
JUNE 2021
VOLUME 41
ISSUE 1

THE **IOWA**
ORTHOPEDIC
JOURNAL

**20
21**

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

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David DeMik, MD, PharmD
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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*. Articles will be enthusiastically received from alumni, visitors to the department, members of the Iowa Orthopaedic Society, residents, friends, and colleagues.

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THE IOWA ORTHOPEDIC JOURNAL

2021 • Volume 41 • Issue 1

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2021-2022
DEPARTMENT OF ORTHOPEDICS AND REHABILITATION
SCHEDULE OF LECTURESHIPS AND CONFERENCES

Carroll B. Larson Shrine Memorial Lecture
2021 Canceled

Spring 2022 to be arranged.
Contact Nancy Love: (319) 356-1872

2021 Senior Residents' Day
June 10-11, 2021

John C. Clohisy, MD
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June 10-11, 2022

Discussants to be arranged.
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2021 IOJ EDITORS' NOTE



From left to right: Drs. David DeMik (2021 Resident Editor), Christopher Cychosz (2021 Resident Business Manager), Alan Shamrock (2021 Resident Editor), Lawrence Marsh (Staff Advisor), Christopher Carender (2021 Resident Editor), Jose Morcuende (Staff Advisor).

We are pleased to present the 41st edition of the Iowa Orthopedic Journal (IOJ). While 2020 and 2021 have been years unlike any other, it is encouraging orthopedic surgeons managed to stay motivated and work to advance our field through research during the COVID-19 pandemic. We received a record number of submissions, over 100, from institutions across the United States and world this academic year. Due to the continued success of the IOJ, we are fortunate to continue the tradition of publishing a Fall electronic issue for a third consecutive year.

We would like to recognize our graduating class of senior residents: Drs. Cameron Barton, Emily Connor, Christina Hajewski, Sarah Schippers, Elizabeth Scott, and John Yanik. We have fond memories of them all and are grateful for their mentorship, teaching, and service to the department over the past several years. They absolutely will be missed as they move on to fellowship and enter practice. We wish them all the best.

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 assumed primary responsibility for the publication of the journal this year and has done a fantastic job. We thank Dr. Chris Cychosz 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 assistance. We thank Dr. Jose Morcuende for his continued guidance as faculty advisor to the journal. Finally, we would like to recognize Kyle Kesler as Resident Reviewer of the Year for the exceptional quality and quantity of his reviews this year.

It has been an honor to serve as this year's editors and we feel privileged to be a part of the longstanding legacy at of the IOJ.

Christopher Carender, MD
David DeMik, MD, PharmD
Alan Shamrock, MD
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2021 DEDICATION OF THE IOWA ORTHOPEDIC JOURNAL

PROFESSOR JAMES V. NEPOLA

*Founder of the Orthopedic Trauma and Orthopedic Shoulder Services, Founder of the Bone Healing Research/
Iowa Spine Laboratory*



James V. Nepola, MD

The 2021 edition of the Iowa Orthopedic Journal is dedicated to Dr. James V. Nepola. It is both a pleasure and a privilege for me to submit this tribute to Dr. Nepola, also affectionately known to many of the faculty and orthopedic residents as “The Nipper Badger.” The origin of that nickname is for another time. Dr. Nepola has had

a profound influence over countless orthopedic residents and medical students. The following paragraphs will try to capture why that has happened.

James “Jim” Vincent Nepola was born and raised in New Jersey. He attended Yale University, graduating with a BS in 1974. He completed medical school and then residency in orthopedic surgery at Columbia University in New York City. In 1984, Dr. Reginald Cooper recruited him to start his career at the University of Iowa. He was young, brash, and full of East Coast swagger.

Thirty-five years later, Jim’s career is remarkable for his efforts at starting and building clinical and research programs. When he arrived in Iowa City, he quickly established the orthopedic trauma service, also known in the department as “The Red Team.” In order to generate enthusiasm, for many years, his office was painted red. He established himself as a leader in orthopedic trauma and was a trendsetter in the use of external fixation for fractures. As the volume of trauma increased, Dr. Cooper and Jim recruited Dr. Larry Marsh to join Jim on the orthopedic trauma team. Together, Dr. Nepola and Dr. Marsh were the first to introduce the Morning Pass-Ons Conference, a case-based discussion of patients seen at the hospital the night before. The Morning Pass-Ons Conference continues to this day and is an integral part of patient care and resident education within the department.

In research, Jim was passionate about having a lab. He was a fracture surgeon, so it was logical that bone healing was his research passion. He envisioned a bone healing translational research laboratory; he recruited Dr. Doug Fredericks to lead the effort, resulting in the establishment of the Bone Healing Research/Iowa Spine Laboratory at the University of Iowa. Jim continues to serve as the Director of the laboratory. Under his direction, the lab has developed an outstanding national reputation in



Dr. Nepola early in his orthopedic career.

orthopedic translational research. It continues to be a leader in the bone graft substitutes and preclinical studies used in the FDA approval process.

As time passed, the trauma service continued its upward trajectory. Jim helped recruit more surgeons to join the team, including Dr. Todd McKinley and Dr. Matt Karam. With the trauma team now in good hands,

Jim began looking for new ways to improve patient care, education, and enhance the reputation of the department. As a result, Jim started the shoulder service. A logical choice since one of his mentors at Columbia was Dr. Charles S. Neer, founder of the American Shoulder and Elbow Society (ASES). For a second time in his career, Jim elevated the level of patient care in the department and quickly established himself as a thought leader and expert in shoulder surgery.

Jim’s most recent accomplishment is founding and leading the Work Injury Recovery Center (WIRC), the first clinic of its kind at the University of Iowa. This innovative program is entirely focused on injured Iowa workers and has a goal of primary assessment, diagnosis, and treatment designed to lead workers to recovery and return to work as soon as possible. Suffice it to say, by starting and establishing the trauma and shoulder services, the Bone Healing Research Laboratory, and the Work Injury and Recovery Center - Jim has established himself as a consummate physician-scientist, innovator, trendsetter, and leader of multiple clinical services.

As his career began to take off, he eventually convinced his better half Cathy to leave the East Coast, get married, and move to Iowa City. I have known her for several years, and she is indeed a calming presence. Over time, four children entered the picture, daughters Alessandra (31) and Jacqueline (29) and sons Christopher (26) and Thomas Edward “Teddy” (23). Jim’s grandson Benjamin is the most recent addition to the family. Jim has a passion for Sheep Dogs, and they have often been part of the Nepola family. His dog Jersey was almost as well known in the Iowa City area as Jim. Numerous times, Jersey was caught trespassing inside of Hancher Auditorium, the VA Hospital, and other businesses throughout



Dr. Nepola and Dr. Emily "Nepola" Wagstrom, Class of 2015.



Dr. Nepola and Dr. Ernest "Ernie" Found at the 100th year anniversary celebration of the University of Iowa Department of Orthopedics and Rehabilitation.



Dr. Nepola doing what he does best - teaching residents.

Iowa City. His new dog Walter is somewhat ornery. It's interesting how dogs seem to take on the personality of their owner.

Jim and Cathy became Iowans with an East Coast twist. Jim is a die-hard New York Giants and Mets fan but also a passionate Hawkeye. Politics is always an interesting topic of conversation with Jim, and he is not shy about sharing his opinions. He is also one of the most loyal people I have ever met. Over the last couple of years, I've witnessed that loyalty as one of his best friends struggled with a terminal illness. Jim thought nothing of putting everything aside to spend time with his friend. Golf is also one of his passions. For those that know Jim, just about the only time he is quiet is on the golf course.

My journey in Orthopedics started in the fall of 1986 as a medical student on the trauma service at the University of Iowa. I saw that Jim brought boundless energy and passion to patient care. Jim helped convince me that there was nothing I would rather be than an orthopedic surgeon. He became my mentor and helped guide me at the start of my career. In fact, I will never forget that we celebrated together on match day at The Vine over some cold beverages. During my career, I always looked up to Jim and tried to follow his example when I took care of a patient. Many years later, Jim contacted me and indicated that he would be in Des Moines for the day. We met at a McDonald's of all places, made small talk, and within a few minutes, he took his French fry container and wrote a number on it. He passed it to me and asked if that was enough to change my career path and come back to the University of Iowa and join the department. With the blessing of my wife Julie, I enthusiastically accepted his offer. Much of what I am as an orthopedic surgeon is due to Jim. I will always be grateful for the profound impact he has had on my career. I have welcomed the opportunity to pay back my debt to him by helping young medical students and residents pursue the best specialty in all of medicine.

Jim has been a favorite faculty member for generations of orthopedic residents. When the department first started a faculty teacher of the year award, the graduating senior residents selected Jim as the first winner. I have no doubt that he treasures that award more than any other accolade or recognition he has received in his 37-year career in orthopedics. As he accepted his award and was asked to say a few words, he was speechless and overcome with emotion: not a common problem for Jim.

The department has had many icons of orthopedic surgery both past and present. By virtue of his career-long contributions, innovation, leadership, and memorable personality Jim Nepola is one of those icons. It is entirely fitting that he be honored with the 2021 Iowa Orthopedic Journal Dedication. If you are a graduate of this medical school or residency program and have a moment, please thank Dr. Nepola for his mentorship. I know his influence on my career is something that I will never forget.

-Cassim M. Igram, MD

Epilogue

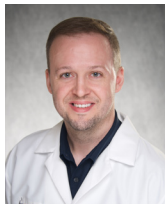
As part of the COVID-19 pandemic, faculty and residents of the department were provided with masks, courtesy of the College of Medicine. Printed on them was the origin of the word "doctor": from the Latin verb *docere* ("to teach"). Appropriately, Dr. Nepola took to this mask right away - proudly wearing it over the top of his blue hospital mask. Dr. Nepola truly embodies what it means to be a doctor. His generosity with his personal time and enthusiasm for teaching residents is unmatched. Rotating on Dr. Nepola's service, residents learn quickly that taking the time to listen to patients, working up complaints systematically, and treating people with empathy is not only his way - it is the only way. On behalf of all the residents, both past and present, we would like to extend our gratitude to Dr. Nepola for his efforts as an educator and mentor, guiding us to be better surgeons, teachers, and people.

-Editors of the Iowa Orthopedic Journal

DEPARTMENT OF ORTHOPEDICS AND REHABILITATION FACULTY 2020-2021



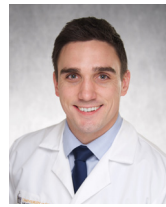
Dr. Donald Anderson



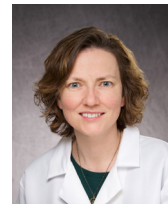
Dr. Adam Arendt



Dr. Eric Aschenbrenner



Dr. Nicholas Bedard



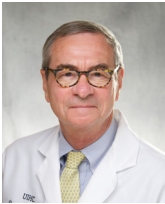
Dr. Heather Bingham



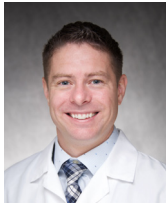
Dr. Matthew Bollier



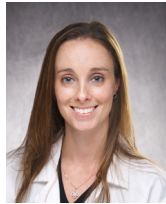
Dr. Timothy Brown



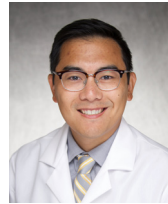
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Dr. Joseph Buckwalter V



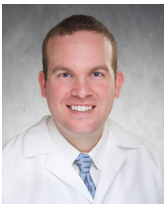
Dr. Lindsey Caldwell



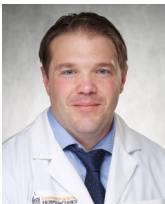
Dr. Philip Chen



Dr. Cesar de Cesar Netto



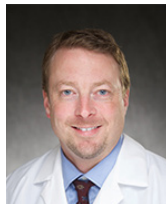
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Dr. Jacob Elkins



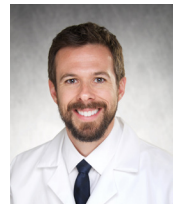
Dr. John Femino



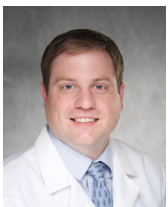
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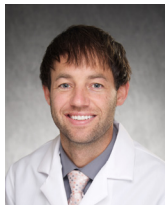
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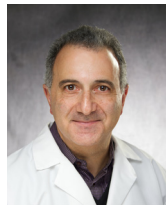
Dr. Mederic Hall



Dr. Matthew Hogue



Dr. Joshua Holt



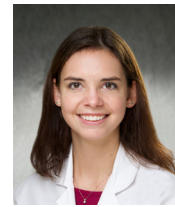
Dr. Cassim Igram



Dr. Matthew Karam



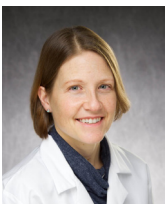
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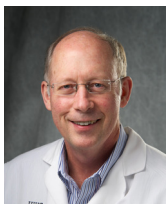
Dr. Heather Kowalski



Dr. Ryan Kruse



Dr. Ericka Lawler



Dr. J. Lawrence Marsh



Dr. James Martin



Dr. Benjamin Miller



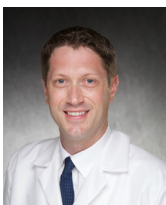
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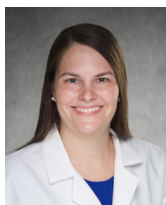
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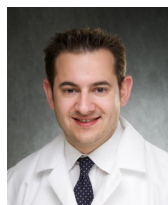
Dr. Nicolas O. Noiseux



Dr. Brendan Patterson



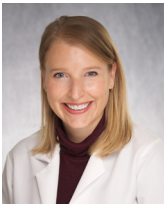
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Dr. Andrew Pugely



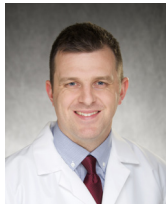
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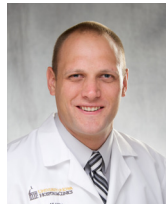
Dr. Kathleen Vonderhaar



Dr. Stuart Weinstein



Dr. Robert Westermann

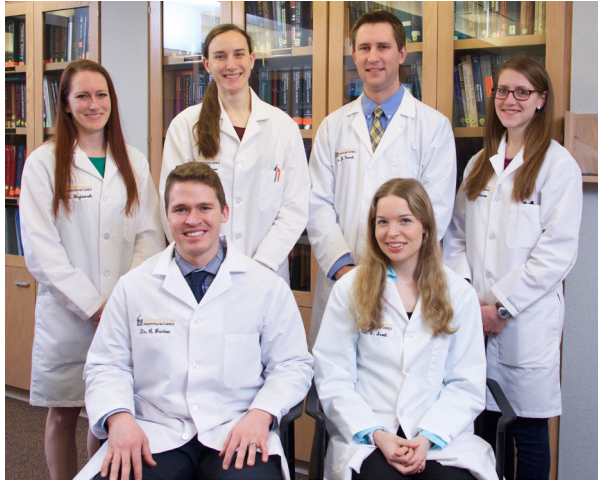


Dr. Michael Willey

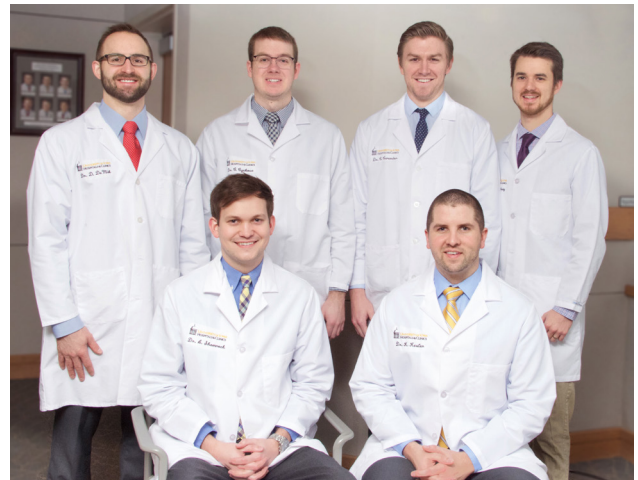


Dr. Brian Wolf

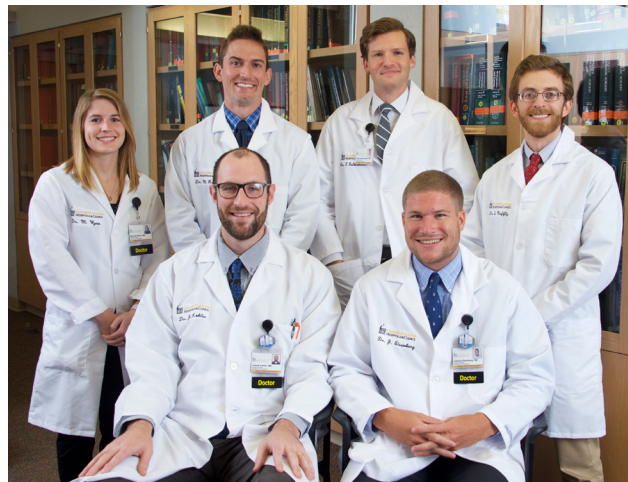
DEPARTMENT OF ORTHOPEDICS AND REHABILITATION RESIDENTS 2020-2021



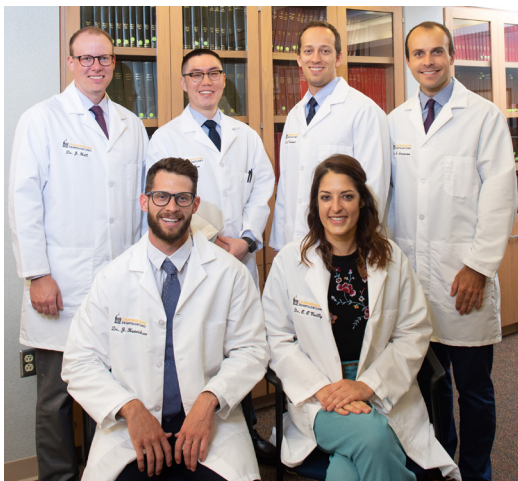
PGY5-Class of 2021. Back row (left to right): Drs. Christina Hajewski, Emily Connor, John Yanik, and Sarah Schippers. Front row (left to right): Drs. Cameron Barton and Elizabeth Scott.



PGY4-Class of 2022. Back row (left to right): Drs. David DeMik, Christopher Cychosz, Christopher Carender, and Christopher Lindsay. Front row (left to right): Drs. Alan Shamrock and Kyle Kesler.



PGY3-Class of 2023. Back row (left to right): Drs. Malynnda Wynn, Michael Russell, Trevor Gulbrandsen, and Scott Muffly. Front row (left to right): Drs. James Kohler and Joshua Eisenberg.

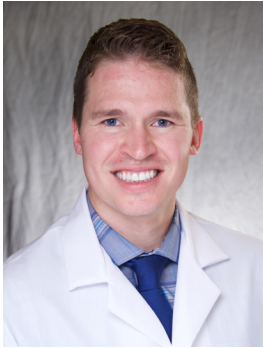


PGY2-Class of 2024. Back row (left to right): Drs. James Hall, Burke Gao, James Cardinal, and Samuel Swenson. Front row (left to right): Drs. Jacob Henrichsen and Olivia O'Reilly.



PGY1-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.

2021 GRADUATING ORTHOPEDIC RESIDENTS



Cameron Barton, MD

Cameron was born in Colorado Springs, Colorado to Scott and Denise Barton. He grew up in Monument, CO with his younger siblings, Landon and Emily. They spent most of their time outdoors, enjoying mountain biking, snowmobiling, rock climbing, and dirt biking. These outdoor passions eventually culminated in downhill mountain bike racing, the downhill skiing equivalent of cycling, for the CU

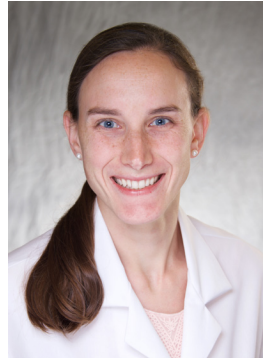
Cycling Team during his undergraduate years.

Cam earned his Bachelor of Arts degree in Molecular, Cellular, and Developmental Biology from the University of Colorado-Boulder (CU). He served as president of the Volunteer Resource Center at CU and later founded a non-profit organization called The International Relief Fund. Through this organization, he organized a trip to rural Nepal, where his group developed a curriculum to teach proper hygiene and handwashing to primary schools in the area. He also served as a bioskills/cadaveric lab organizer at the Scientific Education and Research Institute. At this facility, he designed and coordinated physician training courses for surgeons from all over the country. He also coordinated the student internship for the program, which is where he met his wife, Aubrey.

Cam started medical school at the University of Colorado Anschutz Medical Campus. His decision to pursue a career in orthopaedics was strongly influenced by both his love of outdoor sports, as well as by his mentor, Dr. Evalina Burger. His dedication to orthopaedic research as a medical student earned him the William Winter Memorial Award for Outstanding Academic Orthopaedic Performance upon graduation. He also presented his research in Guangzhou, China for the annual SICOT meeting.

Dr. Barton was honored to match at the University of Iowa. He has had the distinct pleasure of learning from some of the greatest names in the field, as well as his brilliant and supportive co-residents. He's completed a number of research projects with a focus on spine, joint arthroplasty, and ACL clinical outcomes. He has also been able to pursue his other interests, including but not limited to mountain biking, paddle boarding, beer-drinking, brisket-smoking, and boating. Cam extends his most sincere thanks to the faculty of UIHC Ortho for their patience, guidance, and wisdom during his training here. He will complete a fellowship in joint arthroplasty at Rush Midwest Orthopaedics in Chicago.

Cam has many people to thank for their love and support during his training. He credits his immediate family, Scott, Denise, and Emily, for providing him with a passion for serving others and steadfast encouragement along the way. His brother, Landon, has always been his go-to companion for adventure and camaraderie. He thanks his in-laws, Bryan and Paula, for their always accessible advice and support. His brother-in-law, Brett, has provided him with comic relief, facial hair goals, and many outdoor adventures. His daughters, Blake and Lainey, are the light of his life and his greatest accomplishments to date. And finally, none of this would have been possible without his loving wife, Aubrey, who has been the love of his life, his best friend, a constant source of unwavering support and motivation, and the rock of the family.



Emily Connor, MD

Emily Connor grew up in Manchester, Iowa. She attended West Delaware High School where she participated in various sports, including volleyball, basketball, and soccer. When she was not busy with sports and school, she worked at the local Fareway grocery store and with her dad in construction. Her senior year culminated with her earning Iowa 3A volleyball player of the year and graduating

valedictorian.

After graduating from high school, she attended Drake University in Des Moines, Iowa. At Drake, she participated on the women's volleyball team and studied Biochemistry, Cell and Molecular Biology. Although she was told by the head of the biology department when choosing her major that she would not succeed at earning a science degree while also playing a sport, she graduated summa cum laude with a 4.0GPA and achieved ESPN Academic All-District honors in volleyball, while also working at Kemin Industries in the specialty crop improvement plant sciences program.

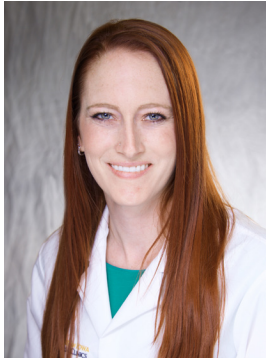
Inspired by her mom who works as a nurse, Emily aspired to pursue a career in the medical field. She was not certain she had what it took to become a doctor, but with a boost of confidence from her mom (who was also the one who instructed her to ignore the doubting biology professor in college), she applied to and attended Washington University School of Medicine in Saint Louis.

Between 1st and 2nd year of medical school, Emily married her high school sweetheart, Billy. In third year of medical school, Emily fell in love with orthopedics after her surgery rotation block. She did an away rotation at Iowa during her fourth year and knew this was the program she was hoping to match into for residency.

Emily has been grateful for the opportunity to train here at Iowa. She is especially thankful for her mentors Dr. Kowalski and Dr. Karam, and the rest of the simulator project team including Geb Thomas, PhD; Don Anderson PhD; Steven Long PhD, et al.; who have all been instrumental in her success with her supracondylar humerus fracture simulator.

Upon completion of residency, Emily will begin her career in general orthopedics at Winneshiek County Hospital in Decorah, Iowa as part of the Mayo Clinic Health System.

Emily would like to thank her parents, John and Lorrie Hefernen, for raising and instilling in her strong work ethics and moral attributes; her siblings (Josh, Heather, Sara) for all the FaceTime calls, weekends and holidays spent together taking her mind off the stresses of residency from time to time; and most of all, she would like to thank her husband, Billy, who has been by her side since age 16, always allowing her career path to dictate the next step in their lives together and always being there at the end of the day.



Christina Hajewski, MD

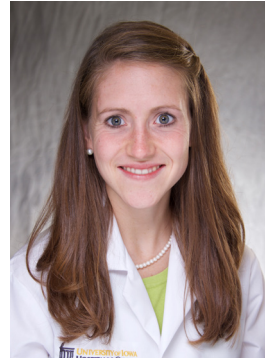
Tina was born and raised in Dallas, TX to Katie and Mark Rau. She spent her first eighteen years there along side her younger brother Tony. She swam competitively since the time she was eight, and it was swimming that brought her to the University of Miami, FL, for undergraduate. There she obtained a degree in Geological Sciences and swam on the varsity swim team.

She continued to pursue her interest in the earth sciences by attending graduate school at Brown University in Providence, RI. During that time, she kept up her athletics by participating in triathlons and distance running. Her research at Brown brought her to the Mojave desert and to the middle of the Pacific Ocean where she participated in two four week research cruises to put seismometers on the ocean floor. Her research focused on studying earthquakes and imaging the earth's interior with seismic tomography. She obtained her master's degree and passed her comprehensive exams for her PhD, but when most of the rigor of her work was taken away and she was left to focus on her research it became clear that this was not the career path for her. Her love of athletics and keeping active as well as a passion to help people inspired her to apply to medical school.

Tina then moved to Boulder, CO, to finish taking a few prerequisite classes and to be closer to her brother and other like-minded athletic and outdoorsy people. She happened to meet her husband, Jeff, during this time as he was finishing his first round of graduate school in applied mathematics at the University of Colorado (he later decided to go back to graduate school at the University of Iowa to get a PhD in Computer Science in an effort to out number Tina's degrees; he is currently in the lead).

In the summer of 2012, Tina moved back to Miami, FL for medical school and introduced Jeff to the vibrant city. Tina kept an open mind during medical school, but orthopedics had always been the plan. They were thrilled to find out that Tina matched at the University of Iowa for her orthopedic surgery residency. During their time here, Jeff and Tina welcomed a goldendoodle, Murph (5 y), and two sons, Tristan (2.5 y) and Liam (2 mos). Following residency, Tina will be completing a fellowship in spine surgery at the Indiana Spine Group.

Tina would first and foremost like to thank her husband Jeff, for always believing in her and getting her through the best of times and worst of times. She would also like to thank her family, particularly her mother Katie, for the unconditional support over the years and even more so with the grandchildren. She would like to thank her sons Tristan and Liam for making her a mother and forever changing her life. She would like to thank the orthopedic faculty and staff at UIHC for the amazing education and training, and particularly Drs. Pugely, Igram, Weinstein and Lawler. Finally, she thanks her co-residents for being the best people with whom to share the last five years.



Sarah Schippers, MD

Sarah was born and raised on a family farm near Wichita, KS. The second oldest of seven children, she spent her childhood working alongside her siblings, father and grandfather on the family farm. She graduated as valedictorian from Garden Plain High School and was awarded a full academic scholarship to the University of Kansas.

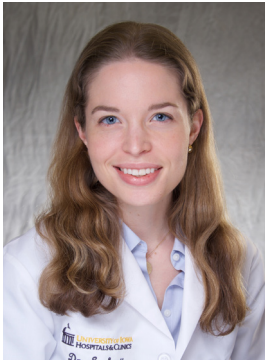
Sarah became interested in healthcare when her father was in a farming accident and needed surgery. The treatment he received inspired her to pursue medicine, so she majored in Exercise Science with hopes of attending medical school. While in college she developed a passion for long-distance running and went on to run 10 marathons. It was also during her time at KU that she met her future husband, Lucas.

She continued her education at the KU School of Medicine. There she developed an interest in orthopedics which combined her passion for applied anatomy with the use of technical skills similar to those she learned growing up on a farm. She was awarded the Ruth Jackson-Steindler Diversity scholarship which allowed her to complete a rotation at the University of Iowa. It was during her clerkship that she fell in love with the program and finally found a reason to leave Kansas. She counted herself very fortunate to match to the University of Iowa for residency and will always be thankful for the education she received.

Thanks to the dedication to long-term patient outcomes at Iowa, she completed a research project that evaluated adult patients who had been born with Poland's Syndrome. She enjoyed evaluating some of Dr. Adrian Flatt's, an innovator in the field of hand surgery, patients and was thankful for the guidance of Dr. Jody Buckwalter, V.

Sarah plans to complete a fellowship in hand and upper extremity surgery by training at Regions Hospital and Hennepin County Medical Center in the Twin Cities. She then plans to return home to Wichita, KS and join a practice with hopes of training orthopedic residents in that community.

Sarah would like to thank her parents, Ned and Teresa, for teaching the importance of faith, family and hard work, her siblings (Fr. Andrew, John, Amy, Peter and Janelle) for keeping her in touch with life outside of medicine over the past decade of training, and her late brother, Brian, who's final earthly actions were the best example of putting others first without regard to your own needs. Most importantly, she is grateful for Lucas, who has sacrificed more for her career than he'll ever acknowledge. He moved to Iowa as her boyfriend but leaves now as her husband and the father of their daughters, Mary & Ruth.



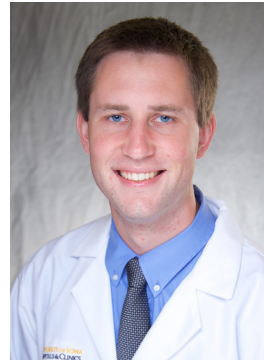
Elizabeth Scott, MD

Liz was born in Durham, North Carolina, a product of her nurse anesthetist mother and OB-Gyn father who met in the OR at Duke University. Like two of her four older brothers she too had an early interest in medicine, although she enjoyed dance, gymnastics, and horseback riding far more than algebra. As an avid reader and science fiction lover, early on in life she hoped to grow up to be like Dr. Leonard McCoy (Star

Trek) or Dr. James Herriot (British veterinary surgeon), eventually settling on surgeon since her Dad claimed they ‘wore pajamas to work’ (aka scrubs).

After moving to Boca Raton, FL, she graduated in 2008 from Saint Andrew’s School, subsequently returning to North Carolina to attend Duke University where she majored in medieval and renaissance studies while also enjoying classes in nutrition, anatomy and dance. She competed with and later taught at the Inis Cairde School of Irish Dance in Raleigh, NC, where she began encountering more and more young children and teenagers with chronic and acute musculoskeletal conditions. Continuing at Duke for medical school offered her the opportunity to continue her passion for dance and begin exploring a career in orthopedic surgery; during her research year she worked with Dr. Will Eward developing a novel mouse model for osteosarcoma and evaluating outcomes following treatment of metastatic bone disease. She was also profoundly impacted as Feagin Leadership Scholar learning from Dr. John Feagin and other prominent figures in the field of sports medicine about leadership, quality improvement, and the importance of team culture in creating meaningful and lasting changes in healthcare.

Having spent little time in the Midwest but looking to expand her horizons, in 2016 Liz came to Iowa City and immediately fell in love with the warmth of the people, the focus on resident education, and the research acumen at Iowa. Although the 18 months after matching were unexpectedly among the toughest in her life (she underwent three hip surgeries while balancing the transition to residency and first year as an intern) in retrospect she is quick to say that this experience is what ultimately propelled her towards a career in hip preservation while also developing her perspective as a surgeon who has been a patient. Her research has focused on long-term outcomes of treatment of developmental dysplasia of the hip, developing physical performance measures for use in adolescent and young adult hip dysplasia treatment, and improvement of the perioperative experience after hip arthroscopy with a text-message based cellphone communication system. She is excited to move next year to Boston, MA for two fellowships at Boston Children’s Hospital, first in Sports Medicine and then Hip Preservation. She is extraordinarily grateful for the support of her parents, her siblings, her friends, and her colleagues both old and new who have helped her through the ups and downs of the last five years. She is humbled by and grateful to the numerous mentors within the Iowa Department of Orthopedics who continually inspire her to create big goals, explore new ideas, and never settle for less than the best one has to offer.



