KOOS-JR scores ranged from 11 to the peak score of 28, and were highly clustered at the peak score showing a strong ceiling effect. Also, the KOOS-JR score is used most frequently for assessing total joints and was selected for use here based on the brevity and simplicity of the score. Another joint score specific to ACL function may be better able to differentiate differences. Further, the measurement occurred across two joints (ankle and knee), while this was done to match methods used in prior studies the inclusion of the ankle in the measurement path assumes a healthy, uninjured ankle. Additionally, the sample size was relatively small. A larger sample drawn from a broader group may help illustrate the relationship between baseline, uninjured bioimpedance and knee function.

## CONCLUSION

The current study demonstrates that this low cost bioimpedance measurement at the knee is a relatively quick and repeatable measurement. The limb to limb differences are relatively small in the majority of uninjured young people, supporting the use of comparing injured limb bioimpedance to a contralateral uninjured limb as a method for tracking recovery. However, persons with lower joint function scores prior to injury may have larger pre-injury differences and this may make this approach less appropriate. Future work should focus on determining whether this tool can provide useful clinical information to help make return to sporting activity decisions for young patients.



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# RETURN TO SPORT AFTER KNEE INJURIES IN COLLEGIATE WRESTLING

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## ABSTRACT

**Background:** Wrestling is known to be a sport of relatively high injury incidence, and knee injuries account for a large percentage of those injuries. Treatment of these injuries varies considerably depending on injury and wrestler characteristics, leading to variability in complete recovery and return to sport (RTS). The purpose of this study was to evaluate injury trends, treatment strategies, and RTS characteristics after knee injuries in competitive collegiate wrestling.

**Methods:** NCAA Division I collegiate wrestlers who sustained knee injuries between January 2010 and May 2020 were identified using an institutional Sports Injury Management System (SIMS). Wrestling-related knee, meniscus, and patella injuries were identified, and treatment strategies were documented to investigate potential recurrent injury trends. Descriptive statistics were used to quantify the number of days, practices, and competitions missed, return to sport times, and recurrent injuries among wrestlers.

**Results:** Overall, 184 knee injuries were identified. After excluding non-wrestling injuries (n=11), 173 injuries remained (77 wrestlers). The mean age at time of injury was  $20.8 \pm 1.4$  years, and the mean BMI was  $25.9 \pm 3.8$  kg/m<sup>2</sup>. There were 135 primary injuries (74 wrestlers), which consisted of 72 (53%) ligamentous injuries, 30 (22%) meniscus injuries, 14 patellar injuries (10%), and 19 other injuries (14%). The majority of ligamentous injuries (93%) and patellar injuries (79%) were treated non-operatively, while the majority of meniscus tears (60%) underwent surgery. Twenty-three wrestlers (22%) sustained recurrent knee injuries, of

which 76% were treated non-operatively after their initial injury. Recurrent injuries consisted of 12 (32%) ligamentous injuries, 14 (37%) meniscus injuries, eight (21%) patellar injuries, and four (11%) other injuries. Fifty percent of recurrent injuries were treated operatively. When comparing recurrent injuries to primary injuries, recurrent injuries had a significantly longer return to sport time (Recurrent  $68.3 \pm 96.0$  days vs. Primary  $26.0 \pm 56.4$  days,  $p=0.01$ ).

**Conclusion:** The majority of NCAA Division I collegiate wrestlers who sustained knee injuries were initially treated non-operatively, and approximately one in five wrestlers sustained recurrent injuries. Return to sport time was significantly increased after a recurrent injury.

**Level of Evidence:** IV

**Keywords:** wrestling, knee injury, return to sport

## INTRODUCTION

Lower extremity injuries represent 30-40% of the total injuries faced by collegiate wrestlers.<sup>1</sup> Understanding the nature of lower extremity injuries, as well as the recovery process, is crucial in maintaining an athlete's short- and long-term health.<sup>2</sup> Knee injuries, in particular, account for nearly 25% of all wrestling injuries, which is the highest percent for any single area of the body.<sup>1,3,4</sup> Common ailments include prepatellar bursitis, meniscus tears, ligamentous injuries, and others.<sup>5,7</sup> When indicated, surgical management of knee injuries often carries a significant recovery burden and complication risk, as compared to conservative management. Frequently cited return to sport (RTS) times for common knee surgeries include 4-6 weeks for meniscus repair and 8-12 months for ACL reconstructions.<sup>8,9</sup>

In 1986, Wroble et al. investigated patterns of collegiate wrestler knee injuries and identified several factors that affect the incidence and longevity of knee injuries, including the competition environment, duration of season, previous injuries, high-speed maneuvers, team rank, and treatment compliance.<sup>5</sup> RTS times after wrestling knee injuries were not assessed. Few studies have evaluated knee injury trends and RTS times in intercollegiate wrestling.<sup>2,4,10,11</sup> Better understanding of common knee injuries, treatment patterns, and RTS times will

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help inform sports medicine providers and wrestlers. The purpose of this study was to evaluate injury trends, treatment strategies, and RTS characteristics after knee injuries in competitive collegiate wrestling.

## METHODS

National Collegiate Athletic Association (NCAA) Division I collegiate wrestlers who sustained knee injuries between January 2010 and May 2020 were identified using an institutional Sports Injury Management System (SIMS). Wrestling-related knee, meniscus, and patella injuries were identified, and treatment strategies were documented to investigate potential recurrent injury trends. A wrestling-related knee injury was defined as an injury to the knee region that was sustained during a typical maneuver during practice or competition. Data regarding concurrent injuries (ligament + meniscus) were not available. Injuries were categorized as primary (initial injury) or recurrent. A recurrent injury was defined as an identical injury diagnosed on the same knee, regardless of time between injuries. The management of each injury was documented, including all conservative and surgical treatments. Data collected included age, height, weight, weight class, year of eligibility (Freshman, Sophomore, etc.), and laterality of injury. Data regarding race, so-

cioeconomic status, and other social factors were not available. Primary outcomes were the number of days, practices, and competitions missed, time to return to sport, and any recurrent injuries. Return to sport (RTS) time was defined as the number of days between the removal of the athlete from participation and the return to full-contact practice and/or competition activities. Descriptive statistics were used to report the results.

## RESULTS

### Wrestling Injury Characteristics

Overall, 184 knee injuries were identified. Eleven were excluded as non-sports related injuries, which left a total of 173 injuries from 77 wrestlers. The mean age at time of injury was  $20.8 \pm 1.4$  years. The average BMI was  $25.9 \pm 3.8$  kg/m<sup>2</sup>. Ninety-five injuries were right-sided and 78 were left-sided. Data regarding the dominant or lead leg was not available. Fifty-seven injuries occurred in a competitive environment while 116 were during practice. There were 103 injuries (60%, 47 athletes) in the lower weight classes (<174 lbs.) and 70 injuries (40%, 30 athletes) in the upper weight classes ( $\geq 174$  lbs.). Injuries were distributed between years of eligibility relatively evenly (Freshman 39, Sophomore 44, Junior 36, Senior 31, Fifth-year 23). The total distribution of knee injuries identified are presented in Table 1.

**Table 1. Total Knee Injuries in NCAA Division I Wrestlers**

Knee Ligament Injuries	84 injuries (49%)
Lateral Collateral Ligament (LCL)	40 (48%) - 33 Grade 1, 7 Grade 2, 0 Grade 3
Medial Collateral Ligament (MCL)	30 (36%) - 18 Grade 1, 11 Grade 2, 1 Grade 3
Anterior Cruciate Ligament (ACL)	11 (13%) - 1 Grade 1, 1 Grade 2, 9 Grade 3
Posterior Cruciate Ligament (PCL)	3 (4%) - 2 Grade 1, 0 Grade 2, 1 Grade 3
Meniscus Injuries	44 injuries (25%)
Medial meniscus tears	23 (52%)
Lateral meniscus tears	17 (39%)
Hypermobility posterolateral meniscus	2 (5%)
Medial meniscus cyst	1 (2%)
Meniscus inflammation	1 (2%)
Patellar Injuries	22 injuries (13%)
Bursitis	12 (55%)
Contusion	6 (27%)
Patellar subluxation	3 (14%)
Cartilage damage	1 (5%)

Number (%) of total knee ligament, meniscus, and patellar injuries in NCAA Division I wrestlers.

**Table 2. Incidence of Primary Knee Injuries in NCAA Division I Wrestlers**

Knee Ligament Injuries	72 injuries (53%)
Lateral Collateral Ligament (LCL)	37 (51%) - 30 Grade 1, 7 Grade 2, 0 Grade 3
Medial Collateral Ligament (MCL)	26 (36%) - 18 Grade 1, 7 Grade 2, 1 Grade 3
Anterior Cruciate Ligament (ACL)	6 (8%) - 1 Grade 1, 0 Grade 2, 5 Grade 3
Posterior Cruciate Ligament (PCL)	3 (4%) - 2 Grade 1, 0 Grade 2, 1 Grade 3
Primary Meniscus Injuries	30 injuries (22%)
Medial meniscus tears	17 (57%)
Lateral meniscus tears	12 (40%)
Medial meniscus cyst	1 (3%)
Primary Patellar Injuries	14 injuries (10%)
Bursitis	7 (50%)
Contusion	4 (29%)
Patellar subluxation	2 (14%)
Cartilage damage	1 (7%)

Number (%) of primary knee ligament, meniscus, and patellar injuries in NCAA Division I wrestlers.

**Table 3. Incidence of Recurrent Knee Injuries in NCAA Division I Wrestlers**

Recurrent Knee Ligament Injuries	12 injuries (32%)
Lateral Collateral Ligament (LCL)	3 (25%) - 3 Grade 2
Medial Collateral Ligament (MCL)	4 (33%) - 4 Grade 2
Anterior Cruciate Ligament (ACL)	5 (42%) - 1 Grade 2, 4 Grade 3
Recurrent Meniscus Injuries	14 injuries (37%)
Medial meniscus tears	6 (42%)
Lateral meniscus tears	5 (36%)
Hypermobile posterolateral meniscus	2 (14%)
Meniscus inflammation	1 (7%)
Recurrent Patellar Injuries	8 injuries (21%)
Bursitis	5 (63%)
Contusion	2 (25%)
Patellar subluxation	1 (13%)

Number (%) of recurrent knee ligament, meniscus, and patellar injuries in NCAA Division I wrestlers.

There were 135 primary injuries (74 wrestlers), which consisted of 72 (53%) ligamentous injuries, 30 (22%) meniscus injuries, 14 (10%) patellar injuries, and 19 (14%) other injuries. The other injuries included seven contusions, three hyperextension injuries, two popliteus strains, two cases of ilio-tibial band syndrome, and one each of biceps femoris strain, parameniscal cyst, prepatellar fat pad irritation, puncture wound, and degeneration. Primary knee ligamentous injuries consisted of 37 lateral collateral ligament (LCL), 26 medial collateral ligament (MCL), six anterior cruciate ligament (ACL), and three posterior cruciate ligament (PCL) injuries (Table 2).

Twenty-three wrestlers (22%) sustained a recurrent injury (38 total injuries), of which 76% were initially treated with non-operative measures after their primary injury. Recurrent injuries consisted of 12 (32%) ligamentous injuries, 14 (37%) meniscus injuries, eight (21%) patellar injuries, and four (11%) other injuries. The other injuries included one each of knee joint arthritis, general pain/inflammation, knee joint loose bodies, and anterior subluxation. Recurrent knee ligamentous injuries consisted of three LCL, four MCL, five ACL, and no PCL injuries (Table 3).

### Treatment of Wrestling Injuries

Overall, the majority of wrestling injuries identified were treated conservatively (n=128, 74%). Eighty-one per-

**Table 4. Return to Sport Times By Injury Characteristic in NCAA Division I Wrestlers**

Recurrency	N	Mean	SD	Median	Range	P-Value
Recurrent	38	68.3	96.0	27.0	0.0-361.0	0.01
Non-recurrent	135	26.0	56.4	6.0	0.0-312.0	
Treatment						
Non-operative	128	12.5	24.7	3.0	0.0-165.0	<0.001
Operative	45	100.9	105.5	55.0	6.0-361.0	
Setting						
Competition	57	36.6	69.7	9.0	0.0-300.0	0.89
Practice	116	35.0	69.7	8.0	0.0-361.0	
Weight Class						
Upper Weight Classes	70	34.3	69.0	9.0	0.0-361.0	0.86
Lower Weight Classes	103	36.3	70.1	8.0	0.0-341.0	

Return to Sport Times By Injury Characteristic, in days. N, number of wrestlers; SD, standard deviation.

cent of primary injuries were treated with non-operative measures, and the remaining 26 injuries were treated surgically (19%). The majority of primary ligamentous injuries identified (67, 93%) were treated non-operatively with physical therapy (32 wrestlers), corticosteroid injection (four wrestlers), or other measures (i.e., ice, medication, etc.). The remaining five wrestlers underwent ACL reconstruction. The majority of meniscus tears (18, 60%) were treated operatively, including 13 partial meniscectomies, four meniscus repairs, and one synovectomy. Eleven of 14 patellar injuries (79%) were treated conservatively with either physical therapy, corticosteroid injection, or other measures. Fifty percent of recurrent knee injuries were treated operatively. Four of five (80%) recurrent ACL injuries underwent ACL reconstruction, while 12 of 14 recurrent meniscus tears underwent knee arthroscopy with partial meniscectomy (75%) vs. meniscus repair (25%). Of the eight identified recurrent patellar injuries, six were treated non-operatively, including four with corticosteroid injections or knee joint aspiration.

### Return to Wrestling

Overall, mean RTS time was  $35.5 \pm 69.7$  days for all injuries (Table 4). The mean number of practices and competitions missed were  $10.1 \pm 20.8$  and  $2.6 \pm 5.8$ , respectively. Mean RTS time for knees treated non-operatively was  $12.5 \pm 24.7$  days vs.  $100.9 \pm 105.5$

**Table 5. Return to Sport Times of LCL and MCL Injuries by Grade in NCAA Division I Wrestlers**

LCL	N	Mean	SD	Median	Range	P-Value
Grade 1	33	6.0	6.6	4.0	0.0-20.0	0.02
Grade 2/3	7	34.7	22.1	39.0	3.0-66.0	
MCL						
Grade 1	18	6.4	7.29	4.5	0.0-30.0	<0.001
Grade 2/3	12	27.7	14.9	27.0	7.0-55.0	

Return to Sport Times of LCL and MCL Injuries by Grade, in days. N, number of wrestlers; SD, standard deviation.

days for injuries treated operatively. For ACL injuries, non-operative RTS (n=2) was  $161.5 \pm 3.5$  days, or  $5.3 \pm 0.1$  months, while operative RTS (n=9) was  $290.9 \pm 46.3$  days, or  $9.5 \pm 1.5$  months. All other ligamentous injuries were treated conservatively. There was an average gap between injury and removal from play of  $2.3 \pm 8.4$  days, and for those that underwent surgery, a gap of  $36.9 \pm 58.5$  days between injury and surgery.

There were no differences in RTS time between injuries sustained in the practice and competition environments, nor was there a difference between the upper and lower weight classes. Grade 1 LCL injuries had a significantly shorter RTS than grade 2 or 3 LCL injuries ( $6.0 \pm 6.6$  days vs  $34.7 \pm 22.1$  days, or  $0.9 \pm 0.9$  weeks vs  $5.0 \pm 3.1$  weeks,  $p=0.02$ ). Similarly, Grade 1 MCL injuries had a significantly shorter RTS than grade 2 or 3 MCL injuries ( $6.4 \pm 7.3$  days vs  $27.7 \pm 14.9$  days, or  $0.9 \pm 1.0$  weeks vs  $4.0 \pm 2.1$  weeks,  $p<0.001$ ) (Table 5). Mean RTS time after partial meniscectomy was significantly shorter than meniscus repair procedures ( $37.0 \pm 23.7$  days vs.  $92.4 \pm 58.0$  days,  $p=0.03$ ). When comparing recurrent injuries to primary injuries, recurrent injuries had a significantly longer RTS time (Recurrent  $68.3 \pm 96.0$  days vs. Primary  $26.0 \pm 56.4$  days,  $p=0.01$ ).

## DISCUSSION

Knee injuries continue to be one of the most common and significant injuries among collegiate wrestlers. In this study, we found that athletes with knee injuries missed an average of 36 days, but that number varied widely depending on the characteristics of the injury.

This study suggests that a large percent of knee injuries in collegiate wrestlers are acute, non-recurrent injuries that can be treated non-operatively. While more injuries occurred during practice compared to competition, there was no difference in RTS between the two. This could likely be due to the greater time spent in practice but is potentially counterbalanced by the greater intensity of wrestling seen during competition.

Stratification into injury types and recurrent versus primary injuries helped more accurately analyze injury and treatment trends, but decreased study power. Ligamentous injuries were more likely to be primary injuries (52% of all primary injuries versus 32% of all recurrent injuries), whereas meniscus injuries were found to be recurrent more often (22% of primary vs 37% of recurrent), and patellar injuries also followed this trend (10% of primary vs 21% of recurrent). The vast majority of recurrent meniscus injuries were treated with surgery (12 of 14).

Meniscus injuries that were treated non-operatively recovered quicker than surgical cases. Among the surgical cases, those that underwent meniscectomy returned faster than those who underwent meniscus repair. This is expected given the nature and invasiveness of each treatment type. Meniscus repair surgeries require a longer non-weightbearing period to ensure proper healing, and therefore experience more muscle atrophy and associated longer RTS. Knowing this, medical personnel can be assured that among meniscus injuries, RTS times align with the extent of injury and intensity of treatment. Patellar injuries did not show a difference between non-operative and operative treatments, suggesting that less invasive treatment should be performed when possible, as this study found no difference in recovery times.

In this study's cohort, most ACL injuries were treated operatively while all LCL, MCL, and PCL injuries were treated conservatively. In both LCL and MCL injuries, grade 1 sprains returned to sport quicker than grade 2 or 3 injuries. A larger sample size with a greater variation of treatment is needed to fully appreciate any further differences in RTS as well as other recovery and injury characteristics.

There are several limitations to this study. The retrospective nature of the study limits its applicability to current clinical practice and makes it susceptible to changes in practice and procedures throughout the 10-year time period of chart review. Additionally, this study grouped several injury characteristics and specifics for analysis. This was accounted for by stratifying select injury and treatment variables for subgroup analysis. Identification of patients based off the SIMS database may not have included all injuries within the study's timeframe and did not include injuries prior to college. Wrestler race, socioeconomic status, and other social factors were not accounted for in this study. Several non-operative injuries lacked imaging and are thus presumptive diagnoses. The number of days missed in this study were reported as the days between removal from play and return to full-contact participation; however, there is the possibility of variation between athletes and injuries including delays in reporting and treatment, the usage of bracing

or pain medications, and other similar factors. These inherently impact removal from and return to play and, therefore, RTS. Additionally, timing of treatment and RTS is affected by the timing of the injury relative to the competitive schedule. Finally, this study is limited by its cohort of collegiate wrestlers at a single institution.

Subsequent studies should strive to compare management of knee injuries in wrestlers across several institutions and age ranges to improve external application potential. A larger cohort would also allow expansion on areas that showed variation of treatment, such as meniscus and patella injuries, and would allow for comparison of RTS and management results across several institutions to incorporate varying treatment philosophies.

### CONCLUSION

Knee injuries are common in wrestlers and can lead to significant time away from sport. Each injury is influenced by several factors that can lead to variations in return to sport and should be addressed in the context of each athlete. This study can be used to help guide clinical judgement and adjust treatment algorithms for future knee injuries in wrestlers.

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# FOOD INSECURITY IS COMMON IN THE ORTHOPEDIC TRAUMA POPULATION AT A RURAL ACADEMIC TRAUMA CENTER

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## ABSTRACT

**Background:** Food insecurity is an increasingly recognized public health issue. Identifying risk factors for food insecurity would support public health initiatives to provide targeted nutrition interventions to high-risk individuals. Food insecurity has not been investigated in the orthopedic trauma population.

**Methods:** From April 27, 2021 to June 23, 2021, we surveyed patients within six months of operative pelvic and/or extremity fracture fixation at a single institution. Food insecurity was assessed using the validated United States Department of Agriculture Household Food Insecurity questionnaire generating a food security score of 0 to 10. Patients with a food security score  $\geq 3$  were classified as Food Insecure (FI) and patients with a food security score  $< 3$  were classified as Food Secure (FS). Patients also completed surveys for demographic information and food consumption. Differences between FI and FS for continuous and categorical variables were evaluated using the Wilcoxon sum rank test and Fisher's exact test, respectively. Spearman's correlation was used to describe the relationship between food security score and participant characteristics. Logistic regression was used to determine the relationship between patient demographics and odds of FI.

**Results:** We enrolled 158 patients (48% female) with a mean age of  $45.5 \pm 20.3$  years. Twenty-one patients (13.3%) screened positive for food insecurity (High security:  $n=124$ , 78.5%; Marginal security:  $n=13$ , 8.2%; Low security:  $n=12$ , 7.6%; Very Low security:  $n=9$ , 5.7%). Those with a household income level of  $\leq \$15,000$  were 5.7

times more likely to be FI (95% CI 1.8-18.1). Widowed/single/divorced patients were 10.2 times more likely to be FI (95% CI 2.3-45.6). Median time to the nearest full-service grocery store was significantly longer for FI patients ( $t=10$  minutes) than for FS patients ( $t=7$  minutes,  $p=0.0202$ ). Age ( $r= -0.08$ ,  $p=0.327$ ) and hours working ( $r= -0.10$ ,  $p=0.429$ ) demonstrated weak to no correlation with food security score.

**Conclusion:** Food insecurity is common in the orthopedic trauma population at our rural academic trauma center. Those with lower household income and those living alone are more likely to be FI. Multicenter studies are warranted to evaluate the incidence and risk factors for food insecurity in a more diverse trauma population and to better understand its impact on patient outcomes.

**Level of Evidence:** III

**Keywords:** food insecurity, trauma, nutrition, incidence

## INTRODUCTION

Malnutrition is an increasingly recognized risk factor for adverse outcomes following musculoskeletal trauma. The incidence of malnutrition in the orthopedic trauma population has been reported as 18% to 45%,<sup>14</sup> but previous investigations have focused almost exclusively on the geriatric population. Other studies in both orthopedic and non-orthopedic populations have identified malnutrition as a risk factor for mortality, non-union, wound complications, readmission, and increased healthcare costs.<sup>5-13</sup>

Malnutrition has a clear adverse effect on public health. One likely contributor to this multifactorial issue is food insecurity. The United States Department of Agriculture (USDA) defines food insecurity as a limited or uncertain availability of safe, nutritious foods and/or difficulty obtaining such foods.<sup>14,15</sup> This often results in poor dietary intake and has been associated with diet-related comorbidities such as type II diabetes mellitus that are known to impair healing.<sup>16</sup> As of 2018, food insecurity was identified in 11.1% of households in the United States and noted to disproportionately impact high risk populations such as low-income communities and communities of color.<sup>17</sup>

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Food insecurity is common nationwide and serves as a potentially modifiable risk factor for many of the adverse effects of malnutrition. However, the prevalence of food insecurity in the orthopedic trauma population is not yet characterized. Better understanding the commonality of this problem and its associated risk factors will allow healthcare providers to develop more targeted nutritional interventions to aid in healing and, in turn, significantly improve outcomes following musculoskeletal trauma. The present study aims to evaluate the prevalence of food insecurity and its associated risk factors in the orthopedic trauma population at a rural academic medical center.

METHODS

This cross-sectional study was approved by our Investigational Review Board as a quality improvement project and the surveys were completed from April 27, 2021 to June 23, 2021. We recruited patients who underwent operative fixation of an acute pelvic or extremity injury by one of four board certified trauma surgeons at a single Midwest academic level I trauma center (University of Iowa Healthcare). Patients within six months of injury completed the survey. Members of the research team approached potential enrollees both in the outpatient clinic and in the inpatient setting between surgery and discharge. The latter was intended to account for patients who may have difficulty attending follow-up appointments. There was no age restriction and verbal consent was obtained from all subjects and/or caregivers. In the case of patients under 18 years old, a parent or guardian gave verbal consent and, depending on the age of the child, completed the survey on behalf of the patient.