John Yanik, MD

John was born in Asheville, North Carolina. He is the youngest son of Joe and Shelli Yanik, and he has one older brother, Mark. His interests growing up included soccer, basketball, frisbee, scuba diving and working on cars. He was an Eagle Scout and high school valedictorian.

John attended North Carolina State University where he majored in biomedical engineering with

an emphasis in biomechanics. He graduated summa cum laude and valedictorian with a Bachelor of Science in 2012. He was then accepted to Wake Forest University School of Medicine where he earned his medical degree in 2016. As a third-year medical student, he completed an away rotation in the Department of Orthopedics and Rehabilitation at the University of Iowa. He considers himself incredibly fortunate to have matched here.

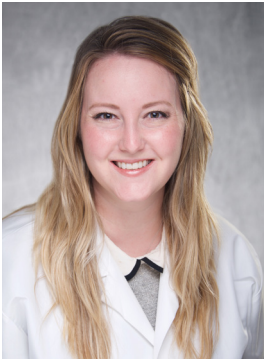
While in college, John met his wife Ellen Anne. They married in the fall of 2014. Their first child, Holden Albert Yanik, was born in John’s fourth year of residency on April 25, 2020.

John’s prior research interests include biomechanical studies investigating fracture repair techniques, engineering of cell growth substrates, outcomes after total joint arthroplasty, and bio design. In residency, he has primarily focused his research on the opioid crisis, the culmination of which has been a randomized controlled trial investigating the effect of a refill-based prescription method on narcotic distribution and consumption.

After graduation, John will continue his training with a fellowship in hand and upper extremity surgery at Vanderbilt University Medical Center in Nashville, Tennessee. His plan is to establish a complex hand and upper extremity practice, and to seek ways to give back to others through volunteer work both nationally and internationally.

John would like to thank all of those who have helped him along the journey: His mentors and teachers, for their constant guidance, endless patience, and generous donation of time and resources; His family, for molding him into the person that he is today; His friends and coresidents, for their never-ending ability to find laughter and enjoyment in life; And finally his wife, for her unwavering faith, steadfast love, and continuous support through it all.

2021 GRADUATING FELLOWS

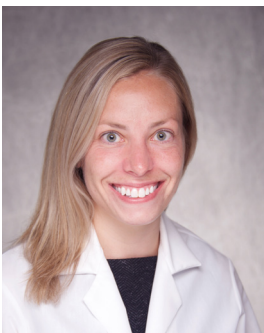


Madelyn Lauer, MD

Maddy is the current hand surgery fellow. Originally from the Twin Cities, she studied biology and played volleyball at Carleton College before attending medical school at the University of Minnesota. She and her husband couples' matched in Kansas City where they welcomed their daughter and became barbeque aficionados. After completing

her orthopedic training at the University of Missouri-Kansas City, she was excited and honored to join the hand team at the University of Iowa for a year of dedicated upper extremity experience.

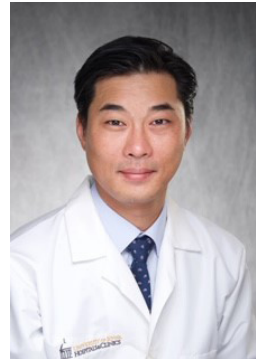
Following the completion of her training, Maddy and her family will head back to the northern tundra of Minnesota where she will join a private practice. She is grateful to each of the hand faculty for their support in both her professional and personal development throughout the year.



Meaghan Tranovich, MD

Meaghan Tranovich is the current orthopedic sports medicine fellow. She was born and raised in Pittsburgh, Pennsylvania before moving to Columbus to pursue her B.S. in biology and French at Ohio State University. She then completed medical school at Marshall University and her

orthopedic surgery residency at the University of Toledo. She is extremely grateful for her time in Iowa and the mentorship she has received from Drs. Wolf, Bollier, Westermann, and Duchman.



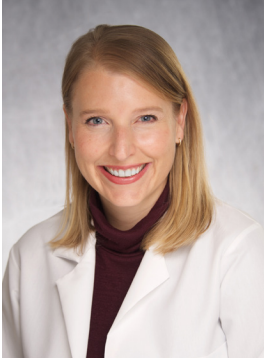
Hee Jong Lee (John), MD

Dr. Hee Young Lee (John) is the current fellow in foot and ankle surgery. He was born and raised in Seoul, South Korea. He earned his undergraduate degree and MD in Yonsei University in Seoul graduating in 2006, and then finished his residency in orthopaedic surgery also at Yonsei university, Severance Hospital in

2011. After three years of military service as a captain, He completed his first fellowship in Shoulder and Elbow Service at Seoul National University and started his practice. He finally decided to pursue further academic training in the US and successfully graduated from Sports Medicine Fellowship at University of Missouri and joined foot and ankle team in Iowa as an fellow. He is going to Baltimore for another foot and ankle fellowship at Medstar Union Memorial Hospital after graduation.

John is deeply grateful to all his mentors Drs. Femino and Cesar at the University of Iowa who have helped set his foundation as an foot and ankle specialist and feels happy that he has found life time mentorship here in Iowa. He also would like to thank his research co-fellows who helped him with a lot of meaningful research projects and shared enjoyable time with him together.

NEW ORTHOPEDIC FACULTY



***Kathleen Vonderhaar,
MD***

Dr. Kathleen Vonderhaar is a Physiatrist who joined the Department of Orthopedics and Rehabilitation in the fall of 2020. She is a graduate of the University of Iowa, Carver College of Medicine. She completed her Physical Medicine and Rehabilitation residency at the University of Minnesota followed by a

Pediatric Rehabilitation Medicine fellowship at Gillette Children's Specialty Healthcare in St. Paul, MN. She is looking forward to building a Pediatric Rehabilitation Medicine practice at UIHC. She lives in Iowa City with her husband Kevin and daughter Greta.

The 2021 Michael Bonfiglio Award for Student Research in Orthopaedic Surgery

The 2021 Iowa Orthopaedic Society Medical Student Research Award for Musculoskeletal Research



Mary Kate Skalitzky, M4
Michael Bonfiglio Recipient



Mustafa Hashim, M2
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 on the basis of originality and scientific merit. The winner presents their work at the spring meeting of the Iowa Orthopaedic Society as well as at a conference in the Department of Orthopedics and Rehabilitation.

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

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

This year the selection committee consisted of Drs. Charles R. Clark, Joseph Buckwalter, Heather Kowalski. They recommended that Mary Kate Skalitzky, M4, receive the 2021 Michael Bonfiglio Student Research Award. Mary Kate's award was based on her project, "Impact of Iowa Legislation Change on Firework Injuries Prevalence and Severity." Her advisor was Dr. Joseph Buckwalter V.

The selection committee recommended that the Iowa Orthopaedic Society Medical Student Research Award be given to Mustafa Hashim, M2, for his research titled "Novel Scoring Criteria for Preoperative Prediction of Neoadjuvant Chemotherapy Response in Osteosarcoma." His advisor was Dr. Benjamin Miller.

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

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

ORTHOPEDIC SURGERY RESIDENCY APPLICATION PROCESS IN 2020 – HAS DIVERSITY BEEN AFFECTED?

Lindsey S. Caldwell, MD¹; Ericka A. Lawler, MD¹

ABSTRACT

Background: Orthopedic surgery is currently the least diverse field in medicine. COVID-19 necessitated a virtual rotation and interview process for orthopedic residency applications in 2020. Given the pressing need to address disparities within the field, any change in the application process should be examined with regard to the potential effects it could have on the diversity of trainees in orthopedic surgery. The purpose of this study was to evaluate the effect of virtual rotations and interviews on the demographic distribution of applicants to orthopedic surgery residency.

Methods: A retrospective review of orthopedic surgery residency applicants was performed comparing the 2018 and 2020 application cycle. Self-reported ethnicity on Electronic Residency Application Service (ERAS) forms was recorded for all applicants who met prescreening criteria, were invited to interview and who completed interviews. The proportion of underrepresented minority (URM) applicants was compared between these two cohorts.

Results: There were no significant differences between the 2018 and 2020 application cohorts in terms of number or proportion of URM applicants that met initial screening criteria ($p=0.7598$), female applicants that met initial screening criteria ($p=0.3106$), URM applicants who were invited to interview ($p=0.6647$), or female applicants who were invited to interview ($p=0.63$). Overall, applicants in the 2018 cycle were 2.38 times more likely to be invited to interview (OR 2.38, 95% CI 1.6886-3.3623, $p<0.0001$) and applicants who were invited to interview were 20.96 times more likely to interview in the 2020 cycle than in the 2018 cycle (OR 20.96, 95% CI 4.89-90.09, $p<0.0001$).

Conclusion: The proportion of URMs applying to orthopedic surgery residency was not significantly different after transitioning to a virtual rotation and interview platform at the single institution studied. Applicants were 2.38 times more likely to be invited to interview in 2018 and were 20.96 times more likely to attend the interview in 2020.

Level of Evidence: III

Keywords: virtual interviews, virtual rotations, diversity in orthopedic surgery

INTRODUCTION

The COVID-19 pandemic has affected the medical field in a myriad of ways. Programs and applicants have been forced to re-evaluate and adapt their application processes to comply with restrictions on travel and exposure. The result was a year of virtual rotations and virtual interviews that was fundamentally different than in previous years.

Visiting rotations, in which a medical student spends time in their chosen field at institutions not affiliated with their home educational program, have historically been considered an essential part of the orthopedic surgery residency application process. Performance during visiting rotations is consistently listed as an important factor in resident selection in orthopedic surgery.^{1,4} A survey study published in 2016 found 98.8% of orthopedic surgery applicants participated in visiting rotations and 56% of those applicants matched at either their home program or one where they had rotated.³ A similar study found that applicants were 1.5 times more likely to match at a program where they had rotated compared to one where they had not.¹ In a competitive surgical specialty where the did-not-match rate is 19%, visiting rotations are viewed as an extended interview opportunity that can substantially increase your likelihood of gaining a coveted residency position.⁴

Similarly, participation in on-site interviews has historically been necessary to match in orthopedic surgery. Programs typically only rank applicants they have interviewed, and evaluations of the interviewee by faculty and residents are important factors in determining ranking order of applicants.⁵ Prior to the COVID-19 pandemic, the interview season required taking time away from educational and clinical responsibilities, traveling to

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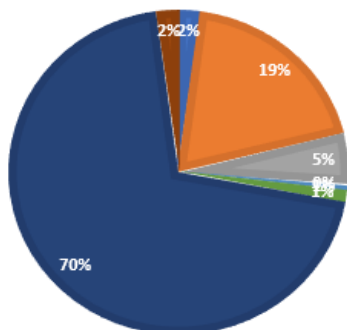
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Disclosures: The authors report no potential conflicts of interest related to this study.

Sources of Funding: No sources of funding declared.

2018 SCREENED APPLICANTS

■ African-American ■ Female ■ Hispanic ■ Hawaiian/PI
 ■ American Indian ■ Other ■ non-URM ■ Unknown



2020 SCREENED APPLICANTS

■ African-American ■ Female ■ Hispanic ■ Hawaiian/PI
 ■ American Indian ■ Other ■ non-URM

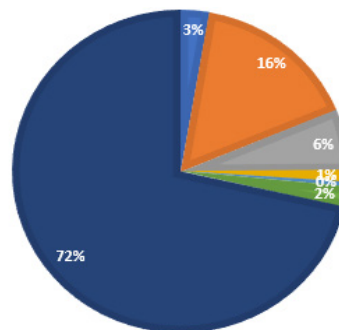


Figure 1. Pie chart representation of the demographics of screened applicants for 2018 and 2020. There was no significant difference between the 2018 and 2020 application cohorts in terms of number or proportion of URM applicants ($p=0.7598$) or female applicants ($p=0.3106$) that met initial screening criteria.

the program site and participating in a one to two-day series of activities allowing the program to evaluate the applicant and vice-versa.

The cost of residency applications, visiting rotations and in-person interviews is substantial. A 2016 study found that the mean cost to the applicant was \$5,500 but with a large range – including approximately 8% of applicants spending twice that amount or more.¹ This cost has likely increased since the publication of the Camp et al. study, as their applicants applied to an average of 71 programs and attended 11 interviews. In 2019, the average successful applicant submitted 84 applications and interviewed at 13 programs.⁶ This applicant would additionally have participated in at least one visiting rotation, and likely two or three.³

Orthopedic surgery remains the least diverse specialty with respect to both female and minority representation.⁸ While many efforts are underway to increase diversity within the field, the pace of change has not matched that achieved in other specialties.⁷⁻⁸ An increasing body of literature addresses the role of the residency application process in promoting diversity.⁹⁻¹¹ Given the pressing need to address these disparities, any change in the application process should be examined with regard to the potential effects it could have on the diversity of trainees in orthopedic surgery.

The purpose of this study is to evaluate the impact of virtual rotations and virtual interviews on the demographics of applicants to an orthopedic residency program. Virtual rotations and virtual interviews decrease the cost of the application process but also decreases the degree of familiarity an applicant can have with a program they have never physically visited. It is unclear how this year of virtual recruitment affects the decisions of applicants on where to apply, interview and ultimately match.

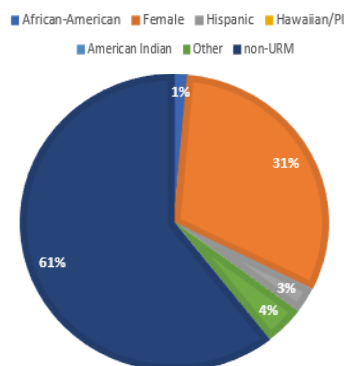
METHODS

We compared applicants from the 2018 application cycle to applicants from the 2020 application cycle to gauge what effect our “new normal” has had on the demographic distribution of applicants to orthopedic surgery residency. Applications were reviewed in a retrospective manner after interviews were completed for the respective application cohorts.

Electronic Residency Application Service (ERAS) applications for orthopedic surgery received by our institution are pre-screened for USMLE Step 1 criteria. Applications that 1) met minimum USMLE requirements, 2) are from medical students at our institution and 3) are from medical students that rotated at our institution, are further considered. Qualifying applications are forwarded to the Residency Applicant Review Committee where each application is scored independently by a group of 3-4 faculty reviewers and a composite score is assigned. In a typical interview season, the candidates with the top 10-15% of scores are then invited to interview. For the 2018-2019 application season, visiting rotations and interviews were completed in-person. For the 2020-2021 application season, rotations and interviews were completed virtually.

The applications that met the pre-screening criteria from 2018 and 2020 were included in this study. Each cohort was retrospectively reviewed for the applicant’s self-selected gender and race/ethnic group on their ERAS form. Those that selected female gender and/or race other than white/European/Asian were considered an underrepresented minority (URM) within orthopedic surgery, similar to previous studies.⁹ The proportion of URM applicants that 1) met pre-screening criteria, 2) completed a virtual rotation, 3) were invited to interview

2018 SCREENED APPLICANTS



2020 SCREENED APPLICANTS

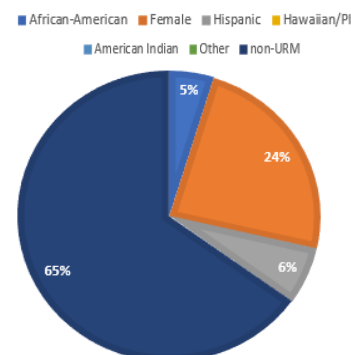


Figure 2. Pie chart representation of the demographics of interviewed applicants for 2018 and 2020. There was no significant difference between the 2018 and 2020 interview cohorts in terms of number or proportion of URM applicants ($p=0.6647$) or female applicants ($p=0.63$).

and 4) completed an interview was compared using Chi-square analysis. All data analysis was completed by SAS 9.4 with statistical significance set at $p<0.05$.

RESULTS

A similar number of applications met criteria for screening in both 2018 (420) and 2020 (433). In 2018, 113 (26.9%) of these applicants met URM criteria, 9 (2.14%) had unknown URM status and 298 (70.9%) were non-URM. A similar distribution was seen in 2020 with 117 (27%) URM and 316 (73%) non-URM. Visiting rotations in 2018 were completed by 22 students, 3 (13.6%) of whom were URM. Virtual rotations in 2020 were completed by 20 students, 6 (30%) of whom were URM. (Figure 1)

In 2018, 118 (28.1%) applicants were invited to interview. Of those, 41 (34.7%) were URM, 5 (4.23%) had unknown URM status and 72 (61%) were non-URM. A total of 69 (16.4% of screened applicants) completed interviews, with 23 (33.3%) URM, 3 (4.35%) unknown and 43 (62.3%) non-URM. In 2020, 61 (14.1% of screened applicants) were invited to interview, and all but two (59 out of 61, 96.7%) completed their virtual interviews. Among those who interviewed, 18 (30.5%) were URM and 41 (69.5%) were non-URM. Both of the applicants who cancelled their interviews were in the URM group. (Figure 2)

There were no significant differences between the 2018 and 2020 application cohorts in terms of number or proportion of URM applicants that met initial screening criteria ($p=0.7598$), female applicants that met initial screening criteria ($p=0.3106$), URM applicants who were invited to interview ($p=0.6647$), or female applicants who were invited to interview ($p=0.63$). Overall, applicants in the 2018 cycle were 2.38 times more likely to be invited to interview (OR 2.38, 95% CI 1.6886-3.3623, $p<0.0001$) and applicants who were invited to interview were 20.96 times more likely to interview in the 2020 cycle than in the 2018 cycle (OR 20.96, 95% CI 4.89-90.09, $p<0.0001$).

DISCUSSION

The 2020 Orthopedic residency selection process differs greatly from previous years due to the COVID-19 pandemic. Despite changes to the visiting rotation and interview process during the 2020 orthopedic surgery residency application cycle, the number and proportion of URM students who applied to our institution and were interviewed remained similar. While twice as many URM applicants completed virtual rotations in 2020 (6 applicants) than completed visiting rotations in 2018 (3 applicants), the small “n” makes this difficult to interpret statistically.

Applicants to our program in the 2018 on-site interview season were 2.38 times more likely to be invited to interview than those applying in 2020. In a typical year of on-site interviews, a set number of interview slots are offered to medical students. Medical students then select which interview offers to accept. Considerations that affect this choice can include location, expense and time away from their home programs. Oftentimes interview dates will conflict, further necessitating a choice by the applicant. If an interview is declined, this opportunity is offered to another student. In 2018, 118 applicants were invited to fill 69 interview slots.

In 2020, the virtual interview process provided applicants with an opportunity to interview without concerns of expense or time away from their home institution. The elimination of travel time, social events and academic programming substantially decreased the overall amount of time necessary to interview at a single program. Applicants could easily interview at one program one day and another the next – or even the same day – even if the programs were physically thousands of miles away from each other. Thus, conflicting interview dates were less likely to be an issue. This is evidenced by the 2020 applicants being 20.96 times more likely to attend their interview than their 2018 counterparts. In fact, all but two of those invited to interview in 2020 completed their

interview, which is in stark contrast to the 49 invited applicants who did not complete their interviews in 2018.

The virtual interviewees being 20.96 times more likely to attend their interview has potentially significant downstream effects. It substantially decreases the number of applicants who received an interview invitation compared to previous years and has an unknown effect on the subsequent match process. If other institutions experienced a similar interview attendance rate it could suggest that the same subset of applicants are being interviewed by a large proportion of programs. This could result in a higher non-match rate for the applicants outside of that subset as well as institutions going substantially further down their rank list in filling their residency positions. This study did not evaluate rank lists or match characteristics and further research is needed to determine the prevalence and effect of increased virtual interview attendance relative to previous years.

Ultimately, there was no significant difference in the proportion of URM applicants who were invited and who interviewed in 2018 vs. 2020. In both years studied a higher proportion of interviewees were URM (33.3% in 2018 and 30.5% in 2020) than screened applicants (26.9% in 2018 and 27% in 2020) suggesting that URM applicants were invited to interview at a higher rate than non-URM applicants.

This study has several limitations. First, this study evaluates data from a single institution which may have different advantages or disadvantages than other institutions in recruiting a diverse applicant pool. For example, our program is located in a state that is 90% white.¹² Additionally, our department has a diversity committee and an overall institutional commitment to increasing diversity within orthopedic surgery. This study does not look at the role these factors play in recruitment. Second, this study relies on self-identification of URM status. Third, the study is retrospective in nature. Fourth, as detailed above, the data collected in this study does not include rank lists and cannot comment on the match outcomes of this application cycle.

Overall, these data suggest that the transition to virtual rotations and interviews had no major effect on the proportion of URM applicants who applied, were invited to interview and who completed the interview process at our institution. While it is encouraging that the transition to virtual rotations and interviews does not appear to present a barrier to diverse applicants, it does not appear to effectively promote diversity either. Further research is needed to elucidate effective means to improve diversity within orthopedic surgery.

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IDENTIFYING BARRIERS: CURRENT BREASTFEEDING POLICY IN ORTHOPEDIC SURGERY RESIDENCY

Malynda Wynn, MD¹; Lindsey Caldwell, MD¹; Heather Kowalski, MD¹; Ericka Lawler, MD¹

ABSTRACT

Background: Family planning is a challenge for physicians at all stages of their careers but can be particularly difficult during residency. As the field of orthopedic surgery strives to increase diversity and recruit exceptional female candidates, barriers to entry should be identified. For many women, successful family planning including pregnancy, breast-feeding, and childcare, presents a daunting endeavor during residency training and a difficult topic to broach with superiors when planning future careers. Prospective residents often look to websites to obtain information regarding potential residency programs. We sought to identify current breast-feeding policies available at orthopedic residency programs via a thorough review of individual programs websites.

Methods: Residency program websites from 178 ACGME-accredited orthopedic surgery residencies were reviewed to determine currently available departmental lactation policies and facilities. Region and number of female staff and residents were recorded and organized into a central database. Descriptive analyses to determine programs with available resources was performed. Logistic regression to determine association between region and number of programs written policy available was also performed.

Results: 178 ACGME-accredited orthopedic surgery programs were reviewed. Five (2.8%) programs were found to have written breastfeeding policies available on the orthopedic surgery residency website. Thirty-six (20%) programs provided links to institutional GME websites which gave written lactation policies. Dedicated lactation facilities were mentioned for 3 (1.7%) programs. The average number of female attendings per program

was two (range 0-19), and the average number of female residents per program was three (range 0-14). The odds of a program having a written breastfeeding policy increased along with an increasing number of female attendings, OR 1.1 (CI 1.03-1.24, p=0.01). Programs in the Southwest region of the U.S. were found to have a higher association with presence of a written breastfeeding policy, OR 3.7 (CI 1.01-13.4, p=0.04).

Conclusion: Scarce information is available to prospective orthopedic surgery residents regarding breast-feeding policies and available lactation facilities. Only 2.8% of current programs have website information discussing breastfeeding support. Ensuring available breastfeeding support for female orthopedic surgeon trainees and the transparency of these policies by orthopedic departments could contribute to an improved perception of childbearing during residency.

Level of Evidence: IV

Keywords: breastfeeding, lactation policy, barriers in orthopedic residency

INTRODUCTION

Family planning is a challenge for physicians at all stages of their careers, but particularly difficult during residency. Residency commonly occurs during prime childbearing years and is associated with long work hours and inflexible schedules. Furthermore, after childbirth, if mothers decide to breastfeed, inflexible surgical subspecialties prevent new mothers from finding regular time to express milk.^{1,2} The Accreditation Council for Graduate Medical Education (ACGME) offers recommendations for residency programs to “facilitate access to childcare and lactation facilities,” however no specific program guidelines exist regarding availability of lactation areas or expectations of faculty regarding breastfeeding during the workday.³

In a recent article investigating perceptions of current surgical residents toward parental leave and pregnancy during residency, 92% of female residents had “concerns related to breastfeeding.”¹ In specialty-specific literature, general surgery residents have reported barriers to breastfeeding including “being too busy, not having a

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

Sources of Funding: No sources of funding declared.

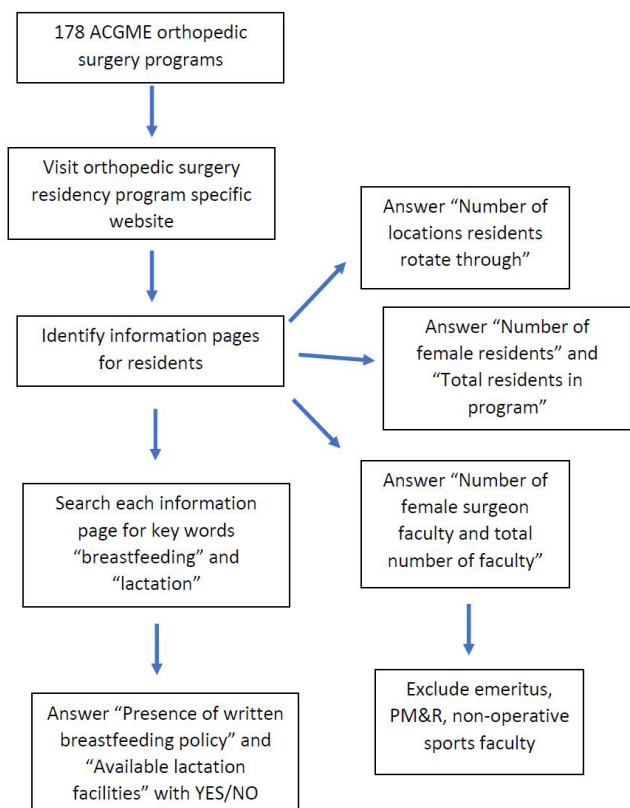


Figure 1. Method of collecting information from individual program websites.

place to pump milk, and feeling unsupported by attending surgeons and resident colleagues.”² Despite these challenges and a desire to recruit women into surgical fields, little has been done to improve resources available for female resident trainees choosing to breastfeed.^{3,4}

Orthopedic surgery is a specialty that is striving to encourage diversity and inclusion of women in a predominantly male dominated field.^{5,6} Orthopedic surgery has the lowest recruitment of women in all surgical fields and remains the medical specialty with the lowest proportion of female residents (14%).⁷ Further, the National Resident Matching Program Match Communication Code of Conduct prohibits interviewers from addressing gender, marital status, and intent to bear children, so the burden of introducing such topics falls on the interviewees.^{8,9} These topics can be difficult to discuss with potential employers, especially when weighed against the pressure to obtain a competitive position through the Match. With the perception that asking about childbearing and breastfeeding may potentially damage their application, female residents often leave interviews with incomplete information and lingering questions.

Unfortunately, secondary information resources such as residency program websites lack information regarding important topics such as breastfeeding poli-

cies and availability of lactation facilities. The availability of resources for female residents in orthopedic surgery choosing to breastfeed has not been investigated in current literature. We sought to identify current breast-feeding policies available at orthopedic residency programs via a thorough review of individual program websites.

METHODS

From November 2020 through January 2021, the authors reviewed breastfeeding policies for 189 (ACGME) accredited orthopedic residency programs. Programs were excluded if they did not have an available website for review or if the website did not have dedicated information related to the orthopedic surgery residency program. This resulted in a total of 178 programs for review. Orthopedic residency websites were searched for 1) written breastfeeding policy on dedicated orthopedic residency website, 2) link to institutional GME website which discussed lactation policy, 3) information on lactation facility availability, 4) number of locations residents rotate through, 5) number of female residents in the program, 6) total number of residents in the program, 7) number of female surgeon faculty, and 8) total number of faculty.

To answer these questions, all pages contained within the orthopedic surgery residency website for prospective residents were evaluated. Key words searched on orthopedic surgery residency websites qualifying web pages included “lactation” and “breastfeeding” with subsequent related links visited and evaluated for policy related to available lactation facilities or breastfeeding (Figure 1). Institutional websites (including institutional ACGME office websites) were not evaluated or searched unless specifically linked to by the orthopedic surgery residency website. Additionally, exhaustive searches of institutional resources or other departmental policies, word of mouth, and sources other than program websites were not used in completing data collection. We hypothesized that program applicants would not have the time or ability to do an in-depth search of these types of resources for each program

Data were collected and organized into a central database. The median and range of female attendings and residents per program as well as the number and percentage of programs with breastfeeding policies and lactation facilities were determined. The relationships between odds of having a breastfeeding policy and number of female attendings, number of female residents and U.S. region were evaluated using logistic regression. Analyses were completed using SAS statistical software version 9.4 (SAS Institute, Inc, Cary, NC).

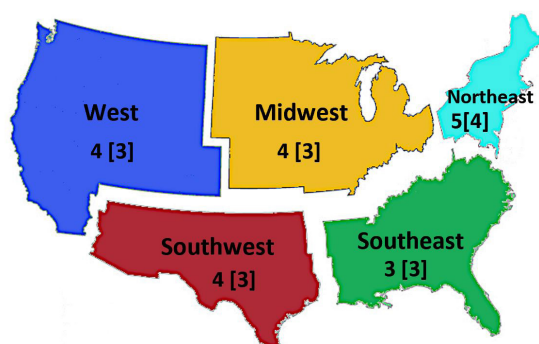


Figure 2. Average number of female residents and [female attendings] per region of U.S.

RESULTS

A total of 178 ACGME-accredited programs were reviewed. Only 5 (2.8%) programs were found to have written breastfeeding policies available for review on the orthopedic surgery residency specific website. Links to GME websites, which gave written lactation policies, were available for 36 (20%) programs. Dedicated lactation facilities were only listed as available for 3 (1.7%) programs. Average number of female attendings per program was 2 (range 0-19), and average number of female residents per program was 3 (range 0-14) (Figure 2).

The odds of a program having a written breastfeeding policy was found to increase along with an increasing number of female attendings, OR 1.1 (CI 1.03-1.24, $p=0.01$). There was not a statistically significant association between having a written breastfeeding policy and increasing number of female residents ($p=0.09$). Programs in the Southwest region of the U.S. were more likely to have a link to their institutions GME website, OR 3.7 (CI 1.01-13.4, $p=0.04$) (Table 1).

DISCUSSION

The American Academy of Orthopedic Surgeons (AAOS) has made recruiting underrepresented minorities and women into the field of orthopedics a stated goal.^{5,7} Societies such as the Ruth Jackson Orthopedic Society, J. Robert Gladden Orthopedic Society, and pipeline programs such as the Perry Initiative are aimed at offering mentorship, recruiting diverse applicants, and celebrating diversity in the field.^{5,7} In a recent study investigating the representation of women in surgical subspecialties, it was found that to reach gender parity with the trainee population, orthopedic surgery will require 117 years.¹⁰ As we aim to increase the number of female candidates that are recruited to orthopedic residencies, questions regarding pregnancy, breastfeeding and parenthood need to be addressed. Despite the lag in recruitment behind other surgical subspecialties, there has been an increasing trend in the number of

Table 1. Association Between Region of Country and Chance of Direct Link to ACGME Breastfeeding Policy Identified

Region of U.S.	OR	95% Confidence Limits		p-value
Northeast	1.8	0.63	4.89	0.28
Midwest	ref			
Southeast	1.4	0.41	4.49	0.61
Southwest	3.7	1.02	13.38	0.047
West	1.5	0.43	5.44	0.51

female orthopedic residents in recent years.^{9,10} With this change come new questions and concerns surrounding the topics of pregnancy, parenthood, childcare, and breastfeeding during residency training. Secondary information sources such as residency program specific websites are underutilized in providing important policy information that may otherwise be uncomfortable to ask during an applicant interview. Our study demonstrated that only 2.8% of current ACGME-accredited websites have available breastfeeding policies on their websites.