Surveys and Assessments

All patients responded to basic demographic questions as well as a food consumption survey (Figure 1). Food insecurity was assessed using the United States Department of Agriculture (USDA) Household Food Security questionnaire (Figure 2).<sup>14</sup> Based on patient responses, this questionnaire generates a numerical food security score ranging from 0 to 10. Scores of 0 indicate high security, 1 to 2 marginal security, 3 to 5 low security, and 6 to 10 very low security. Food insecurity was defined as a food security score  $\geq 3$ . For each subject enrolled, research team members also performed a chart review and calculated a Charlson Comorbidity Index (CCI) score estimating the patient’s 10-year survival percentage.<sup>18,19</sup>

Statistical Analysis

Descriptive statistics were calculated for all continuous variables for both the Food Secure (FS) and Food Insecure (FI) cohorts. This included age, CCI score, food

security score on the USDA Household Food Security Score, weekly hours worked, and time to nearest full-service grocery store. Categorical variables were also assessed including gender, ethnicity, household income level, education level, occupation, marital status, history of diabetes, and food consumption frequency. Differences between the FS and FI groups in continuous and categorical variables were evaluated using the Wilcoxon sum rank test and Fisher’s exact test, respectively. Spearman’s correlation coefficient was used to describe the relationship between food security score and participant characteristics. Odds ratios were calculated for the development of FI. Logistic regression was used to determine the relationship between patient demographics and odds ratio for FI.

RESULTS

Demographics

158 patients (76 females, 48%) completed the survey with a mean age of  $45.5 \pm 20.3$  years (range 4 to 89). Thirty-two patients declined to participate. Ninety-four percent of participants identified as white and 95% as neither Hispanic nor Latino. The median CCI score of all subjects was 1 (range 1 to 10) correlating to an estimated 96% 10-year survival.

Food Insecurity Assessment

Twenty-one patients (13.3%) screened positive for FI with scores  $\geq 3$  on the USDA Household Food Security questionnaire (Table 1). High food security was found

1) Approximately how long (in minutes) does it take to drive to your nearest full-service grocery store?	
2) How many times do you eat fast food or other ready-to-eat food ?	<input type="radio"/> Less than once per week <input type="radio"/> Once per week <input type="radio"/> 2-4 times per week <input type="radio"/> 5-6 times per week <input type="radio"/> Once per day <input type="radio"/> 2-3 times per day <input type="radio"/> More than 3 times per day
3) How often do you drink sugar-sweetened beverages (soda, sweetened iced tea, energy drinks, coffee drinks, sports drinks, fruit juice)?	<input type="radio"/> Less than once per week <input type="radio"/> Once per week <input type="radio"/> 2-4 times per week <input type="radio"/> 5-6 times per week <input type="radio"/> Once per day <input type="radio"/> 2-3 times per day <input type="radio"/> More than 3 times per day
4) How often do you eat vegetables, NOT including potatoes?	<input type="radio"/> Less than once per week <input type="radio"/> Once per week <input type="radio"/> 2-4 times per week <input type="radio"/> 5-6 times per week <input type="radio"/> Once per day <input type="radio"/> 2-3 times per day <input type="radio"/> More than 3 times per day
5) How often do you eat fruit, NOT including fruit juice?	<input type="radio"/> Less than once per week <input type="radio"/> Once per week <input type="radio"/> 2-4 times per week <input type="radio"/> 5-6 times per week <input type="radio"/> Once per day <input type="radio"/> 2-3 times per day <input type="radio"/> More than 3 times per day
6) How often do you eat protein containing foods (beef, chicken, pork, fish, eggs, Greek yogurt, cottage cheese, milk, protein supplements or shakes, beans or tofu)?	<input type="radio"/> Less than once per week <input type="radio"/> Once per week <input type="radio"/> 2-4 times per week <input type="radio"/> 5-6 times per week <input type="radio"/> Once per day <input type="radio"/> 2-3 times per day <input type="radio"/> More than 3 times per day

Figure 1. Food consumption survey.

These next questions are about the food eaten in your household in the last 12 months, since (current month) of last year and whether you were able to afford the food you need.

[IF ONE PERSON IN HOUSEHOLD, USE "I" IN PARENTHESES, OTHERWISE, USE "WE."]

Which of these statements best describes the food eaten in your household in the last 12 months:	<input type="radio"/> Enough of the kinds of food we want to eat <input type="radio"/> Enough but not always the kinds of food we want <input type="radio"/> Sometimes not enough to eat <input type="radio"/> Often not enough to eat <input type="radio"/> Don't Know or Refused
Now I'm going to read you several statements that people have made about their food situation. For these statements, please tell me whether the statement was often true, sometimes true, or never true for (you/your household) in the last 12 months-that is, since last (name of current month).	
[IF SINGLE ADULT IN HOUSEHOLD, USE "I," "MY," AND "YOU" IN PARENTHESES; OTHERWISE, USE "WE," "OUR," AND "YOUR HOUSEHOLD."]	
The first statement is "(I/we) worried whether (my/our) food would run out before (I/we) got money to buy more." Was that often true, sometimes true, or never true for (you/your household) in the last 12 months?	<input type="radio"/> Often true <input type="radio"/> Sometimes true <input type="radio"/> Never true <input type="radio"/> Don't Know or Refused
"The food that (I/we) bought just didn't last, and (I/we) didn't have money to get more." Was that often, sometimes, or never true for (you/your household) in the last 12 months?	<input type="radio"/> Often true <input type="radio"/> Sometimes true <input type="radio"/> Never true <input type="radio"/> Don't Know or Refused
"(I/we) couldn't afford to eat balanced meals." Was that often, sometimes, or never true for (you/your household) in the last 12 months?	<input type="radio"/> Often true <input type="radio"/> Sometimes true <input type="radio"/> Never true <input type="radio"/> Don't Know or Refused
In the last 12 months, since last (name of current month), did (you/you or other adults in your household) ever cut the size of your meals or skip meals because there wasn't enough money for food?	<input type="radio"/> Yes <input type="radio"/> No <input type="radio"/> Don't Know
How often did this happen-almost every month, some months but not every month, or in only 1 or 2 months?	<input type="radio"/> Almost every month <input type="radio"/> Some months but not every month <input type="radio"/> Only 1 or 2 months <input type="radio"/> Don't Know
In the last 12 months, did you ever eat less than you felt you should because there wasn't enough money for food?	<input type="radio"/> Yes <input type="radio"/> No <input type="radio"/> Don't Know
In the last 12 months, were you every hungry but didn't eat because there wasn't enough money for food?	<input type="radio"/> Yes <input type="radio"/> No <input type="radio"/> Don't Know
In the last 12 months, did you lose weight because there wasn't enough money for food?	<input type="radio"/> Yes <input type="radio"/> No <input type="radio"/> Don't Know
In the last 12 months, did (you/you or other adults in your household) ever not eat for a whole day because there wasn't enough money for food?	<input type="radio"/> Yes <input type="radio"/> No <input type="radio"/> Don't Know
How often did this happen-almost every month, some months but not every month, or in only 1 or 2 months?	<input type="radio"/> Almost every month <input type="radio"/> Some months but not every month <input type="radio"/> Only 1 or 2 months <input type="radio"/> Don't Know
Are there children under the age of 18 in the household?	<input type="radio"/> Yes <input type="radio"/> No
Thank you. This concludes the survey.	
SELECT APPROPRIATE FILLS DEPENDING ON NUMBER OF ADULTS AND NUMBER OF CHILDREN IN THE HOUSEHOLD.	
Transition into Child-Referenced Questions: Now I'm going to read you several statements that people have made about the food situation of their children. For these statements, please tell me whether the statement was OFTEN true, SOMETIMES true, or NEVER true in the last 12 months for (your child/children living in the household who are under 18 years old).	
"(I/we) relied on only a few kinds of low-cost food to feed (my/our) child/the children) because (I was/we were) running out of money to buy food." Was that often, sometimes, or never true for (you/your household) in the last 12 months?	<input type="radio"/> Often true <input type="radio"/> Sometimes true <input type="radio"/> Never true <input type="radio"/> Don't Know or Refused
"(I/we) couldn't feed (my/our) child/the children) a balanced meal, because (I/we) couldn't afford that." Was that often, sometimes, or never true for (you/your household) in the last 12 months?	<input type="radio"/> Often true <input type="radio"/> Sometimes true <input type="radio"/> Never true <input type="radio"/> Don't Know or Refused
"(My/Our child was/The children were) not eating enough because (I/we) just couldn't afford enough food." Was that often, sometimes, or never true for (you/your household) in the last 12 months?	<input type="radio"/> Often true <input type="radio"/> Sometimes true <input type="radio"/> Never true <input type="radio"/> Don't Know or Refused
In the last 12 months, since (current month) of last year, did you ever cut the size of (your child's/any of the children's) meals because there wasn't enough money for food?	<input type="radio"/> Yes <input type="radio"/> No <input type="radio"/> Don't Know
In the last 12 months, did (CHILD'S NAME/any of the children) ever skip meals because there wasn't enough money for food?	<input type="radio"/> Yes <input type="radio"/> No <input type="radio"/> Don't Know
How often did this happen-almost every month, some months but not every month, or in only 1 or 2 months?	<input type="radio"/> Almost every month <input type="radio"/> Some months but not every month <input type="radio"/> Only 1 or 2 months <input type="radio"/> Don't Know
In the last 12 months, did (your child/any of the children) ever not eat for a whole day because there wasn't enough money for food?	<input type="radio"/> Yes <input type="radio"/> No <input type="radio"/> Don't Know
In the last 12 months, (was your child/were the children) ever hungry but you just couldn't afford more food?	<input type="radio"/> Yes <input type="radio"/> No <input type="radio"/> Don't Know

Figure 2. USDA household food security questionnaire.

in 124 patients (78%), marginal security in 13 (8.2%), low security in 12 (7.6%), and very low security in 9 (5.7%).

## Risk Factors

Table 2 compares potential risk factors for FI. Among subjects who screened positive for FI, 67% (n=14) were female. Forty-five percent of food secure subjects were female (n=62). Mean age was  $43.86 \pm 15.36$  (range 22-80) in the FI cohort and  $45.50 \pm 20.16$  (range 4-89) in the FS cohort. There was no significant difference in patient demographics between the FS and FI groups. In the FI group, 81% of individuals identified as White and 70% identified as non-Hispanic. Mean CCI score for the FI and FS groups were  $1.14 \pm 1.65$  (range 0-6) and  $1.38 \pm 1.92$  (range 0-10), respectively (p=0.595).

There was a significant difference in household income level between the two groups such that patients with a household income  $\leq \$15,000$  were 5.7 times more likely to be FI (95% CI 1.8-18.1). Furthermore, patients who were widowed/single/divorced were 10.2 times more likely to be FI compared to those who are married or living with their partner (95% CI 2.3-45.6). Median time to travel to the nearest full-service grocery store was significantly longer for FI patients (t=10 minutes) compared to FS patients (t=7 minutes, p=0.0202). There was no significant difference between the groups in terms of gender, ethnicity, education level, hours worked per week, or diabetes history (Table 2). There was also no difference in food consumption practices between groups (Table 3).

Both time to grocery store and CCI score demonstrated statistically significant associations with food security score. Time to grocery store had a weak positive correlation (r=0.23, p=0.0041). CCI score also had a positive, yet weaker, association with food security score (r=0.16, p=0.0483). Patient age (r= -0.08, p=0.327) and hours worked per week (r= -0.10, p=0.429) demonstrated weak to no correlation with food security scores (Table 4).

Table 1. Food Security Scores on USDA Household Food Security Questionnaire

Security Level (USDA Score)	Number of Patients (%)
Food Secure	137 (86.7)
High (0)	124 (78)
Marginal (1-2)	13 (8.2)
Food Insecure	21 (13.3)
Low (3-5)	12 (7.6)
Very Low (6-10)	9 (5.7)



**Table 2. Risk Factors for Food Insecurity**

	Food Secure (%)	Food Insecure (%)	P-Value
Gender			0.072
Male	75 (55)	7 (33)	
Female	62 (45)	14 (67)	
Ethnicity			0.2879
Hispanic or Latino	6 (4)	2 (10)	
Not Hispanic or Latino	131 (96)	19 (90)	
Education Level*			0.8843
Some College to Professional	80 (59)	12 (57)	
No College	56 (41)	9 (43)	
Yearly Household Income*			<0.0001
≤ \$15,000	13 (12)	13 (65)	
> \$15,000	95 (88)	7 (45)	
Marital Status			0.0006
Married/Partnered	65 (47)	1 (5)	
Single/Divorced/Widowed	72 (53)	20 (95)	
Diabetes*			0.2671
Yes	14 (10)	4 (19)	
No	122 (90)	17 (81)	

\*Missing responses: Education – 1; Income – 30; Diabetes – 1.

## DISCUSSION

With growing recognition of the role of malnutrition in healing after surgery and trauma, it is important to identify potentially modifiable risk factors such as food insecurity. This single center cross-sectional study at a rural Midwest Level 1 trauma center demonstrated an estimated food insecurity prevalence of 13.3%. Patients with a lower combined household income and those who live alone are significantly more likely to experience food insecurity. Additionally, the severity of food insecurity positively correlated with the amount of time needed to travel to a grocery store and with the number of comorbidities as measured by CCI score.

The estimated prevalence of food insecurity in our study suggests that food insecurity may be modestly more common in the orthopedic trauma population than recent national estimates (11.1%).<sup>17</sup> Studies in other patient populations have identified food insecurity in 11% of pregnant women,<sup>20</sup> 37% of households with children,<sup>21</sup> and 40.8% of patients in primary care clinics.<sup>22</sup> Comparing our data to these studies further suggests that food insecurity is common in orthopedic trauma patients at our institution but may not be as high as rates in other patient groups. However, even this is

**Table 3. Food Consumption Practices by Food Security**

	Food Secure (%)	Food Insecure (%)	P-Value
Fast Food or Ready-to-Eat Food			0.511
< Once per week	81 (59)	14 (67)	
≥ Once per week	56 (41)	7 (33)	
Sugar-Sweetened Beverages			0.7304
< Once per week	51 (37)	7 (33)	
≥ Once per week	86 (63)	14 (67)	
Vegetables*			1
< Once per week	14 (10)	2 (10)	
≥ Once per week	123 (90)	19 (90)	
Fruits			0.2256
< Once per week	23 (17)	6 (29)	
≥ Once per week	114 (83)	15 (71)	
Protein-Containing Food			0.0733
< Once per week	5 (4)	3 (14)	
≥ Once per week	132 (96)	18 (86)	

\*Not including potatoes.

**Table 4. Correlations Between Food Insecurity Risk Factors and Food Security Scores**

Risk Factor	Correlation Coefficient (r)	P-Value
Age	-0.08	0.337
CCI Score	0.16	0.0483
Hours Worked per Week	-0.1	0.429
Time to Grocery Store	0.23	0.0041

difficult to determine as not all studies used the same measurement of food insecurity and many opted for shorter questionnaires containing as few as one to two responses. It is possible that on a more nuanced scale such as the USDA Household Food Security survey, the rates of food insecurity in certain populations may trend closer to that seen in orthopedic trauma clinics and in pregnant women.

Prior studies on the risk factors for food insecurity have primarily focused on trends within the general population rather than individual patient populations. A recent systematic review performed by Jung et al. found that the odds for household food insecurity were 40% for female respondents to a nationwide survey and that female-led households had a 75% higher risk of food

insecurity compared to male-led households.<sup>23</sup> We did not see a significant gender difference in the FI and FS cohorts in our study; however, the latter result is at least partly supported by our findings. Jung et al. suggested that women tend not to have the same employment opportunities as men and receive unequal pay compared to their male counterparts. As such, a female-led household with lower income has a higher probability of poverty.<sup>23,25</sup> In our population, the two significant risk factors for food insecurity were low household income and living alone. Though these two factors may not have been associated with gender in the orthopedic trauma population, it seems plausible that a single-income home will tend to have a comparatively lower gross income than a dual-income home thus putting an individual at a higher risk of food insecurity.

The relationship between CCI score and food insecurity also seems to correlate well with the present literature. The CCI factors in age as well as diabetes, coronary artery disease, peripheral vascular disease, and chronic kidney disease among other comorbidities. With each of these conditions, there is often a component of patient lifestyle contributing to their development and progression. The current literature has demonstrated a clear connection between food insecurity and conditions such as obesity, hypertension, dyslipidemia, and end-stage renal disease<sup>26,27</sup> further underscoring the lifestyle contributions to these comorbidities. As such, it follows logically that a patient with a higher degree of food insecurity is likely to have more medical comorbidities and, in turn, a higher CCI score.

Finally, our data indicated that longer times needed to travel to a grocery store were associated with more severe food insecurity scores. Though this correlation was weak, we feel that it may be at least partly unique to our patient population as a rural Midwest hospital. A 2009 study evaluated access to food in rural communities in Iowa and Minnesota finding that a relative lack of variety and high cost of food in rural counties prompted individuals to travel further to grocery stores for more desirable food. However, this added transportation costs that potentially impacted food choices.<sup>28</sup> This notion is further supported by a 2006 study that associated increased travel time to grocery stores with a higher odds ratio for obesity.<sup>29</sup> Taken together, these findings suggest that the physical separation seen in rural communities places individuals at a higher risk for food insecurity and its adverse health effects. It is possible this effect may not be seen in more condensed or heavily populated communities.

Overall, our findings underscore the importance of increasing awareness of food insecurity and its associated risk factors within orthopedic trauma patients. The

next and perhaps more important step is to identify upstream interventions to address this apparently common issue. Studies assessing such interventions appear to favor public policy initiatives over community-based programs like food pantries. Where social assistance and education programs have been associated with a decrease in food insecurity rates,<sup>30,33</sup> food pantries have demonstrated mixed results and may face other challenges including a reliance on donations, social stigmas, and difficulty providing healthy, nutritious food.<sup>34-38</sup> More investigation is needed to better identify ways to reduce food insecurity in the community.

Beyond directly addressing food insecurity, targeted nutrition supplementation could also play a role in mitigating the adverse effects of food insecurity. Prior studies have suggested that conditionally-essential amino acid supplementation can reduce complications and the rate of muscle loss in the early recovery phase after trauma.<sup>39,40</sup> Whether it be through social programs, targeted supplementation, or other methods, optimizing nutrition in orthopedic trauma patients at risk for food insecurity has the potential to significantly improve their clinical outcomes. Future work should focus on nutrition supplementation as an intervention to reduce complications and functional muscle loss during the healing phase after trauma.

### **Limitations**

This study was performed at a single Midwest institution and our enrollees were homogenous with greater than 90% identifying as non-Hispanic White. Such a cohort does not accurately represent orthopedic trauma patients across the country which limits the generalizability of our findings. Future investigations should include multiple centers in different regions of the country to increase the diversity of the study population. This multicenter design will more accurately estimate the true prevalence of food insecurity in orthopedic trauma patients, better determine its risk factors, and improve the overall generalizability of the results.

Another limitation is although some patients were approached in the inpatient setting, most enrollments occurred in the outpatient clinics. This could introduce selection bias as individuals who are of lower socioeconomic status and potentially higher risk for food insecurity may not be able to reliably attend scheduled clinic follow-up visits. As such, it is possible we have underestimated the commonality of food insecurity at our institution. This may also impact the associations seen between food insecurity and the potential risk factors included in our study.

Finally, although food insecurity has been shown to adversely affect outcomes in prior studies, the cross-

sectional design of our study limits any assessments of patient outcomes. We did incorporate into our surveys the number of surgeries needed to treat each patient's injury in hopes of identifying a relationship between FI and injury severity. This metric did not reach statistical significance. As such, the present data allow us to say that food insecurity is common in our rural orthopedic trauma population but we cannot speak to its clinical relevance in this cohort. We feel the questions of clinical relevance and potential interventions can be addressed in future investigations and that our data will serve as a basis for such studies going forward.

### CONCLUSION

Food insecurity is common in the musculoskeletal trauma population. Those with lower household income and those living alone are more likely to experience food insecurity. Time spent traveling to full-service grocery store was strongly associated with food insecurity. Multicenter studies are warranted to evaluate the incidence and risk factors for food insecurity in a diverse population of trauma patients. Our findings indicate a need for public health initiatives to improve food security in high-risk populations and highlight the potential benefits of providing nutrition supplementation to musculoskeletal trauma patients to improve outcomes.

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# A CASE SERIES OF YOUNG PATIENTS WITH LOW-ENERGY FEMORAL NECK FRACTURES

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## ABSTRACT

**Background:** Fragility femoral neck fractures are traditionally seen in elderly patients after a low-energy fall. In contrast, displaced femoral neck fractures in young patients are usually associated with high-energy mechanisms such as a fall from height or high-speed motor vehicle collisions. However, patients under the age of 45 with fragility femoral neck fractures represent a unique population, and one that is not well-described. This study aims to describe this population and their current workup.

**Methods:** A single institution retrospective chart review of patients who underwent open reduction internal fixation or percutaneous pinning of femoral neck fractures from 2010-2020 was conducted. Inclusion criteria were patients 16-45 years old and femoral neck fractures with a low-energy mechanism of injury (MOI). Exclusion criteria were high-energy fractures, pathologic fractures, and stress fractures. Patient demographics, MOI, past medical history, imaging studies, treatment plan, lab values, DEXA results, and surgical outcomes were recorded.

**Results:** The average age in our cohort was  $33 \pm 8.5$  y/o. 44% (12/27) were male. Vitamin D level was obtained in 78% (21/27) patients and 71% (15/21) those patients were found to be abnormally low. A DEXA scan was obtained in 48% (13/27) of patients and abnormal bone density was found in 90% (9/10) of available results. 41% (11/27) patients received a bone health consultation.

**Conclusion:** A significant portion of femoral neck fractures in young patients were fragility fractures. Many of these patients did not receive bone health

workup and their underlying health condition remained untreated. Our study highlighted a missed opportunity of treatment for this unique and poorly understood population.

**Level of Evidence:** III

**Keywords:** low energy femoral neck, hip fracture, femoral neck, fragility fracture, bone health

## INTRODUCTION

Femoral neck fractures occur in a bimodal distribution. In elderly patients, these fractures are traditionally seen as fragility fractures after a ground-level fall.<sup>1</sup> In contrast, displaced femoral neck fractures in young patients are usually associated with high-energy mechanisms, such as a fall from height or high-speed motor vehicle collisions.<sup>2,3</sup> Femoral neck fractures in young patients are a rare occurrence<sup>1</sup> but are associated with complications and surgical challenges.<sup>2,4</sup> Low-energy femoral neck fractures in young patients represent a unique population. There is a paucity in the literature regarding the prevalence, treatments, and outcomes of young patients with low-energy femoral neck fractures.

To establish the standard of care for hip fractures, the American Academy of Orthopaedic Surgeons has published the clinical guideline on the management of fragility hip fractures. The guideline encompassed surgical treatments as well as perioperative management and osteoporosis workup. However, the guideline only applies to elderly patients. It is unclear if younger patients with fragility femoral neck fractures would benefit from similar management and workup nor if the workup will reveal significant abnormalities. With the aim of describing the unique cohort of patients under the age of 45 with low-energy femoral neck fractures, we designed a retrospective review reporting their injuries, medical problems, treatments, osteoporosis workup, and outcomes.

## METHODS

A retrospective chart review was performed at our hospital system after Institutional Review Board approval. Inclusion criteria were patients aged between 16-45 years old who underwent open reduction and internal fixation (ORIF) of femoral neck hip fractures (Current Procedural Terminology (CPT) code 27236) or closed

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reduction percutaneous pinning (CRPP) (CPT 27235) of a femoral neck fracture from 1/2010 – 6/2021. The exclusion criteria included high-energy fractures (fall from height and motor vehicle accidents), stress fractures, and pathologic fractures. A total of 27 patients met the inclusion and exclusion criteria.

Chart review was completed to record age, sex, body mass index (BMI), race, self-reported tobacco use and drug abuse, past medical history, mechanism of injury, surgical treatment, medical treatment, and postoperative outcomes. Radiographic review was used to classify fracture types according to the Garden and AO OTA classification systems.<sup>5</sup> Medical charts were reviewed for a bone health evaluation, bone density scan, or serum lab values obtained within 3 months of the date of injury. At our institution, a bone health evaluation is performed by an orthopaedic advanced nurse practitioner. The evaluation consists of a DEXA scan, lab works, a review of activity level, fracture history, and fall risk. Patients are encouraged to begin an exercise program, limit alcohol intake, quit smoking, and supplement with calcium and vitamin D, as outlined by the American Orthopedic Association's Own the Bone Program.<sup>6</sup> Labs of interest included calcium, vitamin D 25-OH, albumin, total protein, parathyroid hormone (PTH), thyroid-stimulating hormone (TSH), and aspartate aminotransferase (AST). The complications reviewed were readmissions within 90 days and complications including nonunion, avascular necrosis, deep vein thrombosis, pulmonary emboli, infection, and sepsis. Descriptive summary statistics were reported as mean and standard deviation. Frequency and percent were used for categorical and binary variables Microsoft Excel (Redmond, WA).