Breastfeeding post-partum is well known to have significant health benefits to both the mother and baby.^{11,12} Mothers experience less postpartum blood loss, lower rates of post-partum depression, more rapid weight loss, as well as lower rates of diabetes, cardiovascular disease, breast and ovarian cancer.^{11,12} Infants experience decreased rates of hospitalization, infections, allergies, obesity and sudden infant death syndrome, as well as improved gastrointestinal health and neurodevelopment.^{11,12} The American Academy of Pediatrics recommends exclusive breastfeeding for 6 months, with continued breastfeeding complemented with additional foods for 12 months.^{11,12} Despite this recommendation, previous studies have demonstrated that there is a higher likelihood of earlier cessation of breastfeeding for female surgeons.^{11,13} In a survey to female surgeon trainees regarding the resident experience of childbearing during training, 200 out of 347 of respondents (58%) reported stopping breastfeeding earlier than they wished because of poor access to lactation facilities and challenges leaving the operating room to express milk.¹⁴ Further, 85.2% of respondents reported they were uncomfortable asking attending surgeons for permission to step away from an operation to express milk.¹⁴ Perception surrounding breastfeeding could be due to lack of written policy, guidelines, and expectations set by individual departments.

In a recent specialty specific questionnaire of 307 female plastic surgery trainees, 29.4% noted lactation facilities near the operating rooms. Further, only 61% of female trainees breastfed for 6 months, and 19.5% continued for 12 months. Only 12% of respondents reported

their program had a formal lactation policy.¹⁵ Our study demonstrated that only 2.8% of orthopedic surgery residency programs listed a department breastfeeding policy, while only 1.7% of programs demonstrated dedicated lactation facilities available for use. This is significantly lower than previously reported survey responses, however this could be explained by incomplete information on individual websites.

In addition to written policy and resource availability, resident advocates play a role in promoting discussion and combating stereotypes associated with family planning during a surgical residency. Increasing diversity within departments allows for a broader range of perspectives and experiences which can lead to an improved experience for residents. Our data showed that the odds of a program having written breastfeeding policies increases along with an increasing number of female attendings (OR 1.1). This could be a result of additional advocates within a department for female-specific family planning needs. Recruiting individuals with a broad range of experience and backgrounds can ensure residents have relatable and approachable mentors to discuss barriers such as family planning.

Various barriers to both childbearing and breastfeeding during residency can contribute to surgeon burnout, and ultimately result in overall job dissatisfaction.¹¹⁻¹⁵ Policies which allow regular breaks for nursing mothers and provide convenient lactation facilities equipped with resources such as refrigerators and computers for multitasking are essential to enable breastfeeding. Additionally, in order to avoid ambiguity, written department-wide expectations for both staff and residents can help avoid fear of judgment should a female trainee wish to breastfeed.

Limitations of this study include a narrow range of search for breastfeeding policy within a program which could lead to lack of identification of all relevant policies. We sought to identify easily accessible policies that an interested applicant would be able to identify within a program website. We attempted to decrease the subjective nature of answers by creating dichotomous answers regarding policy. Additionally, this study does not provide information on the effect of the presence or absence of a breastfeeding policy might have on applicants/residents or evaluate the adherence to a stated policy. Further dedicated research would be necessary to answer those questions.

CONCLUSION

Currently, scarce information regarding breastfeeding policies and lactation facilities is available to prospective orthopedic surgery residents. Recruiting additional women into the specialty of orthopedic surgery has been

an ongoing effort over time, with significant barriers to this goal surrounding family planning and commitment, including breastfeeding. Ensuring breastfeeding support for female orthopedic surgeon trainees could improve both trainee and child health, burnout rates, and the perception that childbearing during residency is too difficult to undertake. Written breastfeeding policies and expectations of orthopedic department faculty may help to ensure the comfort of a trainee pursuing their right to breastfeed post-partum.

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RESIST THE RISE OF IRRELEVANT OUTCOME MEASURES IN CLINICAL RESEARCH

Benjamin J. Miller, MD, MS¹

Length of stay is not an outcome. Consistently, I return to this thought while writing, reviewing, and reading manuscripts, revealing a trend that has become clear: the orthopaedic community is not talking about pathologic basis of disease anymore. The manuscripts that draw our attention today discuss issues of efficiency, cost, pain management, discharge location, and patient experience. It is a remarkable change from a generation ago, where reports were consistently centered on describing diagnostic techniques, new methods of treatment, and objective measures of outcome directly related to an underlying disease process.

The optimistic explanation, which is also logical and generally accurate, is that many of the most important historical problems in orthopaedics have been adequately addressed. Joint arthroplasty for osteoarthritis is the most accessible example, where indoctrinated procedures and reliable implants now provide improved quality-of-life and decades of durable outcome for hundreds of thousands of patients. There simply is not a need for novel reports describing the histologic appearance, radiographic characteristics, physical exam findings, or natural history of osteoarthritis. The paucity of residual big and unanswered questions leaves a vacuum being filled by motivated investigators with goals to contribute positively to our shared knowledge.

The most familiar historical outcomes are tangible and anchored – death, infection, revision. These are end results with purpose and power, but their prior relevance has dissipated as essentially all modern treatments are satisfactorily safe and effective viewed by traditional metrics. In short, proving that a treatment extends life, prevents infection, or lasts for an extended period of time is no longer adequate.

The essential challenge of modern clinical research is to define and report optimal outcome measures. This is an issue of critical importance and should motivate

investigators to consider and advocate for measures most relevant to patient care, or risk having outcomes assigned by non-clinical entities and not accurately reflective of appropriate treatment goals. The manner by which to complete this task is not easy or obvious, but needs to be motivated by the intent to record measures that quantify the success of an intervention in terms of function and quality-of-life, and presented in a way that is meaningful to the patients receiving treatment. Many of these types of assessments, in particular PROs (patient-reported outcomes), have become part of the healthcare lexicon to the extent that any reasonable investigation of clinical outcome will include some measure of direct patient response. This should be applauded, and these measures will become increasingly important to improve the quality of care, engage patients in medical research, and modify our healthcare system. However, vigilance is required to avoid having outcome measures of importance be supplanted by the less relevant data points of patient satisfaction, cost, and length of stay.

Patient satisfaction has unquestionably arrived and is not going anywhere. The various surveys and comparisons are ubiquitous to practitioners and administrators. While seemingly noble in intent, there is much to criticize. Queries intending to assess compassion, empathy, respect, communication, patient understanding, and involvement in the decision-making process are important reflections on the virtues of healthcare providers and can be meaningful in the correct context. However, there are substantial limitations in how these surveys should be used, and attempts to judge the effectiveness of an individual or healthcare system to eradicate disease by reporting “patient satisfaction” should provoke skepticism. Any facility-related issue (e.g. parking, food service, aesthetics) cannot be convincingly argued to correlate with the most important issues in medical care, such as accurate diagnoses, appropriate treatments, minimal complications, and optimal function. There also is a problematic perverse incentive to focus more intently on the perception of the patient’s experience rather than the medical goals of treatment. For example, if a patient is referred for consideration of a surgical procedure, insofar as their expectation is that they will receive it, and the consulting provider does not deem that intervention indicated, the patient may

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

Sources of Funding: No sources of funding declared.

leave the visit dissatisfied and complete a survey as such. Outwardly the appearance insinuates a negligent or incompetent provider, and theoretically manifests as an unwelcome suggestion that patient desires should be held in higher regard than medical appropriateness.

Cost of care is of critical importance in the modern US healthcare system, and should not be ignored. Healthcare is a limited resource, and the current level of spending, along with the consistent trends of increasing financial liability, are unsustainable and worrisome. The principal problem with exploring cost in clinical research is that there is no agreement on what it is, how to measure it, or where to find it. The first consideration is simply one of agreement in definitions. "Cost" should be understood to indicate the amount of currency required to provide a service or intervention; this is rarely available. As a surrogate, many investigations report "charges" (the bill an institution sends a patient or payer) or "reimbursement" (what is actually paid by insurance and patients). Neither charges nor reimbursement represents the true cost of care and are therefore of limited utility. The second issue is that neither of the two parties involved in medical decision-making (patient and provider) has a clear idea of the true or relative cost of an intervention. It's quite embarrassing to me that I would have no idea how to respond if a patient asked me how much a procedure would cost – I could easily be off by a factor of 10. Almost as concerning, there is no clear repository in which to find this information. This leaves a gap impeding any use of cost consciousness in medical decisions. Patients are not able to make financial-based decisions as there is not a reliable mechanism to compare hospitals or interventions in any meaningful way. This problem has to be sorted out by increasing transparency in pricing, making the information easily accessible, and creating measures to determine the true cost of medical care, not charges or reimbursement.

Finally, length of stay is often reported and implied to be representative of treatment outcomes. There are arguments to be made for length of stay as a surrogate measure to represent superiority in hospital efficiency, such as preoperative discharge planning, perioperative pain control, and appropriate setting of expectations in elective procedures. Less time in the hospital could lead to fewer hospital-related complications and reason supports that most patients would prefer to spend as little time in the hospital as possible. But we must resist the inertia pushing length of stay to become synonymous with high quality care. In its essence it has nothing to do with the important aspects of medical treatment or recovery. There is no connection to accurate diagnosis, intelligent surgical planning, masterful execution of treatment, or effective rehabilitation protocols. At best, this

is a general assessment of hospital discharge capability. At worst, it is a false idol that will incentivize surgeons and institutions to work toward a meaningless objective that has almost nothing to do with restoring health or alleviating suffering.

The priorities of clinical research are continuing to evolve and it is best not to resist these changes. Questions of quality and efficiency are important in modern healthcare, and for most practitioners and patients making an accurate diagnosis and effectively delivering interventions are more important than knowledge of the fundamental pathologic basis of disease. Clinicians and researchers must recognize that current and future outcomes will be more nuanced than in the past. If we do not continually advocate for outcome measures that truly represent success after medical treatment, with a focus on function and quality-of-life, we risk having less important measures mandated for use for reasons of administrative utility at the expense of clinical relevance.

SOCIAL MEDIA UTILIZATION TRENDS IN ORTHOPAEDIC SURGERY RESIDENCY PROGRAMS DURING THE COVID-19 PANDEMIC

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ABSTRACT

Background: The COVID-19 pandemic has changed the way orthopaedics programs are educating and recruiting residents and applicants. With an increased focus on online and virtual programming, there has been an uptick in social media usage by orthopaedics residencies as a means of communicating with applicants. This study investigated the growth in utilization of social media platforms by residency programs since the beginning of the COVID-19 pandemic.

Methods: Instagram and Twitter were queried for each orthopaedic surgery residency program. It was determined if each program with a corresponding social media account was created before or after March 1, 2020. The number of posts per month were tabulated for accounts that existed prior to March 1, 2020.

Results: 187 orthopaedic surgery residency programs were identified using the AAMC ERAS database. Of these programs, 74 (41.6%) were found to have an Instagram profile, and 50 (26.7%) were found to have a Twitter page. Of the 74 Instagram profiles, 45 were created after March 1, 2020, representing a 155% increase. Of the 50 Twitter pages, 15 were created after March 1, 2020, representing a 43% increase. Instagram accounts that were active before the pandemic had a 96% increase in the number of posts per month, on average, after March 1, 2020.

Conclusion: Over one-third of programs are utilizing social media for recruitment purposes. There has been an 155% increase in Instagram and 43% increase in Twitter usage by residency programs since March 1, 2020. Instagram accounts created prior to the pandemic also demonstrated a near

doubling of increased utilization after March. This represents a new, cost-effective way to connect with applicants in a time when in-person interactions are limited.

Level of Evidence: III

Keywords: residency recruitment, social media, covid-19

INTRODUCTION

Social media and networking platforms have been increasing in popularity amongst the medical community over the past decade. In the field of orthopaedic surgery, social media presence has become an increasingly popular tactic for marketing to patients and has been correlated with improved patient review scores.^{1,3}

The novel coronavirus (COVID-19) global pandemic has placed residency programs and applicants in uncharted territory. Programs rely on in-person audition rotations and interviews to both assess applicants and to market their program. Students similarly rely on these face-to-face encounters to gauge the overall culture and environment of the training program as well as to demonstrate their merit. On average, students applying to orthopaedics attend 2.4 away rotations and successful applicants attend 11.5 interviews.⁴ With the recommendation by the American Orthopaedic Association's (AOA) Council of Orthopaedic Residency Directors (CORD) to cancel the majority of in-person visiting rotations and interviews for the 2020-2021 application season, many residency programs have taken to social networking sites to connect with applicants.⁵

The purpose of this investigation is to evaluate the use of common social networking platforms by orthopaedic residency programs and determine the change in usage of these platforms since the beginning of the COVID-19 pandemic in the United States.

MATERIALS AND METHODS

The Association of American Medical College's (AAMC) Electronic Residency Application Service (ERAS) was used to identify all accredited orthopaedic surgery residency programs. Once identified, these programs were searched on the social media platforms Instagram (Instagram from Facebook; Menlo Park, CA) and Twitter (San Francisco, CA). We identified

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

Sources of Funding: No sources of funding declared.

Table 1. Programs Using Instagram and Twitter Pre-/Post-COVID

	Total # of programs	Instagram: Before COVID	Instagram: After COVID	Percent Increase	Twitter: Before COVID	Twitter: After COVID	Percent Increase
West	27	9 (33.3%)	15 (55.5%)	66.7%	4 (14.8%)	10 (37.0%)	150%
Midwest	52	4 (7.7%)	15 (28.8%)	275%	6 (11.5%)	7 (13.5%)	16.7%
Northeast	55	8 (14.5%)	20 (36.4%)	150%	11 (20%)	17 (30.1%)	54.5%
South	53	8 (15.1%)	14 (26.4%)	75%	14 (26.4%)	16 (30.2%)	14.3%
Total	187	29 (15.5%)	74 (39.6%)	155%	35 (18.7%)	50 (26.7%)	42.9%

Instagram and Twitter Utilization Pre- and Post- Covid (a summary).

accounts using all combinations of full and abbreviated program names and “ortho”. Accounts and posts were verified to belong to the residency program, and not to an individual. Accounts were excluded if there were no posts related to the residency program or graduate medical education. Additionally, the CORD AOA public residency spreadsheet and each program’s website were referenced to identify any pages that may have been missed. Once identified, it was determined whether the account was active prior to or after March 1, 2020 to identify which accounts were created to supplement the upcoming application cycle following the declaration of the coronavirus global pandemic in the United States. The number of monthly Instagram posts for accounts that existed prior to March 1st were tabulated as a means of determining increase in utilization of social media surrounding COVID-19.

For our data analysis, the programs were divided by region – West, Midwest, Northeast, and South – to determine if there were any regional differences in the utilization of social media platforms. Social media usage, regional counts and increase in monthly posts were analyzed using descriptive statistics by the authors.

RESULTS

187 orthopaedic surgery residency programs were identified using the AAMC ERAS database. Of these programs, 74 (41.6%) were found to have an Instagram profile, and 50 (26.7%) were found to have a Twitter page. Of the 74 Instagram profiles, 45 were created after March 1, 2020, representing a 155% increase. Of the 50 Twitter pages, 15 were created after March 1, 2020, representing a 43% increase (Figure 1).

Regionally, West coast programs were most likely to have both Instagram and Twitter pages, with 55.5% (15/27) and 37.0% (10/27) of programs having accounts on the two platforms, respectively. Southern programs were least likely to have an Instagram page, with 26.4% (14/53) of programs using the platform; Midwestern programs were the least likely to engage in Twitter, with 13.5% (7/52) of programs having a page. However, Midwestern programs did show the largest percent increase in Instagram use, with a 275% increase after March 1, 2020. Midwest and West coast programs responded with the largest growth in Twitter utilization, with a 67% increase after March 1 (Figure 2a and 2b). Regional social media usage is outlined in Table 1.

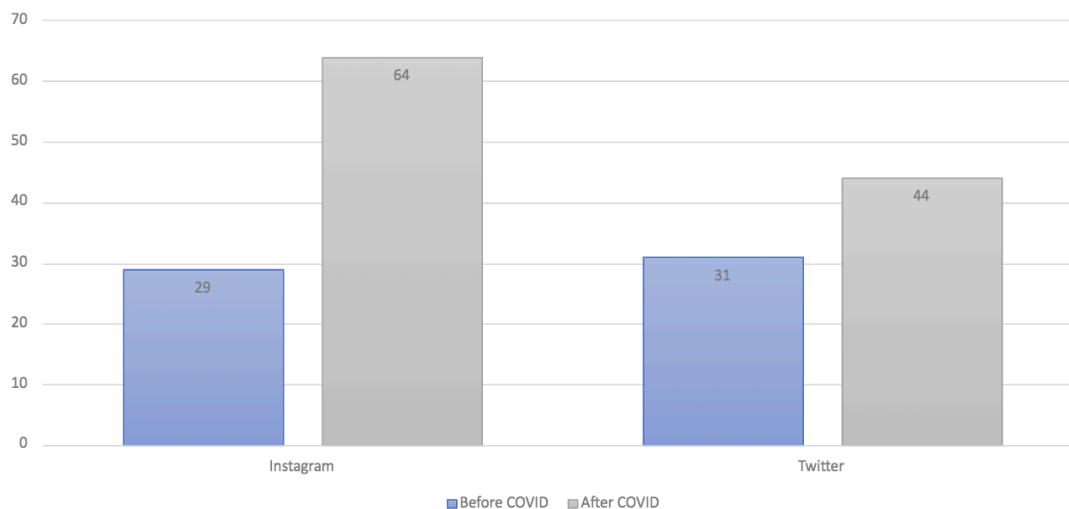


Figure 1. Orthopaedic Surgery Residency Programs Using Social Media. This figure demonstrates the overall number of programs utilizing the social media platforms Instagram and Twitter before and after the COVID-19 pandemic.

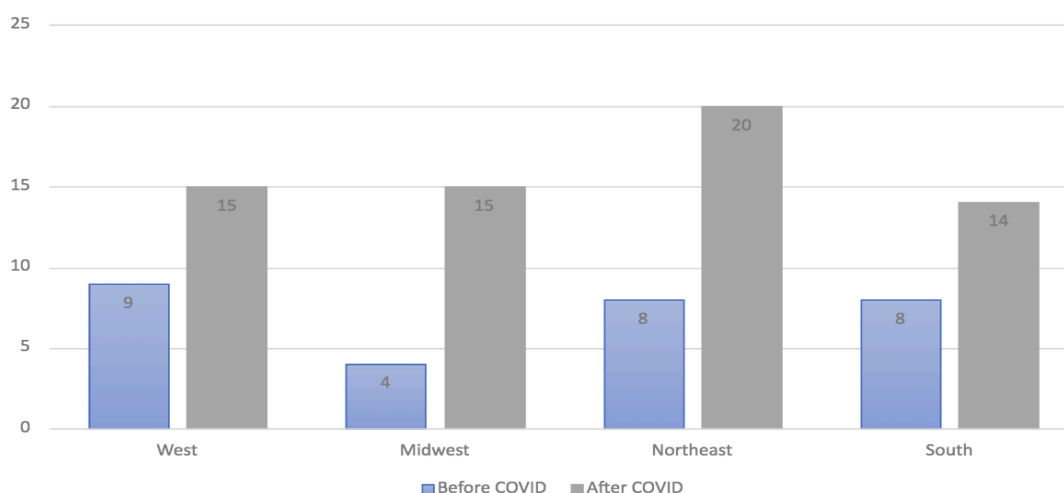


Figure 2a. Instagram Use by Region. Figure 2a focuses specifically on Instagram usage by program before and after COVID-19. The figure breaks down usage by region (West, Midwest, South, and Northeast).

Instagram was the most utilized platform for orthopedic surgery residency programs. It was determined that programs with an existing Instagram account (n=29) posted on average 3.76 times per month prior to the onset of the COVID pandemic in the United States. These same programs increased their frequency of posting to 7.36 times per month, on average, after the onset of the pandemic. This represents a 96% increase in frequency of posting on Instagram.

DISCUSSION

The purpose of this study was to investigate the increase in the utilization of social media platforms for the recruitment of orthopedic surgery applications and the promotion of residency programs. In a field in which away rotations are viewed as a necessity for both applicants and programs the coronavirus pandemic brought

on new challenges to how programs would advertise themselves and how applicants would learn about programs. Based on observation, social media seemed to be an excellent medium to fill this role. In this study, the authors sought to quantify this trend.

Virtual learning and conferences have become commonplace throughout the COVID pandemic and there has likewise been a drastic rise in free, accessible, online programming intended for residents and applicants.^{6,9} Similarly, graduate medical education recruitment efforts have transitioned online. While many programs have begun using social media in this capacity for the first time, the idea of promoting programs virtually is not new. A recent systematic review of the plastic surgery literature demonstrated an overall trend towards residency programs establishing a social media presence as a cost-effective opportunity to communicate with

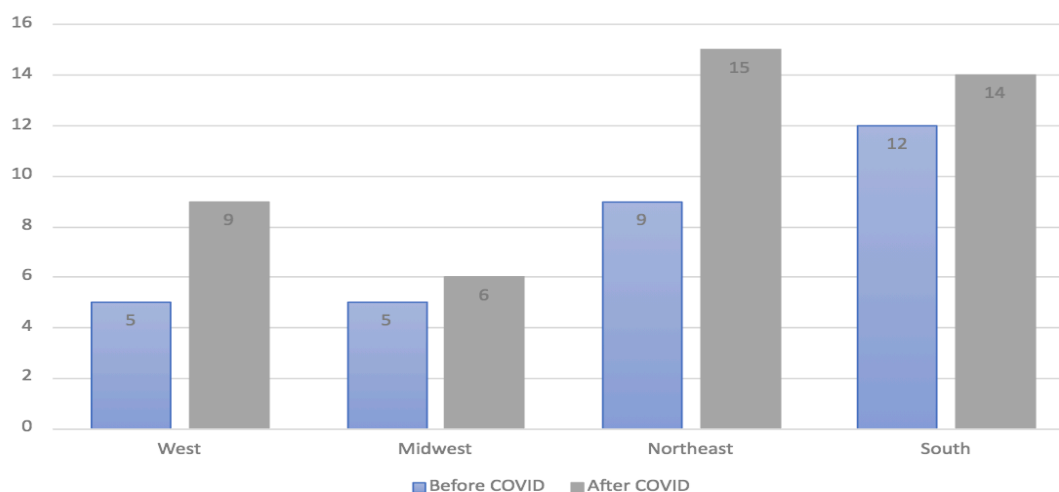


Figure 2b. Twitter Use by Region. Represents Twitter pages by region before and after COVID-19.

students.¹⁰ In 2018, 21% of plastic surgery programs were noted to have active Instagram accounts, and 30% of urology programs used Twitter in 2017.^{11,12} Applicants have also voiced placing an increasing importance on social media in the residency application process. A sample of radiology applicants reported that 85% of interviewees used social media platforms to learn more about individual programs.¹³ Similarly, in a survey of 992 medical students and trainees, 10% of respondents noted that a program's social media presence would influence their residency decisions.¹⁴

Applicants often rely on interviews and away rotations to gauge several important factors while evaluating programs. A survey of 742 orthopaedic applicants demonstrated that the most important factors when making a rank list included perceived happiness/quality of life, resident camaraderie, and impression following an audition rotation.¹⁵ Programs have been using social media in a variety of ways to engage applicants and answer these questions. Residency programs are using these platforms to spotlight the culture of their program by highlighting social events and overall resident and faculty camaraderie. Other programs have posted videos and pictures highlighting "a day in the life" of a resident. Many programs are hosting both anonymous and live question and answer sessions. Lastly, social media is being used to feature research and academic pursuits, including recent publications, presentations, and educational conferences. It was found that as programs became more active on social media accounts after the onset of COVID, a large number of their posts were dedicated to the recruitment activities listed above.

Several publications have recently demonstrated the high costs associated with application to an orthopaedic surgery residency program. As noted previously, students complete an average of 2.4 away rotations throughout the application process, with an average cost of \$2,799.¹⁶ A survey of 48 orthopaedic applicants estimated an overall cost of \$7,119 throughout the interview season. Seventy-two percent of respondents to one survey reported borrowing money in order to finance interviews. Similarly, 28% of applicants reported canceling interviews due to financial burdens.¹⁰ Social media is a free, readily available resource that programs and applicants can use to connect throughout the application season and may prove to decrease the financial burden on students.¹⁷

Limitations of this study include the pure observational nature of the study. No programs were contacted to identify their rationale for creating a social media page, so it can only be implied that this was intended to augment recruitment practices. Further, it remains to be determined whether this is an effective method of

communicating with applicants. This application cycle is an anomaly in terms of the exposure which applicants have to programs and vice versa. The authors encourage future studies to investigate the success of these newly utilized recruitment methods, including applicant perception and interaction with these platforms.

Our investigation revealed that over one-third of orthopaedic residency programs are utilizing social media platforms as a means of communicating with applicants. There has been a dramatic increase in use of these programs since the beginning of the COVID-19 pandemic and the announcement limiting in-person interviews and rotations for the 2020-2021 season. The most popular platform utilized by programs is Instagram, followed by Twitter. This suggests that programs are increasingly utilizing these platforms to reach applicants in novel ways. A substantial number of programs created new accounts during the 2020 application cycle, while those that had accounts prior to the COVID pandemic also demonstrated a meaningful increase in usage. Social media and online programming may prove to be a cost-effective way for applicants and programs to connect during the often cost-prohibitive application season. Further consideration into how applicants interact with these platforms can help programs maximize their virtual reach during the recruitment and application season.

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PREGNANCY AND PARENTAL LEAVE DURING ORTHOPAEDIC SURGERY RESIDENCY

Jocelyn Compton, MD¹; Christina J. Hajewski, MD²; Andrew J. Pugely, MD, MHCDS²

ABSTRACT

Background: Gender diversity in the field of orthopedic surgery has lagged behind other surgical subspecialties. One potential barrier to the recruitment and retention of female orthopedic surgeons lies in controversies surrounding pregnancy and parental leave during residency training, for which no clear guidelines exist. Trainees and residency programs face the challenge of balancing clinical and surgical competency with the health and well being of the mother and her child. This article addresses the current policies, health considerations, perceptions of parental leave and future recommendations regarding pregnancy and parental leave for orthopedic residents.

Level of Evidence: V

Keywords: pregnancy, diversity

INTRODUCTION

In spring 2019, the American Academy of Orthopaedic Surgeons (AAOS) introduced a five-year strategy to increase diversity within orthopedics, specifically citing gender disparities as a primary target for improvement. Although other surgical subspecialties, such as neurosurgery, vascular surgery, and thoracic surgery have seen an increasing proportion of female trainees, orthopedics continues to lag behind in the recruitment of women.¹ Identification and discussion of the unique challenges posed to female orthopedists may illuminate areas for institutional and cultural reform.

Although many factors influence diversity recruitment within orthopedics, pregnancy and the impact of parental leave during training are important considerations for female medical students. In a survey done in 2013, approximately 40% of residents planned to have children

during training after medical school.² Female medical students cite the challenge of maintaining work-life balance as a major deterrent from orthopedic surgery training.³ A study of general surgery residents showed that women who faced challenges surrounding childbearing during residency were more likely to advise female medical students against a surgical career.^{4,5} Furthermore, the nature of orthopedic residency and practice (for example, long work hours, physical nature of the work, and an unpredictable schedule) may pose a relatively larger barrier as compared with other surgical specialties to pregnancy and parenthood.⁶

The impact of pregnancy and parental leave during residency training has been a growing topic of national interest.^{5,7} Although there is a relative paucity of data regarding orthopedics within the published literature, survey data of general surgery and surgical subspecialties offer key insights into issues surrounding childbearing and rearing during training. Policy, health concerns, and the perceptions of parental leave are all important topics that characterize the training experience and future careers. Importantly, many of these issues are modifiable for the benefit of resident and faculty recruitment and retention. Within this review, we intend to create the first comprehensive guide for both orthopaedic trainees and faculty surrounding issues of pregnancy and parental leave.

Current Policy

Despite decades of dialog and changing demographics of medical students and trainees, parental leave policies across specialties and institutions often lack flexibility, transparency, and standardization.⁸ Parental leave requires the balance of competing interests: clinical competency of the trainee and the health and wellbeing of the parent and child.⁹ In addition to the impact on the individual, program directors across the country expressed concerns that extended leave placed additional work burden on other residents within their program.¹⁰ Recently, Worthington et al. cited the benefits of parental leave and urged the Accreditation Council for Graduate Medical Education (ACGME) and American Board of Medical Specialties to embrace sweeping reform, including eight weeks of paid leave for all residents without

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

Sources of Funding: No sources of funding declared.

Table 1. Maternity Leave Policies

Governing Body	Leave Policy
ABOS	At least 46 weeks of full time orthopaedic education per year; averaged over five years
ACGME	No unified policy; institution must provide written institutional policies that comply with applicable laws
US Dept of Labor (FMLA)	Unpaid, job protected leave for 12 weeks in a 12 month period
UIHC GME	6 weeks paid maternity leave for each pregnancy; maximum additional 4 weeks before or after delivery for medical related reasons associated with pregnancy. Parental leave: 5 working days per event of paid time off for a non-birth parent

Summary of maternity leave policies according to different governing bodies including the authors' institutional leave policy as an example. ABOS – American Board of Orthopedic Surgery; ACGME – American Council of Graduate Medical Education; FMLA – Family Medical Leave Act; UIHC – University of Iowa Hospitals and Clinics

training extension in order to reduce gender disparities and promote resident well-being.¹¹

Lack of a formal maternity leave policy has been associated with residents “consider[ing] leaving” the training program.^{4,5} Recently, a survey study of general surgery residents’ perception of parental leave highlighted a lack of awareness of parental leave policies: only 3.8% of respondents were able to correctly identify the current American Board of Surgery parental leave policy.¹² In 2018, the Journal of the American Medical Association specifically published specialty board leave policies for resident physicians.¹³ Despite the recent press regarding parental leave policies, fringe benefits and parental leave amongst orthopedic programs across the nation vary considerably. In one study from 2016, only 55% of orthopedic programs offered parental leave beyond vacation time.¹⁴ Although formal and informal policies exist at each institution, maternity, paternity and adoptive leave policies between institutions vary widely; additionally, over 60% of programs reported no utilization of leave by trainees.¹⁵

National governing bodies in the United States leave flexibility within programs with regards to parental leave (Table 1). Within orthopedic surgery residency, the ABOS requires 46 weeks of orthopedic education per year, on average over 5 years. Thus, six weeks per year may be utilized for leave. A recent survey of female orthopedic surgeons showed that the average amount of maternity leave taken while in residency was 6.3 weeks.¹⁶ Currently, the Family Medical Leave Act (FMLA) allows 12 weeks of leave, and thus many programs must rec-

oncile these conflicting policies. Formal parental leave policy for new mothers, fathers, and adoptive parents will likely gain traction as work-life balance and burn-out amongst resident physicians garners more attention. Lack of a formal, universal leave policy appears to be a major barrier for many residents to taking appropriate leave after the birth of a child.¹²

Health Considerations

Surgical residency training is often associated with exposure to unhealthy lifestyle habits such as lack of sleep, high levels of stress, poor diet, and lack of exercise. Childbearing under these conditions may pose health concerns for both mother and fetus. Orthopedic residents report an increased rate of preterm labor, preterm delivery, and overall complication rate related to pregnancy- at a rate between 26 and 31% which is well above the national average of 14.5%.^{6,17} The risks are multi-faceted, including difficulty with fertility before pregnancy, occupational hazards during pregnancy, and post-partum wellness. Within our program for example, in a span of 12 months, three female residents delivered children, two thirds of which were complicated by pre-term birth.

Many trainees delay starting a family during surgical training.¹ The average age of first pregnancy amongst women in orthopedics is around 33 years of age, which is similar to other surgical subspecialties.^{16,17,18} Almost a third of female surgeons report difficulty with fertility, resulting in increased utilization of fertility workup and services.¹⁸ Orthopedists reported the third-highest (second to otolaryngology and general surgery) rate of infertility amongst female surgeons.¹⁸

Women who work night shifts, rotating shifts, or more than 55 hours a week have been shown to have a higher risk for preterm labor,¹⁹ a statistic that has been corroborated amongst orthopedists working more than 60 hours per week during pregnancy.⁶ Amongst surgical residents, over 80% worked an unmodified surgical schedule up until birth, and yet over 60% were concerned that their work schedule adversely affected their health or the health of their child.⁵ Furthermore, upon return to work, over 50% of surgical residents reported cessation of breast feeding sooner than desired due to lack of lactation facility access and difficulty leaving the operating room to express milk.⁵

The standard 6-week parental leave policy common to many training programs for maternity leave has a variable influence on extension of training and eligibility to enter the board certification examination process. Duration and timing of parental leave is a common consideration for residents who plan to start a family during residency.²⁰ Evidence suggests that a longer duration of maternity leave may reduce not only maternal

complications (such as post-partum depression) but also promote breastfeeding, child vaccination, and reduce infant mortality rates.²¹

The duration of maternity leave also influences job satisfaction; greater than 8 weeks of leave has been associated with lower rates of burnout amongst female residents.²² Physician burnout has received considerable attention in both the lay press and academic literature. In 2017, a survey of general surgery residents showed challenges associated with childbearing during residency caused a significant number of women to consider leaving residency for a nonsurgical career and increased career dissatisfaction.^{4,5} A multicenter study of women across 25 unique specialties showed that 50% of mothers experienced burnout after childbirth.²³ Rates of burnout vary across surgical subspecialties, but orthopedic residents appear more at-risk than their attending-level counterparts, and it seems likely that female orthopedists are at higher risk than their male counterparts.²⁴ The American Orthopedic Association recognized burnout as a significant issue for young orthopedists, and called for the development of interventions and strategies to prevent burnout and career dissatisfaction.²⁵ Parental leave and considerations for the childbearing resident appear to be a prime target for institutional reform.

Perceptions of Parental Leave

Despite an increasing desire to attain work-life balance, significant stigma persists amongst training programs regarding parental leave. In addition to duty hour restrictions and work force limitations, there is also pressure to progress along a rigid training program that is rooted in time-based service rather than competency-based milestones.⁸ These factors cast extended time away from training in an inherently negative light.

Residents who take parental leave experience bias, not only from co-residents, but also from faculty within their departments.¹ Approximately one quarter of all trainees find arranging maternity or paternity leave difficult or very difficult, and a similar percentage of women did not feel supported by their department.^{12,26} Although 61% of women felt they had returned to a normal level of work by 6 months post-partum,²⁶ 61% percent of program directors reported a negative impact on female trainees work after childbearing.¹⁰ In a study of internal medicine residents, mean peer evaluations of female residents in the post-partum period were systematically lower, though the reasons remain unclear.²⁷

It seems childbearing and parental leave is negatively perceived not only by women who choose to start a family in residency, but also by co-residents, program directors, and attending physicians working with new mothers. The data in this area is limited by subjective survey data, however, consistently highlights a negative

association with parental leave. It also underscores a lack of objective data on trainee performance by which to objectively evaluate the effects of parental or other forms of leave. Further work in this area is needed to understand implicit bias regarding leave and the limitations of training programs to support pregnancy.

Future Recommendations

The rigor and stress of orthopaedic surgical training presents significant challenges to personal wellbeing regardless of background. However, as diversity becomes a valued workplace attribute, institutions must consider modifying aspects of their training programs to accommodate challenges that systematically present barriers to large classes of trainees. Work-life balance, and more specifically, starting a family, is an important consideration for many female medical students and residents. We propose the following recommendations for training programs to consider in order to make parental leave more protected and predictable for future residents.

First, we must adopt transparent, unified, and accessible parental leave policies with an emphasis on enhancing health and gender equity. Formalizing parental leave policy will alleviate pervasive ambiguity amongst not only residents who wish to start a family, but also co-residents, faculty, and ancillary staff who ultimately support these residents. Specifications about extension of training and board eligibility will allow trainees to plan accordingly and make informed decisions. Policies that address male, female, and adoptive parents are paramount for encouraging open dialog and an environment of inclusion.

Second, development of competency and skill-based metrics for resident evaluation will allow us to evaluate the impact of extended leave on surgical training. Objective metrics will not only help identify way to support trainees by targeting educational goals, but also challenge biases and perceptions about performance after parental leave.

Finally, and perhaps most importantly, much of the current literature regarding parental leave is survey-based and focuses on general surgery residents. Unfortunately, the few studies that query orthopedists are limited by low response rates. In order to understand the challenges that face our specialty, we must continue to study ourselves in order to identify and limit bias and discrimination. Equally important is consistent participation in these studies and encouraging residents and educational leadership to critically evaluate their training programs for disparities.

CONCLUSION

Surgical training is deeply rooted in tradition. However, as the demographics of surgical trainees normalize

to the population at large, we must examine the modifiable aspects of surgical practice to accommodate a more diverse set of needs. Transparency and consistency for parental leave, consideration of major health issues presented to pregnant residents and new parents, and battling negative perceptions associated with parental leave each present an opportunity to increase recruitment and decrease burnout and attrition.

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TRENDS IN RURAL OUTREACH BY ORTHOPEDIC SURGEONS

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ABSTRACT

Background: Sixty million rural residents have limited access to orthopedic care due to a small rural orthopedic surgery workforce. Increases in specialized training add to the challenge of attracting orthopedic surgeons to rural communities. Answering the call for research on models to meet the needs of rural orthopedic patients, we examine long-term trends in visiting consultant clinics (VCCs) in Iowa, a state with a large rural population.

Methods: The Office of Statewide Clinical Education Programs (Carver College of Medicine) compiles an annual report of outreach clinic locations, frequencies and participating physicians. Trends in the total number of VCCs, days and locations (1989-2018) were analysed using joinpoint analysis.

Results: Total clinic days grew rapidly from 1992-1997 (Average Percent Change: 19.7%) before a decline ending in 2009 (APC: -4.1%). A new growth period (2009-2013, APC: 7.5%) preceded another decline (APC: -3.6%) ending in 2018. The number of cities hosting a VCC grew from 56 (1989) to a peak of 90 (1999) and fell an average of 0.9% a year thereafter. More than 80% of all VCCs in the last ten years were offered 2 or more times per month. The average participation rate for Iowa-based orthopedic surgeons was 44%. The mean number of VCCs staffed by a single physician was 1.32 (std. dev. = 0.53) with a median of 1. The average number of VCC days per month for a participating physician was 3.22 (std. dev. = 2.41) with a median of 2.66.

Conclusion: The VCC model of rural outreach is sustainable (30+ year history) and self-funded. Most clinics occur with sufficient frequency to allow timely follow-up care. This model of rural out-

reach is supported by the participation of a large segment (44%) of Iowa's orthopedic surgeons. Visiting orthopedic surgeons provide access to care in 65 of the 76 Critical Access Hospitals in Iowa offering orthopedic services compared to 8 staffed by a local orthopedic surgeon.

Level of Evidence: V

Keywords: visiting consultant clinic, critical access hospital, outreach, rural

INTRODUCTION

Providing access to orthopedic surgery in rural areas has been recognized as a challenge for decades.^{1,2} Comparatively few orthopedic surgeons practice in rural areas of the US^{3,4} and their average age is higher than that of their urban counterparts.⁴ Unfortunately, recent trends militate against expanding (or even maintaining) the number of orthopedic surgeons practicing in rural areas. The country as a whole is facing a shortage of orthopedic surgeons^{5,6} at a time when the Baby Boom generation is moving into older age. A coincident increase in obesity in the general population is leading to further increases in the demand for orthopedic care.⁷

Within the profession, the trend towards increased specialization results in fewer new physicians with the more generalized training associated with a rural practice.^{8,9} There are few concrete solutions to some of the perceived personal and professional limitations associated with practicing in a rural community, e.g., spousal employment opportunities, lower pay, call coverage, etc. Finally, some studies suggest that patient outcomes for some complex procedures are better in large volume hospitals.¹⁰⁻¹²

Recent articles in academic¹³ and professional¹⁴ outlets highlight the challenges facing the orthopedics profession in providing care for rural patients in the US and other countries. An AOA Critical Issues Symposium was held in 2016 to stimulate a national conversation about the issues surrounding orthopedic care in underserved areas.¹³ One focus of his discussion involves, "which model of orthopedic care in rural areas will best serve our profession and fulfill our foundational obligation to society."¹³ This study intends to contribute to this conversation by describing the long-term experience of Iowa, a state with a large rural population, with the visiting consultant clinic (VCC) model of providing access to orthopedic care in rural communities.

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

Sources of Funding: No sources of funding declared.

An orthopedic surgery VCC is a joint arrangement between a visiting orthopedic surgeon (or group practice) and an outreach location, usually a rural hospital or clinic.¹⁵⁻¹⁷ A formal contract stipulates the frequency of the clinics, services offered in the outreach clinic location, payments for the space used by the visiting orthopedic surgeon, etc.¹⁵⁻¹⁷ Initiating a VCC agreement includes a review of the visiting physicians' credentials and malpractice insurance.¹⁵ These agreements are reviewed annually by both parties and may be amended, for example, to accommodate new physicians to staff the clinics.

Almost all orthopedic VCC sites are rural communities that are too small to support a full-time orthopedic surgeon. While the majority of physicians staffing these outreach clinics are from urban areas, some have their primary practice locations in rural areas.^{14,17} Like their urban counterparts,¹⁸ rural orthopedists use VCCs to expand their catchment area while serving patients in underserved rural locations.¹⁴ The VCC model for orthopedic surgery outreach has been established in Iowa for more than 30 years.¹⁵ In addition to Iowa, cross-sectional studies have documented the presence of orthopedic surgery VCCs in Kansas¹⁹ and 38% of rural hospitals in Florida, Nebraska, West Virginia, Arizona and Montana surveyed in 2011.²⁰

Despite their long history and presence in several states with large rural populations, orthopedic VCCs are still not well understood. For example, a recent article equates VCCs with a "fly in-fly out" model for surgery apparently used in isolated areas of Australia.¹³ It is suggested that both models of rural outreach suffer from a lack of follow-up care, questionable results, etc. However, such a comparison reveals a fundamental misunderstanding about orthopedic surgery VCCs in rural areas of the U.S. To illustrate a most salient difference, consider that the Australian Orthopedic Association "does not support" the fly-in fly-out model¹³ whereas 45% of Iowa-based orthopedic surgeons¹⁷ were involved in rural outreach through a VCC in 2014.

Prior research on orthopedic VCCs shows their positive effect on access to orthopedic care.¹⁷ However, there are no longitudinal studies on how this model of rural outreach has evolved over time. To better understand this model of serving rural patients, it may be helpful to see how it has changed over the decades. For this study, we utilize information from a unique state-wide database that has been tracking orthopedic surgery VCCs since 1989. Using data from 1989-2018, we modeled how the number of VCCs, clinic days and VCC locations have changed over time. We also analyzed the trends in the frequency of VCCs since clinic frequency affects the timeliness of follow-up care after major procedures. Since VCCs transfer some of the travel burden from rural patients to

orthopedic surgeons, we analyzed trends of the average number of VCC sites visited by a participating surgeon, the average days spent on rural outreach and the accompanying travel burden in terms of total miles traveled to outreach clinic sites

MATERIALS AND METHODS

Data Sources

The primary data source was the Annual Report on Iowa's Visiting Medical Consultant Activity for the years 1989-2018. This report is compiled by the Office of Statewide Clinical Education Programs within the Carver College of Medicine (University of Iowa). This report is compiled using information from the Iowa Physician Information System, a statewide registry of practicing physicians in Iowa. It is updated continuously using multiple data sources including a twice-yearly census of all work sites in Iowa employing licensed health professionals.

The information on each orthopedic surgery VCC includes the location (site and city) and frequency. The names of participating orthopedic surgeons, their primary practice locations and group practice associations, if any, are also included.

All driving distances were estimated between the primary practice city of the participating orthopedic surgeon and VCC location using the Google Distance Matrix API.

To estimate the travel burden for an individual orthopedic surgeon, the total days staffed by a given group practice at a VCC location were allocated equally across all physicians associated with that site.

Statistical Analysis

Trends in the total number of clinic days and VCC locations were modeled using join-point regression.²¹ There were at least three annual observations between joinpoints or between a joinpoint and either end of the data series. Count data were log (base 10) transformed. The joinpoint models were fit using the grid-search method. Confidence intervals for average percentage change (APC) were estimated using the empirical quantile method. Significant results are reported for the $p < 0.05$ level.

RESULTS

Growth in VCC Days and Locations

The number of VCC days and locations, by year, are presented in Figure 1. A separate dashed line indicates the number of VCC days staffed by Iowa-based orthopedic surgeons. Joinpoint analyses are presented in Table 1.

Starting in 1992, the number of clinic days grew rapidly (APC = 19.5%, 95% C.I. = 15.3, 25.3) until 1997. The number of VCC days fell between 1998 and 2009 at an average rate of 4.1% per year (APC 95% C.I. = -3.5%, -5%). A short growth period from 2009-2013 (APC = 7.9%, 95%



Figure 1. Orthopedic surgery visiting consultant clinic (VCC) days in Iowa (1989-2018).

C.I. = 3.6%, 12.5%) was followed by a contraction averaging 3.6% per year (95% C.I. = -1.5, -8.5).

The total number of orthopedic surgery VCC clinics offered in each year is presented in Figure 2 (solid black line) along with the number of cities hosting a VCC (dashed black line). The differences between these lines shows that, in every year, some rural cities hosted more than one VCC. The average number of VCCs per city over all the years was 1.39 with an initial peak of 1.58 in 1999 and a second peak of 1.49 in 2013. As might be expected, the repeated pattern of growth and contraction in the number of orthopedic VCCs was consistent with that of the overall clinic days (see Table 1). The number of cities hosting an orthopedic VCC (Figure 2) grew steadily from 1989 until 1997 (APC 5%, 95% C.I. = 3.3%, 7.8%). After peaking in 1999, the number of cities continued to fall on average 0.9 per year (95% C.I. = -0.5, -1.4) until the end of our study period.

Across the entire study period (1989-2018), 115 different cities in Iowa hosted an orthopedic VCC for at least

one year. The average number of years a community hosted a VCC is 19.97 (std. dev. = 9.52) out of the 30 yearly observations (Median = 23). More than 60% of communities hosted an orthopedic VCC for more than 20 of the last 30 years. At the other end of the distribution, 17 cities (15%) hosted a VCC for 5 or fewer years.

Trends in Clinic Frequency

Our sample includes 3209 VCC-year observations. Of these, few (1.2%) are offered less than once a month. About 20% (19.6%) are clinics offered once a month. Across all VCC-year observations, we find that 79% of orthopedic VCCs are offered 2 times a month or more frequently. Figure 3 shows that percentage of all VCCs with a frequency of 2 or more times per month. Since 2007, the proportion of at least twice-monthly VCCs has been consistently higher than 80%.

Orthopedic Surgeon Participation

A total of 282 different Iowa-based orthopedic surgeons staffed one or more VCCs during our study period. The

Table 1. Joinpoint Analyses of Trends in Orthopedic Surgery VCC Days, Counts and Cities: 1989-2018

	Trend 1		Trend 2		Trend 3		Trend 4		Trend 5	
	Years	APC	Years	APC	Years	APC	Years	APC	Years	APC
Orthopedic surgery VCC days in Iowa	1989-1992	-1.3%	1992-1997	19.5%*	1997-2009	-4.1%*	2009-2013	7.5%*	2013-2018	-3.6%*
Orthopedic surgery VCCs in Iowa	1989-1998	8.3%*	1998-2010	-3.2%*	2010-2013	7.9%*	2013-2018	-6.0%*		
Iowa cities with an Orthopedic Surgery VCC	1989-1997	5.1%*	1997-2018	-0.9%*						

Abbreviations: APC, annual percent change; VCC, visiting consultant clinic. (*) Significant at p < 0.05

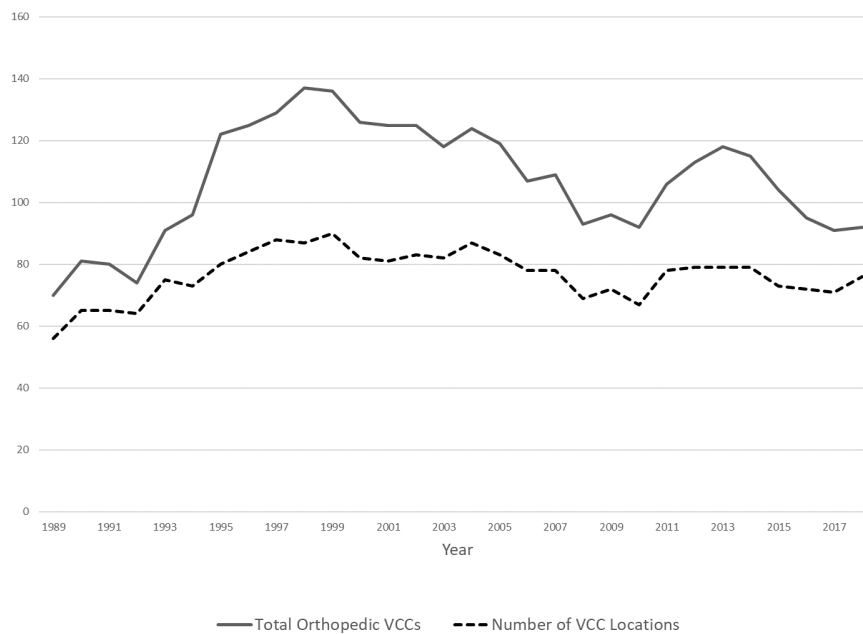


Figure 2. Number of orthopedic surgery VCCs and locations in Iowa (1989-2018).

number of participating orthopedic surgeons varied from 47 in 1989 to 109 in 1998. Using the data from the Iowa Physician Information System, we computed the proportion of participating orthopedic surgeons as a total of all Iowa-based orthopedic surgeons. The resulting proportions are presented in Figure 4. The average participation rate across all 30 years is 44% (std. dev. = 6.5%). The median participation rate is 43%. Over the last 10 years (2009-2018), the average participation rate is 41% (std. dev. = 2.5%).

Outreach Involvement of Individual Orthopedic Surgeons

While an orthopedic surgeon may staff more than one VCC location, 50.3% of Iowa-based orthopedic surgeons are associated with only one VCC location in a given year. The average number of VCC locations staffed by an individual physician is 1.32 (std. dev. = 0.53) The median is 1.

The average number of days per month that an orthopedic surgeon dedicates to VCC outreach varies somewhat depending on the year (Figure 4). The overall average across all years is 3.58 (std. dev. = 3.10) days

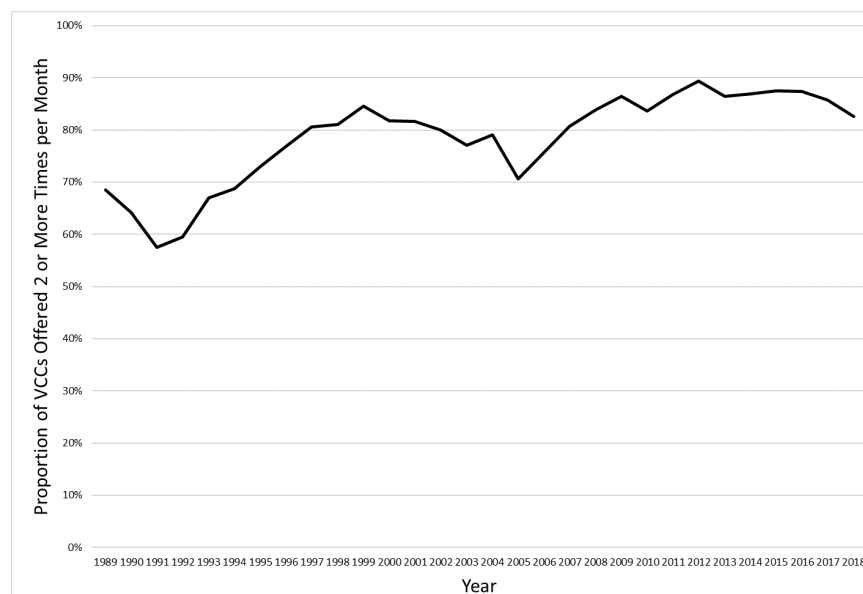


Figure 3. Proportion of orthopedic surgery VCCs in Iowa offered 2 or more times per month (1989-2018).



Figure 4. Proportion of Iowa orthopedic surgeons participating in VCC outreach (1989-2018).

per month. The median number of days is 2.66. In the last 10 years, the average number of days is 3.41 (std. dev. = 2.80) and the median is 2.25.

Travel is associated with rural outreach. The average monthly travel burden for a participating orthopedic surgeon is 279.08 (Median = 193.4) miles. The standard deviation of 269.1 miles per month reflects high variation in the number of VCCs staffed by a given physician as well as differences in clinic frequency and distance from one's primary practice location. In the last ten years, the average travel burden is comparable at 280.46 miles (std. dev. = 269.83).

DISCUSSION

As in many rural states, the orthopedic surgery workforce is primarily concentrated in urban areas.¹⁷ However, through the mechanism of the visiting consultant clinic model of rural outreach, patients in more than 70 rural locations (on average) have been able to receive orthopedic care in their own communities. It is important to note that the impact of VCCs on access to orthopedic care in Iowa is "hidden in plain sight." Consider that 76 Critical Access Hospitals (CAHs) in Iowa offer orthopedic services.²³ Of these, 65 are staffed by visiting orthopedic surgeons while 8 are associated with a local, rural-based orthopedic surgeon. The staffing in the remaining 3 CAHs is unknown.

In contrast to centrally planned (and funded) rural outreach programs in other countries,²² orthopedic VCCs in Iowa are organized by individual physician groups and rural hospitals or clinics. Their "market-based" nature is best illustrated in the 30-year repeated pattern of high growth followed by retrenchment illustrated in Figure 1. From the changes in the number of locations reported

in Figure 2, some of the original expansion (1992-1997) included sites that turned out to be not economically feasible. We also note that the second wave of growth in the number of clinic days coincided with the onset of the Affordable Care Act in 2010. However, as before, some of the expansion was apparently not sustainable in the longer term. Despite all of these changes over time, a majority (60%) of rural locations were served by an orthopedic surgery VCC for 20 or more of the 30 years covered by our study, suggesting that the participating physicians found this core set of rural locations to be sustainable in the long run.

While the VCC model does not meet the needs of rural communities for emergency or trauma care, they are held frequently in most communities (80% occurring twice a month or more often). This level of frequency allows for timely follow-up care for elective procedures. For example, a survey of Hip Society members in 2011 found that the average time for the first follow-up visit after a total hip replacement was 4.9 weeks with only 1.2% of respondents following up in a week.²⁴ A twice-monthly VCC schedule would accommodate the follow-up practice patterns of more than 98% of this sample of orthopedic surgeons.

The support of Iowa's orthopedic surgery workforce has been high and consistent for decades. More than 4 in 10 orthopedic surgeons in Iowa staff a VCC in a given year. Over the 30 years covered by this study, 282 Iowa-based orthopedic surgeons and 68 out of state orthopedic surgeons staffed rural outreach clinics in Iowa. We limited much of our analysis to Iowa-based physicians since we have no information on other possible outreach activities by non-Iowa orthopedic surgeons.

The benefits of VCC outreach for rural patients come at a cost. While there are wide variations across individuals, most (50.3%) orthopedic surgeons staff only a single VCC site each year. The monthly average commitment by an individual physician in terms of clinic days is 3.41 (over the last 10 years) and miles traveled is 280 (in the last 10 years). [Of course, depending on the individual physician, these time and travel burdens may be much higher.] Due to travel time, travel costs, space rental costs, etc., there is a considerable economic expense associated with rural outreach.¹⁵ These costs have been absorbed by the participating physicians. New models of reimbursement for procedural orthopedic care should be reviewed for their ability to support rural outreach whether through a VCC model or some other system. Without accounting for these “hidden” costs of serving rural patients in their own communities, payment reform may worsen rather than improve access to orthopedic care for rural patients.

This study is subject to limitations due to its focus on a single rural state. Differences in geography, demographics, insurance coverage, history, etc. between Iowa and other rural states may reduce the appropriateness of the VCC model for other situations. Our data is limited to measurements of the participation of physicians in rural outreach and, therefore, does not inform us about the quality of the care being provided in the VCC setting. Furthermore, while the in-person VCC model of rural outreach has a long legacy, the future for follow-up care, for example, may lie in telemedicine.²⁵

CONCLUSION

As a model for rural outreach, VCCs offer potential benefits to patients as well as participating providers. Rural patients can meet in-person with an orthopedic surgeon in one’s own community. Furthermore, VCCs can improve coordination of care for patients with primary care providers.¹⁵ What is unknown is how well this model fulfills the needs of patients for “local” care when major procedures are often referred to larger, nearby urban hospitals.

In their concluding remarks on “Orthopedic Care in Underserved Areas,”¹³ the authors called for, “providers who see the value in and are willing to practice in rural communities.” While most of the Iowa-based orthopedic surgeons who participate in VCC outreach reside in urban areas, they apparently see value in maintaining these relationships for years. However, with changes in provider reimbursement and other health system reforms, the viability of this type of rural outreach may be reduced. Therefore, in addition to studying the option of training and financially supporting an orthopedic surgeon to work in a rural area, further research is needed on how to maintain and possibly expand currently working models of rural outreach.

ACKNOWLEDGEMENTS

The authors would like to thank Linda Theisen and Francisco Olalde for their help with obtaining the data for this project.

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ASYMPTOMATIC PRE-OPERATIVE COVID-19 SCREENING FOR ESSENTIAL AND ELECTIVE SURGERIES: EARLY RESULTS OF UNIVERSAL SCREENING AT A MIDWESTERN ACADEMIC MEDICAL CENTER

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ABSTRACT

Background: During the novel Coronavirus 2019 (COVID-19) worldwide pandemic, viral testing has largely focused on patients presenting with fever and respiratory symptoms. Although Centers for Disease Control has reported 1,551,095 cases in the United States as of May 21, 2020, asymptomatic infection rates remain unknown within the U.S., especially in geographically disparate regions.

Methods: On April 7, 2020 our hospital established universal SARS-CoV-2 screening using RT-PCR RNA detection from nasopharyngeal swabs from asymptomatic patients prior to essential and elective surgeries. This study included 1,997 asymptomatic patients undergoing surgical procedures and 1,797 admitted for medical management at a Midwestern academic hospital between April 7, 2020 and May 21, 2020.

Results: As of May 21, asymptomatic testing for SARS-CoV-2 infection had been completed for 1,997 surgical patients and 1,797 non-surgical patients. Initial testing was positive in 26 patients, with an additional four positive tests occurring during repeat testing when greater than 48 hours had elapsed since initial testing. Overall asymptomatic infection rate was 0.79%. Asymptomatic infection rate was significantly lower in surgical patients (0.35% vs. 1.28%, $p=0.001$). Surgical patients tended to be older than non-surgical patients, although this was not statistically significant (51, IQR 27-65 vsx 46, IQR 28-64, $p=0.057$). Orthopedic surgery patients were significantly younger than those from other surgical services

(42 vs. 53 yrs, $p<0.001$), however orthopedic and non-orthopedic surgical patients had similar asymptomatic infection rates (0.70% vs. 0.25%, $p=0.173$).

Conclusion: Among asymptomatic patients tested at a Midwestern academic medical center, 0.79% were infected with SARS-CoV-2 virus. These findings will help guide screening protocols at medical centers while providing essential and elective procedures during the COVID-19 pandemic. While the asymptomatic infection rate was low, this data substantiates the threat of asymptomatic infections and potential for community viral spread. These results may not be generalizable to large urban population centers or areas with high concentrations of COVID-19, each region must use available data to evaluate the risk-benefit ratio of universal testing vs universal contact precautions.

Level of Evidence: IV

Keywords: covid, covid-19, coronavirus, sars-cov-2, asymptomatic, essential surgeries, elective surgeries, screening, pre-operative, midwestern

INTRODUCTION

During the emergence of the worldwide novel coronavirus disease 2019–2020 pandemic (COVID-19), state, national, and international health agencies have recommended aggressive social distancing and isolation measures to minimize spread of the disease. Following a brief period of near complete closure of elective hospital surgical volume, the nation grappled with the magnitude of the domestic disease burden, essential surgical procedures have gradually resumed as local and regional conditions have allowed. The resumption of surgical and clinical services has been coordinated in a manner to minimize unnecessary consumption of personal protective equipment (PPE) and unnecessary exposure to patients and healthcare workers while allowing for timely treatment of patients with time-sensitive indications for surgical interventions.

Consensus recommendations have strongly encouraged screening of asymptomatic patients for SARS-CoV-2 prior to surgery or hospital admission to reduce asymp-

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

Sources of Funding: No sources of funding declared.

Table 1. Demographic Characteristics of Patients Presenting for Non-Surgical Admission and Surgical Procedures

Variable	Non-Surgical Admission (n=1797)	Surgical Procedures (n=1997)	p-value	Non-Orthopedic Procedures (n=1569)	Orthopedic Procedures (n=428)	p-value
Age: median (IQR)	46 (28-64)	51 (27-65)	0.057	53 (30-67)	42 (22-60)	<0.001
Min-max	0-98	0-97		0-91	0-97	
BMI: median (IQR)	27.3 (22.7-32.8)	27.9 (23-33.6)	0.073	27.8 (23.0-33.6)	28.3 (23.4-33.5) 12.1-106.2	0.244
Min-max	10.7-71.0	8.5-119.1		8.5-119.1	(n=7 missing)	
	(n=67 missing)	(n=11 missing)		(n=4 missing)		
Gender (n, % female)	940 (52.3%)	1025 (51.3%)	0.545	825 (52.6%)	200 (46.7%)	0.032
Coronary Artery Disease	89 (5.0%)	116 (5.8%)	0.244	102 (6.5%)	14 (3.3%)	0.011
Hypertension	418 (23.3%)	563 (28.2%)	<0.001	470 (30.0%)	93 (21.7%)	<0.001
Congestive Heart Failure	28 (1.6%)	58 (2.9%)	0.005	53 (3.4%)	5 (1.2%)	0.016
Asthma	111 (6.2%)	101 (5.1%)	0.134	87 (5.5%)	14 (3.3%)	0.057
COPD	72 (4.0%)	96 (4.8%)	0.231	82 (5.2%)	14 (3.3%)	0.098
Type II Diabetes	188 (10.5%)	232 (11.6%)	0.257	193 (12.3%)	39 (9.1%)	0.068

omatic transmission. In addition to identifying patients with asymptomatic SARS-CoV-2 infection, screening allows for conservation of PPE in critically short supply, such as filtering respirators, when caring for non-infected patients. In many areas without population testing, these screening efforts add critical information to rates reported by state and national public health officials. Addition of these screening test results may improve the accuracy of available estimates regarding community prevalence of COVID-19 infection.

METHODS

This study underwent formal review by local Institutional Review Board and was determined to be exempt.

Participants

A total of 3,794 asymptomatic patients admitted for medical management or surgical procedures from April 7, 2020 to May 21, 2020 underwent screening for recent symptoms and testing for SARS-CoV-2 with RT-PCR within 48 hours of surgery of hospital admission. Upon presentation, all patients were identified as symptomatic or asymptomatic via screening by healthcare staff for the presence of symptoms including fever, cough, chest pain, or shortness of breath within the previous 24 hours; patients answering yes to any of these symptoms were identified as potential COVID-19 patients, whereas those without self-reported symptoms were identified as asymptomatic. SARS-CoV-2 testing was ordered within

the electronic health record according to the presence or absence of symptoms during initial screening: testing for patients endorsing symptoms was ordered as “NOVEL CORONAVIRUS (COVID-19)” whereas testing for patients denying symptoms was ordered as “COVID-19 ASYMPTOMATIC SCREEN BY PCR.” Both test orders required the ordering licensed independent practitioner to select radio buttons within the order to confirm the patient met criteria for the selected viral test.