## RESULTS

We identified 94 patients ages 16-45 years old who underwent ORIF or CRPP for a femoral neck fracture from 1/2010 - 6/2021. 51 patients were excluded for high-energy mechanisms. Of the 43 remaining patients with low-energy mechanisms, 11 were excluded due to a stress fracture and five were excluded due to a pathologic fracture. 27 patients with fragility fractures of the femoral neck were included for the final analysis.

The average age of these patients was  $33 \pm 8.5$  years old with BMI of  $24 \pm 6.5$ . Twenty-one (78%) patients had comorbid conditions including seven patients (26%) with neuromuscular disorders, three (11%) with a history of malnutrition or an eating disorder, and four (15%) with a history of endocrine disease, including two (7.4%) diabetics (Table 1). The majority of patients did not smoke, did not drink or used illicit drugs. Among 11 patients (41%) with a fracture history, five patients reported a ground level fall as the cause of the previous fractures.

Two-thirds of fractures were displaced in 18 patients (67%) with AO OTA 31B.3 and Garden III/IV fractures (Table 2). The majority of fractures were treated with open reduction internal fixation (74%, N=20). Four patients were treated with CRPP (15%) and three patients were treated with arthroplasty (11%).

There was significant variability in the workup for each patient. 15 patients (71%) had abnormally low vitamin D levels. DEXA scans were ordered in 19 patients (70%); however, only 13 (48%) of those patients actually received a DEXA scan. Of the DEXA results available through chart review, 10% (1/10) had a normal bone density, 50% (5/10) had low bone mass or osteopenia,

**Table 1. Patient Characteristics**

Number of Patients	27 patients
Gender	15 females (56%)
Age	$33 \pm 8.5$ years old
BMI	$24 \pm 6.5$
≤ 18.5 (underweight)	6 patients (22%)
normal-overweight	16 patients (59%)
≥ 30 (obese)	5 patients (19%)
Social History	
Smoking	8 patients (30%)
Alcohol use	9 patients (33%)
Illicit drug use	3 patients (11%)
Medical History	
Neuromuscular disorders	7 patients (26%)
Endocrine disorders	4 patients (15%)
Malnutrition	3 patients (11%)
Previous fractures	11 patients (41%)

**Table 2. Fracture Description, Mechanism and Intervention**

	Percent (n)		Percent (n)
Fracture Pattern		Mechanism	
Garden I	26% (7)	Ground Level Fall	74% (20)
Garden II	7% (2)	Fall From Height (< 5 Feet)	15% (4)
Garden III	52% (14)	Running	11% (3)
Garden IV	15% (4)		
AO OTA Classification		Intervention	
31B.1	26% (7)	ORIF	74% (20)
31B.2	7% (2)	CRPP	15% (4)
31B.3	67% (18)	Arthroplasty	11% (3)

**Table 3. Frequencies and Results of Workup**

Test	% Obtained (n)	% Abnormal (n)
Calcium	100% (27)	15% (4)
Vitamin D 25-OH	78% (21)	71% (15)
Albumin	44% (12)	25% (3)
Total Protein	41% (11)	27% (3)
PTH	59% (16)	25% (4)
TSH	52% (14)	21% (3)
AST	44% (12)	8% (1)
DEXA Scan	48% (13)	90% (9/10)

and 40% (4/10) had osteoporosis (Table 3). Bone health consultations, which include a series of blood work and bone density testing, were initiated in 11 patients (41%).

Three patients developed post-operative complications requiring re-admissions and reoperations. One patient was readmitted for sepsis and a new humeral fracture, one patient with avascular necrosis required conversion to total hip arthroplasty, and one patient had a dynamic hip screw exchange and then painful hardware removal.

21 of the 27 patients were able to return to independent ambulation at last follow up. Three patients could not ambulate unassisted prior to surgery, including a patient with a history of cerebral palsy, a patient with a history of muscular dystrophy, and a patient with a history of HIV and morbid obesity. One patient required an AFO (ankle foot orthosis) prior to surgery, and at last follow up could only ambulate short distances. One patient was last noted to be walking without crutches 90% of the time but also had a meniscus injury on an unspecified date and did not know if his disability was due to his knee or hip. Finally, one patient transferred care out of state and was lost to follow up.

## DISCUSSION

Although femoral neck fractures in young patients are generally thought to result from high-energy mechanisms,<sup>2,3</sup> about half (46%) of the femoral neck fractures reviewed in younger patients resulted from low-energy mechanisms when including pathologic and stress fractures. After excluding pathologic and stress fractures, a significant portion (29%) of the total fractures resulted from a fragility fracture. Previous studies on low-energy femoral neck fractures in young patients focused on stress and pathologic fractures.<sup>7-13</sup> Our findings suggest that the prevalence of both low-energy fractures and fragility fractures of the femoral neck in younger patients is significant.

Our cohort's serum lab values are representative of previous literature on fragility fractures. Of the 21 patients who had a vitamin D level checked, 15 patients

(71%) had inadequate vitamin D levels. In a study of inpatient fracture management in Australia, patients presenting with fractures were likely to be vitamin D deficient, and most fractures were low-energy.<sup>14</sup> Although the Australian study did not specifically study femoral neck fractures, it supports our findings that low-energy femoral neck fractures are correlated with low vitamin D levels. A study of hip fractures in young patients similarly found that the majority of the femoral neck fractures were low-energy with normal calcium levels. They also found normal phosphorus, and alkaline phosphatase levels;<sup>12</sup> however, those lab values were not measured in our study. The previous literature strengthens the correlation we found between low-energy femoral neck fractures and low vitamin D levels, along with normal serum levels of calcium and other common serum labs.

Our study highlights a missed bone health workup opportunity for young patients with low-energy femoral neck fractures. Bone health consultations, which include a series of blood work and bone density testing, were initiated in 11 patients (41). 9/10 patients with an available DEXA scan report had abnormal bone density. Five patients (19%) even had a history of prior low-energy fractures. Although the majority of our patients had low vitamin D levels, six patients (22%) did not have a vitamin D level checked within three months of injury. We suspect these problems may be common in other institutions considering that there is not currently a guideline for the management and workup of young patients with low-energy femoral neck fractures. Several studies have reported abnormal bone density testing among young patients with hip fractures regardless of the mechanism of injury and proposed more aggressive testing for young patients at risk.<sup>15-17</sup> The lack of consensus on this patient cohort's workups suggests clinical guidelines should be expanded to younger patients. We recommend that all adult patients with fragility fractures be given a referral for a bone health consultation.

Prior literature reported significant rates of neuromuscular, endocrine and malnutrition disorders among young patients with low-energy femoral neck fractures.<sup>8,13</sup> In this study, we report a lower rate of 26% of patients with neuromuscular disorders and 15% with endocrine disorders. Similarly, the majority of our patients did not smoke, drink, or use illicit drugs. Our findings suggested that these low-energy fractures could happen even in healthy appearing patients with no known past medical history.

Our cohort had relatively low but significant complication rates (11.5%, N=3) compared to a similar previous study. A study of 22 young adults with femoral neck fractures found a high incidence of non-union (59%) and aseptic necrosis (86%), with only 3/22 (14%) patients



having a viable femoral head by the end of follow-up.<sup>18</sup> Due to these complications, femoral neck fractures among young patients remain a challenging diagnosis for orthopaedic patients.

This study has several limitations. The cohort is small and is only limited to a single institution and geographical location. The information available by retrospective chart review was limited. Several patients followed up with providers outside of our hospital system, and their charts were not available for review. Three patients had a DEXA scan taken, but the results were not viewable. Documentation of patients' fracture histories was often incomplete. Additionally, there was variability in workups between providers.

### CONCLUSION

Our study is unique because it describes a poorly understood population that has not been well characterized in the literature. A significant portion of femoral neck fractures in young patients were fragility fractures. Our study highlights some of the risk factors associated with fragility fractures of the femoral neck, including low BMD, low vitamin D levels, previous fracture history, and poor health. Many of these patients did not receive a bone health workup and their underlying health conditions remained untreated. Our study highlighted a missed opportunity for treatment of this unique and poorly understood population.

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# EARLY VERSUS DELAYED SURGERY FOR MIDSHAFT CLAVICLE FRACTURES: A SYSTEMATIC REVIEW

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## ABSTRACT

**Background:** Orthopaedic surgeons debate the timing of and necessity for surgical intervention when treating displaced midshaft clavicle fractures (MCFs). This systematic review evaluates the available literature regarding functional outcomes, complication rates, nonunion, and reoperation rates between patients undergoing early versus delayed surgical management of MCFs.

**Methods:** Search strategies were applied in PubMed (Medline), CINAHL (EBSCO), Embase (Elsevier), Sport Discus (EBSCO), and Cochrane Central Register of Controlled Trials (Wiley). Following an initial screening and full-text review, demographic and study outcome data was extracted for comparison between the early fixation and delayed fixation studies.

**Results:** Twenty-one studies were identified for inclusion. This resulted in 1158 patients in the early group and 44 in the delayed. Demographics were similar between groups except for a higher percentage of males in the early group (81.6% vs. 61.4%) and longer time to surgery in the delayed group (4.6 days vs. 14.5 months). Disability of the arm, shoulder, and hand scores (3.6 vs. 13.0) and Constant-Murley scores (94.0 vs. 86.0) were better in the early group. Percentages of initial surgeries resulting in complication (33.8% vs. 63.6%), nonunion (1.2% vs. 11.4%), and nonroutine reoperation (15.8% vs. 34.1%) were higher in the delayed group.

**Conclusion:** Outcomes of nonunion, reoperation, complications, DASH scores, and CM scores favor early surgery over delayed surgery for MCFs.

However, given the small cohort of delayed patients who still achieved moderate outcomes, we recommend a shared decision-making style for treatment recommendations regarding individual patients with MCFs.

**Level of Evidence: II**

**Keywords:** clavicle, midshaft, early, delayed, fracture, surgery

## INTRODUCTION

Clavicle fractures account for 2.6% of all fractures, and of these, 81.3% are midshaft clavicle fractures (MCFs).<sup>1</sup> The necessity for and timing of surgical treatment for clavicle fractures has long been a subject of debate. Historically, orthopaedic surgeons have treated all MCFs nonoperatively with success, and early research reported increased rates of nonunion in acute fixation of MCFs.<sup>2</sup> However, later research reported increased risk of nonunion in displaced diaphyseal clavicle fractures treated nonoperatively, concluding that while most MCFs can be treated nonoperatively, comminution and displacement increase subsequent nonunion risk.<sup>3</sup> Concordantly, studies comparing open-reduction and plate fixation of displaced MCFs with nonoperative treatment showed plate fixation significantly reduced the risk of nonunion and malunion.<sup>4</sup> Several reviews have supported acute fixation for markedly displaced, shortened, or comminuted fractures to decrease nonunion and malunion rates, and increase functional outcomes.<sup>5-7</sup>

A recent Cochrane review found no clinically significant improvement in upper arm function at one or more years following surgery for displaced or angulated MCFs, nor any difference in pain or quality of life. Low quality review evidence suggested surgery may reduce the risk of symptomatic nonunion, malunion, or other complications.<sup>8</sup> With studies showing varying complication rates for surgical fixation of MCFs, unclear clinical efficacy, and no financial benefits,<sup>9</sup> one might suggest all midshaft fractures be treated nonoperatively, reserving surgery for those patients who experience nonunion or malunion.

This review sought to comprehensively evaluate the outcomes of early versus delayed surgical fixation of MCFs. If delayed surgical treatment results in similar outcomes as early surgical treatment, it is possible that all clavicle fractures could be managed nonoperatively

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initially. Then, only those fractures that did not heal with nonoperative treatment would be surgically treated. We hypothesize that early fixation of MCFs would provide similar functional outcomes, union rates, complication rates, and reoperation rates when compared to delayed fixation.

## METHODS

### Data Sources and Search Strategy

Search strategies were developed with the assistance of a health sciences librarian with expertise in searching for systematic reviews. Search strategies, including both index and keyword methods to maximize sensitivity, were devised for the following databases: PubMed, CINAHL (EBSCO), Embase (Elsevier), Sport Discus (EBSCO), and Cochrane Central Register of Controlled Trials (Wiley) (Table 1). Total yield for the search is illustrated in the flow diagram (Figure 1).

## Search Results

Our search strategy identified 3,416 articles. After removing duplicates, 1,681 articles remained for screening. Two independent reviewers screened the titles and abstracts to exclude reviews, non-English language publications, case studies, nonoperative treatment, biomechanical studies, and studies with less than one-year follow up. All clavicle fixation methods were included for this study. This screening process resulted in the identification of 646 articles (Figure 1).

Two independent authors reviewed the full texts of the remaining articles. Discrepancies in inclusion or exclusion decisions were decided upon by the senior author. Articles were excluded for the following criteria: 1) pediatric population (<18 y/o), 2) distal clavicle fractures, 3) medial clavicle fractures, 4) AC separation, 5) level of evidence of three or lower. Studies also had to specify time to surgery as less than six weeks or exclude fractures older than six weeks to be considered early intervention.

**Table 1. Search Strategies and Results for Each Database at Each Search Date**

Database	Search Strategy	Studies returned at each search			
		6/2016	3/2018	12/2018	1/2021
PubMed	"Clavicle/injuries"[Mesh] OR ("Fractures, Bone"[Mesh] AND "Clavicle"[Mesh]) OR (fracture[Text Word] OR fractured[Text Word] OR fractures[Text Word]) AND (clavicle[Text Word] OR clavicular) AND (middle[Text Word] OR mid shaft[Text Word] OR midshaft[Text Word] OR middle third[Text Word] OR mid [Text Word] OR diaphyseal) AND "Clavicle/surgery"[Mesh] OR "Fracture Fixation"[Mesh] OR "Fractures, Malunited/surgery"[Mesh] OR "Fractures, Ununited/surgery"[Mesh] OR "Internal Fixators"[Mesh] OR "Bone Transplantation"[Mesh] OR ORIF[Text Word] OR fixation[Text Word] OR conservative[Text Word] OR surgery[Text Word] OR surgical[Text Word] OR operative[Text Word] OR delayed[Text Word] OR late[Text Word] OR acute[Text Word] OR early [Text Word] OR management [Text Word] OR treatment [Text Word]...Limited to English	798	199	66	208
CINAHL	#1: MH "Clavicle Fractures+" OR (MH "Fractures+" AND MH "Clavicle") OR TX (fracture* N5 clavic*) AND TX (mid*OR diaphyseal) #2: MH "Fracture Fixation" OR MH "Internal Fixators+" OR MH "Clavicle/SU" OR MH "Fractures+/SU" OR MH "Bone Transplantation" OR TI (ORIF OR fixation OR conservative OR surgery OR surgical OR operative OR delayed OR late OR acute OR early OR management or treatment) OR AB (ORIF OR fixation OR conservative OR surgery OR surgical OR operative OR delayed OR late OR acute OR early OR management or treatment) Limited to English	325	100	35	98
Sport Discus	#1: ZE "clavicle" OR XE "clavicle-wounds and injuries" OR TX (fracture* N5 clavic*) AND TX (mid* OR diaphyseal) #2: ZE "fractures-treatment" OR TI (ORIF OR fixation OR conservative OR surgery OR surgical OR operative OR delayed OR late OR acute OR early OR management or treatment) OR AB (ORIF OR fixation OR conservative OR surgery OR surgical OR operative OR delayed OR late OR acute OR early OR management or treatment)	89	31	7	14
Embase	#1: ('clavicle fracture'/exp OR ('fracture'/exp AND 'clavicle'/exp) OR (fracture NEAR/5 clavic*):ab,ti AND mid* OR diaphaseal #2: 'surgery'/lnk OR 'fracture fixation'/exp OR 'bone transplantation'/exp OR 'internal fixator'/exp OR (ORIF OR fixation OR conservative OR surgery OR surgical OR operative OR delayed OR late OR acute OR early OR management or treatment):ab,ti Limited to English	635	231	74	327
Cochrane (Central)	**Identical to PubMed search strategy, but no English Language Filter was applied	69	48	5	39

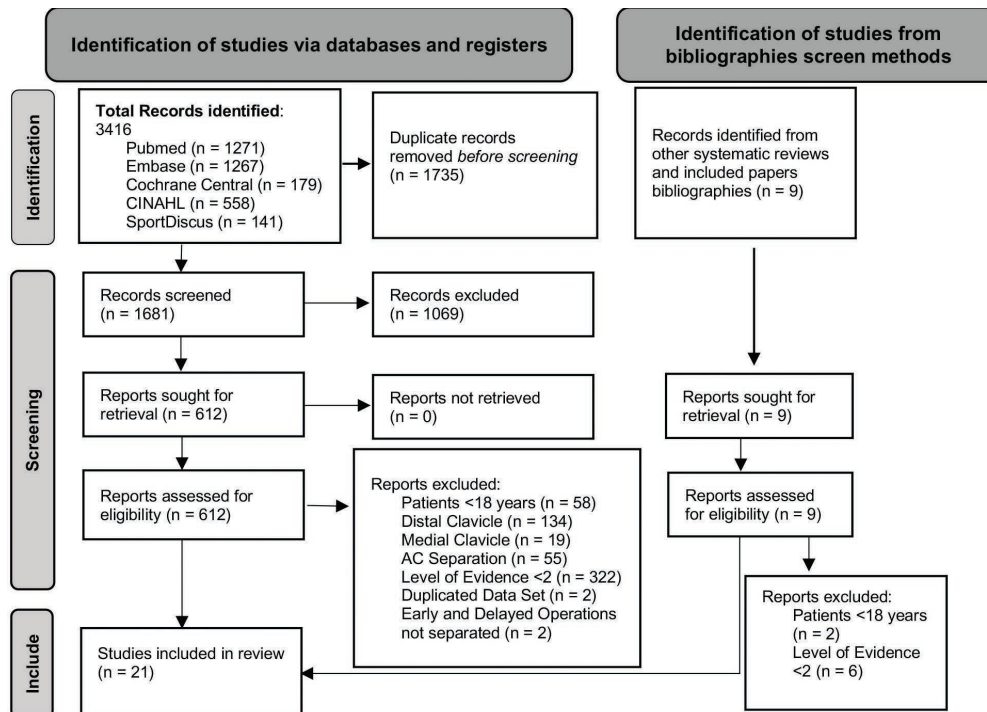


Figure 1. Flow diagram outlining the systematic review process from initial search results to articles included in the study. This chart was adapted from PRISMA. From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ* 2021;372:n71. doi: 10.1136/bmj.n71. For more information, visit: <http://www.prisma-statement.org/>.

Operations were considered delayed for fractures older than six weeks, persistent nonunion, or malunion. Studies were excluded if they did not describe the time from injury to surgery nor mention exclusion of old fractures. All operative techniques were considered for this study. The remaining articles and 26 systematic reviews on midshaft clavicle fracture treatment had their bibliographies reviewed to identify articles missed by our search strategy. Following this process, nine papers were identified and underwent the same screening process outlined above. The whole process identified 21 articles to review.

### Data Extraction

The following factors were extracted from the 21 studies by two independent reviewers: patient age, time to surgery, complications, union rate, number of subsequent surgeries, and post-surgical outcomes at 12 or more months using the Disability of the Arm, Shoulder, and Hand (DASH) score and Constant-Murley (CM) PRO scores. Minor complications included: pain/dysesthesia, skin irritation, skin numbness, implant prominence or irritation due to prominence, superficial infection, unspecified infection, frozen shoulder, functional limitation, dehiscence, malunion, delayed union,

superficial vein thrombosis, and transient brachial plexus symptoms. Major complications included: implant failure or loosening, deep infection, refracture, nonunion, or cardiovascular events. Additively, major and minor complications made up total complications.

If subsets of patients within each paper did not meet exclusion criteria, this subset was not included in analysis while keeping the group of patients that did meet exclusion criteria. Papers describing two early surgical treatment groups had data from each group entered and kept separately in tabulations but were ultimately pooled into the final results.

### Quality Assessment

To assess study quality, two independent reviewers utilized the NIH Study Quality Assessment Tools to rate each study as good, fair, or poor. For randomized controlled trials (RCT), we used the “Quality Assessment of Controlled Intervention Studies” tool, and for prospective cohort studies (PCS), we used the “Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies” tool.<sup>10</sup> For this process, no discrepancies were encountered between the two reviewers.

**Table 2. Reviewed Articles with Demographic Data From Individual Study Cohorts**

Author	Year	Title	LOE	Fixation	n	n Males	Age (mean)	TTS (days)
Acute								
Assobhi et al.	2011	Reconstruction plate versus minimal invasive retrograde titanium elastic nail fixation for displaced midclavicular fractures	1	plate	19	17	32.6	9.5
				nail	19	16	30.3	10.2
Calbiyik et al.	2016	Prospective randomized study comparing results of fixation for clavicular shaft fractures with intramedullary nail or locking compression plate	1	plate	40	25	39.07	1.4
Calbiyik et al.	2018	Surgical treatment of displaced clavicle fractures with a novel intramedullary device; comparison of less-invasive versus standard technique	1	nail	36	23	35.22	2.11
				nail	35	21	41.82	1.85
Jiang et al.	2012	Operative treatment of clavicle midshaft fractures using a locking compression plate: comparison between mini-invasive plate osteosynthesis (MIPPO) technique and conventional open reduction	1	plate	32	NR	40	7
				plate	32	NR	45	7
Judd et al.	2009	Acute operative stabilization versus nonoperative management of clavicle fractures	1	nail	29	27	28	NR
Kulshreshtha et al.	2011	Operative versus nonoperative management of displaced midshaft clavicle fractures: a prospective cohort study	2	plate	45	43	32	3.5
Kundangar et al.	2019	Clinical outcome of internal fixation of middle third clavicle fractures using locking compression plate: Comparison between open plating and MIPO	2	plate	16	16	NR	3
				plate	21	18	NR	3
Mirza-tooei et al.	2011	Comparison Between Operative and nonoperative treatment methods in the management of comminuted fractures of the clavicle.	1	plate	26	20	36	NR
Narsaria et al.	2014	Surgical fixation of displaced midshaft clavicle fractures: elastic intramedullary nailing versus precontoured plating	1	plate	32	26	40.2	7.2
				nail	33	24	38.9	6.9
Qvist et al.	2018	Plate fixation compared with nonoperative treatment of displaced midshaft clavicular fractures: a randomized clinical trial	1	plate	75	64	40	NR
Robinson et al.	2013	Open Reduction and Plate Fixation Versus Nonoperative Treatment for Displaced Midshaft Clavicular Fractures	1	plate	95	83	32.3	NR
Sahu et al.	2018	A comparative study between plating versus titanium elastic nail system in mid-shaft clavicle fracture management	1	nail	25	18	33.28	NR
				plate	25	18	34.76	NR
Shen et al.	2008	A three-dimensional reconstruction plate for displaced midshaft fractures of the clavicle	2	plate	67	39	43.8	NR
				plate	66	36	44.7	NR
Smekal et al.	2011	Elastic stable intramedullary nailing is best for mid-shaft clavicular fractures without comminution: Results in 60 patients	1	nail	60	54	36.8	3
Sohn et al.	2015	Clinical comparison of two different plating methods in minimally invasive plate osteosynthesis for clavicular midshaft fractures: A randomized controlled trial	1	plate	19	18	46.7	4.3
				plate	18	17	50.4	4.1
Tamaoki et al.	2017	Treatment of Displaced Midshaft Clavicle Fractures: Figure-of-Eight Harness Versus Anterior Plate Osteosynthesis: A Randomized Controlled Trial	1	plate	59	53	30.5	NR
van der Meijden et al.	2015	Operative treatment of dislocated midshaft clavicular fractures: plate or intramedullary nail fixation? A randomized controlled trial	1	plate	58	53	38.4	NR
				nail	62	60	39.6	NR
Virtanen et al.	2012	Sling Compared with Plate Osteosynthesis for Treatment of Displaced Midshaft Clavicular Fractures	1	plate	28	24	41	NR
Woltz et al.	2017	Plate Fixation Compared with Nonoperative Treatment for Displaced Midshaft Clavicular Fractures: A Multicenter Randomized Controlled Trial	1	plate	86	80	38.3	NR
Delayed								
Kabak et al.	2004	Treatment of midclavicular nonunion: comparison of dynamic compression plating and low-contact dynamic compression plating techniques	1	plate	16	10	40	10.2*
				plate	17	9	42.7	11.4*
Nowak et al.	2001	A prospective comparison between external fixation and plates for treatment of midshaft nonunions of the clavicle	2	Ex-Fix	11	8	37	25.6*

NR= not reported. \*These time to surgery values are reported in months.

## Data Analyses

Excel v.1808 (Microsoft Inc, Redmond, WA) was utilized to perform basic demographic calculations such as weighted average patient age and percent of male patients. Additionally, weighted averages and percentages were calculated for outcome variables: the comparative DASH scores and CM scores, and occurrence of non-unions, complications, and reoperations among early versus delayed fixation patients.

## RESULTS

This systematic review process identified 18 RCTs and 3 PCSs that met inclusion criteria (Figure 1). Nine studies compared early fixation with a plate or nail to nonoperative management,<sup>11-19</sup> and we analyzed only the operatively treated patients; 10 studies compared two methods of early surgical fixation,<sup>20-29</sup> and two studies compared two methods of surgical fixation for delayed clavicle fractures.<sup>30,31</sup> This yielded 1,158 patients receiving early operative intervention, and 44 patients receiving delayed operative treatment. Notably, a delayed plate fixation intra-study cohort in the Nowak et al. paper was excluded due to inclusion of pediatric patients.<sup>31</sup> Eighteen studies<sup>11-23,25-29</sup> reported mean age of patients and eighteen studies<sup>11-22,24-29</sup> reported the number of

males in each cohort (Table 2). The weighted average age was 38.0 years in the early fixation group and 40.3 years in the delayed group. The percentage of male patients was 81.6% in the early fixation group and 61.4% in the delayed fixation group (Table 3). Nine early fixation studies<sup>12,16,20-25,28</sup> and both delayed fixation studies<sup>30,31</sup> reported average time to surgery (Table 2). The weighted average time to operation in the early fixation group was 4.6 days and 14.5 months in the delayed group (Table 3).

## DASH Score

Nine studies<sup>13,15-19,21,26,29</sup> in the early fixation group and one study<sup>30</sup> in the delayed fixation group reported mean DASH scores at 12 or more months (Table 4). Analysis found weighted average DASH scores of 3.6 in the early intervention group and 13.0 in the delayed intervention group (Table 3).

## Constant-Murley Score

Thirteen early intervention papers<sup>13,15,16,18-22,24-26,28,29</sup> and one delayed intervention paper<sup>31</sup> reported mean CM scores at 12 or more months (Table 4). The weighted average from studies describing early surgery was 88.5. However, when Sahu et al. was excluded because of outliers, the weighted average CM score from 12 studies was 94.0.<sup>26</sup> In the delayed group, only one study reported an average CM of 86.0 (Table 3).

## Nonunion

Seventeen early intervention papers,<sup>11-26,28</sup> and both delayed intervention papers<sup>30,31</sup> reported on nonunion (Table 4). In the early fixation group, there were 11 nonunions versus five in the delayed fixation group. This equates to 1.2% of initial operations resulting in nonunion in the early fixation group compared to 11.4% of initial operations resulting in nonunion in the delayed fixation group (Table 3).

## Complications

All early<sup>11-29</sup> and delayed<sup>30,31</sup> studies reported on complications (Table 4). The percent of initial fixations resulting in a minor complication in the early group was 25.0% and in the delayed group was 52.3%. The percentage of patients experiencing major complication was 6.4% in the early group and 11.4% in the delayed group (Table 3). One paper by Van der Meijden et al. only reported some of their complications as “total complications,” these values were added to the final total complications but not minor or major categories.<sup>29</sup> Additionally in the Kabak et al. paper describing plate fixation of two delayed MCF cohorts, five minor complications were pooled in our analysis that were not explicitly stated to be experienced by one of the intrastudy cohorts.<sup>30</sup> Overall,

**Table 3. Pooled Results of Outcome Variables Following Systematic Review**

	Acute	Delayed
Average Age	38.0	40.3
Percentage of Males	81.6	61.4
Average Time to Operation	4.6 days	14.5 months
DASH score	3.6	13.0
Constant-Murley score	88.5	86.0*
Constant-Murley score without Sahu et al.	94.0	86.0*
Percent Minor Complications	25.0	52.3
Percent Major Complications	6.4	11.4
Percent Total Complications	33.8**	63.6
Percent Nonunion	1.2	11.4
Percentage of Reoperation	21.7	34.1
Percentage of Nonroutine Reoperation	15.8	34.1

\*Only one value reported by Nowak et al., this represents an average of 11 patients.<sup>31</sup>

\*\*van der Meijden et al. reported some complications only as total complications without delineation of minor or major, therefore, those were included in the final comparison of total complications.<sup>29</sup>

Averages Were Weighted Depending on Study Population and Percentages Were Calculated Using Pooled Study Population.



**Table 4. Outcome Data Reported in the Reviewed Articles Included in This Systematic Review**

Author	DASH	Constant-Murley Score	Minor Complications	Major Complications	Total Complications	Non-Routine Reoperation	Total Reoperations
Acute							
Assobhi et al.	NR	89.9	4	3	7	2	2
	NR	95.5	3	0	3	3	3
Calbiyik et al.	8.19	90.1	11	3	14	2	2
Calbiyik et al.	NR	94.38	4	2	6	NR	NR
	NR	92.85	1	2	3	NR	NR
Jiang et al.	NR	NR	2	0	2	NR	NR
	NR	NR	12	0	12	NR	NR
Judd et al.	NR	NR	17	5	22	8	31
Kulshrestha et al.	NR	NR	8	2	10	6	6
Kundangar et al.	NR	96	13	1	14	NR	NR
	NR	94	5	1	6	1	1
Mirzatoiooei et al.	8.6	89.8	11	3	14	2	2
Narsaria et al.	NR	96.2	5	3	8	22	22
	NR	94.6	1	2	3	1	33
Qvist et al.	1.7	NR	44	5	49	17	17
Robinson et al.	3.4	92	40	5	45	16	16
Sahu et al.	1.87	9.36	2	0	2	NR	NR
	4.8	15.08	4	4	8	NR	NR
Shen et al.	NR	NR	1	0	1	1	1
	NR	NR	8	0	8	8	8
Smekal et al.	0.5	98	8	10	18	12	12
Sohn et al.	NR	95.7	2	2	4	6	6
	NR	97.2	1	0	1	3	3
Tamaoki et al.	3.3	NR	14	1	15	3	3
van der Meijden et al.	2.4	99.2	0	0	36	5	5
	3.9	91.3	33	0	43	10	12
Virtanen et al.	4.3	86.5	4	3	7	0	0
Woltz et al.	4.5	95.4	17	13	30	23	23
Delayed							
Kabak et al.	NR	NR	9	2	11	10	10
	NR	NR	1	0	1	2	2
	N/A	N/A	5*	0*	5*	N/A	N/A
Nowak et al.	NR	86	8	3	11	3	3

NR= not reported, N/A= not applicable. \*Complications not specified as to which study group they belonged to in the study by Kabak et al.<sup>30</sup>

the percentage of patients experiencing any complication was 33.8% in the early fixation group and 63.6% in the delayed fixation group (Table 3).

### Reoperation Rates

Reoperation was reported in seventeen early intervention papers<sup>11-22,24,25,27-29</sup> and both delayed intervention papers (Table 4).<sup>30,31</sup> When all reasons for reoperation were considered, 21.7% of all early fixation patients and 34.1% of all delayed fixation patients had reoperation. After excluding routine implant removals, 15.8% of early fixation patients and 34.1% of delayed fixation patients underwent reoperation (Table 3).

### Limitations

Following evaluation of the RCTs with the NIH tool, six were found to be of good quality,<sup>14,17,23,28-30</sup> nine studies were found to be of fair quality,<sup>11,13,15,18-20,25-27</sup> and three studies were found to be of poor quality.<sup>16,21,22</sup> For the PCSs, evaluation showed all three studies to be of poor quality.<sup>12,24,31</sup> Notably, one delayed study and five early studies were rated as poor quality. Additionally, very few qualifying studies described delayed surgical repair of midshaft clavicle fractures, making direct statistical comparison challenging. Specifically, seventeen RCTs described early surgery,<sup>11,13-23,25-29</sup> and two of the PCSs described early surgery,<sup>12,24</sup> while only one RCT<sup>30</sup> and one PCS<sup>31</sup>—two studies total—described delayed surgery. The scarcity of studies directly comparing early versus delayed surgery with a level of evidence greater than three made it difficult to conduct a high-level systematic review comparing the two surgical-timing protocols.

## DISCUSSION

In the present review, the numerical differences observed often favored early operation when comparing early and delayed surgery for MCFs. Demographically, patients in the early intervention papers and delayed intervention papers were similar with exception of percentage of males in each population. Notably, the percentage of patients in the early operative group experiencing nonunion, complication, and reoperation for any reason was lower than that seen in delayed intervention studies. Additionally, DASH scores were lower and CM scores were higher in early fixation studies.

To our knowledge, this is the first systematic review comparing level I and II evidence of early and delayed surgery in MCFs. However, some retrospective studies have sought to directly compare outcomes of early vs. delayed surgery for MCFs. In one study comparing immediate MCF fixation versus fixation of nonunion or malunion six or more months from initial fracture (mean 63 months), Potter et al. found CM scores were superior

in immediate operations (89 vs 95,  $p=0.04$ ), and DASH scores were not statistically different despite being lower in patients receiving early intervention (7.2 vs. 3.0,  $p=0.15$ ).<sup>32</sup> Das et al. prospectively compared the outcomes of early fixation within three weeks of fracture with a delayed fixation group receiving an operation from three weeks to three months after their initial fracture. In their study, they found no difference in functional outcomes between early and delayed surgery for MCFs when assessed using a shortened version of the DASH, the quickDASH.<sup>33</sup> Our systematic review showed improved DASH scores and CM scores for early fixation of MCFs, but CM score in the delayed group only represents the results of 11 patients from a single study. Interestingly, the Das et al. study did not find significant differences when the delayed surgeries were completed within three months, whereas our study and Potter et al.'s study showed larger differences between the functional outcome scores of early and delayed surgeries when delay was extended beyond a year. Therefore, it seems that a transition point may exist sometime between three months and one year where early and delayed surgery no longer result in equitable functional outcomes.

In the present study, post-surgical complications were common in both delayed and early MCF operations. However, there was a propensity for complications in the delayed group of almost two times the percentage in the early group when examining major, minor, and total complications. Das et al. considered nonunion, wound healing, infection, symptomatic metal work, and scars as complications. In their study, they discovered no significant difference in complication rates between early and delayed operation.<sup>33</sup> A study by Sawalha & Guisasola retrospectively compared the outcomes of 90 acute fixations at an average of 10 days to 20 delayed surgeries for nonunion at an average of 15 months. They found no significant difference between total complications nor major complications in their study population.<sup>34</sup> In our study, the most prevalent complications in the early intervention group were pain/dysesthesia ( $n=71$ ) and implant prominence ( $n=68$ ), while functional limitation ( $n=9$ ) and pain/dysesthesia ( $n=7$ ) were highest in delayed interventions. Hence, the most common complications observed tend to be minor complications, yet these still can cause significant morbidity that may lead to reoperation.

In our study, the rate of nonunion and reoperation between early and delayed surgery for MCFs was lower in the early fixation group. Interestingly, Sawalha & Guisasola found no difference between the acute and delayed surgery groups in terms of nonunion rates and reoperation rates. In their study the most common reason for reoperation in the acute group was prominent metal work

( $n=7$ ), whereas persistent delayed union or nonunion was the most common reason in the delayed group ( $n=5$ ).<sup>34</sup> The most common reason for reoperation following delayed fixation in our study was implant removal for cosmesis or pain, compared to implant removal for infection, symptomatic implant, prominence, bending, or pain in the early group. The delayed group in our study had five reoperations for nonunion compared to four in the early group, which is substantial when considering five of 44 patients required nonunion reoperation with delayed surgery. Das et al. reported one nonunion in their early group and zero nonunions in their delayed group but did not report the number of reoperations in each group.<sup>33</sup> Based on the present study and these previous studies, nonunion and reoperation appear to be more common in delayed operations. Importantly, persistent symptomatic nonunion usually requires a much more involved reoperation with bone grafting to reconstruct the clavicle. The risk of nonunion and subsequent reoperation is an important consideration to discuss when recommending initial nonoperative treatment to patients with MCF.

Despite evidence of poorer outcomes in delayed fixation, some studies have performed surgical delay, opting for initial nonoperative treatment, in an attempt to elucidate the best predictors of failed nonoperative treatment. Das et al. was able to withhold operation for most patients, successfully treating them nonoperatively, reserving operation only for patients with initially high-risk fractures or fractures that did not begin the healing process. However, they acknowledge limitations because more severe fractures were probably more likely to be treated by early surgery, meaning even fractures that did not heal using nonoperative treatment and required delayed surgery were likely less complex.<sup>33</sup> Similarly, Nicholson et al. conducted a prospective cohort study that examined nonoperatively treated patients 6 weeks after their initial injury to determine if predictive factors of nonunion existed. They found that during this delayed assessment, combined findings from examining the patient with the quickDASH questionnaire, looking for callus formation on radiographs, and observing fracture movement during physical examination could accurately predict nonunion in these patients. They used receiver operating curve analysis with these variables to deduce an area under the curve of 87.3%, meaning they could predict nonunion with relatively good accuracy.<sup>35</sup> Given these results, it seems even short delays of a few weeks have the potential to significantly reduce the number of procedures performed while maintaining the same level of successful care provided to all patients.

For displaced midshaft clavicle fractures, this systematic review suggests early operative fixation results in improved outcomes in midshaft clavicle fractures;

yet definitive conclusions about the utility of delayed surgery are difficult with data from such a small cohort. With some studies showing promise of initial delay in all patients and the present study still showing moderate results for delayed surgery, we suggest the best approach to deciding when to operate likely involves surgeons using a shared decision-making style to develop the best treatment plan for each patient. Surgeons should discuss the complications associated with early surgical fixation, nonoperative treatment, and delayed surgery with each patient so they can make an informed decision that suits their expectations. Still, the lack of prospective studies directly comparing early versus delayed surgery is remarkable; therefore, a prospective study comparing early and delayed fixation of MCFs is warranted to appropriately evaluate the two interventions and conclusively recommend the best initial treatment for displaced MCFs.

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# NEEDLE ARTHROSCOPY AS A REDUCTION AID FOR LOWER EXTREMITY PERI-ARTICULAR FRACTURES: CASE SERIES AND TECHNICAL TRICKS

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## ABSTRACT

**Background:** Intra-articular fractures represent a challenging group of injuries that can occur in many different locations. In addition to restoring the mechanical alignment and stability of the extremity, accurate reduction of the articular surface is a primary goal for the treatment of peri-articular fractures. A variety of methods have been deployed to assist in the visualization and subsequent reduction of the articular surface, each with a unique set of pros and cons. The ability to visualize the articular reduction must be balanced against the soft tissue trauma required for extensile exposures. Arthroscopic assisted reduction has gained popularity for the treatment of a variety of articular injuries. Recently, needle based arthroscopy has been developed, predominantly as an outpatient tool for the diagnosis of intra-articular pathology. We present an initial experience with and technical tricks for the use of a needle based arthroscopic camera in the treatment of lower extremity peri-articular fractures.

**Methods:** A retrospective review of all cases where needle arthroscopy was used as a reduction adjunct in lower extremity peri-articular fractures at a single, academic, level one trauma center was performed.

**Results:** Five patients with six injuries were treated with open reduction internal fixation with adjunctive needle based arthroscopy. Early experience and tips and tricks for successful utilization of this technique are presented.

**Conclusion:** Needle based arthroscopy may represent a valuable adjunct in the treatment of peri-articular fractures and warrants further investigation.

## Level of Evidence: IV

**Keywords:** arthroscopic assisted reduction, needle arthroscopy, articular fracture

## INTRODUCTION

Treatment of lower extremity peri-articular injuries must achieve the restoration and/or maintenance of a congruent articular surface while minimizing the surgical insult to the surrounding soft tissues. While the absolute requirements of reduction vary by joint, the overarching principles of a stable, congruent joint remain consistent. Varied methods exist to accomplish these goals; however, this often involves some form of operative management. Surgical management of these injuries can include external fixation (traditional or Ilizarov), limited open reduction, arthroscopically aided reduction, open reduction internal fixation (ORIF), or any combination of these.

Arthroscopy has become a viable and accepted adjunct in the treatment of a wide variety of articular injuries with reported benefits including accurate assessment of fracture patterns and soft tissue injuries, anatomic reduction, the ability to perform additional procedures, and minimizing insult to the soft tissues.<sup>1</sup> One of the principal benefits is the direct visualization of the articular surface while preserving soft tissues.<sup>2</sup> In the treatment of ankle fractures, arthroscopy allows for direct detection and treatment of intra-articular pathology,<sup>3</sup> which may prove beneficial as over 60% of ankle fractures were found to have chondral injuries in a systematic review.<sup>4</sup> Arthroscopy has also been used as an adjunct in tibial plateau fractures<sup>5</sup> as it allows the surgeon to protect soft tissues, directly visualize the articular surface, evaluate for concomitant intra-articular injuries (e.g. meniscal injury), and employ alternative minimally invasive fixation strategies.<sup>6</sup> In pilon fractures it has been used to allow percutaneous screw placement<sup>7</sup> and in conjunction with external fixation to obtain articular reduction without soft tissue complications.<sup>8</sup>

These reports discuss the use of standard arthroscopic equipment and set up, requiring significant additional equipment in the operating theater in the form of arthroscopy towers, fluid pumps, and video monitors, not to mention potential changes to otherwise standard operative table selection and patient position-

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ing that would otherwise be used for fracture surgery. Additional concerns have included significant soft tissue edema with standard arthroscopy that may pose a risk for compartment syndrome and wound compromise in traumatized limbs.

Needle arthroscopy has recently gained popularity as an office based intra-articular assessment tool.<sup>9</sup> Multiple vendors have developed small needle arthroscopy camera systems, which obviate the above concerns, while potentially providing the benefit of adjunct arthroscopy in the treatment of articular fractures. The fluid is delivered through a syringe attached to the camera, which can attach to a table positioned in the room at the surgeon's convenience. This removes the need to change operating room tables, have arthroscopy monitors, towers, and fluids in the operating room, and is compatible with any patient positioning.

We report on an initial series of the use of needle arthroscopy during open reduction and internal fixation of lower extremity peri-articular fractures to facilitate the identification of intra-articular pathology, change intra-operative decision-making regarding quality of the reduction, decrease the need for additional joint visualization techniques (such as osteotomies, external fixators, and femoral distractors), and permit smaller incisions. We present technical tips and tricks for the use of needle-based arthroscopy as an adjunctive aid for open reduction and internal fixation of articular fractures.

## METHODS

A retrospective chart review was performed of all cases where a needle arthroscopic camera was used to assist with ORIF of peri-articular lower extremity fractures at a single, academic, level one trauma center. Patient injury characteristics, operative techniques, and the intra-operative use of the camera were recorded. Specific attention was paid to uses of a needle arthroscopic camera to assist in obtaining and confirmation of the articular reduction. The use of needle arthroscopy was at the sole discretion of the attending surgeon (HRM) for all cases. All cases in this series utilized the Mi-Eye (Trice Medical, Malvern, PA) system which is a Food and Drug Administration (FDA) approved handheld device designed for diagnostic and operative arthroscopic procedures that provides a 120-degree field of view through a retractable 2.26 mm needle allowing live imaging and video capture.

## RESULTS

### Case 1

A 74-year-old female sustained bilateral tibial plafond injuries temporized with external fixation in another state four weeks prior to presentation. X-rays demonstrated in-

adequate initial reduction at the time of external fixation. Computed Tomography (CT) scan of the right leg demonstrates the classic three articular segments, posterior dislocation of the talus, and shortening of the extremity. CT scan of the left leg demonstrates a more comminuted articular block in the posterior column and shortening of the extremity. The decision was made to treat these injuries with definitive fixation in a staged manner. The right side was approached with medial and lateral approaches to address both the tibia and the fibula. The articular reduction was visualized and confirmed using the needle arthroscopic camera, confirming that clamp placement provided anatomic articular reduction and compression (fig 1). This allowed for a less soft tissue stripping and dissection. Postoperative CT confirmed reduction of the articular block. Subsequently, the left tibia was fixed utilizing a direct anterior approach due

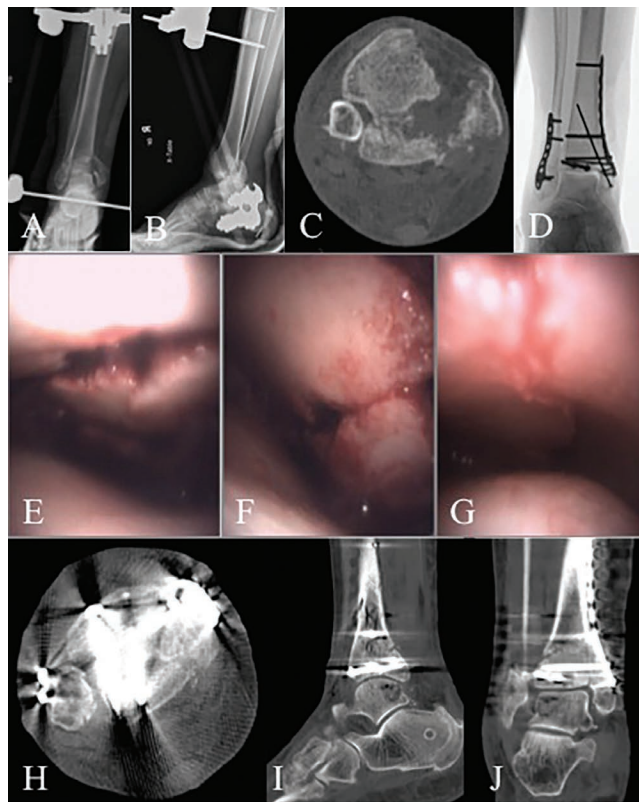


Figure 1. 74-year-old female transferred from another facility after spanning external fixation of an intra-articular pilon fracture. Initial x-rays upon presentation demonstrating inadequate reduction in frame, (A) mortise ankle, (B) lateral ankle. (C) Axial computed tomography demonstrating classic pilon articular fragments. Intraoperative fluoroscopy of final reduction and fixation construct (D). Pre clamp placement view with camera looking at articular surface (E), and post clamp placement view using camera (F) to confirm reduction and compression across fracture lines. View at medial shoulder confirming reduction of anterior, medial, and posterior fragments (G). Axial post op CT at joint (H), sagittal post op CT (I) confirming reduction of anterior and posterior articular fragments, and coronal post op CT confirming medial reduction (J).



to medial soft tissue concerns despite extensive soft tissue rest in the frame. Needle arthroscopy was used to confirm reduction and allow for a less invasive approach than otherwise would have been required to confirm anatomic reduction of the articular block. Associated technical trick – While both the main surgical incision or the use of an accessory portal are viable options for needle arthroscopy, the main point to consider is what specific structure(s) need to be visualized (in this case, which part of the articular reduction) and what trajectory will your working instruments be approaching this area from? Choose an incision to insert the camera that allows direct visualization of the area of interest, which may require a separate small needle stab arthrotomy. This will leave your main surgical incision free to use to manipulate and reduce fracture fragments without obstruction.