All patients were tested with Nasopharyngeal swabs collected by clinical staff according to standard practices. Samples were processed to extract nucleic acids according to Centers for Disease Control and Prevention (CDC) 2019 Novel Coronavirus (2019-nCoV) Real-Time RT-PCR Diagnostic Panel.¹ Extracted specimens underwent nucleic acid extraction amplification using reverse transcriptase polymerase chain reaction. Diagnostic panels included a no template control, SARS-CoV-2 positive control, and human specimen control.

Study Design

This retrospective study evaluated asymptomatic patients admitted for medical management or surgical procedures at a Level 1 Midwestern Academic Medical Center from April 7 to May 21, 2020. We aimed to determine the proportion of positive tests among asymptomatic patients undergoing mandatory preadmission or preoperative testing for SARS-CoV-2 infection. All patients scheduled for surgery underwent testing unless

Table 2. Asymptomatic Test Results of Patients Presenting for Non-Surgical Admission or Surgical Procedures

Measure	Non-Surgical Admission	Surgical Procedures	p-value	Service		p-value
				Orthopedic Procedures	Non-Orthopedic Procedures	
Asymptomatic Tests	1797	1997	0.001	428 (21.4%)	1569 (78.6%)	0.173
Asymptomatic Positive Tests	23	7		3 (42.9%)	4 (57.1%)	
Positive Test Rate	1.28%	0.35%		0.70%	0.25%	

delay for testing was believed to place the patient at unacceptable risk for serious adverse outcome including loss of life or limb. Patients indicated for emergency surgery that could not be delayed for testing were excluded from testing requirement prior to surgery and all staff involved in care of these patients observed airborne, contact precautions and eye protection including face shield and N95 mask use during and after the procedure until testing was completed.

Statistical Analysis

All statistical analyses were performed using SAS statistical software version 9.4 (SAS Institute, Inc., Cary, NC). Demographics were compared to assess differences between patients with positive and negative SARS-CoV-2 tests. Between-group means were compared using t-tests and frequencies were compared using Fischer’s exact test where appropriate. Statistical significance was defined as $p < 0.05$.

RESULTS

Nasopharyngeal swabs were obtained from 3,794 asymptomatic patients prior to surgery or hospital admission and tested for SARS-CoV-2 nucleic acid. Table 1 provides a comparative breakdown of demographic characteristics among patients presenting for non-surgical admissions and those undergoing surgical procedures. Patients presenting for surgical procedures are further separated into non-orthopedic surgery patients and orthopedic surgery patients. Among all asymptomatic patients, 1,997 (52.6 %) underwent surgical procedures and 1,797 (47.4%) were admitted for non-surgical management. Among patients undergoing surgical procedures, 1,569 patients had non-orthopedic procedures (78.6%), while 428 had orthopedic procedures (21.4%).

Patients undergoing surgical procedures had slightly higher median age than those admitted for non-surgical management (51, IQR 27-65 years vs. 46, IQR 28-64 years), however this did not reach statistical significance ($p=0.057$). There was no significant difference in the distribution of gender between surgical and non-surgical cohorts, with females accounting for 52.3% of non-surgical patients and 51.3% of surgical patients. Pa-

tients undergoing surgical procedures had significantly greater rates of hypertension and congestive heart failure (28.2% and 2.9%, respectively) compared to non-surgical patients (23.3% and 1.6%, respectively) ($p<0.001$ and $p=0.005$ respectively). There were no significant differences between surgical and non-surgical cohorts for rates of coronary artery disease, asthma, COPD, or type II diabetes mellitus (Table 1).

Patients undergoing surgical procedures were classified by whether they underwent orthopedic surgery procedures or non-orthopedic surgical procedures (Table 1). Within the surgical cohort, patients undergoing orthopedic procedures were significantly younger than those undergoing non-orthopedic procedures (42, IQR 22-60 vs. 53, IQR 30-67, $p<0.001$). females accounted for a significantly smaller portion of orthopedic patients compared to non-orthopedic surgical patients (46.7% vs. 52.6% respectively, $p=0.032$). Compared to patients undergoing non-orthopedic procedures, patients undergoing orthopedic surgery had significantly lower rates of coronary artery disease, hypertension, congestive heart failure, asthma, and type II diabetes mellitus (Table 1). There was no difference in rate of COPD between orthopedic and non-orthopedic patients (Table 1).

There were 30 positive tests for SARS-CoV-2, suggesting an overall asymptomatic infection rate of 0.79% in this case series (Table 2). Initial SARS-CoV-2 testing resulted in 26 positive tests (0.69%). Testing was repeated for 422 patients due to passing of greater than 48 hours since initial negative tests, 4 of which were subsequently positive (0.95%) for a total of 30 patients with positive SARS-CoV-2 tests. A third RT-PCR test was performed for 96 patients, with all 96 testing negative for SARS-CoV-2 RNA. The asymptomatic infection rate among the 1,997 surgical patients was 0.35% (7 of 1,997), which was significantly lower than asymptomatic infection rate of 1.28% within the non-surgical cohort ($p=0.001$). Asymptomatic infection rates among orthopedic surgery patients and non-orthopedic surgical patients were statistically similar (0.25% vs. 0.70%, $p=0.173$).

When all patients were grouped by SARS-CoV-2 test results, patients with positive tests were significantly

Table 3. Demographic Characteristics Among Patients Testing Positive or Negative for SARS-CoV-2 Virus

	Total (n=3,794)	Negative SARS-CoV-2 (n=3,764)	Positive SARS-CoV-2 (n=30)	P-value (+ vs. -)
Age	49 (0-98) IQR: 28-65	49 (0-98) IQR: 28-65	31 (0-78) IQR: 18-56	0.005
Gender (Female)	1,954 (51.8%)	1,950 (51.8%)	15 (50.0%)	0.843
BMI	27.6 (8.5-119.1) IQR: 22.9-33.3 (n=3,716)	27.6 (8.5-119.1) IQR: 22.9-33.3	25.8 (12.8-46.3) IQR: 18.4-33.7	0.237

younger than those with negative SARS-CoV-2 tests (31, IQR=18-56 yrs vs. 49, IQR=28-65 yrs, p=0.005). The youngest patient testing positive for SARS-CoV-2 was <1 year old and the oldest was 56 years old. Among patients younger than 18 years of age, the positive test rate was 1.4%, compared to 0.7% among patients 18 or older (p=0.118). There were no differences in distribution of gender or BMI between patients with positive or negative SARS-CoV-2 testing (Table 3). Prevalence of coronary artery disease, hypertension, congestive heart failure, asthma, COPD, and type II diabetes mellitus were statistically similar between patients with positive or negative SARS-CoV-2 testing (Table 4).

DISCUSSION

Asymptomatic community transmission of SARS-CoV-2 has been identified as a potential major obstacle to containment of the ongoing COVID-19 pandemic.² To our knowledge, this is one of the first domestic reports of SARS-CoV-2 infections rate among a large cohort of asymptomatic patients without known prior exposure to an infected patient. In addition, we were able to compare asymptomatic infection rates among patients undergoing orthopedic procedures with patients undergoing non-orthopedic procedures and patients present-

ing for non-surgical admissions. The three key findings from this study include the asymptomatic infection rates, conversion of multiple patients who initially tested negative, and the younger age of patients with asymptomatic infections.

Mandatory screening prior to essential surgeries was adopted following consensus recommendations from multiple national and international healthcare agencies. Results of our hospital-wide SARS-CoV-2 asymptomatic testing policy suggest an overall 0.69% rate of asymptomatic or pre-symptomatic patients tested at a Midwestern academic tertiary referral center. However, the asymptomatic infection rate was significantly lower among patients undergoing surgical procedures compared to those asymptomatic patients admitted for non-surgical management. We also identified a non-statistically significant trend toward lower asymptomatic infection rates among patients undergoing orthopedic procedures compared to those undergoing non-orthopedic procedures.

Previous domestic reports of SARS-CoV-2 infection rates have been limited to targeted high risk populations, such as nursing home residents, persons with known exposure to patients with confirmed COVID-19, or those with symptoms consistent with the disease.^{3,4} The positive test rate from endemic areas have ranged from 13.7%

Table 4. Medical Comorbidity Prevalence Among Patients Testing Positive or Negative for SARS-CoV-2 Virus

	Negative SARS-CoV-2 (n=3,764)	Positive SARS-CoV-2 (n=30)	P-value
Coronary Artery Disease	205 (5.5%)	0 (0.0%)	0.406
Hypertension	976 (25.9%)	5 (16.7%)	0.248
Congestive Heart Failure	86 (2.3%)	0	1.000
Asthma	212 (5.6%)	0	0.411
Chronic Obstructive Pulmonary Disease	167 (4.4%)	1 (3.3%)	1.000
Type II Diabetes Mellitus	419 (11.1%)	1 (3.3%)	0.246

among asymptomatic women admitted for delivery to 46.8% of 12,594 patients tested at New York University.^{4,5} These rates are markedly different than those observed in the current study, demonstrating marked variability among geographically disparate regions.

In addition to differences among geographically disparate regions, the asymptomatic SARS-CoV-2 infection rates we have reported are markedly lower than the 16.6% positive test rate reported by the Iowa Department of Public Health (IDPH) that representing a similar geographic area: As of April 29, IDPH reported 6,843 positive cases, along with an additional 34,494 negative tests.⁶ Although it is unknown how many of the test patients reported to IDPH were asymptomatic, it is likely that the majority of these tests represent patients presenting with symptoms concerning for active COVID-19 infection or close contact with a confirmed or suspected COVID-19 positive patient given the ongoing shortage of community-based screening in this region. Since March 1, 2020, a similar cumulative positive SARS-CoV-2 test rate of 18.4% has been reported to CDC by state and local public health, clinical, and commercial laboratories across the nation.⁷

Our asymptomatic infection rate of 0.69% may be most similar to a subset of patients presented in the recently published results of population screening in Iceland which reported 13 of 2,283 randomly sampled persons from the population tested positive (0.57%).⁸ This same study also reported results of targeted high risk screening, with 1,221 of 9,199 high risk persons testing positive for SARS-CoV-2 (13.27%).⁸ Of note, 11.9% of patients in the randomly selected Icelandic population screening group reported having symptoms, with 6 of 13 patients with positive tests reporting symptoms (46.2%). While the presence of symptoms in over 10% the Icelandic population screening group is in contrast to our asymptomatic cohort, it is likely more important to consider the sampling methods and disparate sociodemographic tendencies that might drive exposure and infection rates both domestically and abroad. Results from both our study and the population screening results from Iceland suggest an asymptomatic infection rate of less than 1%, whereas targeted high risk screening and results from endemic areas have reported infection rates ranging from 13.7% to 46.8%.^{4,8}

During this study, we identified four of 422 patients with initial negative test results that later converted to positive tests upon repeat testing (0.95%), suggesting a possible association between repeated hospital encounters and positive test rates. All four of these patients converted on a second test, with none of the 96 patients in our case series undergoing a third test converting to a positive test. None of the four patients who converted

on repeat testing exhibited typical symptoms, such as fevers, cough, or dyspnea. Based on these four cases, our experience strongly supports repeated testing of patients prior to surgical procedures even in the absence of clinical symptoms.

Our internal testing policy has evolved throughout the COVID-19 pandemic. Based on initial recommendations, we required a negative test within 7 days of a surgical procedure. However, as case reports of patients converting to positive SARS-CoV-2 tests became available this policy was adjusted to testing within 48 hours of procedures even if the patient had quarantined since a previous test. Following conversion of three patients at our medical center, our testing policy now requires SARS-CoV-2 testing within 24 hours of planned surgeries. Identification of asymptomatic or pre-symptomatic infections is particularly critical for protecting healthcare providers during procedures including endotracheal intubation or other aerosol generating procedures, as these are particularly high risk for viral transmission.

In addition to guiding precautions taken by healthcare providers, testing of patients prior to elective procedures enables surgeons to delay elective surgeries for patients testing positive for SARS-CoV-2. Patients with asymptomatic infection experience markedly increased rates of severe pulmonary disease including 44.1% ICU admission rate and 20.5% mortality rate.⁹ Recent Clinical Practice Guidelines released by the International Consensus Group (ICM) and Research Committee of the American Association of Hip and Knee Surgeons has strongly recommended risk stratification including preoperative RT-PCR testing for SARS-CoV-2 prior to elective cases and delaying elective surgery in patients with active COVID-19 until recovery from infection.¹⁰

Limitations

There are several limitations to these findings: Nearly all patients in this cohort were from a largely rural geographic area including the entire state of Iowa and surrounding. However, these results can be interpreted in the context of regional and national tests results reported from IDPH and CDC. Our hospital-wide screening policy took effect early in on during the emergence of the COVID-19 pandemic within the United States. We have observed increasing rates of positive tests in asymptomatic patients that parallel the number of confirmed cases within our region. These results are also limited by a relatively small cohort patients compared to the overall regional population. Surveillance data from a forthcoming TestIowa.com statewide testing effort will help expand upon these early results and help to identify further areas of concentrated COVID-19 cases to focus surveillance and mitigation efforts.

CONCLUSION

We report an asymptomatic or pre-symptomatic SARS-CoV-2 infection rate of 0.69% in patients screened prior to essential surgeries at a regional tertiary referral center, with asymptomatic infection rate increased to 0.95% among patients with repeat testing during subsequent healthcare encounters. We also observed that patients testing positive for the virus were significantly younger than those with negative testing. Although asymptomatic or pre-symptomatic infection rates remain low, these results reiterate the risk of asymptomatic community spread, and should reinforce the need for preventive measures including social distancing and meticulous hygiene practices. These findings strongly support repeat testing after 48 hours lapse from prior tests in advance of surgical procedures or hospital admissions to identify infected patients without symptoms and mitigate asymptomatic SARS-CoV-2 transmission.

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ARE JUNIOR RESIDENTS COMPETENT AT CLOSED REDUCTION AND CASTING OF DISTAL RADIUS FRACTURES IN CHILDREN?

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ABSTRACT

Background: At many institutions, junior orthopaedic surgery residents perform the closed reduction and casting of pediatric distal radius fractures (DRFs). The purpose of this study was to evaluate the competency of junior residents compared to senior residents in the initial management of pediatric DRFs.

Methods: This investigation was a case-control study analyzing the outcomes of children with displaced DRFs treated by junior versus senior residents. The cohorts were matched with respect to fracture type. Radiographs were measured to assess fracture angulation, displacement, and cast index. Comparisons of patient characteristics, fracture characteristics, and outcome variables were made between the cohorts.

Results: A total of 132 patients (99 males; mean age 10.7±2.6 years) were included. Junior residents achieved a similar rate of acceptable initial reduction compared to senior residents (82% versus 79%; $p=0.66$). Twenty-four (23%) patients were found to have loss of reduction (LOR), though the rate of LOR was similar in the junior (16.7%) and senior resident (28.9%) cohorts ($p=0.13$). Overall, only 6 patients (3.7%) required surgery (1.5% in junior versus 7.6% in senior; $p=0.09$). The odds of LOR were 2.7 times higher in the first three reductions of the rotation for all residents ($p=0.049$).

Conclusion: Junior residents perform similarly to senior residents in the closed reduction and casting of pediatric DRFs. However, residents per-

forming one of their first three closed reductions during a rotation—regardless of seniority—were more likely to experience subsequent loss of reduction, suggesting the need for close supervision during the beginning of each rotation.

Level of Evidence: III

Keywords: junior resident, resident, closed reduction, pediatrics, fracture, distal radius

INTRODUCTION

Wrist fractures are among the most common fractures in children, with distal radius fractures (DRFs) accounting for 20-30% of such injuries.^{1,2} While closed reduction and cast immobilization remains standard of care and generally yields satisfactory outcomes in children with distal radius fractures, there are instances where fracture reduction is lost and requires additional management, including more aggressive measures such as surgery. Loss of reduction (LOR) rates have been reported to range from less than 10% to over 45%, though the overall rate is believed to be approximately 33%.²⁻⁶ The ability to achieve anatomic reduction and to apply a well-molded cast are critical factors known to help prevent loss of reduction and are often related to the experience of the orthopaedic surgeon.⁷⁻⁹

Orthopaedic surgery residents have traditionally acquired and developed clinical skills through practical experience with real patients.¹⁰ This practice, however, can put patients at risk for increased complications or suboptimal outcomes, which can subsequently compromise patient safety, especially when an inexperienced trainee is delivering care.¹¹⁻¹³ Though there is great variance between training programs, with some residents receiving more surgical supervision and less opportunity to operate independently, in many orthopaedic residency training programs trainees are expected to perform emergency-based fracture reductions and casting, including DRF care, independently and not always under the direct supervision of an attending physician. Due to restrictions on duty hours by the Accredited Council for Graduate Medical Education (ACGME), however, residents are also being expected to develop essential clinical skills in less time than their predecessors.^{11,12}

Orthopaedic residency training has been critically examined and well-documented in medical literature with

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

Sources of Funding: No sources of funding declared.

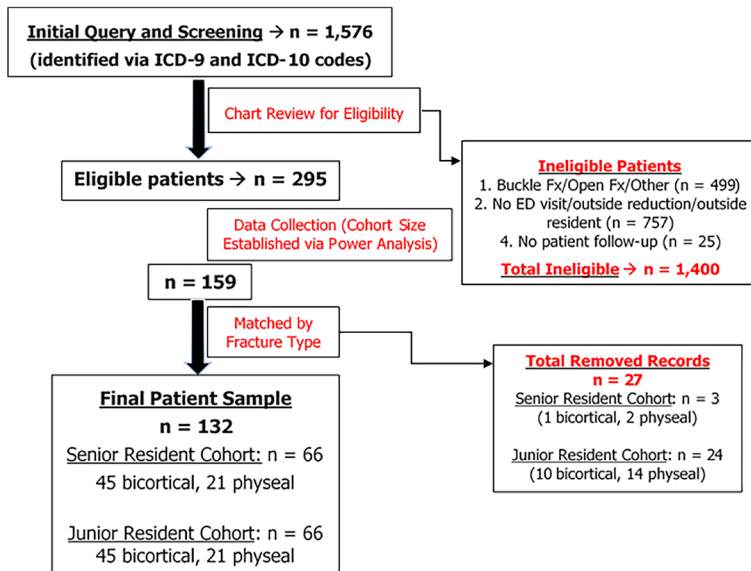


Figure 1. Flow diagram for patient eligibility, inclusion and exclusion.

special attention to the current limits of traditional testing methods of surgical proficiency.¹⁴ While residents are increasingly operating without direct attending guidance, particularly with regard to a basic, early-level orthopaedic skill such as DRF reduction, there are multiple studies highlighting the surgical competency of orthopaedic residents.^{15,16} To date no study has examined what degree of experience residents require to perform minor fracture care in the emergency department without supervision. To that end, the principal objective of this study was to compare the outcomes of closed reduction for DRF between junior and senior residents at a major pediatric hospital.

METHODS

After obtaining Institutional Review Board approval, a retrospective case-control investigation of displaced pediatric distal radius fractures was performed in order to compare outcomes of closed reduction between junior (PGY-2) residents and senior (PGY-4) residents.

Patient Sample

A review of the electronic medical record was completed for all DRFs in children aged 4-18 years old that underwent closed reduction and casting at our single institution between July 1, 2013 and June 30, 2017 (Fig. 1). Patients were queried based on ICD-9 and ICD-10 codes for distal radius fractures and CPT codes for closed reduction. 1,576 cases were reviewed in consecutive order yielding 222 eligible patients. A statistical power analysis

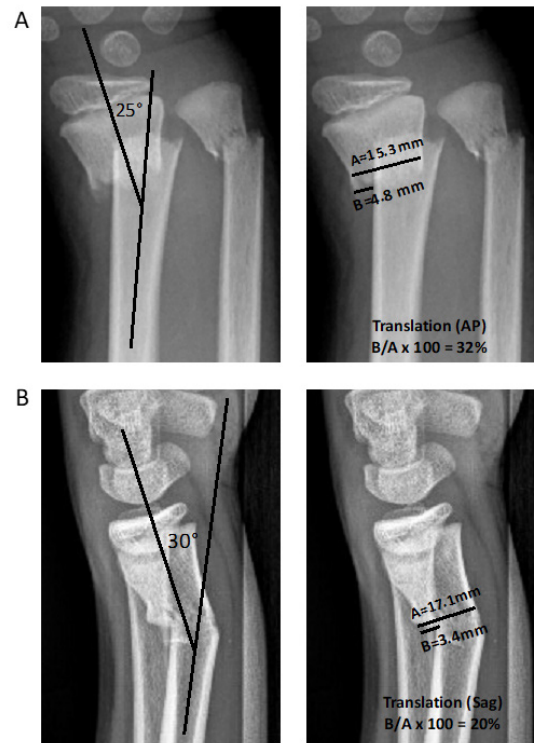


Figure 2. Radiographs of two separate distal radius fractures evaluated in this study which demonstrate sample angulation and translation measurements in the (A) coronal and (B) sagittal planes on anteroposterior (AP) and lateral radiographs, respectively.

was completed to determine the number of patients required to detect differences between junior and senior residents with respect to our primary outcome variable (loss of reduction). Accordingly, 132 total patients were added to the cohorts, which were matched with respect to fracture number and type (physeal versus bicortical). Only closed, displaced physeal or bicortical metaphyseal fractures located at or distal to the radial metaphyseal-diaphyseal junction were included. Patients with buckle fractures (n=398), greenstick fractures (n=60), open injuries (n=41), or with concomitant upper extremity fractures (n=42) other than distal ulna fractures were excluded from analysis. Patients who underwent a previous reduction attempt at an outside hospital (n=753), who lacked adequate imaging (n=35), or who had less than four weeks of follow-up (n=25), were also excluded. Only patients treated by residents from our single training program were included and any patients with reductions performed by residents who previously trained at outside programs or who were visiting from outside programs were also excluded. All reductions were performed in the emergency room of our large pediatric level I trauma center under conscious sedation. Patients underwent casting following reduction and none of the patients

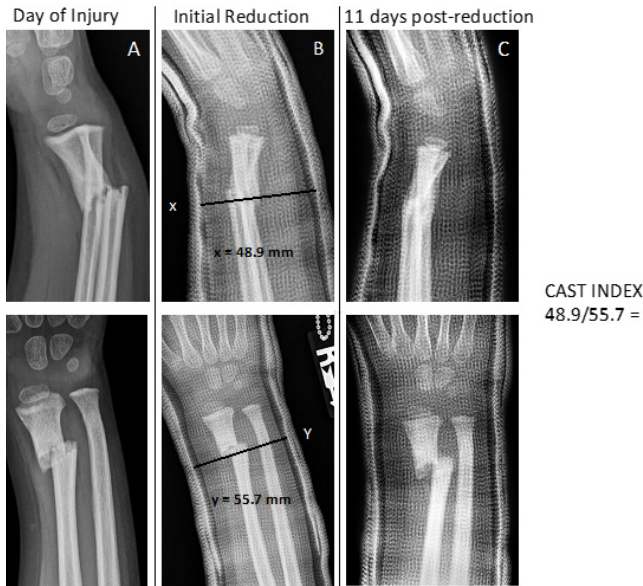


Figure 3. Pre-reduction (A), initial reduction (B) and 11 days post-reduction (C) anteroposterior (AP) and lateral radiographs of a distal radius fracture which underwent a successful initial reduction. The cast index was > 0.8 and reduction was lost at 11 days.

included in analysis underwent a trial of splinting prior to casting. Data were not captured with respect to cast wedging or molding.

Radiographic Measures

The diagnosis of a displaced DRF was confirmed on the initial wrist radiographs. Each displaced fracture was classified as a physeal fracture or a bicortical (metaphyseal) fracture. The initial, post-reduction, and final fracture angulation and translation were measured for each patient on the anterior posterior (AP) and lateral radiographs. Fracture angulation on both AP and lateral radiographs was measured as the angle between the two lines bisecting the mid-portion of each fracture fragment (Fig. 2). Fracture translation for both the AP and lateral radiographs, which was recorded as a percentage, was calculated as the width of the non-overlapping portion of the distal fracture fragment at the level of the fracture (Fig. 2). Rotational malalignment was not considered since these were distal radius fractures and no diaphyseal fractures. The cast index was determined to represent how well the cast applicator achieved interosseous molding to maintain reduction, and calculated as the width of the cast at the level of the fracture site in the lateral radiograph divided by the width of the cast at the level of the fracture site in the AP radiograph (Fig. 3). All patients were imaged using the same model fluoroscopy device performed by either the junior or senior orthopaedic resident. Loss of reduction was determined from the radiograph with the greatest degree of redisplacement.

For the purposes of our investigation, loss of reduction was defined as:¹⁷

1. Younger than 10 year old: > 20 degrees of angulation OR $> 50\%$ displacement OR surgery.
2. 10 years or older: > 10 degrees of angulation OR $> 25\%$ displacement OR surgery.

To determine if initial reduction was successful, the above criteria were applied to the most immediate post-reduction image after initial closed reduction attempt. There were no strict criteria for surgical intervention.

Comparison Between Junior and Senior Residents

The patients were divided into two cohorts: those that had been treated by a junior resident and those that were treated by a senior resident. First, patient characteristics, fracture characteristics, and pre-reduction radiographic characteristics were compared between the two cohorts to determine whether the groups were comparable. Second, the two cohorts were compared to determine if there were any differences in fluoroscopy time, radiation dose, cast index, post-reduction radiographic characteristics, loss of reduction (LOR), and rate of surgery. The primary outcome of interest was LOR.

In an effort to evaluate the impact of recent DRF reduction experience on patient outcomes, we compared the rates of successful initial reduction and LOR for the first three reductions of each resident's (junior and senior) 3-month rotation versus all subsequent reductions on the rotation.

Statistical Analysis

Standard descriptive summaries were used to summarize demographic variables. Comparisons were made between the junior and senior resident cohorts via univariate analyses of patient and fracture characteristics using independent samples t-tests or Mann-Whitney-U tests, depending on the distribution of the data. Chi-squared or Fischer's exact test was performed for categorical data. All analyses were performed using SPSS Statistics (Version 23, SPSS Inc., Chicago, IL).

RESULTS

A total of 132 patients (99 males; mean age 10.7 ± 2.75 years) with displaced DRFs that underwent closed reduction and casting by junior or senior residents were included. There were 45 bicortical and 21 physeal fractures in each resident cohort (Table I). There were 101/132 DRFs with an associated ulna fracture (77%), with 55 in the junior resident cohort and 46 in the senior resident cohort. The median fracture displacement for all patients in the study is shown in Table I. Patient age, sex, presence of an associated distal ulna fracture and initial fracture displacement (translation and angulation)

Table 1. Statistical Analyses Comparing Patients Treated by Junior Versus Senior Residents

Variable	All patients	Junior Residents	Senior Residents	P-value
Age (years) [mean + SD]	10.7 + 2.75	10.9 + 2.73	10.7 + 2.8	0.88
Sex (M/F)	M: 99 F: 33	M: 50 F: 16	M: 49 F: 17	1.00
Fracture Type	Bicortical: 90 Physeal: 42	Bicortical: 45 Physeal: 21	Bicortical: 45 Physeal: 21	1.00
Distal Ulna Fracture (Y/N)	Y: 101 N: 31	Y: 55 N: 11	Y: 46 N: 20	0.10
Angulation – Coronal (°)	9 (4 – 15)	9 (4 – 14)	9 (4 – 16)	0.62
Angulation – Sagittal (°)	23 (14 – 31)	23 (15 – 31)	23.5 (13 – 32.3)	0.80
Translation – Coronal (%)	14 (8 – 32.3)	14 (9 – 28.8)	16 (8 – 33.5)	0.68
Translation – Sagittal (%)	33.5 (16 – 85.6)	34.5 (17.3 – 97.8)	32 (16 – 74)	0.30

All values are expressed as medians and interquartile ranges and numbers unless otherwise specified. Patient characteristics, fracture characteristics, pre-reduction radiographic characteristics.

in any plane were not statistically different between the junior- and senior-resident cohorts.

Of all 132 DRFs, 106 (80%) underwent a successful initial reduction (Table II). There was not a statistically significant difference in the performance of the junior versus senior residents in initial reduction, as junior residents achieved a successful reduction in 82% of children compared to 79% for senior residents (p=0.66). There were no significant differences between the junior and senior residents in the residual post-reduction displacement of the fracture in any plane (p=0.24-0.87), cast index (p=0.11), fluoroscopy time (p=0.82), and radiation dose (p=0.59). Cast type (short versus long) was also not different between the cohorts, with 10/56 (17.9%) of junior residents and 9/57 (15.8%) of senior residents placing a short-arm cast.

Of the 106 DRFs which underwent a successful initial

reduction, 24 (22.6%) were found to have LOR at follow-up, though there was no statistically significant difference in the rate of reduction loss in the junior (16.7%) versus senior (28.9%) residents (p=0.13) (Table III). Overall, only 6 patients (3.7%) required surgery, with 1.5% of patients treated by junior residents and 7.6% of patients treated by senior residents (p=0.09).

In a comparison of the rates of successful initial reduction and LOR for the first three reductions of each resident’s rotation versus all subsequent reductions, successful initial reduction was achieved in 82% of cases during the first three, compared to 78% in subsequent reductions, which was not a statistically significant difference (p=0.49). However, of the 61 fractures that underwent successful initial reduction on a resident’s first three DRFs, 18 (30%) went on to lose reduction, while only 6/45 (13%) of fractures in subsequent reductions

Table 2. Post-reduction Outcomes (in cast), Time Under Fluoroscopy, and Radiation Dose with Statistical Analyses Comparing Patients Treated by Junior Versus Senior Residents

Variable	All patients	Junior Residents	Senior Residents	P-value
Cast Type	Short: 19 Long: 113	Short: 10 Long: 56	Short: 9 Long: 57	1.00
Cast Index	0.7955 (0.7518 – 0.8565)	0.8185 (0.7580 – 0.8610)	0.7745 (0.7463 – 0.8500)	0.11
Fluoroscopy Time (sec)	19 (14 – 30.5)	19 (14 – 29.8)	18.5 (15 – 32.8)	0.82
Radiation Dose (mGy)	8.4 (5.8 – 12.9)	8.4 (5.7 – 12)	8.4 (6 – 13.8)	0.59
Angulation – Coronal (°)	4 (2 – 7)	4 (2 – 7)	4 (2.3 – 7)	0.87
Angulation – Sagittal (°)	6 (3.8 – 11.3)	6 (4 – 9)	5 (1 – 17)	0.24
Translation – Coronal (%)	8 (0 – 14)	6 (0 – 13)	9 (1 – 17)	0.25
Translation – Sagittal (%)	11 (5 – 18.3)	12 (5 – 17)	10 (5.3 – 20.8)	0.69
Successful Initial Reduction*	106 (80.3%)	54 (81.8%)	52 (78.9%)	0.66

*Criteria for Successful Initial Reduction
 Patients < 10 years old: <20° of angulation AND < 50% displacement
 Patients > 10 years old: < 10° of angulation AND < 25% displacement

Table 3. Final Outcomes (out of cast) with Statistical Analyses Comparing Patients Treated by Junior Versus Senior Residents.

Variable	All Patients	Junior Residents	Senior Residents	P-value
Angulation – Coronal (°)	5 (2 – 9)	4.5 (2.3 – 8.8)	5.5 (2 – 9)	0.97
Angulation – Sagittal (°)	8 (4 – 15)	8.5 (4 – 15)	8 (3 – 15)	0.70
Translation – Coronal (%)	8 (0 – 12.3)	7 (0 – 10.75)	8 (5.3 – 14.8)	0.06
Translation – Sagittal (%)	13 (6 – 19.3)	10 (5 – 17)	14 (7 – 20)	0.19
Loss of Reduction*	24 (22.6%)	9 (16.7%)	15 (28.8)	0.13
Requiring surgery	6 (4.5%)	1 (1.5%)	5 (7.6%)	0.09

All values are expressed as medians and interquartile ranges or numbers and percentages

*Criteria for Loss of Reduction:

Patients < 10 years old: > 20° of angulation OR > 50% displacement OR undergoing surgery

Patients > 10 years old: > 10° of angulation OR > 25% displacement OR undergoing surgery

lost reduction (p=0.049) (Table IV). Ultimately, the odds of LOR were 2.72 times [CI: 0.98-7.55] greater if the resident was performing one of their first three reductions of the rotation.