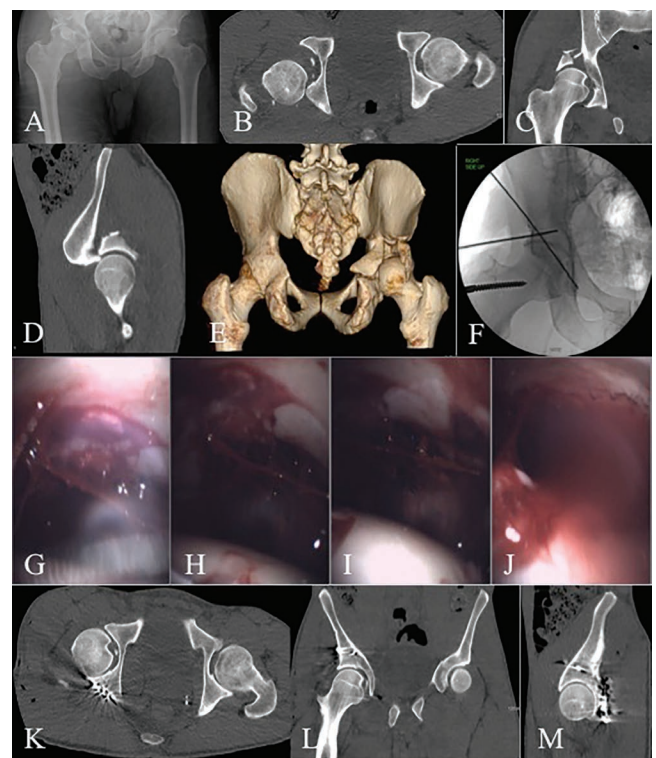
### Case 2

A 39-year-old male fell 14 feet from a ladder, sustaining a right hip dislocation with associated posterior wall fracture. The patient was transferred urgently from another facility and underwent emergent closed reduction in the emergency room. CT scan demonstrated a posterior column and large segmental posterior wall fracture with posterior and superior segments, but without significant marginal impaction (fig 2). With the patient in the lateral decubitus position, a Kocher-Langenbeck approach was performed. The pre-operative CT scan demonstrated the presence of intra-articular debris; therefore, a schantz pin was placed in the femoral neck and utilized to distract the femoral head from the acetabulum. A thorough lavage and removal of all visible debris was performed. The Mi-eye camera was then used to help search the joint for any further retained fracture debris. A small piece was visualized but was confirmed to be in the fovea using the camera and therefore further dissection or osteotomy/dislocation was not performed to remove this fragment. After debris was removed, and the fracture was reduced and fixed with two recon plates, the needle arthroscope was again used to confirm reduction. Post-operative CT confirmed the debris was confined to the fovea with a concentric reduction of the hip. Associated technical trick – No matter the peri-articular injury, a constant balance must be weighed between visualizing the reduction with the ability to achieve fixation and the soft tissue, osseous, and surgical cost of enlarging an exposure, making an additional incision, performing an osteotomy, or the use of an external fixator or distractor. The needle camera can be inserted into small areas to allow direct visualization of a hard to reach area (in this case to improve visualization of the anterior hip) and

help direct decision-making as to whether additional exposure (through whatever means) is needed to improve the quality of the reduction or remove unwanted tissue.

### Case 3

A 47-year-old male sustained a twisting injury and presented with an intra-articular left distal tibia fracture. CT scan confirmed medial and posterior articular fragments in addition to the main articular block which comprised the central, anterior, and lateral plafond, as well as meta-diaphyseal extension (fig 3). The patient had significant fracture blistering on the medial tibia, precluding any sort of extensile medial exposure to reduce and fix this injury. The patient initially underwent spanning external fixation. After soft tissues were allowed to rest, the patient returned to the operating room two weeks later for definitive fixation. A direct anterior approach was



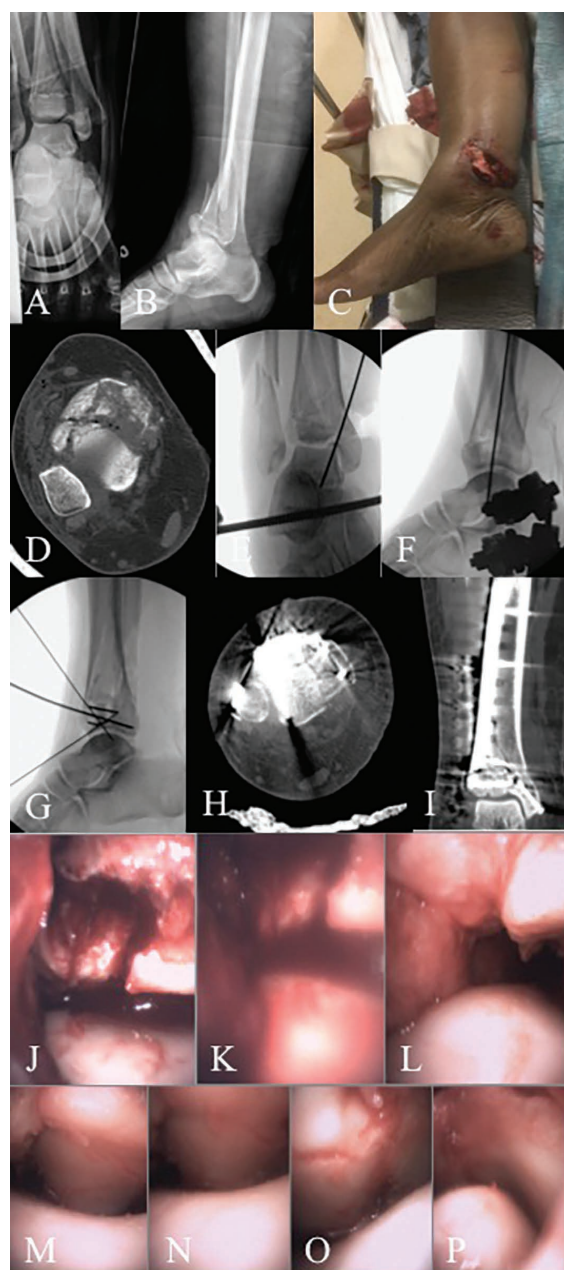
**Figure 2.** 39-year-old male who fell from a ladder sustaining a right hip dislocation with a posterior wall fracture. Injury AP pelvis x-ray (A). Injury axial (B), coronal (C), sagittal (D), and 3D reconstruction (E) computed tomography images demonstrating a comminuted posterior wall fracture with intra-articular debris. Intra-operative fluoroscopy with schantz pin in the femoral neck for distraction and provisional reduction stabilized with k-wires. Intra-operative use of camera to aid in visualization and judgment of articular reduction as well as assure that no further intra-articular debris needs to be removed (G, H, I, J). Postoperative axial (K), coronal (L), and sagittal (M) computed tomography demonstrating adequate reduction and remaining debris confined to the fovea.



performed and the needle arthroscopic camera was used to confirm reduction of the medial articular fragment, which allowed for MIPO plating of the medial fracture as opposed to a complete medial exposure to visually reduce and fix the articular fragment. This allowed the high-risk medial soft tissues to avoid a surgical incision, while still allowing confirmation of the articular reduction. Associated technical trick – Direct visualization of the articular surface can reduce the need for postoperative computed tomography scans. Many surgeons obtain postoperative CT scans after ORIF of pelvic, acetabular, syndesmotic, and peri-articular fractures to confirm appropriate articular reduction, fixation, and implant safety. Complete visualization of the joint surface with a needle arthroscopic camera can confirm the safety of all implants and reduction of the articular surface, possibly reducing the need for postoperative CT scans and the associated radiation dose.



**Figure 3.** 47-year-old male who sustaining a twisting lower extremity injury. Mortise (A) and lateral (B) x-rays demonstrating a spiral, intra-articular distal tibia fracture. Clinical photo of the patient's limb demonstrating fracture blisters and significant edema (C). Pre-operative axial (D), coronal (E), and sagittal (F) computed tomography slices demonstrating medial and posterior intra-articular fractures, with anterior articular block connecting with anterior-lateral metaphyseal spike. Intra-operative fluoroscopy of mortise (G) and lateral (H) spanning external fixation performed on the day of injury. Intra-operative fluoroscopy two weeks later at time of definitive fixation with provisional reduction and plate balance obtained. Intra-operative images obtained with needle arthroscopic camera of articular surface pre-reduction (K, L, M, N), and images obtained post reduction (O, P, Q, R), confirming articular reduction and obviating the need for post-operative computed tomography to confirm reduction.



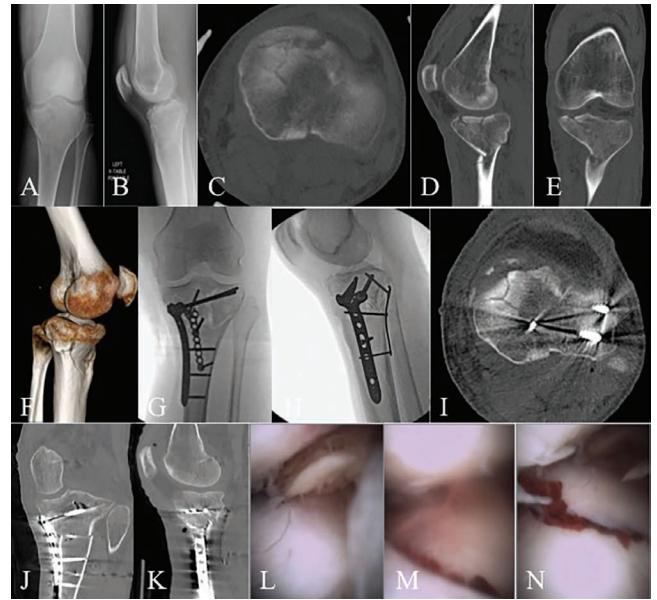
**Figure 4.** 57-year-old female in a motor vehicle collision who sustained a Gustilo-Anderson type 3A open right pilon fracture. Injury mortise (A) and lateral (B) ankle x-rays. Clinical photo of medial, transverse, tension failure wound (C) in the trauma bay. Pre-operative axial (D) computed tomography scan demonstrating significant anterior and medial comminution. Intra-operative fluoroscopy mortise (E) and lateral (F) images during the initial debridement, irrigation, and spanning external fixation demonstrating overall restoration of length, alignment, and rotation. Lateral (G) intra-operative fluoroscopy at the time of definitive fixation with provisional stabilization and reconstruction of the articular block. Post-operative axial (H) and coronal (I) computed tomography demonstrating reduction of the articular block. Intra-operative view of the lateral joint pre reduction (J) to post reduction (K, L). Intra-operative view of the joint post reduction progressing from the central joint space to the medial joint space (M, N, O, P) confirming accurate medial reduction without needing to re-open the traumatic medial wound.

#### Case 4

A 57-year-old female in a motor vehicle collision sustained a Gustilo-Anderson type 3A open right pilon fracture with a medial traumatic wound that underwent debridement, irrigation, and external fixation on the day of initial presentation (fig 4). The medial wound was a transverse, tension failure wound that precluded any extensile exposures on the medial side despite adequate soft tissue rest with temporizing in an external fixator for three weeks. At definitive fixation, direct anterior and posterior-lateral approaches were utilized. A needle arthroscopic camera was used to confirm articular reduction without additional medial exposure, thereby avoiding further surgical insult to a tenuous soft tissue envelope. Associated technical trick – Obtaining a clear visual field is critical to realizing the benefit of direct arthroscopic visualization, which requires management of the fluid inflow. The surgeon can choose to attach a syringe with sterile fluid to the camera and control the amount and timing of the fluid inflow to establish a clear visual field. Alternatively, gravity flow can be established by attaching plastic tubing to the camera and a sterile fluid bag (in the same manner used for irrigation), and then adjust the height of the bag on an IV pole to control the rate of fluid introduced to the field. Much the same as with traditional arthroscopy, this can be done with or without a tourniquet inflated at the surgeons' preference.

#### Case 5

A 48-year-old male pedestrian struck by an automobile sustaining a predominantly antero-medial tibial plateau fracture (fig 5) with an additional large posterior-medial fragment as well as an ipsilateral pilon fracture (fig 6). An anterior-lateral approach to the distal tibia was performed, the articular fragments were disimpacted, the metaphyseal fragments reduced to restore length and alignment. For the tibial plateau, a medial approach was performed and the medial plateau was reduced. The needle arthroscopic camera was used to verify anatomic reduction both before and after implant placement for both the pilon and plateau. Associated technical trick – Using needle arthroscopy can permit percutaneous reduction techniques and allow for minimally invasive fixation strategies. The camera can be used to confirm that articular fragments have been dis-impacted and the articular surface restored using percutaneously placed bone tamps and elevators prior to filling metaphyseal voids. Once confirmation of the restoration of the articular block is confirmed, limited dissection can be employed to allow for definitive fixation.



**Figure 5.** 48-year-old male pedestrian struck by an automobile sustaining a left sided tibial plateau fracture and an ipsilateral pilon fracture (see Fig 6). Injury AP (A) and Lateral (B) knee x-rays and axial (C), sagittal (D), coronal (E), and 3D reconstruction (F) computed tomography images demonstrate a predominantly antero-medial injury with an additional large posterior-medial fragment. Intraoperative final AP (G) and lateral (H) fluoroscopic images demonstrate buttress fixation of both the anterior-medial and posterior-medial fragments. Postoperative axial (I), coronal (J), and sagittal (K) computed tomography images demonstrate reduction and fixation of the articular fragments. Intra-operative images obtained with the needle arthroscopic camera confirming reduction of the articular fragments (L, M, N).

### DISCUSSION

Accurate articular reduction is a primary goal in the surgical management of peri-articular injuries. Therefore, a multitude of exposures, adjuvant instruments, reduction techniques, and visualization tools have been utilized to further this aim across a multitude of injuries.<sup>10</sup> Extensile exposures offer improved direct visualization but come at the cost of additional soft tissue injury. Any technique that is used to improved reduction quality must be balanced against the associated potential cost to the soft tissues. External fixators and distractors are powerful tools to obtain length, alignment and a provisional reduction, but are bulky, may interfere with the ability to achieve definitive fixation goals, and if not applied carefully can cause subtle (or overt) malreduction forces, make it more difficult to obtain adequate fluoroscopic images, and tension incisions, thereby reducing visualization.

Arthroscopy has been used for the direct visualization of articular surfaces<sup>1,2</sup> but requires an additional complete arthroscopy set up in the operating room in addition to fracture fixation equipment, and comes with concerns about irrigating with pressure a fracture where fluid



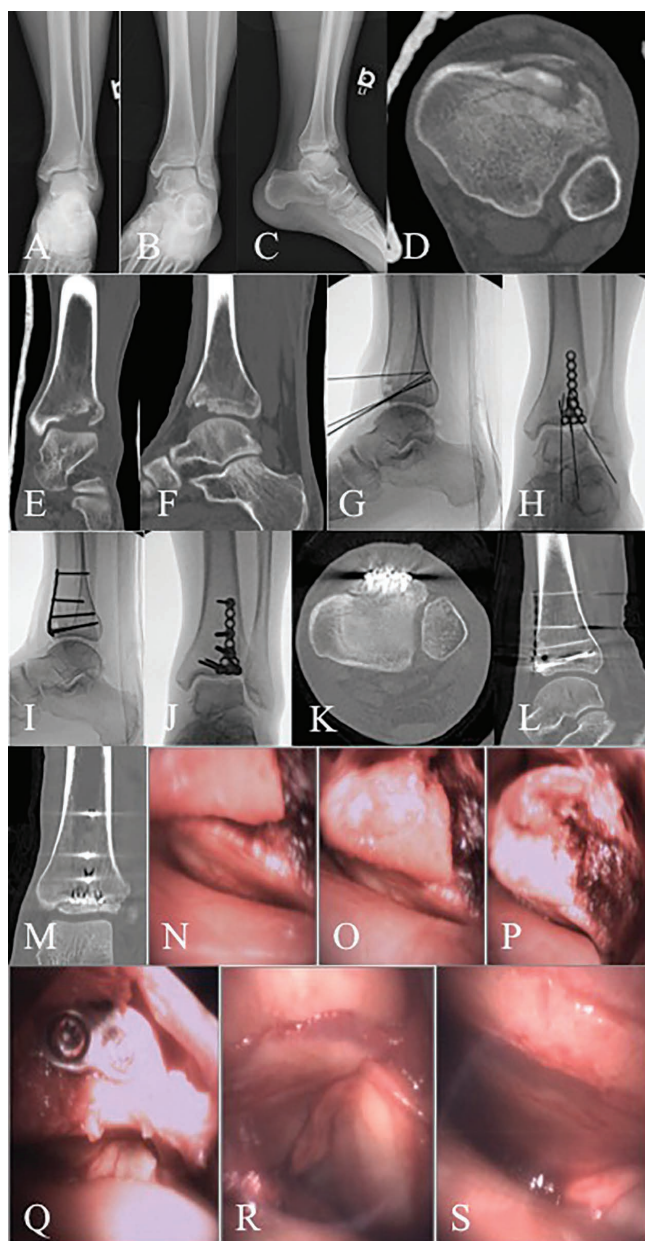


Figure 6. Pilon fracture sustained by the same patient illustrated in figure 5. Injury AP (A), mortise (B), and lateral (C) x-rays, and axial (D), coronal (E), and sagittal (F) computed tomography slices demonstrate an anterior crush injury to the distal tibia. Intraoperative fluoroscopic lateral (G), and mortise (H) with provisional reduction obtained and stabilized with k-wires. Final lateral (I), and mortise (J) intra-operative fluoroscopy. Postoperative axial (K), sagittal (L), and coronal (M) computed tomography scans confirming reduction of anterior joint. Intra-operative needle arthroscopic camera images pre-reduction (N, O, P), and post reduction (Q, R, S), confirming reduction and hardware safety.

extravasation may egress into a closed space. A handheld, syringe pressured, disposable arthroscopy camera may provide much of the benefits of formal arthroscopy without the associated risks. Needle arthroscopes can be easily inserted and removed a multitude of times and at various stages of an operation. Additionally, due to the small size of the camera and portable nature of the viewing tablet, the surgeon can easily arrange for sequential or simultaneous use of the needle arthroscope with traditional fluoroscopic assessment.

Several techniques can be employed to improve the surgeon's ability to obtain a clean visual field and accurately assess the articular reduction. As this is a low-pressure arthroscopic system that is under the surgeons' control (via the handheld syringe or the gravity flow tubing), the concern for fluid pressurizing a potentially closed system or intraosseous space is limited. Surgeon control of the arthroscopic fluid, as well as the ability to have a pneumatic tourniquet inflated where feasible can help improve visualization.

Finally, direct visualization of the articular surface can reduce the need for postoperative computed tomography scans. Many surgeons obtain postoperative CT scans after ORIF of pelvic, acetabular, syndesmotom, and peri-articular fractures to confirm appropriate articular reduction, fixation, and implant safety. Complete visualization of the joint surface with a needle arthroscopic camera can confirm the safety of all implants and reduction of the articular surface, possibly reducing the need to obtain postoperative CT scans and the associated radiation dose.

This case series represents only an initial experience and there are several limitations to consider. First, objectively measured radiographic or patient reported outcomes are not presented, so no conclusions about the quality of the reduction obtained and/or the return of function of the patients treated in this method can be inferred. Second, no comparison group of similar injuries treated with alternative means is presented, so any potential benefit in patient care is theoretical and requires further investigation. Third, while no complications believed to be due to the use of the needle arthroscopic camera were observed, it is possible with widespread use, unanticipated outcomes could be observed.

These cases represent an initial experience with a needle arthroscopic camera for the adjunctive treatment of lower extremity peri-articular injuries. Needle arthroscopy represents an additional tool available for surgeons to utilize in the treatment of peri-articular injuries to assist in obtaining and confirm anatomic reduction of the articular surface. The potential exists to more easily identify concomitant intra-articular pathology, change intra-operative decision-making regarding reduction qual-

ity, utilize smaller incisions, avoid additional visualization aids, and reduce the need for post-operative CT scans. Further study is warranted to determine if the use of needle arthroscopy for peri-articular fractures improves patient outcomes or is a cost-effective strategy compared to other traditional techniques.

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# OUTCOMES OF THE FIRST GENERATION LOCKING PLATE AND MINIMALLY INVASIVE TECHNIQUES USED FOR FRACTURES ABOUT THE KNEE

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## ABSTRACT

**Background:** Locking plate technology was developed approximately 25-years-ago and has been successfully used since. Newer designs and material properties have been used to modify the original design, but these changes have yet to be correlated to improved patient outcomes. The purpose of this study was to evaluate the outcomes of first-generation locking plate (FGLP) and screw systems at our institution over an 18 year period.

**Methods:** Between 2001 to 2018, 76 patients with 82 proximal tibia and distal femur fractures (both acute fracture and nonunions) who were treated with a first-generation titanium, uniaxial locking plate with unicortical screws (FGLP), also known as a LISS plate (Synthes Paoli Pa), were identified and compared to 198 patients with 203 similar fracture patterns treated with 2nd and 3rd generation locking plates, or Later Generation Locking Plates (LGLP). Inclusion criteria was a minimum of 1-year follow-up. At latest follow-up, outcomes were assessed using radiographic analysis, Short Musculoskeletal Functional Assessment (SMFA), VAS pain scores, and knee ROM. All descriptive statistics were calculated using IBM SPSS (Armonk, NY).

**Results:** A total of 76 patients with 82 fractures had a mean 4-year follow-up available for analysis. There were 76 patients with 82 fractures fixed with a First-generation locking plate. The mean age at time of injury for all patients was 59.2 and 61.0% were female. Mean time to union for fractures about the knee fixed with FGLP was by 5.3 months for acute fractures and 6.1 months for nonunions. At final follow-up, the mean standardized SMFA for all patients was 19.9, mean knee range of motion

was 1.6°-111.9°, and mean VAS pain score was 2.7. When compared to a group of similar patients with similar fractures and nonunions treated with LGLPs there were no differences in outcomes assessed.

**Conclusion:** Longer-term outcomes of first-generation locking plates (FGLP) demonstrate that this construct provides for a high rate of union and low incidence of complications, as well as good clinical and functional results.

**Level of Evidence:** III

**Keywords:** LISS plate, tibial plateau fracture, tibial fracture, first generation locking plate, second generation locking plate, FGLP, locking plate, distal femur fracture

## INTRODUCTION

There are multiple options for the surgical treatment of acute articular and periarticular fractures and non-unions about the knee. These include locked plates and screws, retrograde and anterograde intramedullary nails, condylar blade plates, and condylar buttress plates.<sup>1-3</sup>

Locking plates were developed roughly 25 years ago and the first generation locking plate (FGLP), Less Invasive Skeletal Stabilization Plate (LISS Plate, Synthes, Paoli Pa), was the first dedicated, commercially available system for minimally invasive fracture surgery.<sup>4</sup> These FGLP plates have been used in our institution for over 20 years with subjectively good clinical and radiographic results.

Some initial studies of the FGLP reported excellent results with these implants, such as Shütz et al. in his 2001 multicenter clinical study,<sup>5</sup> while others reported mixed results and complications.<sup>6</sup> Industry followed with the development of plates and screws with similar designs, but alterations to avoid patent infringement. The introduction of stainless-steel locking plates was accompanied with increased rates of fracture nonunion owing to a relative increase in construct stiffness, with many studies examining this phenomenon.<sup>7-10</sup> Responses to these problems have since changed the landscape of locking plates, as surgeons developed new strategies such as far cortical locking screws and active plates. The stiffness provided by these constructs is intended to mimic the action of an external fixator more closely than

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locking plates without dynamization. These products are theorized to promote secondary healing through achieving more optimal levels of interfragmentary motion, stimulating callus formation.

To our knowledge, there has been no medium or longer-term clinical outcome analysis of the FGLP since the introduction of these newer technologies. The purpose of this study is to evaluate the result of fracture fixation about the knee with the FGLP to determine if treatment with these implants resulted in adequate healing and acceptable clinical outcome rates in areas including: nonunion, malunion, need for secondary operation, persistent post-operative pain, or patient dissatisfaction. The secondary aim of this study was to compare these outcomes with a similar cohort of patients treated during the same period, by the same surgeons with 2nd and 3rd generation locked plates, or later generation locking plates (LGLPs), to determine how the first generation implants performed in comparison.

## METHODS

### Patient Cohort

Over a 18-year period between 2001 to 2018, 376 patients with 386 distal femur or proximal tibia acute fractures or nonunions treated by two surgeons were retrospectively identified in prospectively collected registries. Of these, 100 patients with 107 fractures were treated with a first generation locking plates (FGLP). Of those, 81 patients with 87 (81.3%) distal femur or proximal tibia acute fractures or nonunions had at least 1 year follow up. Of the 87 fractures or nonunions identified, 76 patients with 82 fractures (94.3%) had complete data and radiographs (Figure 1). These patients were all treated with the first generation locking plate (FGLP) system. This system includes 3 lengths of pre-contoured, titanium monoaxial locking plates and limited length uni-cortical screws (LISS plate, Synthes, Paoli Pa) that is applied using minimally invasive percutaneous plate osteosynthesis techniques (MIPPO) for acute or ununited proximal tibial fractures, distal femoral fractures, and periprosthetic distal femoral fractures (Figure 2). All patients fixed with a FGLP were treated using a similar protocol. Patients with an acute fracture were treated

using accepted techniques of MIPPO including a small opening portal incision, followed by indirect reduction and percutaneous plate placement with screw insertion using a radiolucent jig.<sup>11,12</sup> In the case of ununited fractures, the nonunion site was opened and debrided with the plate applied without any further soft tissue stripping. In these cases, autogenous or allograft/ BMP was applied to the nonunion site in an open fashion to promote healing. Exclusion criteria included lack of complete data or less than 12 months of follow-up data.

Of the 87 fractures or nonunions identified, 82 (94.3%) were available for evaluation with a mean of 4 years follow-up (range 1-14 years). Longer term outcomes were assessed using the Short Musculoskeletal Functional Assessment (SMFA), radiographic analysis, pain score (VAS), and knee range of motion (ROM) at latest follow-up.

Each visit included a physical examination, radiographic examination, and completion of the Short Musculoskeletal Function Assessment (SMFA) questionnaire. For the purposes of this study, patients were considered to have developed a persistent nonunion if they had not

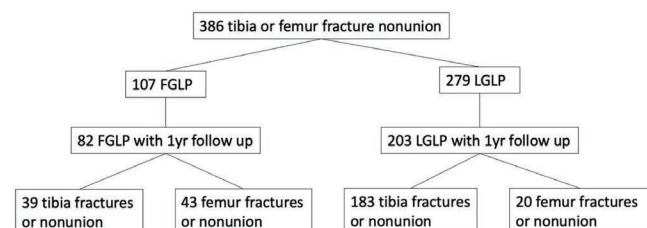


Figure 1. Breakdown of described cohorts.



Figure 2A to 2D. Radiographs of the left leg of a 70-year-old female with a Schatzker 6 tibial plateau fracture status post fall from standing. (2A) An AP radiograph of the left knee demonstrating a left Schatzker 6 tibial plateau fracture, as well as a fibular shaft fracture. (2B) A coronal CT cut of the left leg demonstrating a Schatzker 6 tibial plateau fracture. (2C, 2D) AP and lateral radiographs of the left knee demonstrating ORIF of the previously demonstrated fracture using a FGLP.

achieved union 12 months following surgical intervention or if they underwent surgical repair of nonunion. For the purposes of this study attempts were made to contact patients treated with a FGLP and have them return for a follow visit either in person or on the phone. In addition, longer term follow ups were obtained in many when patients treated with these implants returned for evaluation of new unrelated orthopedic complaints.

### Analysis

Four IRB approved databases at the same institution containing outcomes of prospectively followed patients with lower extremity nonunions, distal femur nonunions, distal femur fractures, and tibial plateau fractures were queried to evaluate outcomes of patients treated with this implant system.

These data were prospectively collected, IRB-approved databases comprised of a consecutive cohort of patients treated at our institution over a 18-year period. Within each database, patients were treated using similar protocols at the discretion of the operating surgeon. All databases include patient demographics, injury characteristics, and operative information. The protocol for follow-up in all databases was identical: enrolled patients were initially followed at 3, 6, and 12 month intervals and then annually thereafter as available. Each visit included a physical examination, radiographic examination, and completion of the Short Musculoskeletal Function Assessment (SMFA) questionnaire. Time to union was determined by clinical and radiographic measures commonly employed in the orthopedic literature including bridging callus on at least 3 of 4 cortices, no gross motion at the nonunion site, and no pain with palpation or weight bearing.<sup>13</sup> Patients were considered to have developed a persistent nonunion if they had not achieved complete bony union by 12 months following initial surgery. Descriptive statistics were calculated using IBM SPSS (Armonk, NY). A secondary analysis was also conducted in which patient outcomes from the FGLPs were compared to clinical, radiographic, and patient reported outcomes for patients within the same databases who were treated with second (3.5 and 4.5 mm stainless steel uniaxial locking plates) and third generation (3.5 and 4.5 mm stainless steel uniaxial locking plates) implants, or later generation locking plates (LGLPs) (Figure 3). These comparisons were done using binary logistic regression and linear regression and controlled for age at injury, sex, body mass index (BMI), Charlson Comorbidity Index (CCI), tobacco use, wound status (open vs closed), and fracture type (tibia vs femur and acute fracture vs nonunion).

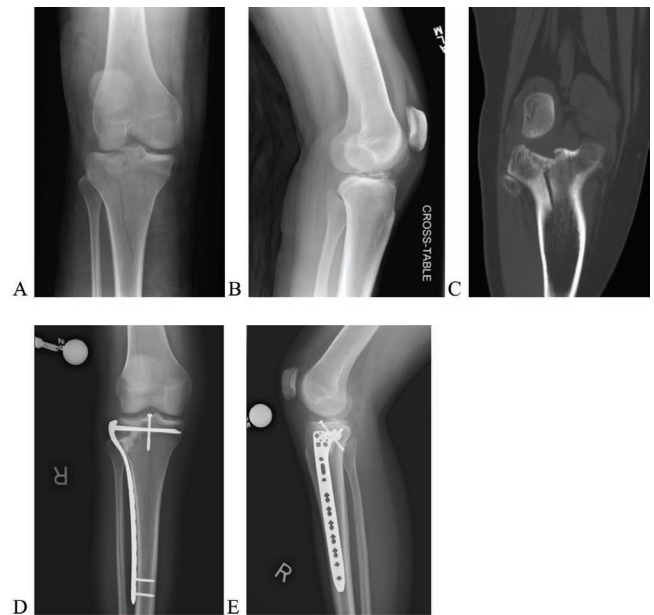


Figure 3A to 3E. Radiographs of the right leg of a 28-year-old female with a Schatzker 2 tibial plateau fracture with shaft extension status post fall while skiing. (3A, 3B) AP and lateral radiographs of the right leg demonstrating a Schatzker 2 tibial plateau fracture with shaft extension. (3C) A coronal CT cut of the right leg demonstrating a Schatzker 2 tibial plateau fracture with shaft extension. (3D, 3E) AP and lateral radiographs of the right knee demonstrating ORIF of the previously demonstrated fracture using a LGLP and calcium phosphate.

### RESULTS

Seventy-six patients with 82 (76.6%) fractures or nonunions of 100 patients with 107 fractures or nonunions treated with a FGLP were available for analysis at a mean follow-up of 4 years (range 1-14). The average age at time of follow-up was 59.2 years old and females comprised 61.0% of patients. Acute fractures were initially open in 17.1% of cases. Forty-three (52.4%) distal femurs were treated using a FGLP. Of these, 4 (4.9% of the overall cohort) were nonunions. Thirty-nine (47.6%) patients with proximal tibial fractures were treated using a FGLP. Of these, 25 involved the tibial plateau and 5 (6.1% of the overall cohort) were primary treatment for tibial nonunion (Table 1). Radiographically, 75 (91.5%) fractures and nonunions healed following initial surgery with the FGLP.

Three patients treated with a FGLP (3.7%) developed acute post-operative infections, each requiring a single irrigation and debridement and long term intravenous antibiotic administration. Six patients with seven (9.6%) acute fractures treated with a FGLP went onto nonunion and underwent secondary surgery consisting of supplemental bone grafting and plate exchange, 100% of the nonunion patients went on to heal radiographically. Of these seven that went on to nonunion, one had broken hardware at the time of nonunion surgery that required



**Table 1. Patient Demographics & Injury Characteristics**

Characteristic	# FGLP (%)	# LGLP (%)
Total	82 (100%)	203 (100%)
Sex		
Male	32 (39.0%)	108 (53.2%)
Female	50 (61.0%)	95 (46.8%)
Charlson Comorbidity Index		
0	58 (70.7%)	155 (76.4%)
1	12 (14.6%)	35 (17.2%)
2	3 (3.7%)	7 (3.4%)
3+	9 (11.0%)	6 (3.0%)
Tobacco Smoker		
Yes	12 (14.6%)	39 (19.2%)
No	70 (85.4%)	164 (80.8%)
Wound Status		
Open	14 (17.1%)	11 (5.4%)
Closed	68 (82.9%)	192 (94.6%)
Fracture Type		
Acute Tibia Fracture	34 (41.5%)	179 (88.2%)
Acute Femur Fracture	39 (47.6%)	4 (2.0%)
Tibia Nonunion	5 (6.1%)	4 (2.0%)
Femur Nonunion	4 (4.9%)	16 (7.9%)
Characteristic	Mean FGLP (range)	Mean LGLP (range)
Age (yrs)	59.2 (18 - 93)	52.0 (20 - 98)
BMI (kg/m <sup>2</sup> )	27.1 (15.4 - 51.7)	27.5 (15.4 - 47.0)
Follow up (months)	48.9 (12 - 167)	32.1 (12 - 120)

fixation revision. Overall, bony union was achieved in the remaining 75 knees (91.5%) by an average of 5.5 months (range 2 to 12 months) post-op. There were no signs of hardware failure in the patients who achieved bony union. Four patients (4.9%) elected to undergo removal of hardware secondary to presumed hardware related pain at an average of 5.1 years post-op. Pain scores at latest follow-up averaged 2.69 on VAS. The average standardized total SMFA index was 19.88, and scores were comparable between tibial and femoral fractures. Mean knee range of motion was 1.6°-111.9° and range of motion of the post-operative knee was on average within 15 degrees of the contralateral side at latest follow-up (Table 2, Table 3).

**Table 2. Statistical Analysis of Long Term Clinical Outcomes Between Plate Groups**

	# of FGLP group (%)	# of LGLP (%)	p value
Non-union (post-fixation)	7 (8.5%)	3 (1.5%)	0.174
Re-operation	20 (24.4%)	23 (11.3%)	0.135
Hardware Failure	4 (4.9%)	4 (2.0%)	0.973
Removal of Hardware (for any reason)	12 (14.6%)	14 (6.9%)	0.247

**Table 3. Statistical Analysis of Long Term Functional Outcomes Reported in Means**

	FGLP group	LGLP group	Difference	Lower 95% CI	Upper 95% CI	p Value
Pain	2.69	3.08	-0.39	-1.28	0.56	0.391
Total SMFA	19.88	20.40	-0.52	-6.19	5.15	0.857
Time to Union	5.46 mos.	6.67 mos.	- 1.21 mos.	-3.93	1.50	0.377
ROM - Extension	1.60°	1.06°	0.54°	-0.49	1.56	0.305
ROM - Flexion	111.93°	122.30°	-9.37°	-12.18	-7.45	0.338

### Secondary-analysis

When compared to the 198 patients with 203 tibial and femoral acute fractures and nonunions with a mean age of 52 years old and a mean follow up of 2.7 years treated with LGLPs for similar injuries, the FGLP group demonstrated no difference in long term outcomes with regards to pain score, standardized total SMFA, fracture healing, knee range of motion in extension and flexion, re-operation rate, hardware failure rate, or need for removal of hardware (Table 2, Table 3).

### DISCUSSION

These data suggest that acute fractures and fracture nonunions treated with a FGLP have done well clinically following treatment. These implants performed well in the short and longer term and allow for fracture healing. Patient reported outcomes suggest long-term patient satisfaction, fracture fixation, and post-operative complications associated with the use of FGLP were well within acceptable limits. Patients did well with FGLP regardless of whether FGLP were used on femur or tibia, and whether they were used to fix fractures acutely or for fracture nonunion repair. The majority of fractures treated in this series were complex juxtaarticular injuries of the distal femur or proximal tibia. These injuries

are associated with a higher rate of complications than simpler fractures.<sup>14,15</sup> While complications including nonunion, infection, and hardware failure did occur in both groups, they were not statistically different from one another and not substantially different from the rates seen in the available literature over the same time period.<sup>14-17</sup>

The surgeons' thought process for implant selection for internal fixation of fractures is based on surgeon experience, characteristics of the fracture, and reported performance of the implant. Preoperative planning must account for fracture pattern, location, soft tissues, and biomechanical considerations. Fracture characteristics dictate optimal selection regarding the function of the plate which includes compression, buttressing, tensioning, and bridging.<sup>18</sup> As knowledge of biological fixation evolved, it became apparent that extensive soft tissue stripping around the bone resulted in delay of healing or, in some instances, non-unions and infections, as well as increased post-operative pain for patients.<sup>19,20</sup>

This revelation led to a paradigm shift in orthopedic traumatology. Previous focus on extensive exposure to facilitate anatomic reduction gave way to techniques that aimed to preserve soft tissue and minimize periosteal stripping. One such method has been indirect reduction, utilizing intraoperative fluoroscopy to assess fracture reduction without direct exposure of the entire injury. The minimally invasive percutaneous plate osteosynthesis (MIPPO) technique was pioneered by Krettek et al. who minimized incision length and placed incisions away from the fracture site before placing long plates placed bluntly in the submuscular space.<sup>11,12</sup> Screws are then inserted through short incisions directly over the screw holes. The goal here is similar to IM Nailing in that length, alignment, and rotation are restored without violating the fracture site and allow for secondary bone healing in the metadiaphyseal regions of the tibia and femur.

The first generation of large fragment locking plates (the LISS system, Synthes Paoli Pa) was created to follow MIPPO principles. FGLPs were anatomically pre-contoured plates with aiming devices that inserted unicortical locking screws percutaneously. FGLPs allowed for the bone to be pulled to the plate with a push-pulling-device ('Whirley Bird'). They are typically used in metadiaphyseal fractures of the distal femur and proximal fractures of the tibia.<sup>18,21</sup> Aside from the advantages of protecting the soft tissue, biomechanical studies have demonstrated that FGLPs offered greater stability to axial loads than other options available at the time such as a blade plate or intramedullary nailing.<sup>22</sup> The original FGLPs, LISS plates, were made using titanium, allowing for increased flexibility and a modulus of

elasticity closer to that of bone again thought to aid in the production of secondary healing.

Laterally applied plates and screws are not without drawbacks. Cadaveric studies have demonstrated the FGLPs to have less resistance to torsional loading compared to angled blade plates and intramedullary nails.<sup>22</sup> Furthermore, some clinical studies have reported that minimally invasive techniques, without direct visualization, may have a higher incidence of axial and rotational malalignment.<sup>6</sup>

With the array of different treatment options for fractures, indications for FGLP and outcomes have been analyzed. Shütz et al. conducted a study to analyze whether the FGLP technique was superior to conventional techniques.<sup>5</sup> They analyzed fracture healing, weight bearing, mobility, and infection rate over a 12-15 month period in patients with distal femur fractures. They found excellent fracture healing rates, range of motion, complication rates, and re-operation rates that were similar to bridge plating as well as retrograde and antegrade nails. They observed the most crucial factor for success of the FGLP was restoration of the correct rotational and axial relationships, concluding that the surgeon's experience and skill are vital to the success of the FGLP.

Rodriguez et al. analyzed FGLPs to find predictive factors of distal femur nonunion.<sup>23</sup> They found that obesity (BMI > 30), open fracture, the occurrence of an infection, and the use of a stainless steel plate were associated with unplanned additional surgical intervention for distal femur fractures treated with FGLPs. Following widespread adoption of locking plate technology, literature began to emerge suggesting that new constructs made of stainless steel were associated with increased rates of nonunion, particularly in fractures of the distal femur. Locking plates, intended to promote secondary bone healing over primary bone healing,<sup>20</sup> were evidently too stiff to generate the motion necessary for the required callus formation.<sup>7-10</sup> Other, similar studies, have found modest rates of nonunion and infection that are comparable to those shown by the data in our study.<sup>24-26</sup>

New methods of "dynamizing" stainless steel locking plates have emerged, with hopes of providing crucial interfragmentary motion. Biomechanical research by Bottlang et al. led to the deployment of far cortical locking screws, which reduced stiffness by utilizing a smaller-diameter screw shaft, effectively over-drilling the near cortex. This allows for a controlled amount of motion within the hole in the near cortex, dynamizing the fracture with minimal loss in construct strength.<sup>7,8</sup> Active plates have also been introduced, using silicone suspension of the locking holes as a dynamization strategy.<sup>9,27,28</sup>

As new technology developed, constructs were engineered that had greater torsional stiffness than FGLPs,

such as polyaxial plating systems. These constructs gained popularity and the FGLP system has been used with decreased frequency. However, our study demonstrates that patients with fractures treated with FGLP do well clinically and thus suggests that not all fractures may require the purported benefits of newer, more costly, plating systems.

Limitations of this study include its retrospective nature and sample size. Additionally, this study utilized prospective data from two surgeons who utilized similar protocols, but were of varying experience. We did not examine the learning curves associated with new technology, nor did we note the extent of experience each surgeon had with each system at the time of each patients' surgery. In addition, over the 18 years of patient collection implant usage changed partially based on implant availability and hospital contracts. This must be considered when assessing the data presented here. Finally, there was a heterogenous nature of the fracture patterns included, however, our goal was to evaluate the implant system, not a specific fracture type. It is possible that the femoral and tibial versions of the FGLP system would perform differently.

### CONCLUSION

Longer term outcomes of first-generation distal femur and proximal tibial locking plates demonstrate that this construct provided for a high union and low complication rate, as well as good clinical and functional results. This paper does not examine a direct comparison to newer locking strategies associated with second-generation locking plates and thus further research is needed to compare long-term outcomes of first-generation locking plates with newly introduced technologies such as far cortical locking screws and active locking plates. Based on the results presented, it seems the rationale for development and changes in this implant technology may have been flawed. For surgeons with experience using FGLPs, we pose that FGLPs can still be used in any situation in which second or third generation plates are used with no substantial difference in outcomes. For surgeons without experience with these plates, a learning curve may be associated. However, this point may be moot as the FGLP may no longer be available for use. Future research should also address implant costs to determine whether the added cost of newer implant designs are justified as it relates to the extent of clinical benefits experienced by patients.

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# THE EVOLUTION, CURRENT STATE AND CLINICAL BENEFITS OF FAR CORTICAL FRACTURE FIXATION

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## ABSTRACT

**Treatment of distal femur fractures have reported high fracture healing complications in several studies. The development of far cortical locking (FCL) technology results in improved fracture healing outcomes. There are biomechanical and animal studies demonstrating that the locked plating incorporating FCL screws provides a more flexible form of fixation compared to traditional locking plates (LP). Clinical studies have shown that the commercially available Zimmer Motionloc system with FCL screws provide good results in distal femur fractures and periprosthetic distal femur fractures. FCL constructs may help resolve fracture healing problems in the future. However, there is not enough available clinical evidence to conclusively indicate whether clinical healing rates are improved with FCL screw constructs compared to traditional LP's. Therefore, further prospective study designs are needed to compare FCL to LP constructs and to investigate the role of interfragmentary motion on callus formation.**

**Level of Evidence: V**

**Keywords: far cortical locking, locked plating, fracture healing, distal femur fracture**

## INTRODUCTION

Distal femur fractures are commonly treated by periarthicular locking plates (LPs),<sup>1</sup> which have largely replaced intramedullary nails, blade plates, and condylar plates. These fractures are frequently comminuted, and LPs are typically placed bridging the zone of comminution. This technique depends on some degree of interfragmentary motion to stimulate callus and osseous union. Studies have demonstrated that fixation with LPs leads to stiffer constructs than fixation with other implants<sup>2-8</sup>

and construct rigidity may delay the fracture healing process. Clinical studies of LP fixation in distal femur fractures have reported higher than expected rates of fracture healing complications including delayed union, nonunion, fixation failure and, bent or broken implants all of which suggest healing delays.<sup>9-16</sup>

Locked plates with far cortical locking screws (FCL) reduce axial stiffness compared with traditional LP's.<sup>2,18-20</sup> These FCL constructs provide more flexible fixation and nearly parallel interfragmentary motion.<sup>2,17-20</sup> They have been shown to increase callus formation in animal studies.<sup>17-18</sup> Recently, the results of FCL constructs for distal femur fractures have been reported in case series with favorable results.<sup>21-23</sup>

This manuscript will review the background that led to the development of FCL technology, the biomechanical and animal studies, the clinical technique, and the reported clinical results of FCL plates for distal femur fractures.

## BACKGROUND AND EVOLUTION

Traditional non locked compression plates were originally designed to provide absolute stability, targeting primary bone healing without callus formation. The axial rigidity of modern locked plating constructs is comparable to that of nonlocked compression plating constructs. In contrast, external fixators were designed to provide sufficient interfragmentary motion to stimulate secondary bone healing by callus formation. External fixators can provide over 10 times more interfragmentary motion in response to a given load than rigid fixation with locked or nonlocked plates. Because locked plating in a bridge plate mode, relies on secondary rather than on primary bone healing, reducing the stiffness of LP construct is important to achieve secondary bone healing.<sup>19</sup>

A couple of decades ago, when locking plates first became popular the distal femur was a logical fracture location to embrace this plate technology. Distal femur fractures are frequently comminuted and off axis bending forces led to varus collapse with traditional condylar plates. Articular comminution and very distal fractures were often not suitable for blade plates or nailing. Associated techniques which allowed locking plate implant insertion through limited approaches led to rapid adoption of LP's for distal femur fractures.

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Treating distal femur fractures with LPs became widely practiced and initial reports indicated that the fracture healed in almost all cases. However, subsequent studies demonstrated that nonunion was more common than previously identified. Ricci et al.<sup>34</sup> found a 14% nonunion rate after treating periprosthetic distal femur fractures with a LP, despite a minimally invasive insertion technique. Henderson et al.<sup>24</sup> found an even higher rate of nonunion (20%) in non periprosthetic distal femur fractures treated with LPs. It was suggested that slow healing or failure to heal may result from excessive construct stiffness,<sup>2,17,18,35</sup> which caused inconsistent and asymmetric formation of periosteal callus.<sup>36</sup>

This background sets the stage for developing techniques for more flexible fixation. For instance, wider spaced screws and long bridge spans by avoiding screws near the fracture site were recommended.<sup>37</sup> However, a finite element analysis of long bridge spans indicated this technique may produce undesirable bending moments and shear stresses instead of axial motion and compression stresses.<sup>38</sup> FCL technology offered a potential flexible solution to produce axial motion.

### BIOMECHANICS OF FCL SCREW PLATE CONSTRUCTS

FCL screws are inserted through a standard bicortical drill hole. (Fig. 1) FCL screws lock into the plate and the far cortex, but have a narrow, flexible shaft that is centered in the near cortex drill hole. As the construct is loaded, the screw shaft deflects elastically, resulting in motion of the bone relative to the plate. (Fig. 2) The amount of motion is directly related to the distance from the screw shaft to the near cortex of the bone. This

motion translates to increased motion at the fracture site and reduced stiffness of the construct. According to Fitzpatrick et al., there are 4 key biomechanical factors important to FCL function:<sup>25</sup> 1. Reduced stiffness 2. Parallel fracture motion 3. Comparable strength to locked constructs 4. Improved in vivo fracture healing.

FCL constructs are optimized to reduce stiffness by the design of the screw (MotionLOC® screws) (Zimmer). Bottlang et al. in a study on bone surrogate specimens of the femoral diaphysis showed that MotionLOC® screws provide an 88% reduction in stiffness,<sup>2</sup> whereas Dynamic Locking Screws (Synthes) (DLS) screws provide a 17% decrease in stiffness.<sup>26</sup> FCL screws are initially flexible, but as the screw shaft engages the near cortex, the stiffness increases to a value similar to a standard locked construct. This biphasic stiffness profile is similar to the biomechanical behavior of an Ilizarov external fixator.<sup>2,19,24</sup> The motion envelope is controlled by the diameter of a collar segment adjacent to the FCL screw head. In some ways, FCL constructs behave like a mono-lateral external fixator, the bar of which has been applied close to the bone surface and the pins of which are

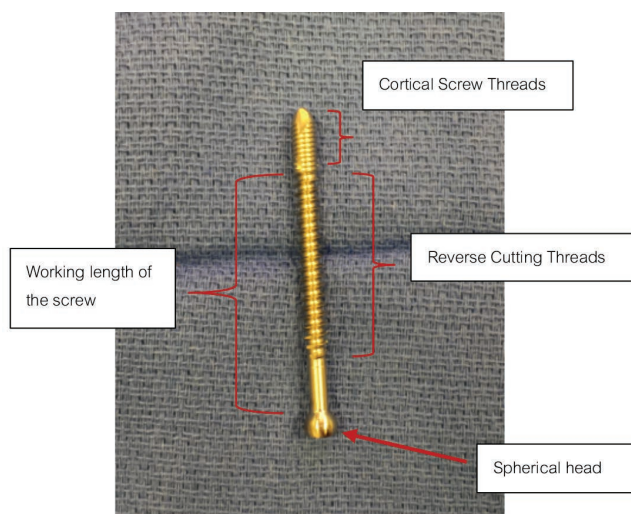


Figure 1. Demonstrates the characteristics of FCL screw comprising of cortical screw thread, reverse cutting thread, spherical head and the working length of the screw.