DISCUSSION

Closed reduction and casting are the mainstay of treatment for the majority of displaced distal radius fractures (DRFs) in children. However, the high rate of loss of reduction (LOR) and redisplacement can be problematic as it may necessitate re-manipulation or surgery and could result in sub-optimal outcomes.^{1,3,5,6,9,18-21} Two of the most important factors in predicting redisplacement risk are operator-dependent: quality of the cast (as reliably measured via cast index)^{9,22-24} and quality of the reduction.^{3,9,18,20,21,25} Despite the importance of these acquired skills—which appear to be dependent upon surgeon experience^{15,26-28}—junior residents at many teaching institutions across the country are responsible for performing the closed reduction and cast application in a largely unsupervised setting.^{15,29,30} Though several authors have recognized the utility of DRF simulation models for trainees,^{12,17,26,27} none have reported the clinical performance of junior versus senior residents with respect to treatment outcomes, which may have implications for both patient safety and resident education.

To our knowledge, previous studies investigating the impact of resident seniority on closed reduction performance in pediatric DRFs have only done so with data collected from simulated models. Seeley et al.²⁶ reported significantly greater residual post-reduction angulation and translation in fractures reduced by junior residents compared those reduced by senior residents and attending surgeons. Similarly, Mayne et al.²⁷ showed that junior residents had lower global rating scale (GRS) and Objective Structured Assessment of Technical Skills (OSATS) scores than senior residents when performing closed reduction on their DRF model. Each of these

studies, of course, is limited by unknown applicability of their models to the technical difficulty and clinical outcomes in living patients. Sumko et al.²⁸ did evaluate resident performance in a clinical context, though their prospective study was not limited to DRFs, and instead included a variety of pediatric upper extremity fractures. Nonetheless, they showed that junior residents, on average, spent a significantly greater amount of time under fluoroscopy per closed reduction compared to senior residents, and thus the residents and patients were exposed to higher doses of radiation. Importantly, the study did not evaluate radiographic or clinical outcomes of their patients.

In our large retrospective study of junior and senior residents at a high-volume pediatric teaching hospital, we show that the performance of junior residents in the closed reduction and casting of pediatric DRFs was similar to that of senior residents based on numerous outcome variables, including time under fluoroscopy and radiation dose, residual post-reduction fracture translation and angulation, cast index, final fracture angulation and translation, rate of achieving a successful initial reduction, rate of reduction loss and number of patients requiring subsequent surgical intervention. Additionally, there we found that there was superior performance by the junior residents with respect to LOR (16.7% versus 28.8%) and number of patients requiring surgical intervention (1.5% versus 7.6%), though neither trend reached statistical significance.

There a few possible explanations for the similar proficiency between junior and senior residents in our

Table 4. DRF Reduction Number and Outcome

Variable	First 3 Reductions	All Subsequent Reductions	P-Value
Successful Initial Reduction	61 (82%)	45 (78%)	0.49
Loss of Reduction	18 (30%)	6 (13%)	0.049

study. First, it is possible that the learning curve for performing a successful closed reduction for pediatric DRFs may not be as steep as previously thought, and junior residents are able to quickly acquire these skills and safely perform the reduction in a clinical context, particularly if they have exposure to reducing pediatric distal radius fractures during their intern year. Second, the emphasis on simulation training for junior residents at our institution^{17,26}—which all of the junior residents in the present study received—may have improved their performance and thus narrowed the gap in overall proficiency between junior and senior residents. A recent study by Jackson et al.¹⁷ demonstrated the clinical impact of simulation training for residents performing closed reductions of pediatric DRFs, reporting that patients treated by simulation-trained residents had significantly lower post-reduction fracture displacement and a significantly lower rate of LOR.

Although DRF outcomes were not dependent upon resident seniority, we did find a greater than 2.5-fold higher odds of LOR for fractures reduced during the first three reductions of the treating resident's pediatric orthopaedics rotation (3 consecutive months during PGY-2 and PGY-4 at our institution) compared to subsequent reductions (30% versus 13%; $p=0.049$). Thus, the most important factor related to reduction proficiency was not resident seniority (and number of total prior reductions performed), but rather the number of prior reductions performed on the given rotation. This finding has a few potential implications. First, the classic dogma surrounding simulation training follows that once a trainee reaches the plateau of a given learning curve, they are proficient at performing this skill indefinitely. However, our finding suggests the learning curve reappears following an extended period of time without utilizing the given skill, regardless of past experience or proficiency. Thus, senior residents may also benefit from undergoing simulation training at the start of a rotation which demands a unique set of skills. Second, it may be beneficial to consider attending or fellow supervision during a resident's first three closed reductions of the rotation, regardless of resident seniority, to reduce the rate of LOR.

Our study has several limitations. First, as a retrospective study, the many biases inherent to this study design are applicable, including our ability to detect only correlation and not causation between resident seniority and treatment outcome. Second, although the junior and senior resident cohorts were adequately matched with respect to many variables, there was a higher number of ipsilateral ulna fractures in the junior resident cohort, though this difference was not statistically significant. Of note, there remains debate in the orthopaedic literature

regarding which variable (fractured or intact ipsilateral ulna) is associated with greater reduction difficulty and poorer outcomes,^{5,6,9,20,21,31} thus it is difficult to accurately evaluate the impact of this difference. Third, our study assessed the "performance" of residents based on fluoroscopic and radiographic data, but did not include functional outcomes data (e.g. range of motion or patient-reported outcomes). Fourth, we were unable to capture number of reduction attempts in either resident cohort as this was not reliably available in our electronic medical record upon retrospective review. Fifth, as there were defined indications for surgery, and the decision to operate after LOR was at the clinical judgement of the attending physician, this may be a confounding factor related to the patients that required surgical intervention. Sixth, some junior residents may have gained additional experience reducing fractures on a prior rotation. Although no junior residents take independent nighttime or weekend call without several weeks of supervised weekday call, there are some junior residents who may have rotated on the trauma service prior to their rotation at our pediatric institution. This may have allowed for variance in the amount of hands-on supervised fracture reduction experience some junior residents had prior to performing pediatric reductions. Lastly, there is no evidence in our electronic medical record when a senior resident was present to assist a junior resident with a given DRF reduction. Typically, when a junior resident begins his/her rotation, they are supposed to shadow a senior resident for a several reductions. The variability in the number of observed or supervised fractures, in conjunction with the potentially variability in prior experience, may also serve as a confounding aspect of the study.

Despite its limitations, our large retrospective study at a high-volume pediatric teaching hospital is the first to assess the performance of junior versus senior residents in the closed reduction and casting of pediatric DRFs—a common procedure with which trainees across the country are often tasked. Ultimately, junior residents who received simulation training appear to be adequately prepared to safely and independently perform closed reduction procedures in children with DRFs. Thus, this skill may be used as a competency benchmark by which junior residents can be evaluated. Importantly, all residents performing one of their first three closed reductions during a rotation were more likely to experience subsequent LOR, suggesting a potential use for simulation training for both junior and senior residents, with close supervision during the beginning of each rotation.

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LIGAMENTUM TERES TRANSFER DURING MEDIAL OPEN REDUCTION IN PATIENTS WITH DEVELOPMENTAL DYSPLASIA OF THE HIP

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ABSTRACT

Background: The ligamentum teres (LT) is believed to have a number of functions, including a role in hip stability, nociception, proprioception, vascular supply to the femoral head, and synovial fluid circulation. The LT is often excised in the process of performing a medial open reduction (MOR) of the hip. We sought to conduct a retrospective review of hips undergoing a MOR for dislocated infantile developmental dysplasia of the hip (DDH) to compare clinical and radiographic outcomes for patients with and without LT reconstruction.

Methods: We performed a retrospective review of 38 hips treated with MOR with or without LT reconstruction with minimum two-year follow-up. Radiographic outcomes were determined using the Severin score. Information regarding avascular necrosis (AVN), concomitant surgical procedures, repeat dislocation, subsequent surgery, limp, pain, and range of motion symmetry was recorded.

Results: Eighteen hips that underwent MOR with LT reconstruction were compared to 20 hips that underwent MOR without LT reconstruction. Mean follow up for this cohort was 70.1 months (median: 61.8; Range: 24.2 to 182.2 months). The group with LT reconstruction had an 11% rate of AVN, the group without LT reconstruction had a 15% rate of AVN ($p=1.0$) No hips in either group re-dislocated or had pain at final follow up. Two hips (5%) had a limp at most recent follow up, all were in the group that did not receive a LT reconstruction ($p=0.488$). Three hips (17%) in the LT reconstruction group and one hip (5%) in the other group had asymmetrical hip range of motion at final follow up ($p=0.328$).

Conclusion: This study offers preliminary data to suggest that ligamentum teres reconstruction is a safe procedure that can minimize the risk for subluxation or re-dislocation that can occur within the post reduction hip spica cast. Although in this study, the patients who did not have LT reconstruction had a similar re-dislocation rate, we believe that ligamentum teres preservation is a useful adjunct to medial open reduction, especially in centers that may only treat occasional cases or have less experience in applying an excellent hip spica cast.

Level of Evidence: III

Keywords: developmental dysplasia of the hip, ddh, medial open reduction, ligamentum teres transfer, ligamentum teres reconstruction

INTRODUCTION

Infants with hip dislocation secondary to DDH are best managed initially with closed reduction. However, in cases where closed methods fail to achieve concentric reduction, or when substantial abduction is necessary to maintain the reduction, open reduction is warranted. The final decision is made intra-operatively after a diagnostic arthrogram has been performed and evaluated. Historically, the open reduction is performed through a standard anterior ilio-femoral approach.

The medial approach was first introduced by Ludloff in 1908, and subsequently modified by Mau in 1971, Ferguson in 1973, and Weinstein and Ponseti in 1979.¹⁻⁴ These

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Disclosures: RB, CJP, JH and JDB have no potential conflicts of interest related to this study. DRW has the following disclosures: Journal of Pediatric Orthopedics, Journal of Children's Orthopedics: Editorial or governing board, Rhino Pediatric Orthopedic Designs, Inc.: Stock or stock Options, Wolters Kluwer Health - Lippincott Williams & Wilkins: Publishing royalties, financial or material support. SJM has the following disclosures: J Children's Ortho Pediatrics: Editorial or governing board. Rhino Pediatric Orthopedic Designs, Inc.: IP royalties; Stock or stock Options. VVU has the following disclosures: BroadWater: Paid presenter or speaker, DePuy, A Johnson & Johnson Company: Paid presenter or speaker, EOS Imaging: Research support, Globus Medical: Paid consultant, Imagen: Stock or stock Options, Nuvasive: Paid presenter or speaker, nView: Research support, OrthoPediatrics: IP royalties; Paid consultant; Paid presenter or speaker; Research support, Pediatric Orthopaedic Society of North America: Board or committee member, Scoliosis Research Society: Board or committee member, Spine: Editorial or governing board, Wolters Kluwer Health - Lippincott Williams & Wilkins: Publishing royalties, financial or material support.

Sources of Funding: This study was supported by Rady's Children's Orthopedic Research and Education.

approaches vary slightly based on the intramuscular interval through the adductors.⁵⁻⁷ Proponents of the medial approach point to decreased dissection and operative time, and more direct visualization of common impediments to reduction. The most significant disadvantages are the risk of avascular necrosis stemming from potential damage to the medial femoral circumflex vessels (which lie in the surgical field but are sometimes not easily visualized) and an inability to perform a capsulorrhaphy to increase hip stability.^{8,9}

Because there is a no capsular repair performed with medial open reduction, there is a potential risk for early post-operative redislocation after medial open reduction. As will be noted later, maintenance of reduction requires an excellent hip spica cast, applied in a precise position. Ideally all centers would have both excellent surgical technique and exacting hip spica application techniques, however because this ideal does not always exist, further aids for optimizing stability have been sought out.

Wenger et al., in recognizing the significant biomechanical properties of the ligamentum, particularly the stability it adds to the hip joint, proposed a technique of ligamentum transfer, tethering the femoral head with the shortened ligamentum to the inferior acetabulum, providing additional restraint to dislocation.⁸ Two groups, Wenger et al.⁸ and Bache et al.,¹⁰ simultaneously reported on this technique which serves to shorten and transfer the ligamentum to improve hip stability during medial open reduction.

Previous theories of the ligamentum teres (LT) being an embryonic remnant are no longer well supported in the literature. It is now believed to have a number of potential functions, including a role in hip stability, nociception, proprioception, vascular supply to the femoral head, and synovial fluid circulation. The LT serves as a hip stabilizer in a variety of ranges of motion such as external rotation/flexion (squatting) and internal rotation/extension (crossing one leg over other), as well as resisting hip adduction.¹¹⁻¹³ The LT thus prevents hip microinstability, femoral head subluxation, and dislocation.^{8,14,15} Animal models have demonstrated increased rates of hip dislocation after the LT was severed.^{16,17} The function of the LT as a hip stabilizer may be even more important in patients with developmental dysplasia of the hip (DDH) and joint hypermobility where primary stabilizers are often deficient.¹⁸

Histologic investigation has revealed the presence of pain-associated free nerve endings in the center of the LT indicating a role in nociception.¹⁹ Lesions of the LT are the third most common cause of hip pain in athletes undergoing hip arthroscopy.²⁰ It likely has an additional proprioceptive function as type IVa somatosensory receptors have been discovered within the LT as well.^{21,22} As

for vascular supply, The LT contains a branch of the obturator artery that supplies the femoral head of the juvenile hip with fluctuating importance through early development.²³ In adulthood, the vessels of the LT rarely supply more than a small subfoveal area at its insertion site.²⁴ The LT has also been theorized to assist in the distribution of synovial fluid within the hip joint through a “windshield wiper” effect, however this has not been well researched.²⁵

Previous studies of the LT reconstruction technique have demonstrated good short term results in a small series of patients with DDH.^{8,10,26} A comparative analysis, however, has not been performed. We sought to conduct a retrospective review of two groups of patients undergoing medial open reduction (MOR) by the same technique with one having the standard approach and the other having LT reconstruction. We reviewed clinical and radiographic outcomes in both groups with minimum 2-year follow-up.

METHODS

Subjects were included from two institutions. The first institution (I-1) routinely includes a ligamentum teres reconstruction when performing a medial open reduction to treat hip dislocations associated with infantile DDH. The second institution (I-2) does not include a ligamentum teres reconstruction when performing a medial open reduction for this condition. Otherwise, the two institutions have a similar protocol for initial treatment of infants with dislocated hips including use of the Pavlik harness, and a step-wise approach to medial open reduction if all other techniques to achieve reduction fail. The surgical technique is identical except for LT reconstruction in I-1.

Institutional review board approval was obtained from both institutions prior to data collection for this retrospective study. Subjects from I-1 were identified by a surgical database query for patients with a dislocated hip treated with an open reduction from 2001 to the year 2015. Subjects from I-2 were identified by surgical database query using associated procedure codes from 2009 to 2017. Inclusion criteria were hips treated with a medial open reduction for a dislocated hip at less than 18 months of age with a minimum of two years follow up.

All subject's charts and radiographs were retrospectively reviewed to collect demographic and radiographic outcomes of interest. Limp, pain, and range of motion symmetry at most recent follow up was recorded. Radiographic outcomes were determined using the Severin score.²⁷ Avascular necrosis (AVN) was assessed using the Kalamchi and MacEwen criteria.²⁷ Concomitant bony procedures, repeat dislocation, and additional surgeries were recorded.

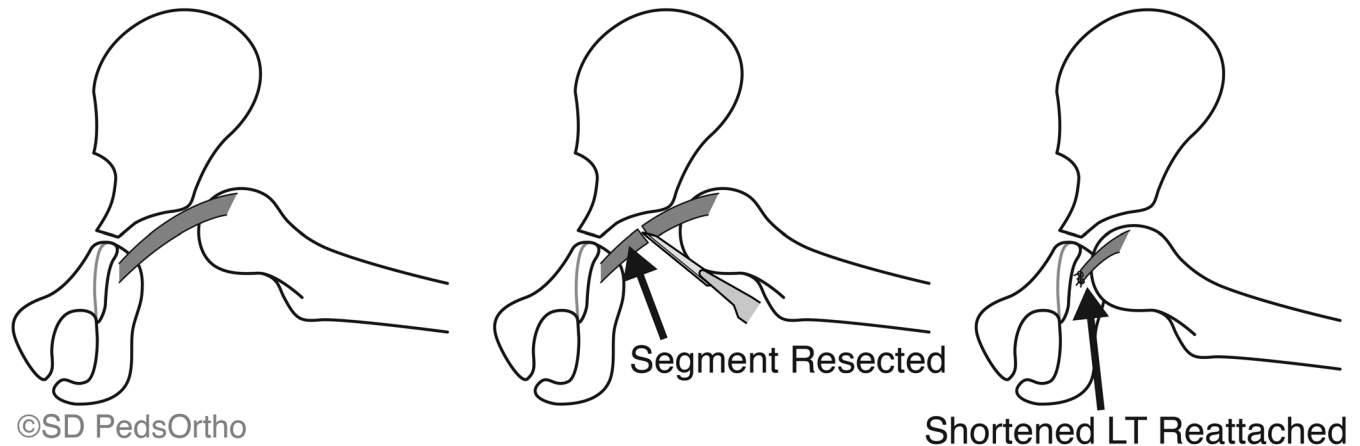


Figure 1. Sequence of drawings demonstrating the technique for ligamentum teres shortening and reattachment when performing the medial Ludloff open reduction. Left image) Femoral head in the dislocated position with elongated ligamentum teres. Center image) Ligamentum teres detached from its origin from the inferior acetabulum, with a segment resected to normalize the ligamentum teres length (approximately 1 cm resected). Right image) The shortened ligamentum teres is sutured into the anterior-inferior acetabular rim using a non-absorbable suture with a Bunnell type suture pattern.

Surgical Technique

The surgical technique used at I-1 was similar to that proposed by Mau, as well as Weinstein and Ponseti.^{2,4,8} A transverse incision is made 1 cm distal to the groin crease. The adductor longus can be divided and lengthened intramuscularly, allowing for blunt dissection above the pectineus muscle. The psoas tendon is identified with an intramuscular lengthening performed, bringing the capsule into view. Care is taken at this point to identify and protect the medial femoral circumflex artery. The capsule is opened in a T-fashion. The LT is identified and transected at its insertion into the base of the acetabulum. The acetabulum is inspected and any residual, excessive fatty tissue is removed and the transverse acetabular ligament is incised. The LT, which remains attached to the femoral head, is then used to pull the femoral head distally into a reduced position. The LT is then shortened and reattached, using a Bunnell type suture, into the anterior/inferior acetabular rim.⁸ The suture is placed near the anterior attachment of the transverse ligament which has been transected (Fig. 1). The usual protocol is to keep the patient in a 1 1/2 hip spica for 6 weeks with the cast then change to a double short leg hip spica for an additional 6 weeks followed by 6 weeks in a hip abduction brace. This assures development of the acetabulum.

The hip stability in various positions is determined and the degree of flexion, abduction, and rotation that provides optimum stability is noted. The child is placed in a 1 1/2 hip spica with the hips held in the “human position”²⁸ with the hip casted in the exact position of optimum stability that was determined earlier.

The surgical technique used at I-2 is identical to the technique used at I-1 except that after opening the cap-

sule, the LT is identified and resected at its origin at the base of the acetabulum and also detached from the femoral head and discarded. The casting position and protocol are as noted above.

Statistical Analysis

Basic descriptive statistics are reported. The hip was used as the unit of analysis. Continuous data were evaluated for normality with the Shapiro-Wilk test of normality. Data identified as normal with the Shapiro-Wilk test was also evaluated with Levene’s test of homogeneity of variances. Data identified as non-normal by either test was evaluated with the Mann-Whitney U, normally distributed data was evaluated with analysis of variance (ANOVA). Categorical data were evaluated with Pearson Chi-square and Fisher’s exact test. All statistical analysis was performed using IBM SPSS Statistics (version 26; IBM, Armonk, New York). Statistical significance was defined as $p < 0.05$. No a priori power analysis was performed.

RESULTS

Thirty-eight hips (30 patients) were included in the study – 18 were treated with ligamentum teres reconstruction, and 20 were treated without ligamentum teres reconstruction. The mean age of the cohort at the time of open reduction was 7.9 ± 4.8 months (median: 5.7; range: 2.9 to 17.6 months). The mean follow up for the cohort was 70.1 ± 36.7 months (median: 61.8; range: 24.2 to 182.2 months). The majority of subjects were female (82%). No hips underwent concomitant bony surgery. None of the hips re-dislocated after MOR. Four hips from each group were found to have AVN at most recent follow up ($p = 0.714$). The hips treated with ligamentum teres recon-

Table 1. Distribution of Subsequent Procedures

	Ligamentum Teres Reconstruction	No Ligamentum Teres Reconstruction
San Diego acetabuloplasty	5	0
Pemberton	2	2
Dega	0	1
San Diego acetabuloplasty, VDRO	1	0
Pemberton, VDRO	0	1

VDRO = varus derotation osteotomy

struction had two hips with group I AVN and two hips with group II AVN. The hips treated without ligamentum teres reconstruction had one hip with group I AVN, two hips with group II AVN, and one hip with group IV AVN. Two hips (5%) had a limp at most recent follow up, both were in the group that did not have a ligamentum teres reconstruction. None of the hips had pain at most recent follow up. Four hips (11%) had asymmetrical hip range of motion at final follow up. Twelve hips (32%) underwent later bony surgery to correct residual dysplasia (Table 1). Additional cohort characteristics and outcomes of interest can be found in Table 2.

DISCUSSION

The LT is believed to have a number of important functions, contributing to hip stability, sensory information,¹⁹⁻²² femoral head vascularity,^{23,24} and synovial fluid circulation.²⁵ The LT serves as a hip stabilizer in a variety of ranges of motion¹¹⁻¹³ thus preventing hip microinstability, femoral head subluxation, and dislocation.^{8,14,15} This has been supported in animal models which demonstrated increased rates of hip dislocation after the LT was severed.^{16,17} The function of the LT as a hip stabilizer may be even more important in patients with developmental dysplasia of the hip (DDH) and joint hypermobility where primary stabilizers are often deficient.¹⁸

Since Weinstein et al. reported results following their modification of the Ludloff procedure in 1997, interest has expanded on the medial open reduction as an alternative to the traditional anterior approach in North America. Although multiple studies have demonstrated favorable outcomes following this procedure, re-dislocation con-

Table 2. Cohort Characteristics and Outcomes of Interest

		Ligamentum Teres Reconstruction	No Ligamentum Teres Reconstruction
Age at surgery (months)	Mean±SD	7.3±4.7	8.5±5.0
	Median	5.6	6.35
	Range	3.0 to 16.4	2.9 to 17.6
Sex	Male	2	5
	Female	16	15
Concomitant bony procedure		0	0
Re-dislocation		0	0
Severin grade at final follow up	1	15	4
	2	2	14
	3	1	1
	4	0	1
AVN grade at final follow up	0	14	16
	1	2	1
	2	2	2
	3	0	0
IHDI grade at final follow up	4	0	1
	I	18	19
	II	0	1
Limp at final follow up		0	2
Pain at final follow up		0	0
Asymmetrical ROM at final follow up		3	1
Acetabular index (degrees) at final follow up	Mean±SD	17.7±10.7°	21.6±7.8°
	Median	20°	23°
	Range	-5° to 44°	12° to 36°
Follow up (months)	Mean±SD	73.4±44.1	61.7±29.3
	Median	66.93	60.96
	Range	24.2 to 182.2	28.5 to 122.8

tinues to be a challenge. This sometimes occurs within the cast soon after surgery, a circumstance that is very stressful for both the family and the surgeon. Tonnis et al. noted a 5-14% dislocation rate following the medial open reduction, compared to a 3% with an anterior approach.^{8,29}

More recent studies note lower rates, ranging from 0% to 6.1% in our literature review.^{5-7,30-40}

Infant hip spica cast application, to maintain hip reduction, is a critical part of medial open reduction. Ideal spica casting is often hard to achieve, particularly in institutions that have a modest volume of DDH cases that would be treated with medial open reduction in this age group. Maintaining the LT may be a useful adjunct to minimize the chance for re-dislocation.

Traditionally, the LT has been thought to be a block to reduction in congenitally dislocated hips. Additionally, it is thought that the increased stress on the ligament in hip dysplasia results in hypertrophy of both the LT and the transverse ligament, decreasing the volume of the acetabulum and making concentric reduction more difficult.⁴¹ Thus, almost all types of open reduction of the hip in young children have included removal of the LT.

Biomechanical properties of the ligamentum have been elucidated in animal models in several studies.^{17,26} In humans, Demange et al. found that resection of the ligamentum increased the maximum adduction of the hip in cadavers.¹³ Phillipon et al. demonstrated a maximum load to failure of 204N using a human cadaver model.⁴² Adaptation to continued strain has been noted in patients with DDH, with elongation and hypertrophy of the ligamentum.^{41,43} Martin et al. additionally noted that the ligamentum is taut in positions of potential hip instability, and hypothesized a potential role in constraining the hip in DDH.¹¹

In this study, we observed no re-dislocations in either group. Rates of avascular necrosis of up to 67% have been reported in the literature with the medial approach.^{9,35,39} Our report compared favorably to this, and is similar to rates of AVN seen with anterior open reductions or closed reduction and casting without open reduction. However, our follow-up is limited with a minimum of 24 months and the true incidence of AVN may increase over time. Clearly, placing an infant in a hip spica, no matter how well designed and applied, increases the chance for AVN. Hip abduction in the hip spica is clearly a double-edged sword, because with too little abduction, the hip is more likely to re-dislocate in the hip spica – while excessive abduction can increase the risk for AVN. Proponents of LT maintenance and re-attachment would suggest that the procedure provides greater hip stability, thus allowing less forced hip abduction in the spica cast.

Twelve of the 38 hips (32%) in our cohort required additional bony surgery for residual dysplasia. Similar results have been noted in other reports of medial open reduction, without ligamentum teres tenodesis.^{6,33,35,37} Bache et al., in their large case series of 109 hips that underwent medial open reduction with ligamentum teres tenodesis, noted additional surgery in 35% of hips.¹⁰ Additionally, they found a

dislocation rate of 2.8%, and 89% of hips demonstrated good or excellent radiographic results on the Severin scale. The AVN rate in their study was 41%, compared to the 21% noted in our study, however their study had longer follow up with more time to detect possible residuals of AVN.

The lack of any cases with re-dislocation in either series is of interest. One reason may be that the cases treated with traditional LT excision occurred in a children's hospital (I-2) with a long history of experience with the medial approach and is a center that helped introduce this technique to North America. In addition, I-2 has a strong tradition for superb casting techniques. In such circumstances, LT maintenance may not be an important component of medial open reduction. In less ideal circumstances, LT re-attachment can be an important addition to medial open reduction, minimizing the risk for early post-operative re-dislocation.

Our findings are primarily limited by a modest sample size and relatively short follow up. It is possible that rates of repeat surgery and AVN could increase with time. Although our study cannot produce definite conclusions due to the magnitude of these limitations, it does offer preliminary data to suggest that ligamentum teres reconstruction is a safe and effective procedure.

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MAGNETICALLY CONTROLLED GROWING RODS FOR EARLY SCOLIOSIS TREATMENT IN COFFIN-SIRIS SYNDROME: CASE REPORT AND LITERATURE REVIEW

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ABSTRACT

Coffin-Siris Syndrome (CSS) is a rare, genetic syndrome characterized by multiple anomalies, including scoliosis. However, there are only a few reports about the management of scoliosis in these patients. We present the case of an 8-year-old female with CSS presenting with a progressive, rigid thoracolumbar kyphoscoliosis. She was successfully treated with a magnetically controlled growing rod, demonstrating improved ambulatory capacity and performance of activities of daily living. In pediatric patients with Coffin-Siris syndrome, magnetic expandable rods can be considered as an option for the management of progressive early-onset scoliosis.

Level of Evidence: V

Keywords: children, Coffin-Siris, early onset scoliosis, MAGEC, magnetically controlled growing rods

INTRODUCTION

Coffin-Siris syndrome (CSS), also known as 'fifth digit syndrome', is a rare genetic disorder and fewer than 200 cases of CSS have been genetically confirmed to date. The exact incidence is unclear, but this disorder is estimated to occur in 1/10,000 to 1/100,000 individuals.¹ Transmission is autosomal dominant with complete penetrance and is associated with mutations involving SMARCB1 gene.² CSS is characterized by intellectual disability, growth restriction, absent or hypoplastic fifth finger terminal phalanx, hirsutism, hypotonia and cardiac, neurological, gastrointestinal and genitourinary anomalies.^{3,4} Scoliosis is present in about 30 percent of children with CSS^{2,3} and the management of early-onset scoliosis (EOS) in these patients has not been well studied. Historically, conservative treatment, such as

casting or bracing, were utilized in an attempt to delay the need for spinal fusion in selected patients.^{5,6} However, recent studies have demonstrated bracing may be less effective in patients with a congenital or neuromuscular etiology.^{7,8} In young patients, early spinal fusion may limit normal spinal growth, resulting in a poor clinical and respiratory outcome.⁹⁻¹¹ Growing or expandable implants allow continued spine and chest growth, while providing curve stabilization, preserving lung function, and delaying the need for spinal fusion.^{12,13} Types of expandable devices include: traditional growing rods (TGR), vertical expandable prosthetic titanium rib (VEPTR) devices, hybrid systems, and magnetically controlled growing rods (MCGR).¹⁴ One type of MCGR, MAGnetic Expansion Controlled (MAGEC) rods, have been increasingly used for the management of early onset scoliosis (EOS), because unlike traditional growing rods, they can be lengthened in the office setting without the need for general anaesthesia and repeated invasive surgery.^{15,16}

While the manifestation of EOS in CSS has been demonstrated, there are few studies describing treatment.^{17,18} Here, we report on an 8-year-old female with CSS and EOS treated with a bilateral rib-to-pelvis MAGEC rods implant, as well as provide a review of the existing literature.

CASE REPORT

Informed consent for publication was obtained from the patient's parents. An 8-year-old female with CSS presented with severe kyphoscoliosis. The diagnosis was suspected due to clinical features and confirmed by genetic analysis, which confirmed the diagnosis by showing heterozygosity for exon 8 of the SMARCB1 gene.³ The patient had several other manifestations, including microcephaly, low-implanted ears, phalanx hypo-aplasia V finger hands and feet [Fig. 1], cleft lip and palate, fine hair, mild hypotonia, intellectual disabilities, and growth delay. Walking and standing positions were remarkably difficult to maintain, even with assistive device. She also experienced seizures, manifesting with worsening hypotonia, loss of consciousness, and short desaturation episodes. Pulmonary evaluation demonstrated mild restrictive lung disease. The patient had a gastrostomy tube in-place for nutritional support. Her height was 110 cm and her body weight was 21 kg.

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

Sources of Funding: No sources of funding declared.



Figure 1. Hands and feet with V finger phalanx hypo-aplasia.

Physical examination and radiographic analysis demonstrated a severe right-sided convex kyphoscoliosis. The lumbar Cobb angle (L1-L5) measured 85° and the compensatory thoracic curve 69° (T7-T11). The thoracic kyphosis curve from T2 to T12 measured 92° with compensatory lumbar lordosis [Fig. 2]. Due to the patient's young age, clinical condition and the severity of her kyphoscoliosis, the patient was treated with MAGEC rods (NuVasive, San Diego, California) and posterior selective spinal correction from T3 to the sacrum. The apical hooks were applied bilaterally on the third, fourth and fifth ribs. Pelvic fixation was performed with iliac screws. We used intraoperative blood salvage and the patient did not require allogenic blood transfusion. Intraoperative spinal cord monitoring was conducted with both somatosensory evoked potentials (SSEP) and motor evoked potentials (MEP) and no significant intraoperative changes occurred. After the procedure, the lumbar curve measured 48° , the thoracic curve measured 47° and kyphosis measured 72° . The patient healed her wound without difficulty and did not experience postoperative infection.

Following placement of the MAGEC rods, symmetrical rods lengthening was performed every 2-3 months and monitored using ultrasound (US) and radiographs. At the 6-months postoperative, radiographs demonstrated rod dislocation due to a bilateral disengagement of the proximal hooks [Fig. 3]. This was managed with revision of the proximal aspect of the construct, by applying a fourth reverse hook on the second rib facing

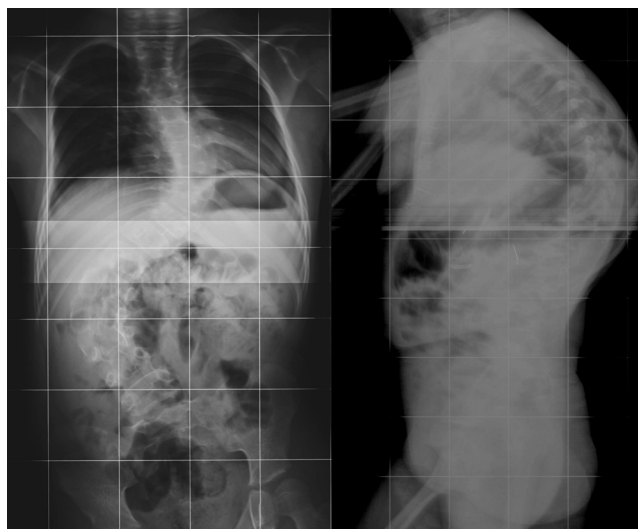


Figure 2. Pre-operative x-ray: anteroposterior (AP) and lateral views.

the regular hook to obtain a ring around the ribs. The post-operative lumbar curve after revision surgery was 59° , the thoracic curve measured 49° , the kyphosis was 68° [Fig. 4].

Following the revision procedure, we continued the lengthening protocol and no further complications occurred. Total lengthening at the two-year follow-up was 21 mm for each rod. Her gait and sitting balance were improved. At one-year follow-up, the patient was able to ambulate without assistive device. At two-year follow-up, the lumbar curve measured 61° , the thoracic curve measured 50° , and kyphosis measured 72° [Fig. 5]. The patient demonstrated further improvements in functional status, as she was able to perform exercises such as sit-to-stand and ascending and descending stairs. The family was highly satisfied with their daughter's improved mobility.

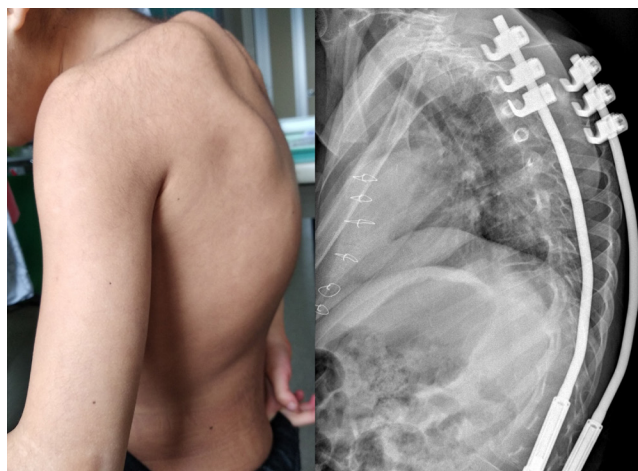


Figure 3. Proximal hooks dislocation: clinical and x-ray lateral view.

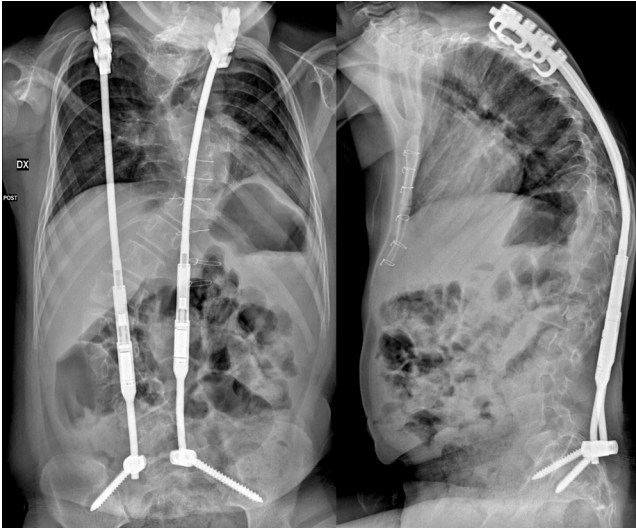


Figure 4. Post-revision x-ray: anteroposterior (AP) and lateral views.

DISCUSSION

We present a case of scoliosis in a patient with CSS treated with MAGEC rods and demonstrating improvement in functional status. We utilized a hook-to-rib construct proximally, with goals of reducing thoracic deformity and preservation of pedicles for possible future spinal fusion. Proximal hook dislocation occurred and has been described as a complication of this technique, with a reported incidence of 11.8%.²³ Distally, pelvic fixation was chosen to avoid pelvic tilt, which is typical of neuromuscular scoliosis. A dual rod construct was utilized, to permit increased distraction forces and capacity for correction.²⁴ To assess rod lengthening, we used US to perform multiple measurements and ensure the lengthening goal was reached. Once the target was achieved, it was confirmed by x-ray, as US has not proven to be superior to x-ray measurements of lengthening and it cannot detect actuator pin fracture.^{29,30} At 2-year follow-up, improvement compared to the preoperative deformity has been maintained without further implant failure.

There are few reports describing the natural history or treatment of scoliosis in CSS, including only two prior surgical reports and not involving use of MAGEC rods.¹⁷⁻²¹ Gross et al. described treatment of a five-year-old female with CSS and a severe EOS with a 94-degree curve, treating using a hybrid growing-rod construct.¹⁷ This case was also complicated by pull-out of proximal hooks, rod fracture, failure of pelvic fixation, and deep infection.¹⁷ Additionally, Wick et al. presented the case of a three-year-old patient with a rigid, 90-degree, managed with halo traction and Phenix magnetic expandable rods.¹⁸ In this case, the patient's postoperative clinical course was uneventful.¹⁸

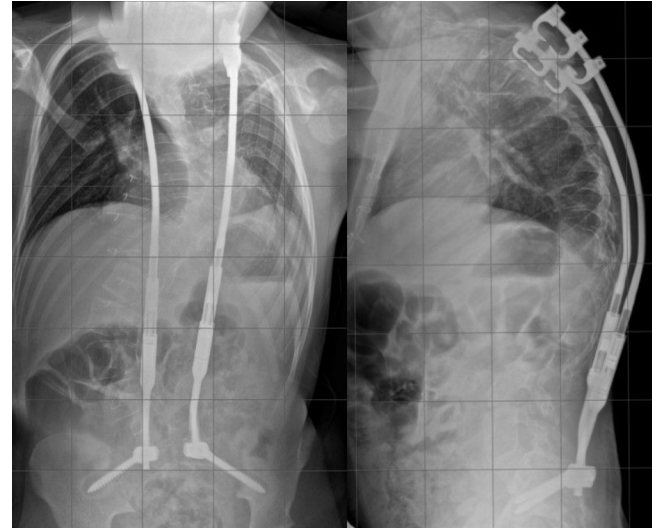


Figure 5. Two-year follow-up x-ray: anteroposterior (AP) and lateral views.

Kyphoscoliosis in patients with CSS is challenging to treat and there is little evidence to guide treatment. Patients with SMARCB1 mutation have been described as having greater curve severity.³ Untreated scoliosis may result in progress deterioration of functional status, quality of life, and pulmonary status.³ While deformity correction may be less than with definitive spinal fusion, expandable constructions allow for preservation of growth and pulmonary function while managing progressive spinal deformity.²² Patients with neuromuscular scoliosis have been shown to experience a higher complication rate after growth-friendly spinal surgeries compared to children with EOS and no neurological impairment.⁷ Therefore, a MCGR implant, which permits spinal lengthening without the need for repeated surgical procedures. This results in fewer episodes of general anaesthesia, less patient discomfort, possibly fewer wound complications, and reduced healthcare expenditures.^{12,25-28}

In conclusion, the present report suggests that MAGEC rods may be used for treatment of scoliosis in paediatric patients with CSS, as an alternative to traditional growing rods.

ACKNOWLEDGEMENTS

The authors are grateful to L. J. Mesh for careful reading of the manuscript and for language assistance.

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HEALTH LITERACY IN CLUBFOOT: A QUANTITATIVE ASSESSMENT OF THE READABILITY, UNDERSTANDABILITY AND ACTIONABILITY OF ONLINE PATIENT EDUCATION MATERIAL

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ABSTRACT

Background: Parents often access online resources to educate themselves when a child is diagnosed with clubfoot and/or prior to treatment initiation. In order to be fully understood by the average adult American, online health information must be written at an elementary school reading level. It was hypothesized that current available online resources regarding clubfoot would score poorly on objective measures of readability (syntax reading grade-level), understandability (ability to process key messages), and actionability (providing actions the reader may take). Additionally, it was hypothesized that the outcomes measured would not correlate with the order of listed search results.

Methods: Patient education materials were identified utilizing two independent online searches (Google.com) of the term "Clubfoot". From the top 50 search results, websites were included if directed at educating patients and their families regarding clubfoot. News articles, non-text material (video), research and journal articles, industry websites, and articles not related to clubfoot were excluded. The readability of included resources was quantified using the Flesch Reading Ease Score (FRES), Flesch-Kincaid Grade Level (FKGL), Simple Measure of Gobbledygook (SMOG) Grade, Coleman-Liau Index (CLI), Gunning-Fog Index (GFI) and Automated Reading Index (ARI). The Patient Education Materials Assessment Tool (PEMAT) was used to assess actionability and understandability using a 0-100% scale for both measures of interest.

Results: Of the 55 unique websites, 37 websites (65.2%) met inclusion criteria. The mean FKGL was 9.2 (+/- 2.1) with only three websites (7.32%) having a reading level ≤ 6 . Mean understandability

and actionability scores were 67.2 ± 12.6 and 25.4 ± 25.2 , respectively. Thirteen (35%) websites met the understandability threshold of $\geq 70\%$ but no websites met the actionability criteria. No readability statistics were statistically associated with Google™ search rank ($p=0.07$). There was no association between readability ($p=0.94$) nor actionability ($p=0.18$) scores and Google™ rank. However, understandability scores did correlate with Google™ rank ($p=0.02$).

Conclusion: Overall, online clubfoot educational materials scored poorly with respect to readability, understandability, and actionability. There is an association with Google™ search rank for understandability of clubfoot materials. However, readability and actionability are not significantly associated with search rank. In the era of shared decision-making, efforts should be made by medical professionals to improve the readability, understandability, and actionability of online resources in order to optimize parent understanding and facilitate effective outcomes.

Level of Evidence:

Keywords: clubfoot, health literacy, readability

INTRODUCTION

Clubfoot, also known as congenital talipes equinovarus, is a relatively common congenital abnormality with a diagnosis being made in approximately 1 in 1,000 live births.¹ Clubfoot occurs at a 2:1 ratio in male to female infants and is bilateral in approximately 50% of cases.² The deformity consists of a combination of four specific foot abnormalities: forefoot adduction, midfoot cavus, hindfoot varus, and ankle equinus. The diagnosis of clubfoot can be distressing and overwhelming for parents, with previous studies reporting extreme stress at the moment of diagnosis related to the explanation of treatments, information about prognosis, and the lack of concrete details surrounding the condition.^{3,4} This emphasizes the need for accessible educational resources to help reduce parental anxiety associated with clubfoot deformity.⁴

Currently, the most widely accepted treatment for clubfoot is the Ponseti method.⁵ While this is a non-invasive procedure that consists of foot manipulation through

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

Sources of Funding: No sources of funding declared.

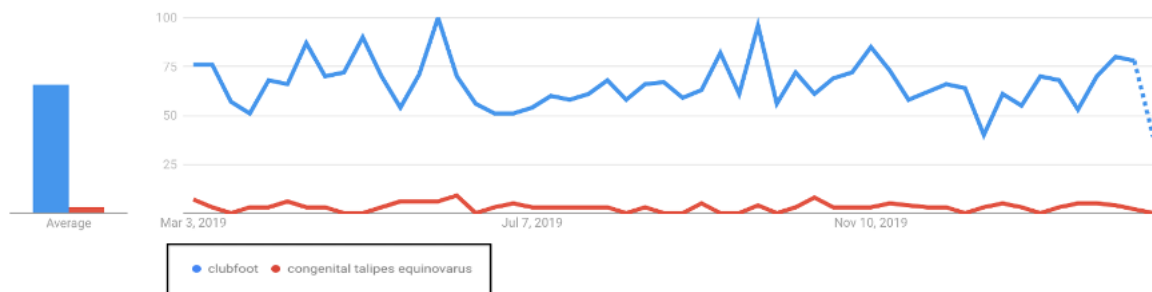


Figure 1. Google Search Trends. Value ranked 0-100 based on Google™ algorithm. A value of 100 indicates peak popularity of the term. Studies demonstrate that “clubfoot” was 21.8 times more likely to be searched by the general public compared to “congenital talipes equinovarus.”

sequential casting and often, percutaneous tenotomy, the Ponseti method is not simple and requires multiple clinic visits.^{3,4,6,7} Once the correction has been achieved, long term success is attained through the utilization of an abduction brace.^{6,8} However, the abduction brace requires significant commitment of the family and should be worn 23-24 hours each day for the first two to three months followed by 10-12 hours at night the subsequent three to four years.⁹ While the Ponseti method is successful at treating 95-97% of clubfoot cases, strict understanding and adherence to making follow up visits and correctly wearing the brace is essential for long term success. It has been previously reported that recurrence happens in 20-41% of cases treated with the Ponseti method, with brace non-compliance being the leading factor associated with relapse of the deformity.^{6,8-12}

The quality of online educational materials regarding clubfoot is currently poorly understood. Previous orthopaedic and surgical literature have analyzed the readability of patient education materials to assess the reading grade level of materials.¹³⁻¹⁵ Readability measures, however, are based on syntax and are limited in the assessment of a resource’s ability to convey information such that readers can process and act on key messages. This limitation has been recognized and the Patient Educational Materials Assessment Tool (PEMAT) has become increasingly used to study patient education materials in surgical fields to evaluate the understandability (defined as the ability of readers to “process and explain key messages”) and actionability (defined as the ability of readers to “identify what they can do based on the information presented”) of educational materials.^{13,14,16-18} There is a paucity of literature evaluating whether online clubfoot patient resources are presented so that readers can efficiently understand the information and/or identify available actions.¹⁹ The purpose of the current study was to utilize PEMAT and validated readability algorithms to quantify readability, understandability, and actionability of online clubfoot patient education resources.^{16,18,20}

METHODS

Collection of Patient Education Material

Using the trends analysis (trends.google.com²¹), the most common searched term “clubfoot” was determined for article identification. (Figure 1).

For internal validity, two Google™ searches were independently performed by two authors on 2/26/2020 (TRG and BG). The Google™ search engine was utilized because Google™ searches comprised 88-92% of online search market share at the time of this study.^{22,23} A target of the first 50 websites from each search were chosen for two reasons. First, analyses of click-through-rates suggest that approximately 70% or more of “clicks” come from the first 10 search results.²⁴⁻²⁶ Second, previous PEMAT studies have ranged from targeting the first 10 to 50 websites, so our search was made to be consistent with these prior analyses.^{17,27,28} The search results from both searches were identified and duplicates were removed. Exclusion criteria included: news articles; personal experiences; primarily audiovisual-based materials; written for reference by health care professionals; peer-review journal studies; focused primarily on the advertisement of a product or service without patient education; articles without patient-oriented tone; or unrelated to clubfoot or clubfoot related treatment. Audiovisual-based websites were excluded because these could not undergo readability analysis.

Content analysis

All included websites underwent qualitative review of their content including the following categories: discussion of operative management; discussion of non-operative management; advertisement of a physician or group who offered the treatments described; discussion of general background information (anatomy, pathology, prognosis, and/or risk factors); discussion of clubfoot prevention; discussion of clubfoot diagnosis and/or preoperative management; discussion of postoperative management; and discussion of complications or risks of treatment. Online resources were categorized as

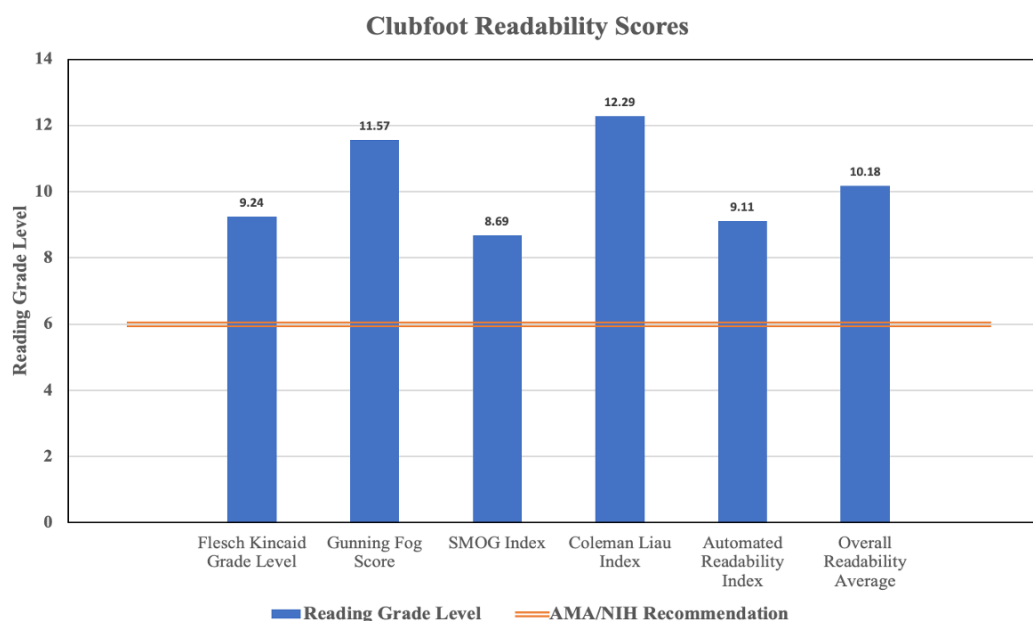


Figure 2. Mean Readability scores. The American Medical Association (AMA) and National Institutes of Health (NIH) recommend health information to be written at a 6th grade or lower reading level (orange line). All readability average scores exceed this recommended reading level.

including advertisements of a medical provider if it stated that a specific institution or group provided the treatments described on the website or a treatment related to clubfoot pathology within the main text of the educational material.

Statistical analysis

Readability

The following objective algorithms were utilized to determine the linguistic readability of the content: Flesch Reading Ease Score (FRES), Flesch-Kincaid Grade Level (FKGL), Simple Measure of Gobbledygook (SMOG) Grade, Coleman-Liau Index (CLI), Gunning-Fog Index (GFI) and Automated Reading Index (ARI). (Figure 2). These five algorithms have been reliably used to utilized in previous readability studies and were obtained using open-source readability software (<https://www.webfx.com/tools/read-able/check.php>).^{14-17,19,27} Text unrelated to patient education including copyright, references, and links outside of main text were excluded from readability analysis.

Understandability and Actionability analyses

The PEMAT is a validated and reliable instrument utilized to assess the understandability and actionability of printed patient education materials. PEMAT analysis yields separate understandability and actionability scores. Scores are expressed as a percentage (0-100%) for each evaluated resource. A higher graded score represents a better level of understandability or actionability. A PEMAT score of 70% is considered the

minimal standard for adequate results. Two reviewers (WL and MKS) individually conducted understandability and actionability analyses using the PEMAT-P form.^{20,29} Interrater reliability was calculated using Cohen's Kappa. The magnitude of the kappa statistic was interpreted by the criteria established by Landis et al.,³⁰ and was utilized by the PEMAT developers to measure the reliability of PEMAT scoring.^{18,31}

Additional statistical analysis

Google™ search engine ranking was averaged from two independently conducted searches. Spearman's rho was used to assess the correlation between variables in this study including search ranking, readability, understandability, and actionability. Statistical significance was defined as $p < 0.05$.

RESULTS

Following the two independent searches and the removal of duplicate websites, a total of 55 unique online materials were identified. Thirty-seven (67.3%) websites met inclusion criteria. Six websites were excluded due to being written for reference by health care professionals, four peer-review journal studies, four audiovisual-based materials; and two personal experiences. Additionally, four websites were excluded as not related to patient-and-family-directed medical education.

Of the 37 included online educational resources, 93% of websites included background information (anatomy, pathology, prognostic factors). 88% of websites described non-operative management of clubfoot, and 67% of web-

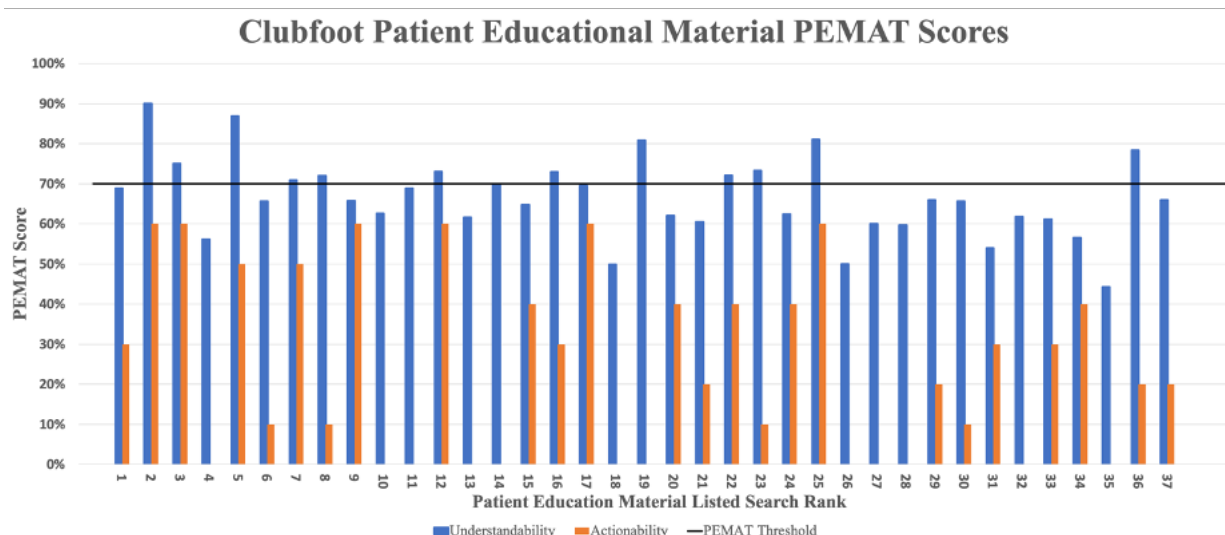


Figure 3. Acceptable understandability and actionability scores are $\geq 70\%$ as established by the PEMAT tool. Only 13 (35%) websites met the 70% understandability threshold, while no (0%) websites scored above the 70% actionability threshold.

sites that discussed operative management. The majority of websites (81%) discussed the workup and diagnosis of clubfoot, while only 45% discussed the postoperative course. Only 30% of websites included risks and complications of clubfoot management. Of the 37 included websites, around half (49%) included an advertisement for a physician or group who provided the described management.

Readability

The mean FRES was 57.5 (SD: 11.2) (Figure 2). Across all readability scores reporting grade-levels, average grade-levels ranged from 5.5 to 13.4. The mean FKGL, SMOG, CLI, GFI, and ARI were 9.24 (SD: 2.1), 8.69 (SD: 1.7), 12.29 (SD: 1.9), 11.57 (SD: 2.4), and 9.11 (SD: 2.3), respectively. Three (8.1%) websites scored \leq 6th grade reading level. (Figure 2)

Understandability and Actionability

Mean understandability and actionability scores were 67.2% (SD: 12.6) and 25.4% (SD: 25.2), respectively (Figure 3). Overall, 13 (n=35%) met the understandability threshold of 70%. However, no websites met the threshold of actionability ($\geq 70\%$). The most frequently missed understandability criteria included a lack of summaries and a lack of clear titles. Importantly, the included online resources were not written in common, everyday language. In regard to actionability criteria, the included resources frequently did not include at least one, specific action to be taken by the reader. Furthermore, if an action was provided, it was not broken down into manageable, explicit steps. Another commonly missed actionability criteria was a lack of visual aids to help facilitate the described actions.

Search Rank

There was no association between readability ($p=0.94$) nor actionability ($p=0.18$) scores and Google™ rank. However, understandability scores did correlate with Google™ rank ($p=0.02$).

DISCUSSION

This study investigated the readability, understandability, and actionability of online resources directed toward patients and family involved with clubfoot treatment. Our results Demonstrated that these commonly utilized resources scored poorly in regard to all variables that were measured.

Access of the internet is common in the United States. As of 2018, 90% of US adults had access to the internet,³² with at least 1 in 3 using the internet to diagnose or learn more about various health conditions.³³ Amid increasing access and utilization of the internet, online resources play an increasing role in patient education. Interestingly, the internet has played a major role in the advancement of clubfoot education through available online patient resources. Morcuende et al. demonstrated the importance of internet resources in the decision making and support of patients and family members involved in the diagnosis and treatment of clubfoot. Through a retrospective review of websites, web based chat groups, and virtual hospital webpages on clubfoot, they discovered an average of 27,334 website visits (hits) per month and information requests from all 50 states as well as 72 countries.³⁴

As access to internet resources continues to expand, there is an increased need to emphasize the importance of well-designed and patient centered online material to

facilitate patient education and decision-making.³⁵ The AMA and NIH currently recommend that public health literature be written at the 6th grade reading level or lower, in order to be understood by the average adult.^{36,37} Our readability analysis demonstrated that the mean grade level was well above these recommendations, at 9.2. This is troubling because it is estimated that 80-90 million Americans have limited health literacy.³⁸⁻⁴⁰ Additionally, parental education for those impacted by clubfoot has been demonstrated to increase parental understanding and compliance with bracing,⁴¹ a critical aspect of long-term success with the Ponseti method.^{5,8-10,41} Equally, studies have demonstrated that lower parental education level is associated with higher rates of relapse.^{9,10,42} A study by Dobbs et al. found that the risk of a clubfoot relapse is increased ten-fold when the parents have an education level of high school degree or less, as compared to parents who achieved education beyond high school.⁹ Interestingly, in the study by Dobbs et al., a subset of patients were referred to the authors' care via clubfoot internet resources with the specific goal of pursuing the Ponseti method. All parents in this specific subset cohort reported full compliance with the bracing and none of the children in this cohort experienced a recurrence. While all parents in this group obtained higher education and may be more motivated to achieve success with the Ponseti method, this finding still does highlight the potential role of online education materials in the bigger context of education, compliance, and recurrence prevention for clubfoot.

In order to improve readability scores, materials should use fewer words per sentence and fewer syllables per word. These factors are the driving variables behind the readability algorithms (Figure 2). Although this may be difficult in the medical field, due to the complexity of medical vocabulary, every effort should be made to utilize common, non-medical language. It is also important to utilize short sentences to avoid complex sentence structures that may exacerbate the level of difficulty.

However, readability is only a small factor in assessing the usefulness of patient educational resources as the effectiveness of educational material depends on more than just vocabulary, syllable count, and sentence structure. While the access to resources is valuable, producing patient education materials that the average adult in the United States can understand is crucial. Unfortunately, similar to other surgical subspecialties,^{16-19,27} the clubfoot patient education materials scored poorly on actionability and understandability. These previous studies have looked at the importance of understandability and actionability for educational efficacy. One such study was completed by Paulsen-Miller et al., who investigated the educational needs of parents of children

being treated for clubfoot deformity.⁴² Of the thirty parents who were interviewed, approximately two-thirds reported initial confusion about the actual Ponseti method itself, despite utilizing their available resources. When asked about compliance with the treatment regimen, parents provided suggestions for ways that providers could enhance success. Parents requested that health care providers provide education on the treatment and risk of relapse, including access to educational materials online with the utilization of visual aids and videos. This demonstrates the need for leaders in the field to tailor website curriculum to be of maximum efficiency to patients and the general public in relation to clubfoot and its associated treatment.

Understandability and actionability are crucial components of effective education. In order to improve understandability and actionability for their audiences, authors of online educational materials should incorporate the components of the PEMAT criteria. For example, the authors should avoid medical vocabulary whenever possible and if the term is necessary, authors should explicitly define included medical terms. Authors should also consider limiting distracting information, simplifying presented data, and utilize the active tense. Visual aids should be non-cluttered, reinforce the written information, and contain informative, but clear captions. One of the most crucial components is to include actions for the reader within the resource. Furthermore, authors should break the action into "manageable, explicit steps" to facilitate action. Other important components of actionability include providing a tangible tool (such as a checklist) or providing a visual aid to accompany the explanation of the intended action. Overall, the PEMAT tool provides authors with numerous criteria that can be incorporated to improve patient education resources.

Limitations and future research

This study has several limitations. First, this study utilized the first 50 search results from a public online search engine. These top 50 results could be different at various times and search locations. In order to mitigate some of this variability, the authors cleared all cookies and cache prior to the search. Another limitation is the subjectivity of the PEMAT grading and implicit bias could not be fully eliminated. To limit this bias and subjectivity, two authors independently performed the grading, which demonstrated agreement with good inter-rater reliability ($\kappa = 0.52 \pm 0.04$), consistent with prior studies.²⁰

Prior to performing both Google™ searches, internet browsing histories and stored cookies were erased.

While previous studies have investigated the impact of education and compliance on clubfoot recurrence rates, we could find no literature that investigated the cost ef-

fectiveness of clubfoot education. Future studies looking into the effectiveness and cost benefits of clubfoot education are needed. Furthermore, future research should be conducted to investigate the accuracy of educational materials, which neither the readability scoring nor PEMAT scoring takes into account.

CONCLUSION

Overall, the online clubfoot patient educational materials scored poorly in readability, understandability, and actionability measures. There is an association with Google™ search rank for understandability of clubfoot materials. However, readability and actionability are not significantly associated with search rank. In the era of shared decision-making and readily available information, efforts should be made by medical professionals to improve the readability, understandability, and actionability of online patient resources in order to optimize parent understanding and facilitate effective decision-making.

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PEDIATRIC SUPRACONDYLAR HUMERUS FRACTURES CAN BE SAFELY TREATED BY ORTHOPAEDIC SURGEONS WITH AND WITHOUT PEDIATRIC FELLOWSHIP TRAINING

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ABSTRACT

Background: The purpose of this study was to compare the outcomes of pediatric patients who were surgically treated for a supracondylar humerus fracture by pediatric fellowship-trained orthopaedic surgeons (PFT) to the outcomes of those surgically treated by orthopaedic surgeons without pediatric fellowship training (NPFT). We hypothesized that there would be no differences in patient outcomes.

Methods: A retrospective review of pediatric patients who underwent surgical treatment for a supracondylar humerus fracture with closed reduction and percutaneous pinning (CRPP) or open reduction and percutaneous pinning (ORPP) at a regional level 1 trauma center over a 5-year period was performed. Exclusion criteria were inadequate follow up or absence of postoperative radiographs.

Results: A total of 201 patients met the inclusion criteria. Pediatric-fellowship trained orthopaedic surgeons treated 15.9% of patients. There was no statistically significant difference in carrying angle, Baumann's angle, or lateral rotation percentage at final follow up between PFT and NPFT groups. There was no permanent neurovascular compromise in either group. Patients treated by NPFT were more likely to return to the operating room for pin removal.