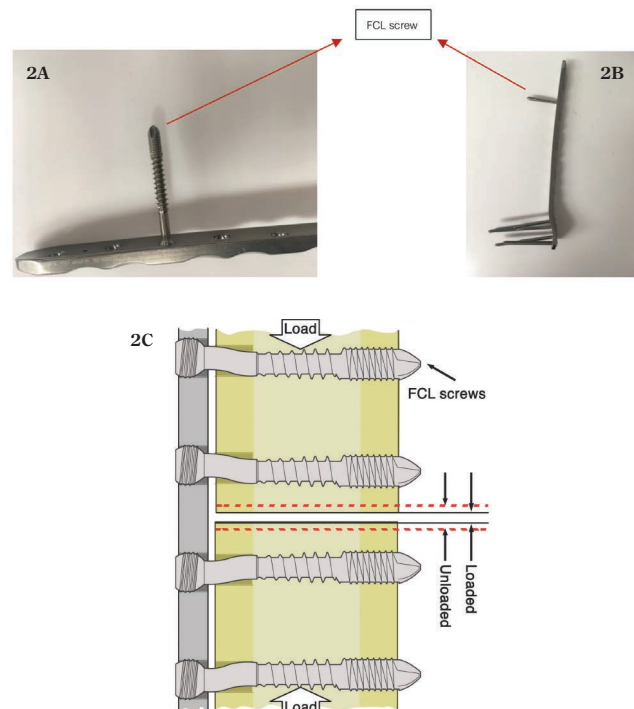


Figure 2A to 2C. Demonstrate a FCL screw assemblies with NCB® plate (Zimmer MotionLoc® technology, Zimmer, Warsaw, IN) (2A) Close view of the FCL screw. (2B) A FCL screw in the proximal portion of a NCB® plate (Zimmer MotionLoc® technology, Zimmer, Warsaw, IN). (2C) FCL screws are locked to the plate and fixed to the far cortex. With loading. The shaft of the screws move in the center of the intramedullary canal resulting in motion in the plate. Motion between the plate and bone increases movement at the fracture site which decrease stiffness of the fixation construct.

secured in the far cortex rather than in the near cortex. Similar to the external fixator, FCL constructs provide fixed-angle but flexible connections between a bridging member and the bone segments, whereby FCL screws approach the working length of external fixator pins. On the other hand, screws of standard locked constructs are rigidly confined between the near and far cortices and therefore have a short working length and do not enable flexible fixation.

According to Bottlang et al. a key feature of these screws is that the screw shaft bends in the intramedullary canal producing a motion that is essentially parallel at the fracture gap. This provides symmetric fracture site motion and symmetric callus formation. The amount of interfragmentary motion is approximately 0.5 mm, which is close to the 0.2 to 1 mm, that is optimal for callus formation.<sup>25</sup>

With the design that allows increased motion through screw bending, assessing the strength of the construct that use these screws is important. In studies by Bottlang et al., FCL constructs tested in healthy bone surrogates showed a slight decrease in axial strength (7%), but an increase in bending (9%) and torsional (21%) strength. FCL constructs perform better in osteoporotic bone. In weak bone surrogates, FCL showed a slight decrease in axial strength (17%) but a significant increase in bending strength (54%) and torsional strength (20%).<sup>2</sup> The authors noted that the increased construct strength in FCL constructs results from the sharing of load by each screw rather than concentrating the load at a single screw as is seen in the case of all traditional locked constructs.<sup>2,25</sup>

### ANIMAL STUDIES

There are not a lot of animal studies assessing FCL plating. However, there is one study that provides a very impressive comparison between FCL and traditional locked plating and provides insight into the better healing in this model that occurs with FCL plating. Bottlang et al. used a sheep tibia gap osteotomy model and compared callus formation and strength of healing between the two methods of locked plating. The gap was in the midshaft of the tibia and the plates were fixed with six threaded screw-holes with the same material and length for each group. Animals were sacrificed at nine weeks. Callus was assessed with radiographs post operatively and weekly intervals.

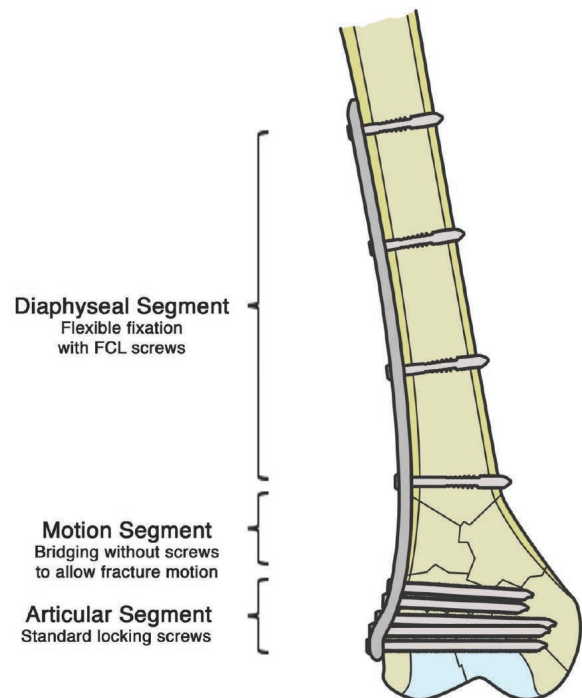
The FCL group demonstrated significantly more radiographic callus beginning at week 3 which continued to be seen until the sheep were sacrificed at week 9. Computed tomography analysis of the fracture callus at week 9 demonstrated more symmetric callus in the FCL group with a 34% higher total callus volume and 44% higher bone mineral content. Half of the bicortical

locked constructs failed to form any callus at the near cortex which has the least motion in these LP constructs. Biomechanical testing of the healed fracture after plate removal demonstrated 54% increased load to failure and 157% higher energy to failure in the FCL group. The histology, callus location and mechanical differences between the two LP techniques in this study were very impressive.<sup>17</sup>

### SURGICAL TECHNIQUE

The surgical technique used for FCL locked plating has only a few variations from traditional locked plating. The motion that is present at the fracture site occurs because of the design of the FCL screws which are used in the diaphysis of the distal femur. The plate geometry and the technique used to insert the plate is similar to other LP's.

The technique to fix the distal femur is considered in three different regions. (Fig. 3) The articular region is the distal condyles of the femur or in periprosthetic fractures it is the distal femur bone that is fixed to the



**Figure 3.** Construct of distal femur fracture fixation with FCL screws is composed of three parts of fixation. Each part has different purposes. 1) Articular segment is the distal femur fixed with a plate and standard locking screws. 2) diaphyseal segment is a diaphysis above the fracture zone which is fixed with three to four FCL screws without any conventional locking screws or compression screws. 3) The fracture area between the diaphyseal segment and articular segment is the motion segment and includes all the metaphyseal fracture fragments. This is the motion segment with motion resulting from the FCL screws in the diaphysis above. This segment is not fixed with any screws.



prosthesis. The diaphyseal region is the non-fractured shaft. The shaft segment is fixed with FCL screws. The region between the diaphysis and the articular region, is the fractured metaphysis which is often comminuted.

The articular region is fixed using standard techniques which include anatomic reduction with absolute stability and often interfragmentary screws. Optimally fixing the distal segment requires locking screws that are adequately spaced. There must be enough area for the screws to have sufficient fixation in the often osteoporotic bone in the distal portion of periprosthetic fractures. The articular portion, does not require FCL screws.

FCL screws are used for all of the diaphyseal fixation. Applying a non-FCL bicortical locking screw to the diaphyseal segment limits motion at the fracture site and the entire load will be concentrated on that one screw. Another principal of the diaphyseal fixation is that the plate must be elevated off the bone enough to permit the bone to have some movement relative to the plate. Therefore, it is essential to loosen each FCL screw approximately one-half turn after all screws are inserted which prevents the plate from being applied too tightly to the diaphyseal bone and allows the plate and bone to move relative to each other. Adding 2 mm. to the length of the diaphyseal FCL screws permits the screws to be backed out while still being sufficiently long in the far cortex. FCL screws must be completely secured into the far cortex to have the necessary proximal fixation.

The number and distribution of the screws in the diaphysis can be chosen based on surgeon preference. Three or four screws are typically chosen. Applying a FCL screw near the fracture site will not increase the stiffness of the construct, like with standard LP's, since deforming the screws leads to fracture site motion rather than plate bending. It is important to center the FCL screws front to back. This optimally places the screws and plates and maximizes screw length which reduces stiffness.

The motion segment consists of the metaphyseal fracture. This area is often comminuted and should be spanned in a typical bridging technique. During the approach and exposure, leaving this fracture area as closed and untouched as possible will preserve vascularity and potentially improve healing. A motion technique with diaphyseal FCL screws can also be applied in a simple short transverse or oblique metaphyseal fracture. To obtain the benefit of motion we seek to obtain an approximate reduction. Lag screws, which will block motion, should not be used.<sup>25</sup>

Post-operative care is the same as what is used for standard LP's. With good fixation the knee is allowed to freely move. Our preference is to allow most patients to partially weight bear. The benefits of fracture motion require some degree of limb loading.

## CLINICAL STUDIES

FCL screw constructs increase parallel interfragmentary motion, and both biomechanical and animal studies suggest that this may lead to clinical advantages through earlier and stronger fracture repair.<sup>2,18</sup> What evidence is there that these advantages lead to better healing in patients with distal femur fractures?

There are only a few clinical studies on patients with distal femur fractures treated with FCL constructs. Adams et al.<sup>21</sup> found no nonunions or implant failures in their small cohort of distal femur fractures. Bottlang et al.<sup>22</sup> reported the results of a prospective observational study of 33 distal femur fractures (OTA/AO types 33A and 33C) with no early implant or fixation failures. There were two patients that required revision surgery. The first was revised because of malrotation within six days after initial surgery. In the second, fixation was revised because of nonunion at six months after surgery. All screws were normally removed during the surgeries; there were no broken screws. The authors concluded that dynamic fixation of distal femur fractures with FCL screws provides safe and effective fixation. In a retrospective review, Ries et al. reported an 88.9% healing rate using FCL constructs to fix periprosthetic distal femur fractures.<sup>23,39</sup> Two cases out of eighteen had to be revised at twelve weeks and nine months after surgery. There were no broken FCL screws, but there was a broken plate in the nine-month revision case. The authors expressed the opinion that callus formed faster and was more robust and visible than traditional locking plates. (Fig.4) Plumarom et al.<sup>40</sup> conducted a retrospective comparative study between FCL and conventional LP constructs that assessed both clinical and radiographic healing. They found that there were no significant difference in terms of union, revision and complication rate. However, there were significantly better mRUST healing scores between FCL and LP groups at all time points—suggesting that in these patients, FCL constructs formed callus earlier than traditional LP constructs. (Fig.5) These differences were also present at the 6-week time point in subgroup analysis of periprosthetic fractures and in those cases with similar metals.

There is not enough available clinical evidence to conclusively indicate whether clinical healing rates are improved with FCL screw constructs compared to traditional LP's. Failures of healing are seen in both groups and a large comparative study will be necessary to clearly demonstrate significant differences.

There will always be a lot of uncontrolled variables that will produce noise in any comparison. The Plumarom study suggests earlier and more callus in fractures treated with FCL. This fits with our clinical experience. Robust medial callus is often seen in FCL cases and is

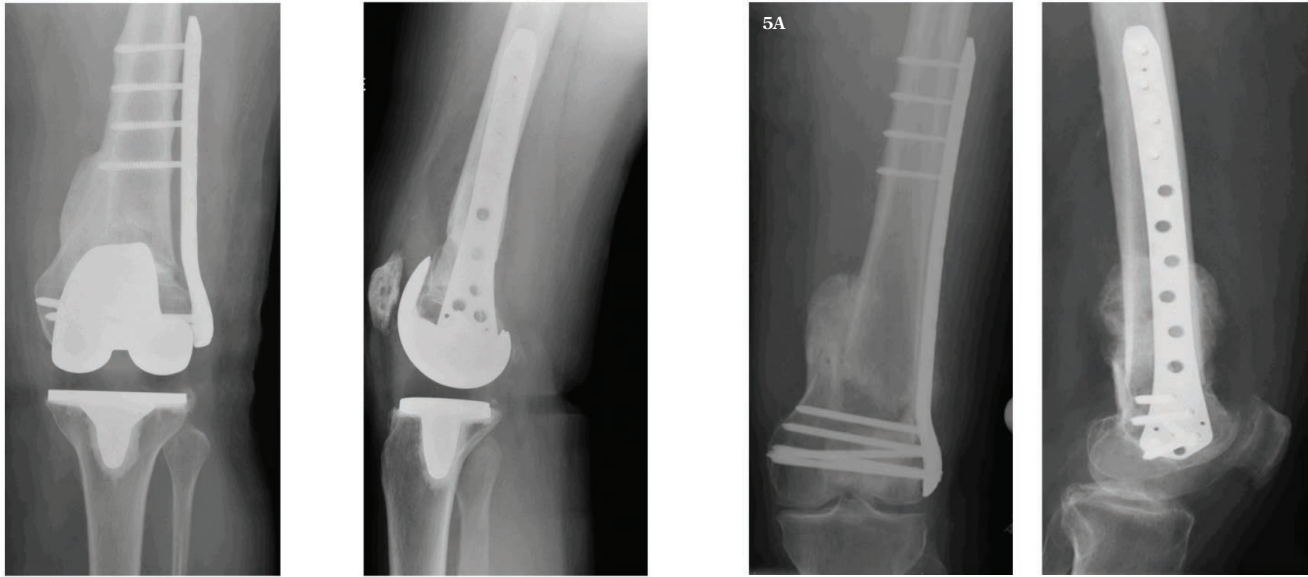


Figure 4. Periprosthetic distal femur fracture was treated and followed up until complete union at 12 weeks after surgery. Radiographic demonstrates fixation with FCL (MotionLoc® screws) and NCB periprosthetic plate. Callus is formed very fast, robust and clear visibility.

less commonly seen with traditional LP's. We believe that this difference in early callus would result in a different rate of healing in an appropriately powered clinical trial.

### CONCLUSION

Locked Plating incorporating FCL screws provides a more flexible form of fixation compared to traditional LP's by virtue of the unique screw design. In a large animal study this screw design was shown to improve callus and strength of repair compared to standard locking screws.

Clinical studies have shown that the commercially available Zimmer Motionloc system with FCL screws provide good results in distal femur fractures and periprosthetic distal femur fractures. There have been no broken screws in several reports. The technique is very similar to other LP systems. There is one comparative study that shows more callus but to date this apparent advantage has not been shown to improve healing. Therefore, further prospective study designs are needed to compare FCL to LP constructs and to investigate the role of interfragmentary motion on callus formation.

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Figure 5A to 5B. Post operative radiographs at 12 weeks after surgery comparing callus formation between FCL construct and traditional locked plating construct. (5A) Post operative radiographs at 12 weeks after surgery with FCL fixation reveals more robust and visible bridging callus. (5B) Post operative radiographs at 12 weeks after surgery with traditional locked plating demonstrate little bridging callus without clear visibility.

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# ULNAR NERVE TRANSLOCATION FOLLOWING A ROUTINE DISTAL RADIUS FRACTURE

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## ABSTRACT

A 35-year-old right hand dominant male sustained a high energy closed right distal radius fracture with associated generalized paresthesias. Following closed reduction, the patient was found to have an atypical low ulnar nerve palsy upon outpatient follow-up. After continued symptoms and an equivocal wrist MRI the patient underwent surgical exploration. Intraoperatively, the ulnar nerve as well as the ring and small finger flexor digitorum superficialis tendons were found to be translocated around the ulnar head. The nerve and tendons were reduced, the median nerve was decompressed, and the fracture was addressed with volar plating. Post-operatively, the patient continued to have sensory deficits and stiffness of the ring and small fingers. After one year, he reported substantial improvements as demonstrated by full sensation (4.0 mm two-point discrimination) and fixed flexion contractures at the proximal and distal interphalangeal joints of the small finger. The patient returned to work without functional limitations.

This case highlights a unique case of ulnar nerve and flexor tendon entrapment following a distal radius fracture. History, physical examination, and a high index of clinical suspicion is essential for proper management of this rare injury.

Level of Evidence: V

**Keywords:** distal radius fracture, wrist fracture, ulnar nerve entrapment, ulnar neuropraxia, guyon's canal

## INTRODUCTION

Distal radius fractures (DRF) are the most common type of fracture in the United States, accounting for 8-18% of all fractures.<sup>1,2</sup> The majority of DRFs resolve uneventfully. However, a small percentage are complicated by an associated nerve injury. The most recognized of these is an acute carpal tunnel syndrome (ACTS), occurring in 3.3-8.6% of all DRFs.<sup>3,4</sup>

Recently, a growing body of literature has demonstrated an association between DRFs and ulnar nerve palsies.<sup>5,6</sup> These nerve injuries are associated with higher-energy trauma, e.g. motor vehicle accidents.<sup>5,6</sup> Similar to ACTS, these palsies are thought to be secondary to nerve contusion, fracture-induced traction, or compression from local edema. Rarely, the ulnar nerve may be lacerated.<sup>7</sup> Ulnar nerve injuries in the presence of DRF remain a diagnostic challenge and their management remains undefined. We report a unique case of a DRF presenting with ulnar neuropraxia secondary to a dorsoulnar translocation of the nerve around the ulnar head, with concomitant entrapment of flexor digitorum superficialis (FDS) tendons. Based on the available evidence we propose a treatment algorithm for these injuries.

## CASE REPORT

A 35-year-old right-hand dominant male presented to the emergency department with a displaced closed left DRF secondary to a 35-mph rollover accident on an all-terrain vehicle (Fig. 1a and b). Upon initial examination, the wrist was grossly deformed with a 1.0 cm dorsal laceration between the long and ring finger webspace. Subjective dysesthesias were noted in all digits but were otherwise sensate to light touch. His motor exam revealed strong flexor pollicis longus (FPL) and extensor pollicis longus (EPL); weak FDS and extensor digitorum communis (EDC) of the index finger; and weak second dorsal/third palmar interossei muscles.

Closed reduction was then performed under fluoroscopic guidance, and a molded bi-valved short-arm fiberglass cast was applied (Fig 2 a and b). Post-reduction

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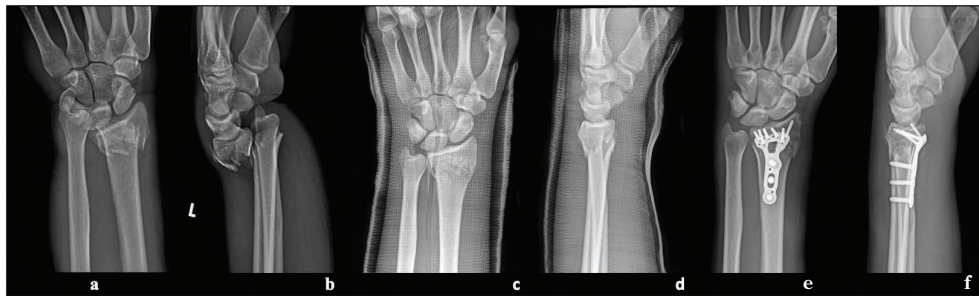


Figure 1A to 1F. AP (1a) and lateral (1b) of a comminuted dorsally displaced left distal radius fracture with approximately 1 cm of shortening. AP (1c) and lateral (1d) post-reduction films. 2-week AP (1e) and lateral (1f) follow-up from open reduction internal fixation.

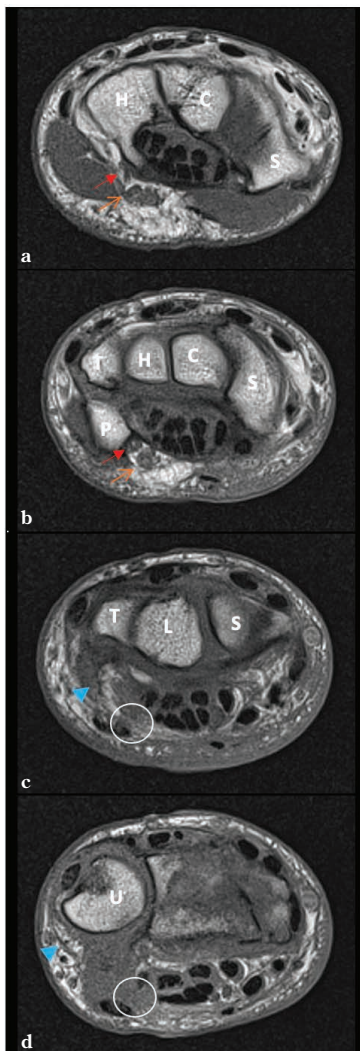


Figure 2A to 2D. T1 Coronal of the left wrist (2a-2d). Visualized is the deep ulnar nerve becoming confluent with the superficial branch (2a) as the wrist is visualized more proximally (2b). The ulnar neurovascular bundle appears translated ulnarly away from its typical location just radial and deep to the flexor carpi ulnaris. Key: Red solid arrow = deep branch of the ulnar nerve, orange open arrow = superficial branch of the ulnar nerve, solid blue arrowhead = suspected ulnar neurovascular bundle, white circle = normal anatomic location of ulnar nerve, C = capitate, H = hamate, P = pisiform, R = radius, S = scaphoid, T = triquetrum, U = ulna.

neurovascular exam demonstrated improved dysesthesias in the median nerve distribution but persistent symptoms in the ulnar nerve distribution. Motor examination was also notable for grade 2/5 strength of the second and third dorsal/palmar interossei. Passive flexion and extension of the ring and small finger elicited pain. After a period of observation, the patient's pain and dysesthesias had modestly improved while the motor exam remained unchanged. The patient was discharged home.

After one week, the fracture reduction was maintained. However, his ulnar nerve dysesthesias persisted, and two-point discrimination (2PD) was diminished: 12 mm in the median distribution and indiscernible in the ulnar distribution. Interossei muscle function remained equivocal. The patient's ring and small finger proximal interphalangeal joints remained in a partially flexed position. Passive extension of these fingers was limited by volar sided forearm pain, but the index and long fingers extended easily.

An MRI of the wrist without contrast was obtained (Fig. 2). The ulnar nerve was visualized at Guyon's canal but obscured at the fracture site. Given the concern for underlying nerve injury, surgical intervention was pursued. The patient underwent open reduction internal fixation of the distal radius, carpal tunnel release, and exploration of the ulnar nerve 10 days after his injury.

A longitudinal midline incision was made along the distal forearm. A carpal tunnel release revealed a contused but intact median nerve. Attention was then directed to Guyon's canal. After identifying the ulnar neurovascular bundle, the structures were traced proximally and appeared to be traveling dorsoulnarly around the ulnar head under moderate tension. The bundle was then re-identified within the forearm and traced distally which confirmed the dorsoulnar translocation. Additionally, the ring and small finger FDS tendinous slips were also found translocated in a similar manner (Fig 3).

Tenolysis and reduction of the entrapped tendons was performed. Unrestricted tendon gliding of the ring and small fingers was visualized. Further exploration re-





Figure 3A to 3B. Surgical images demonstrating translocation of the ulnar nerve traveling dorsally to the ulnar head when traced proximally (3a). Similarly, slips of the FDS are visualized coursing ulnarly and superficially relative to the ulnar head. UH = Ulnar head, green open arrow = neurovascular bundle, purple bracket = triangular fibrocartilage complex, solid blue arrowhead = FDS tendons, white arrowhead = proximal ulnar nerve.

vealed a complete transection of the ulnar artery, which had thrombosed. The ulnar nerve was then reduced without undue tension. The nerve and its deep motor branch were contused and hemorrhagic but were in continuity.

Lastly, the DRF was addressed with an Acu-Loc 2 volar plate (Acumed, Hillsboro, Oregon, USA). Stability of the DRUJ was confirmed under fluoroscopy. A standard closure was performed, and the patient was discharged home in a volar wrist splint.

During the two-week follow-up visit, the patient presented with a flexible claw deformity of the ring and small finger, absent function of all interossei muscles, and diminished light touch with absent 2PD of the ring and small finger. His finding was consistent with a low ulnar nerve palsy. His exam and radiographic imaging were otherwise unremarkable (Fig. 3). The patient was enrolled in hand therapy to maintain flexibility of the claw hand deformity and a thermoplastic splint was fabricated. At his six-weeks, three-months, and four and a half-months follow-ups, he reported subjective improvement, but objective physical exam findings were unchanged. The patient returned to work (car audio installation specialist) three months post-operatively.

At eight months, his claw deformity persisted. The ring finger remained partially flexible while his small finger stiffness worsened secondary to poor adherence to his stretching regimen. His 2PD was 6.0 mm in the ring finger, with negligible small finger 2PD. His first dorsal interosseous muscle improved to 4/5 strength.

At one-year, interossei muscle strength and ring finger sensorimotor function had returned to baseline. Small finger 2PD improved to 4.0 mm. Due to continued difficulties with hand therapy adherence the patient developed a fixed flexion contracture of the small finger distal and proximal interphalangeal joints of 20-30 degrees, and metacarpophalangeal joints of 45-50 degrees.

The patient reported continued frustrations with his activities of daily living due to his flexion contractures. Two years postoperatively, the patient elected to undergo a reoperation. Dense adhesions encased all of the flexor tendons necessitating a radical flexor tenosynovectomy extending from the distal forearm and to the palmar arch. Due to the persistence of a flexion contractures of the small and ring finger, the FDP and FDS were fractionally lengthened utilizing the pie crusting technique allowing the fingers to achieve full extension. Six months post-operatively the patient's flexion contracture was reduced to 10-15 degrees at the distal and proximal interphalangeal joints with complete resolution at the metacarpophalangeal joints.

## DISCUSSION

Ulnar nerve palsy following DRFs is a rare phenomenon, but its association is becoming increasingly apparent in the literature.<sup>3,4</sup> Despite a paucity of literature on this topic, it appears there is no single predictable cause for ulnar nerve injury after a DRF. There have been reports of neurogenic edema, scar formation, and local mass-effect as relatively common sources for ulnar nerve injury, while cases of transection or translocation, such as in this report, are far less common. Appreciating the possible mechanisms of injury can heighten clinical suspicions and allow for quicker identification of a nerve injury.

### Anatomy of the Ulnar Nerve

To better understand the etiology and rarity of ulnar nerve injuries following DRFs, a comparison may be made with the median nerve – the most commonly injured nerve associated with DRFs.<sup>3,4</sup> This higher incidence is due to its anatomic location: lying volar to the distal radius before traveling through the carpal tunnel, which is bordered by the rigid osseous walls of the carpal bones, roofed by an unyielding transverse carpal ligament, and its static volume is further limited by the presence of the flexor tendons.<sup>8,9</sup> Nerve injury may stem from injuries that increase pressure within the carpal tunnel. These include local tissue edema, hemorrhage, osseous deformity, improper wrist immobilization, and/or direct nerve contusion.<sup>5,6,9</sup>

Conversely, the ulnar nerve travels volarly over the ulna, distant from the DRF site, before entering Guyon's



canal.<sup>10</sup> Through the fibro-osseous tunnel (Guyon's canal), the ulnar nerve is embedded fibrofatty tissue alongside the ulnar artery. MRI studies estimate the cross-sectional area of Guyon's canal as  $32 \pm 11 \text{ mm}^2$  with a coinciding ulnar nerve diameter of  $3.0 \pm 1 \text{ mm}$  (cross section  $7.01 \text{ mm}^2$ ).<sup>10</sup> At the level of the wrist the ulnar nerve also remains mobile relative to the median nerve.<sup>11</sup>

The small footprint of the ulnar nerve within Guyon's canal, large excursion potential, and location away from the fracture site are likely protective attributes. Previous reports have hypothesized that ulnar nerve related injuries are secondary to nerve tethering at Guyon's canal, resulting in a stretch neuropraxia.<sup>5,12-15</sup> Younger age and significantly dorsally displaced DRFs appear to elevate risk for associated acute ulnar nerve injury.<sup>5-7,13,15-18</sup>

### Presentation

The presentation of ulnar injury can be separated by its onset. For acute phase injuries, symptoms presenting at the time of injury, or shortly after closed reduction.<sup>5,12-15</sup> Conversely, patients with chronic phase injuries present weeks to months after the injury, and are typically the result of local scar tissue.<sup>16</sup>

### Acute Phase Injuries

In a case series by Soong and Ring, 280 DRFs were reviewed within a two-year period.<sup>5</sup> Five cases of complete ulnar-sensorimotor-deficits following acute DRF were identified. All five underwent internal fixation (locked plating), 3/5 underwent ulnar nerve exploration due to concomitant ACTS and 1/3 demonstrated ulnar nerve entrapment within the fracture. Post-operatively, 80% demonstrated complete ulnar recovery while only one had persistent sensorimotor deficits of the ulnar nerve. The average time to clinical signs of nerve recovery was five months, with maximum recovery around seven months.<sup>5</sup>

In more severe cases, partial or complete transection of the ulnar nerve may be observed. Pogetti et al. reported a 47-year-old male who suffered a subtotal ulnar nerve transection after an open DRF that was acutely repaired. After six months the patient's sensation returned to baseline, with an intrinsic strength deficit of 4/5.<sup>15</sup>

There have been reported cases of ulnar nerve injury and translocation of the ulnar nerve dorsal to the distal radioulnar joint (DRUJ) after a DRF. In one case, a 19-year-old male sustained a DRF following an MVA treated with external fixation and delayed internal fixation eight weeks later. Post-operatively an EMG conveyed ulnar denervation. At exploration the nerve was found translocated through the DRUJ. The patient progressively recovered over an additional nine months with residual ulnar hypoesthesias.<sup>18</sup> Pientka II et al.

described an open DRF/DRUJ dislocation requiring external fixation and DRUJ pinning with post-surgical deficits. During internal fixation eight weeks later, the ulnar neurovascular bundle was noted to have translocated through the DRUJ and wrapped around the ulnar head.<sup>19</sup> Follow-up at two months demonstrated improved ulnar nerve sensation but persistent motor deficits.

### Chronic Phase Injury

A few case reports of ulnar neuropraxia symptoms presenting months after the initial injury have been reported as well. Cho et al. reported two cases of ulnar nerve palsy following a DRF attributed to surrounding tissue fibrosis at the level of Guyon's canal.<sup>6</sup> Each patient was found to have a progressive ulnar nerve palsy and claw hand deformity eight weeks post operatively confirmed on EMG. Both patients underwent decompression with complete motor recovery 3-12 months post-operatively. Another case by Yang et al., described a new claw hand deformity five weeks after ORIF for a closed DRF.<sup>16</sup> After ultrasound examination, a decompression was performed. Six months thereafter the patient's sensation resolved but a mild claw hand deformity persisted.

### Diagnostic Work-up

There are no formalized diagnostic guidelines for ulnar nerve evaluation after a DRF. Advanced imaging modalities like ultrasound<sup>6,16</sup> or MRI can assess for nerve continuity in equivocal cases. However, these studies provide limited utility in ruling out ulnar nerve pathology. Previous reports utilized EMG to functionally assess ulnar nerve injury.<sup>6,7,17,18</sup> These are often performed weeks after presentation and appear limited in the acute phase. Diagnostic work-up relies heavily on clinical exam findings. Negative advanced imaging does not exclude injury and operative intervention should not be delayed if clinical suspicion remains high.

### Timing of Operative Intervention and Recovery

Ideally, nerve injuries should be addressed early; however, multiple reports have demonstrated robust sensorimotor recovery with delayed exploration ranging from a few days up to eight weeks.<sup>5,18</sup> We recommend urgent and early surgical intervention for acute phase ulnar nerve injuries in the setting of closed DRF, however, cases of chronic presentation should be offered operative intervention too. Appropriate counseling regarding the duration of sensorimotor recovery is necessary. Sequelae such as claw hand, stiffness, numbness, and dysesthesias should also be addressed.

## CONCLUSION

This report offers a unique case of ulnar nerve and flexor tendon translocation dorsoulnarly relative to the ulnar head. Our review also emphasizes the importance of close monitoring of patients with atypical exams. Current literature suggests persistent ulnar nerve palsy, independent of acuity, can be an indication for surgical exploration following a DRF with a high likelihood of functional recovery. Advanced imaging may be helpful for presurgical planning but remains inadequate for excluding an ulnar nerve injury. Functional testing modalities such as EMG can also be considered in the appropriate setting.

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# WINQUIST VIEW OF THE FEMORAL NECK: IDEAL VISUALIZATION OF FEMORAL NECK FIXATION

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David Templeman, MD<sup>4</sup>; William W. Cross III, MD<sup>5</sup>

## ABSTRACT

**Background:** Despite the increased frequency of cephalomedullary fixation for unstable intertrochanteric hip fractures, failure with screw cut-out and varus collapse remains a significant failure mode. Proper positioning of implants into the femoral neck and head directly influences the stability of fracture fixation. Visualization of the femoral neck and head can be challenging and failure to do so may lead to poor results; Obstacles include patient positioning, body habitus, and implant application tools. We present the “Winquist View,” an oblique fluoroscopic projection that shows the femoral neck in profile, aligns the implant and cephalic component, and assists in implant placement.

**Methods:** With the patient in the lateral position, the legs are scissored when possible. Following standard reduction techniques, the Winquist view is used to check reduction prior to surgical draping. Intraoperatively, we rely on a perfect image to place implants in the ideal portion of the femoral neck, with a trajectory that achieves the center-center or center-low position of the femoral neck. This is achieved by incorporating the anterior-posterior, lateral, and Winquist view.

**Results:** We present 3 patients who underwent fixation with a cephalomedullary nail for intertrochanteric hip fractures. The Winquist view facilitated excellent visualization and positioning in all

cases. All postoperative courses were uneventful, without failures or complications.

**Conclusion:** While standard intraoperative imaging may be adequate in many cases, the Winquist view facilitates optimal implant positioning and fracture reduction. With lateral imaging, implant insertion guides may obscure visualization of the femoral neck during which Winquist view is the most helpful.

**Level of Evidence:** V

**Keywords:** femoral neck, intraoperative imaging, patient positioning, hip fracture, intertrochanteric fracture

## INTRODUCTION

Cephalomedullary fixation of intertrochanteric hip fractures (OTA 31-A) is favored by most orthopedic surgeons. The American Academy of Orthopedic Surgeons recently revised its clinical practice guidelines to give a strong recommendation for the use of cephalomedullary nails for the fixation of unstable intertrochanteric hip fractures.

Despite the increased use of cephalomedullary fixation, failure with screw cut out and varus collapse remains a concerning mode of failure. Factors that are documented to increase the risk of cut-out include fracture reduction, screw penetration, and excessive tip-apex distance (TAD). This points to the need for precise screw placement in the femoral head, a technical step that is dependent on fluoroscopic imaging.

Clear visualization of the femoral neck with intraoperative fluoroscopy is vital in the treatment of proximal femur and femoral neck fractures. Various implants in these situations include intramedullary nails with cephalomedullary fixation, hip screws, and other fixed angle devices such as blade plates or dynamic condylar screws. Failure to appropriately position implants in the femoral head and neck have led to early failures<sup>1-3</sup> and can lead to less favorable outcomes after revision surgery.<sup>2</sup>

At our institution, we prefer positioning patients in the lateral decubitus position for intramedullary nailing. In comparison to the supine position, it facilitates easier access to the surgical starting point (whether piriformis or trochanteric) and avoids posterior angulation of proximal femoral fractures which commonly occurs during supine positioning.

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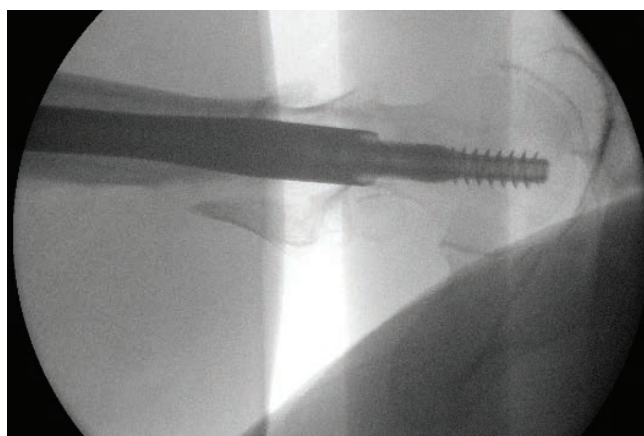


Figure 1A. Winquist View.

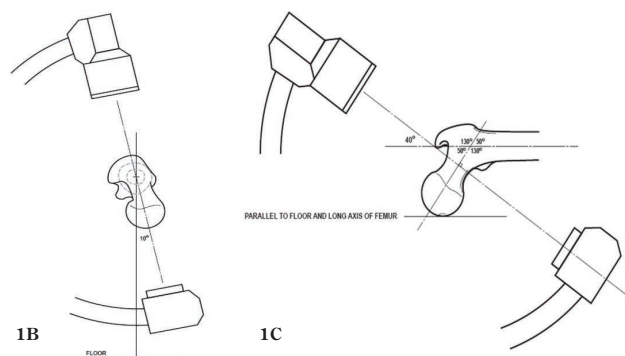


Figure 1B to 1C. (1B) Schematic representing lateral patient positioning and appropriate intraoperative fluoroscopy position taking into account an average femoral anteversion of 10 degrees. Obtaining this angle in addition to the neck-shaft angle comprises the Winquist view. (1C) Schematic representing lateral patient positioning and appropriate intraoperative fluoroscopy position taking into account an average neck-shaft angle of 130 degrees. Obtaining this angle in addition to the anteversion angle comprises the Winquist view.

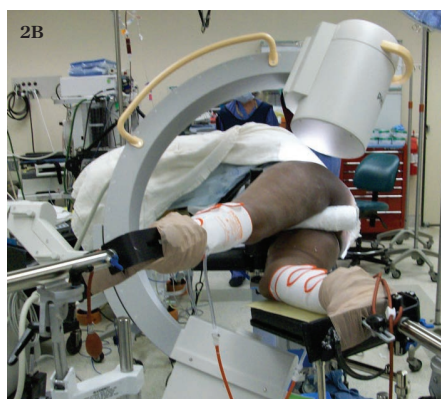
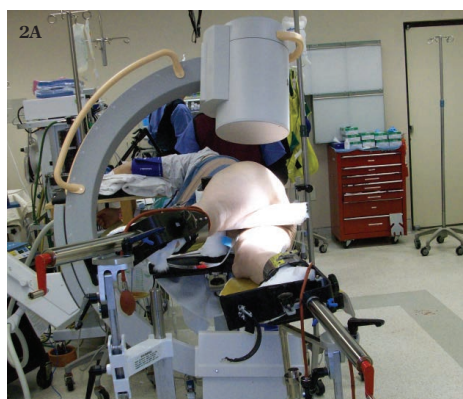


Figure 2A to 2C. (2A) Intraoperative set up. (2B) Proper positioning of intraoperative fluoroscopy with the patient in the lateral position – our preferred patient position for complex proximal femur fractures of the intertrochanteric and subtrochanteric varieties. Note the C-arm position taking the femoral anteversion and neck-shaft angle into consideration. (2C) Intraoperative example utilizing the Winquist view.

To assist in viewing the head and neck segment of the proximal femur, we use an oblique fluoroscopic projection we call the “Winquist view” based upon Dr. Winquist’s instruction (Figure 1A). This view is obtained by rotating /tilting the image intensifier to display a lateral view of the femoral neck and head in a collinear manner (Figure 1B and 1C).

## METHODS

With the patient in the lateral position, we prefer to scissor the legs when possible (Figure 2A-C). Standard reduction techniques are employed during this step. These include traction, hip flexion, and limb rotation. At this point, we routinely check reduction prior to surgical draping and first use the Winquist view. Occasionally,

we will have to modify patient positioning to obtain better imaging at this step. Once we confirm that adequate imaging can be obtained, we proceed with the case as usual with the implant of choice.

Intraoperatively, we rely on a perfect image to place implants in the ideal portion of the femoral neck and with a trajectory that achieves the center-center position of the femoral head. This goal is accomplished by incorporating data from all intraoperative views including the anterior-posterior (AP) view, the lateral view, and the Winquist view. Often, particularly with standard lateral imaging, the implant insertion guides obscures adequate visualization of the femoral neck. It is in this situation that the Winquist view is the most helpful.

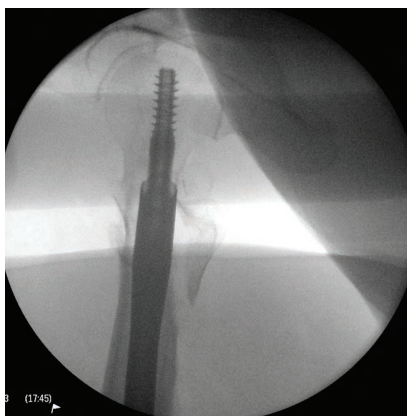


Figure 3. Intraoperative image of the Winquist view with patient in Figure 2A and 2B.

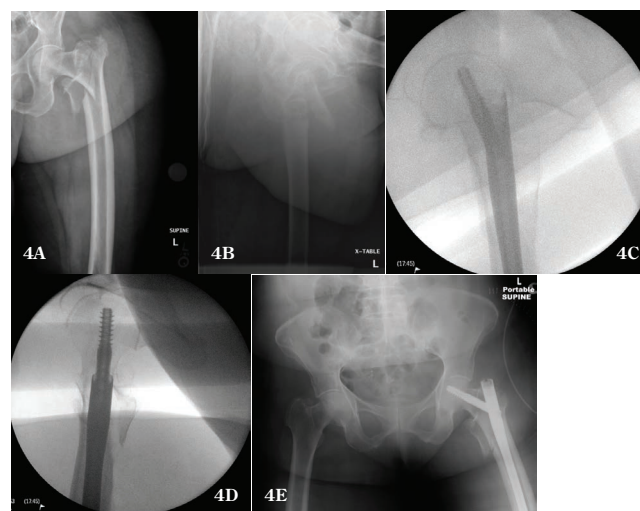


Figure 4A to 4E. (4A, 4B) Injury films including an AP and Lateral view of Case 1's left intertrochanteric hip fracture. (4C) Post-operative lateral image of Case 1. (4D) Post-operative Winquist view of Case 1. (4E) Post-operative AP image of Case 1.

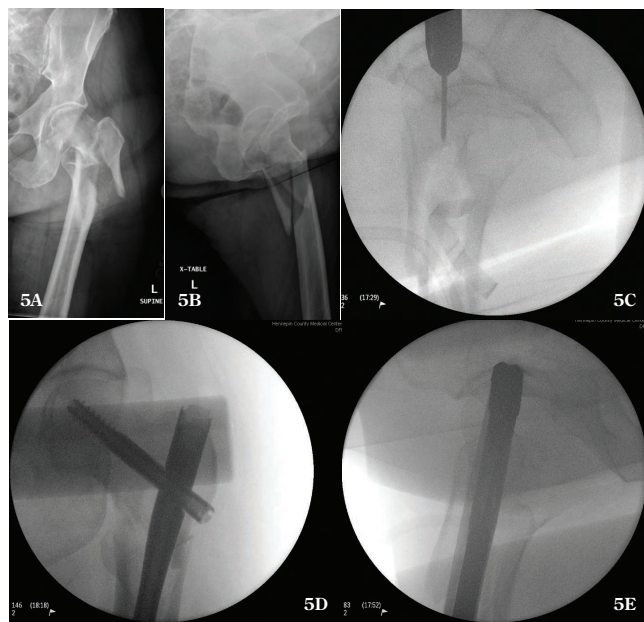


Figure 5A to 5E. (5A) Preoperative AP image of Case 2's left intertrochanteric fracture. (5B) Preoperative lateral image of Case 2's left intertrochanteric fracture. (5C) Intraoperative example of utilizing the Winquist view to obtain perfect positioning of a guide pin into the femoral neck. (5D) Final intraoperative AP image of Case 2. (5E) Intraoperative lateral image of Case 2 demonstrating optimal position of guide.

### CASE REPORT

**Case 1:** A 61-year-old female fell at home after tripping over a lamp cord. She sustained a left intertrochanteric hip fracture (see Figures 4A-B). After appropriate medical evaluation, she underwent closed reduction and internal fixation with a cephalomedullary nail. The surgical procedure and post-operative course had no complications and were uneventful (Figures 3, 4C-E).

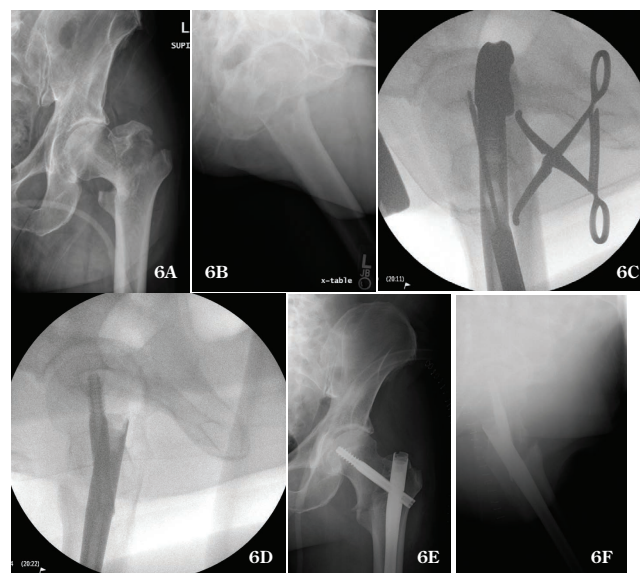


Figure 6A to 6F. (6A) Preoperative AP image of Case 3's intertrochanteric fracture. (6B) Preoperative lateral image of Case 3's intertrochanteric fracture. (6C) Intraoperative image utilizing the Winquist view to see the fracture reduction adequately as well as guidewire placement across the femoral neck. Rotation of the C-arm in the Winquist view both anterior and posterior confirms appropriate cephalic screw position. (6D) Post-operative Winquist view of Case 3 with implant across femoral neck. (6E) Post-operative AP view of Case 3 with implant across femoral neck. (6F) Post-operative lateral view of Case 3 with implant across femoral neck.

**Case 2:** A 66-year-old female fell down the stairs at her home after tripping. She sustained a left reverse oblique intertrochanteric hip fracture (Figures 5A-B). After correction of an elevated INR, she was brought to the operating room and underwent an open reduction



and internal fixation with a cephalomedullary nail. The patient's intraoperative and post-operative courses had no complications and were uneventful (Figures 5C-E).

Case 3: A 75-year-old male was chipping ice off his roof and fell 10 feet to the ground. He sustained a left intertrochanteric hip fracture (Figures 6A-B). After undergoing medical evaluation and normalization of his INR, he underwent an open reduction and internal fixation with a cephalomedullary nail. His intraoperative and post-operative courses were uneventful (Figures 6C-E).

### DISCUSSION

The importance of utilizing TAD to establish optimal screw positioning was first presented by Baumgartner et al. The authors concluded that screw cut out could be avoided in patients with a sliding hip screw, if the surgeon maintains a TAD of less than 25 mm.<sup>4</sup> Since this landmark paper, the importance of avoiding an excessive TAD and maintaining a center-center position has been extrapolated to the nails and lag screws positions to avoid implant failure.<sup>5</sup>

Complete visualization of the femoral neck is critical to ensure appropriate placement of implants through the femoral neck and into the femoral head. Failure to place implants in the correct position or failure to achieve adequate fracture reduction has led to fixation construct failures and poor patient outcomes.<sup>1,2,6-10</sup> Hoffer et al. in a retrospective series of 76 cases reported appropriate lag screw placement in only 55% of cases-included in their series were 5 lag screws in "at risk" positions including superior on AP view (3 patients) and anterior on lateral view (2 patients).<sup>11</sup> While standard AP and lateral intraoperative imaging may be adequate in the many surgical cases, we feel that the application of the Winquist view can aid in implant positioning and fracture reduction. This may be particularly important in academic medical centers or for surgeons with less experience.<sup>11</sup>

The purpose of the present report is to introduce orthopedic surgeons to the Winquist view, providing another method for better visualization of the femoral neck to use in the treatment of fractures involving the placement of implants in this region.

### CONCLUSION

Proper positioning of implants into the femoral neck and head has been shown to directly influence the stability of fracture fixation. The Winquist view can be performed to facilitate optimal visualization of the femoral neck to use in the treatment of fractures. This may be particularly important in academic medical centers or for surgeons with less experience. The routine utilization of this view adds another tool for the surgeon to use to optimize outcomes in the care of these patients.

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