Conclusion: In this study, there was no difference in radiographic outcomes for patients with supracondylar humerus fractures surgically treated by either group. This suggests that pediatric supracondylar humerus fractures may be appropriately treated in communities without a pediatric-fellowship trained orthopaedic surgeon without compromised outcomes.

Level of Evidence: III

Keywords: pediatric orthopaedics, supracondylar humerus fracture, general orthopaedics

INTRODUCTION

In the pediatric population, supracondylar humerus fractures are a common injury. These fractures account for up to 16% of all pediatric fractures, and children 5-7 years old are most often affected.^{1,4} The Gartland classification system is commonly used to decide the appropriate treatment of this injury.⁵ Displaced supracondylar humerus fractures (Gartland type II-IV and flexion type) are usually treated operatively, with restoration of normal elbow range of motion and carrying angle as the goals of treatment.^{1,6} This has been assessed previously using the Flynn criteria.⁷ The surgical treatment for this fracture, closed reduction and percutaneous pinning (CRPP) or open reduction and percutaneous pinning (ORPP), is taught and evaluated as an ACGME milestone in orthopaedic surgery residency training.⁸

Recently, there has been an increasing trend for residents to complete a fellowship in an orthopaedic subspecialty after completion of the five-year orthopaedic surgery residency.⁹ After fellowship, however, these surgeons are often covering general trauma call, where they may be performing operations that they had learned during their residency but had not practiced during their fellowship training. In some hospitals, general orthopaedic surgeons who usually treat adults may be hesitant to treat a supracondylar humerus fracture in a child and will refer the patient to a pediatric fellowship trained orthopaedic surgeon.¹⁰ Recent literature has shown a shift in location for the treatment of pediatric supracondylar humerus fractures away from non-trauma, non-teaching, and non-metropolitan centers.¹¹ While this may be influenced by the growing sub-specialization within orthopedic surgery, the implications are far-reaching. If a pediatric fellowship-trained orthopaedic surgeon must treat a child with a supracondylar humerus fracture, the child may be required to travel outside of their community for treatment and follow-up. This may entail a longer time between presentation and surgical treatment, additional days of hospitalization, and an overall increased cost.¹²

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

Sources of Funding: No sources of funding declared.

Table 1. Demographics

	Overall (n=201)	Treated by pediatric fellowship trained orthopaedic surgeon (n=32)	Treated by orthopaedic surgeon without pediatric fellowship training (n=169)
Age at presentation (years)	5.4 (4.3, 6.8)	4.8 (3.9, 6.9)	5.5 (4.5, 6.8)
Sex			
Male	102 (50.75)	15 (46.88)	87 (51.48)
Female	99 (49.25)	17 (53.12)	82 (48.52)
Laterality			
Left	120 (59.70)	19 (59.38)	101 (59.76)
Right	81 (40.30)	13 (40.62)	68 (40.24)
Gartland Classification			
I	0	0	0
II	94 (46.77)	12 (37.50)	82 (48.52)
III	90 (44.78)	16 (50.00)	74 (43.79)
IV	14 (6.97)	2 (6.25)	12 (7.10)
Flexion	3 (1.49)	2 (6.25)	1 (0.59)
Fracture Type			
Open	3 (1.49)	0	3 (1.78)
Closed	198 (98.51)	32 (100)	166 (98.22)
Ipsilateral Fracture at time of injury			
None	195 (97.01)	30 (93.75)	165 (97.63)
Distal Radius fracture	6 (2.99)	2 (6.25)	4 (2.37)
Diaphyseal forearm fracture	1 (0.50)	0	1 (0.59)
Other	1 (0.50)	0	1 (0.59)
Surgery Type			
CRPP	191 (95.02)	32 (100)	159 (94.08)
ORPP	10 (4.98)	0	10 (5.92)

Age is reported as median (IQR). All other variables reported as frequency (percent). Ipsilateral fracture types are not mutually exclusive.

A recent study showed that type-II supracondylar humerus fractures can safely be treated at an outpatient surgery center, and may not require transfer to a children’s hospital for definitive care.¹³ This may suggest that communities without a pediatric fellowship-trained orthopaedic surgeon may safely treat supracondylar humerus fractures without requiring transfer to a tertiary center. Furthermore, treatment of pediatric supracondylar humerus fractures is a current Orthopaedic Surgery Milestone for orthopaedic surgery residents.⁸ Despite these recent trends, limited research exists on the outcomes of pediatric supracondylar humerus fractures surgically treated by non-pediatric fellowship-trained compared to those treated by a pediatric fellowship-trained surgeon.

Therefore, the purpose of this study was to compare the outcomes of pediatric patients who were surgically treated for a supracondylar humerus fracture by pediatric fellowship-trained orthopaedic surgeons (PFT) to the outcomes of those surgically treated by orthopaedic

surgeons without pediatric fellowship-training (NPFT). We hypothesize that there would be no difference in outcomes between these two populations.

METHODS

After IRB approval, a retrospective review of pediatric patients (aged 0-16 years) who underwent surgical treatment for a supracondylar humerus fracture with closed reduction and percutaneous pinning (CRPP) or open reduction and percutaneous pinning (ORPP) at a single regional hospital with Level 1 trauma verification for both adults and children between January 1, 2013 and December 31, 2017, was performed. Patients with inadequate follow-up or absence of postoperative radiographs were excluded. Study data were collected and managed using REDCap electronic data capture tools.¹⁴

Patient demographics were recorded, including age, sex, and hand dominance. The medical record was reviewed to record the date of the injury and fracture char-

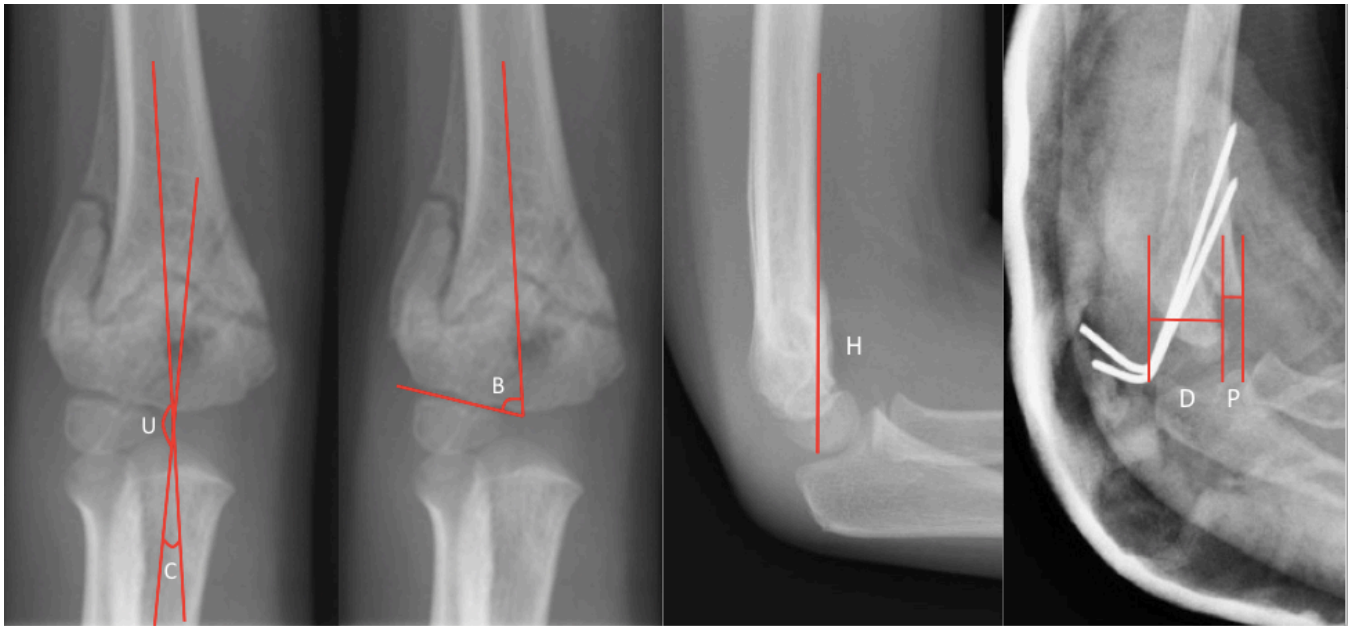


Figure 1. Postoperative radiograph showing measurement of radiographic outcomes, including carrying angle (C) ($C = 180 - \text{ulnohumeral angle (U)}$), Baumann's angle (B), anterior humeral line intersecting the capitellum (H), and lateral rotation percentage. Lateral rotation percentage is calculated by the amount of displacement of the humeral metaphysis proximal to the fracture site (P) divided by the width of the humerus distal to the fracture site (D) multiplied by 100.

acteristics (side, Gartland classification, open or closed injury, and any ipsilateral osseous injury). The time of presentation for the injury to the time of surgery was also recorded. The details of the operative procedure (CRPP or ORPP) and the duration of surgery were recorded. The type of surgeon (pediatric fellowship-trained, trauma fellowship-trained, non-pediatric or trauma fellowship-trained) was documented.

Postoperative final follow-up date and any postoperative complications were recorded. Postoperative complications that were evaluated were pin site infection, iatrogenic nerve or vascular injury, loss of reduction, need for revision surgery, and nonunion. Final postoperative radiographs were reviewed, and radiographic measurements were recorded (ulnohumeral angle, Baumann's angle, presence of anterior humeral line intersecting the capitellum, lateral rotation percentage) (Figure 1). Clinical outcomes from the progress notes were recorded (eg. Flynn's criteria, pain score, neurologic symptoms).

A two-sample t-test was used to test the hypothesis that the average carrying angle of a patient with a supracondylar humerus fracture surgically treated by NPFT orthopaedic surgeons is less than or equal to the average carrying angle of a patient treated by PFT orthopaedic surgeons. We accepted a minimally acceptable average carrying angle difference of no more than 2 degrees as this amount of variation has been reported previously.¹⁵ Significance was declared at alpha of 0.05.

Secondary outcomes included Baumann's angle, lateral rotation percentage, and any complications. Sub-

group analyses were performed to compare orthopaedic surgeons without trauma or pediatric fellowship training to pediatric fellowship-trained orthopaedic surgeons and those with trauma fellowship training. Subgroup analysis was also performed to compare outcomes for patients who sustained a Gartland III, IV, or flexion-type supracondylar humerus fracture. Summary statistics were used to describe the distribution of secondary outcomes of interest. Analyses were conducted using SAS v9.4.

RESULTS

A total of 201 patients were surgically treated for supracondylar fracture with CRPP or ORPP and met the inclusion criteria at our facility during the time period. The mean age of patients was 5.4 years (range 1.2-12.7 years). 49.3% were female. PFT surgeons treated 32 patients (15.9%). The measured demographic variables were similar between patients treated by PFT surgeons and those treated by NPFT surgeons (Table 1).

Of all patients, 191 (95%) patients were treated with closed reduction and percutaneous pinning. Open fractures occurred in three patients (1.5%). Eight patients (7%) sustained an ipsilateral osseous injury at the time of their supracondylar humerus fracture (Table 1). The average amount of time from admission to presentation to the operating room was similar between PFT and NPFT groups (6.5 vs. 9.8 hours), as was the operative duration (73 vs. 60 minutes). More patients treated by NPFT surgeons returned to the OR for pin removal (19.5% vs. 3.1%). Due to the retrospective nature of the

Table 2. Radiographic Outcomes of Patients Surgically Treated by Either Pediatric Fellowship-Trained Orthopaedic Surgeons or Non-Pediatric Fellowship-Trained Orthopaedic Surgeons

	Overall (n=201)	Treated by pediatric fellowship trained orthopaedic surgeon (n=32)	Treated by orthopaedic surgeon without pediatric fellowship training (n=169)
Carrying angle	11.33 (4.78)	11.75 (5.33)	11.25 (4.68)
Baumann's angle	75.01 (5.12)	74.16 (4.00)	75.18 (5.30)
Lateral Rotation Percentage	5.8 (0, 11.3)	4.9 (0, 11.1)	5.95 (0, 11.3)
Anterior humeral line intersecting capitellum in final follow-up x-ray			
Yes	193 (96.02)	32 (100)	161 (95.27)
No	8 (3.98)	0	8 (4.73)

Carrying angle = 180 degrees - ulnohumeral angle. Baumann's angle and carrying angle reported as mean (standard deviation). Lateral Rotation Percentage reported as median (interquartile range).

study, we could not identify whether return to the OR for pin removal was due to surgeon preference, patient preference, or any other reason.

The carrying angle is the measurement of deformity described in Flynn's criteria.⁷ We used the radiographic ulnohumeral angle to describe the carrying angle in our patient population due to inadequate documentation of the clinical carrying angle (Figure 1). The average carrying angle for patients treated by PFT surgeons was 11.75 (SD = 5.33) degrees. The average carrying angle for patients treated by NPFT surgeons was 11.24 (SD = 4.68) degrees (Table 2). A non-inferiority test with a minimally acceptable average carrying angle difference of no more than 2 degrees demonstrated that the average carrying angle between groups was sufficiently close (p=0.0026) (Supplemental Appendix A).

Since a significant portion of pediatric supracondylar humerus fractures are treated by trauma fellowship-trained surgeons at our facility, a subgroup analysis was performed for patients treated by trauma-fellowship trained orthopaedic surgeons, as well as patients treated by orthopaedic surgeons without trauma or pediatric fellowship training. The average carrying angle of patients treated by either group was similar to patients treated by PFT orthopaedic surgeons (Table 3).

A second subgroup analysis was performed to compare the carrying angle of patients who presented with more severe fractures (Gartland III, IV, flexion-type) between the two treatment groups (PFT vs. NPFT). There was no difference in carrying angle for patients treated by PFT surgeons (13.05, SD=4.39) and those treated by NPFT surgeons (10.33, SD=5.13) (p<0.0001).

There were few complications overall. In the PFT group, there was one complication in which the patient developed a pin site infection that was successfully treated with oral antibiotics and pin removal. In the NPFT group, there were 5 complications overall. One patient developed septic arthritis 10 days after the index procedure that was treated with return to the OR for irrigation and debridement, pin removal, and antibiotics. One patient developed a pin site infection that resolved with pin removal and oral antibiotics. Two patients developed a sensory ulnar nerve palsy that improved with pin removal. One patient required a scar excision surgery due to an adherent scar.

DISCUSSION

In our study, there was no difference in radiographic outcomes for patients with supracondylar humerus fractures surgically treated by orthopaedic surgeons

Table 3. Subgroup Analysis of Radiographic Outcomes of Patients Treated by Pediatric-Trained, Trauma-Trained, and Neither Pediatrics nor Trauma-Trained Orthopaedic Surgeons

	Overall (n=201)	Trauma fellowship trained (n=72)	Pediatric fellowship trained (n=32)	Neither trauma nor pediatric fellowship trained (n=97)
Carrying Angle	11.33 (4.78)	11.47 (4.92)	11.75 (5.33)	11.08 (4.51)
Baumann's angle	75.01 (5.12)	74.58 (5.26)	74.16 (4.00)	75.62 (5.31)
Anterior humeral line intersecting capitellum in final follow-up x-ray				
Yes	193 (96.02)	70 (97.22)	32 (100)	91 (93.81)
No	8 (3.98)	2 (2.78)	0	6 (6.19)

Carrying angle and Baumann's angle are reported as mean (standard deviation). Anterior humeral line intersecting capitellum in final follow-up x-ray is presented as frequency (percent).

without pediatric fellowship training compared to those treated by orthopaedic surgeons with pediatric fellowship training. Our subgroup analyses on carrying angle also showed no difference between radiographic outcomes in patients treated by orthopaedic surgeons without trauma or pediatric fellowship training compared to the patients treated by PFT orthopaedic surgeons. Carrying angle varies by age and sex of the patient. The acceptable average carrying angle for pediatric patients is about 10-12 degrees, and ranges from 6-13 degrees depending on age.¹⁶ Furthermore, the acceptable range of Baumann's angle is 64-81 degrees.^{1,17-18} Therefore, both the carrying angle and Baumann's angle in each group fell within the acceptable range of angles for pediatric patients in this series.

Many patients treated for pediatric supracondylar humerus fractures do well. With appropriate surgical technique, malunion is rare and pin site infection is the most common complication.¹⁹ However, many orthopaedic surgeons that take call and primarily treat adult patients are very apprehensive to treat pediatric supracondylar humerus fractures because of the fear of serious complications, which include neurologic injury and vascular compromise.²⁰⁻²² This study was performed at a regional hospital with level I trauma verification for both pediatric and adult patients. On-call coverage is provided by a pool of ABOS board certified orthopaedic surgeons, most of whom have completed an orthopaedic fellowship. Subspecialties represented include pediatrics, trauma, sports medicine, foot and ankle, hand, shoulder/upper extremity, spine, and general orthopedists. Children who present with a supracondylar humerus fracture that requires operative fixation are most often treated by the orthopaedic surgeon on call. Overall, complications in our study were infrequent, with pin site infection being the most common. There was no catastrophic iatrogenic neurologic or vascular compromise in our study. Our study demonstrated that the NPFT surgeons were more likely to return to the OR for pin removal. While this did not correlate to a difference in radiographic outcomes, it certainly has cost implications and may imply that non-pediatric fellowship trained orthopaedic surgeons are less comfortable removing pins in the office. This may lead to an avoidable trip to the operating room.

Knowledge of appropriate operative techniques and awareness of surgical complications are fundamental and part of the educational requirements for surgical subspecialty residency programs. Orthopaedic milestones were developed in 2012 as part of a working group to act as a framework in the development of the resident in key domains to help in assessing competency.⁸ One of the pediatric orthopaedic subspecialty milestones is the surgical treatment of a pediatric supracondylar hu-

merus fracture. It is expected that the resident develop competency in patient care for these fractures, which includes the ability to perform a closed reduction and percutaneous pinning, recognizing obstacles that prevent closed manipulation, the ability to perform open surgical techniques, and recognizing and treating simple complications (eg. Compartment release and wound problems).⁸ This milestone was created by fellowship-trained pediatric orthopaedic surgeons and accepted by the ACGME. This is now adapted as a part of all orthopaedic resident programs and considered to be a skill set for a general orthopaedic surgeon.⁸ A prior study suggested that non-pediatric fellowships trained orthopaedic surgeons have higher complications rates when surgically treating supracondylar humerus fractures when compared to pediatric fellowship-trained orthopaedic surgeons.²³ Our study is the first study to our knowledge that demonstrates surgical treatment of pediatric supracondylar humerus fractures can be safely performed by orthopaedic surgeons without pediatric fellowship training. This supports the concept of orthopaedic milestones and emphasizes this skill set in all orthopaedic resident programs.

Our study presents several limitations, many related to the retrospective design. There was a lack of consistent documentation of clinical outcomes. We were unable to perform an analysis on range of motion and pain score due to inadequate documentation of these outcomes for most patients in the study. We found that many patients were noted to have some decrease in range of motion at their final follow-up appointment and were instructed to return if their range of motion did not improve. While it is likely that most patients had improvement in range of motion over time, it is possible that some patients with persistent decreased motion did not return for care or sought care elsewhere. Furthermore, some of the final postoperative radiographs were taken with the pins still in place, which may alter the radiographic measurements due to the inability to obtain true AP radiographs in full extension.

Despite these limitations, our study suggests that pediatric supracondylar humerus fractures may be safely treated in regional trauma centers even when a pediatric fellowship-trained orthopaedic surgeon is not available. Radiographic measurements demonstrated no difference in outcomes, and overall complications were rare with no serious neurologic or vascular compromise. We conclude that the treatment of pediatric supracondylar humerus fractures can be safely treated by ABOS board certified orthopaedic surgeons that do not have pediatric fellowship training, and care of these injuries and should be emphasized as a part of the educational content in all orthopaedic surgery resident programs.

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IS THERE A ROLE FOR INTRAMEDULLARY TISSUE SAMPLING DURING INTERNAL FIXATION OF METASTATIC DISEASE IN LONG BONES? A SYSTEMATIC REVIEW AND AN INSTITUTIONAL EXPERIENCE

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ABSTRACT

Background: The purpose of this investigation was to identify and summarize the current utility of intramedullary tissue sampling during long bone internal fixation (IF) for metastatic bone disease (MBD). The secondary aim was to provide the experience of a single institution using this technique.

Methods: First, a systematic database query of the Cochrane Central Register of Controlled Trials (1976 to 2020), Cochrane Database of Systematic Reviews, Ovid MEDLINE (1946 to 2020), EMBASE, and PubMed (1964 to 2020) was performed. Following article identification, a description of the method of sampling and yield was recorded. Second, an institutional cohort was identified following Institutional Review Board approval. Cases of MBD treated with IF from 2018 to 2020 were reviewed. Data were collected and recorded from cases during which intramedullary reamings were sent for histopathology.

Results: Ten studies met inclusion criteria. Four of the ten were techniques or technical notes. The remaining six were retrospective reviews in which tissue was sent for histopathology. Among those six, a total of 262 tissue samples were sent, and a negative result was recorded in 37.2% (n = 97) of cases. A total of 18.0% (n = 47) were noted as inadequate for interpretation. For reamings-only studies, the negative rate was higher at 50.5%. In our institutional cohort, a total of 16 tissue samples were sent in the setting of known MBD. The negative rate was 37.5% (n = 6), with zero instances of a change in clinical management after a positive result.

Conclusion: There are limited descriptions of intramedullary tissue sampling during IF of long bones for MBD. The existing literature, along

with our institutional data, suggest this technique is less than optimal for tissue retrieval given the high rates of negative results from samples sent for histopathology. Furthermore, given the lack of clinical impact of a positive sample, we believe a multidisciplinary group should discuss preoperatively the utility of whether treatment might change based off a tissue diagnosis.

Level of Evidence: V

Keywords: biopsy, internal fixation, metastatic bone disease, orthopedics, intramedullary biopsy

INTRODUCTION

Metastatic bone disease (MBD) is a frequently encountered entity in orthopedics. Various tumors may metastasize to bone, though most originate from the breast, kidneys, prostate, lungs, or thyroid.¹ MBD has a predilection for extremity long bones, and the current standard of care advocates for surgical intervention in select cases of impending or actual pathological fracture. Internal fixation (IF) has demonstrated an effective means of surgical treatment, while allowing for adjuvant therapy without a significant increase in morbidity.²

Intramedullary tissue sampling during IF for long bone MBD has been described.⁴ Historically, it was thought that establishing a diagnosis from intramedullary tissue may influence the regimen of adjuvant therapy if an unsuspected primary is found.³ However, in the vast majority of MBD, the primary malignancy is already known, and the suspicion for a new primary is low. During IF for MBD, intramedullary tissue is still often sent via intramedullary reamings. Despite the commonality of this practice, there are very few data to validate its efficacy and subsequent outcome on clinical management. Additionally, the financial impact of intramedullary tissue sampling may merit consideration. There are costs associated with interpreting and reporting the findings of tissue during IF, and the histological diagnosis is often negative despite knowledge of the visceral or hematologic malignancy.⁴⁻⁶

The purpose of this systematic review was to identify the current available literature that describe the efficacy of intramedullary tissue sampling during IF in this setting. Second, the experience of a single institution is described in order to provide a clinical supplement. It

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

Sources of Funding: No sources of funding declared.

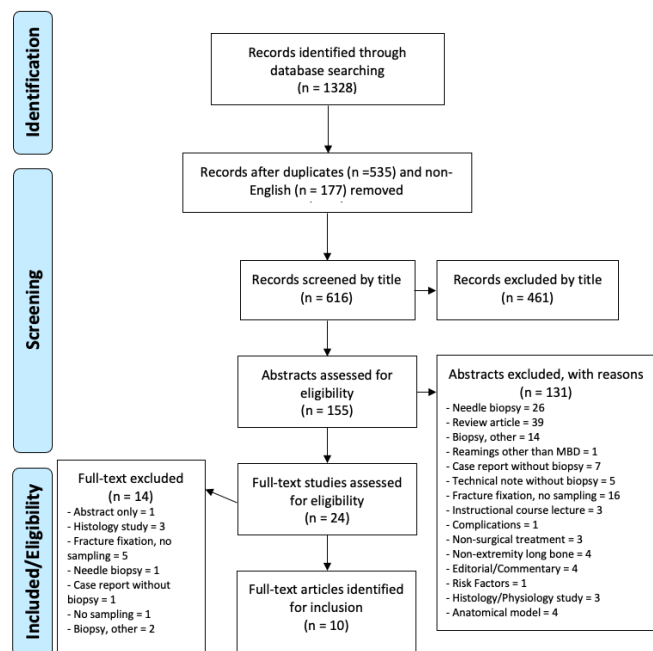


Figure 1. Study flowchart using the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) selection process. MBD, metastatic bone disease.

was hypothesized that the cumulative negative rate of tissue sampling among all studies, along with reamings sent in our institutional cohort, would question the efficacy of intramedullary sampling for long bone MBD during IF. This study also investigated the utility of reamings within our institution, and it was hypothesized that intramedullary reamings would not change the clinical management of these patients.

METHODS

Design

This systematic review was conducted according to guidelines outlined in the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) statement of 2009 (Figure 1). A systematic review of the literature was performed in October 2020 to identify all studies that described intramedullary tissue sampling in the setting of IF for long bone MBD. The current review was registered with the PROSPERO International prospective register of systematic reviews (National Institute for Health Research; CRD42020219993). The initial search was conducted using the following Boolean terms: Biopsy AND (Bone neoplasms/diagnosis OR Bone neoplasms/secondary) AND (Bone and bones/pathology OR Bone and bones/diagnosis OR Bone and bones/surgery) AND (Neoplasm metastasis/pathology OR Neoplasms/pathology). Each phrase was applied to the following databases: Cochrane Central Register of Controlled Trials (1976 to 2020), Cochrane Database

of Systematic Reviews, Ovid MEDLINE (1946 to 2020), EMBASE, and PubMed (1964 to 2020).

Inclusion criteria

All titles queried from each individual database were compiled and systematically screened by C.G. First, titles were screened by duplicate entries and those written in a non-English language. Second, article titles were screened for relevance which included reference to intramedullary biopsy and/or intramedullary tissue sampling. Indistinct article titles were retained for eligibility screening. Remaining titles were then screened for eligibility and relevance to intramedullary sampling in MBD. Editorials and commentaries were excluded, as were reviews, instructional course lectures, and studies describing fine needle aspiration (FNA). Eligible articles underwent a full-text review. In order to meet final inclusion criteria, each article needed to provide evidence intramedullary tissue was retrieved during IF for MBD and/or sent for histopathology. Among those articles that met final inclusion criteria each bibliography was reviewed, and pertinent articles not included in the original query scope were added post hoc. There was no exclusion of articles by of level of evidence or study design.

Extraction, analysis, and synthesis

Data extraction was completed by C.G., and individual characteristics were recorded in a custom data extraction table. For each study, the year, first author, title, design, journal, technique, and country of origin were recorded (Table 1).⁷ For data extraction, the primary goal was to identify the diagnostic yield of intramedullary tissue sampling. The secondary goal was to record the location of metastatic disease and presence of pathological fracture if applicable. This systematic review was primarily qualitative in nature, which precluded a meta-analysis. When possible, however, quantitative data were extracted from each article. These data permitted a pooled analysis of diagnostic yield, which is presented in addition to the findings of our institutional cohort. These quantitative data consisted of percentage and frequency of primary tumor, fracture, and location of metastasis, as well as a description of the tissue sample and pathological characteristics such as crushing or necrosis if they were reported. Of note, the technical notes that were included were not part of the pooled estimate for the overall yield, though were included to describe possible alternative methods to intramedullary tissue retrieval. Last, each study was reviewed to understand whether the tissue retrieval changed the clinical management of the respective patients.

Table 1. Data Extraction

First Author, Year	Title	Journal	Country	Design	Technique
Khan et al., 2019 ⁵	An Audit of Intramedullary Reaming Biopsy in Long Bone Metastatic Disease. Evaluation of Diagnostic Value and Reaming Sample Adequacy	Pakistan Armed Forces Medical Journal	Pakistan	Retrospective	Reamings
Afinowi et al., 2017 ⁶	Diagnostic use of intramedullary reaming biopsy in metastatic long bone disease	The Annals of The Royal College of Surgeons of England	England	Retrospective	Reamings
Xia et al., 2014 ¹¹	Laparoscopic grasper for intra-medullary biopsy: a technique to improve tissue sampling	Singapore Medical Journal	Singapore	Technique	Mixed*
Heaver and Marsh, 2011 ⁹	Femoral intramedullary biopsy: improving tissue sampling	Annals of the Royal College of Surgeons of England	England	Technical Note	Forceps
Wronka et al., 2010 ¹⁰	An innovative technique for long-bone biopsy	Annals of The Royal College of Surgeons of England	England	Technical Note	Forceps
Hassan et al., 2007 ⁴	Intramedullary reamings for the histological diagnosis of suspected pathological fractures	The Surgeon: Journal of the Royal Colleges of Surgeons of Edinburgh and Ireland	England	Retrospective	Reamings
Johnson and Kneisl, 2004 ¹²	Bone marrow sampling in pathologic fractures: intramedullary pediatric chest tube technique	Journal of Orthopaedic Trauma	United States	Technique	Chest tube
Clarke et al., 1993 ¹⁴	Closed intramedullary biopsy for metastatic disease	Journal of the Royal College of Surgeons of Edinburgh	England	Retrospective	Reamings
Smith et al., 1988 ¹³	Closed flexible intramedullary biopsy of metastatic carcinoma	Clinical Orthopaedics and Related Research	United States	Retrospective	Tube
Hebert et al., 1982 ¹⁵	Closed medullary biopsy for disseminated malignancy	Clinical Orthopaedics and Related Research	United States	Retrospective	Forceps

*Mixed (reamings and grasper)

Institutional Cohort

Following Institutional Review Board approval, retrospective review of a prospectively maintained surgical database was also performed, with a date range of 2018 to 2020. The inclusion criteria were patients with MBD who underwent IF of a long bone with intramedullary reamings sent for histopathology. Cases were excluded if there was no confirmation of reamings received by our musculoskeletal pathologists. For each of the included cases, primary tumor characteristics were recorded and analyzed, along with pertinent surgical characteristics and histopathology notes if available. Additionally, medical records were reviewed following a positive tissue sample to ascertain whether clinical management changed as a result. Any changes in medical management which included medication regimen or adjuvant therapy were noted, as were any additional therapy changes such as subsequent referrals, new tests, or additional procedures. Continuous data are represented as the mean or median with a range or standard deviation, and categorical data are described as a frequency and percentage of total counts. All statistical analyses were performed on SPSS version 26.0 (IBM Corp, Armonk, NY, USA).

RESULTS

Study selection

The initial search yielded 1328 articles. Next, 1318 were excluded leaving ten articles that met full inclusion criteria. Each of the included articles was either a technical note on intramedullary tissue sampling during IF or a review of this technique in a retrospective fashion. A PRISMA flowchart of the initial study identification and subsequent screening criteria is highlighted in Figure 1. Each of the included articles and the respective characteristics from data extraction are recorded in Table 1. Four of the ten studies were technical notes describing a means of improving tissue sampling after reaming the intramedullary canal.⁸⁻¹¹ These techniques involved novel use of a Paterson or Lloyd Davis biopsy forceps, esophageal biopsy forceps, laparoscopic grasper under image intensifier guidance, or a pediatric chest tube. The remaining six articles were retrospective in nature and reviewed the outcomes of intramedullary tissue sampling using a combination of reaming only, forceps, and a catheter.^{4-6,12-14} Given that the first four articles were technical notes with few cases, they were not included in the overall diagnostic yield for intramedullary tissue retrieval.

Table 2. Study Characteristics

First Author, Year	Sample Size	Pathological Fracture (%)	Predominant Location (%)	Yield	Inadequate Sample (%)	Conclusion
Khan et al., 2019	53	28 (53)	Femur (67)	40%	15 (28)	Do not support
Afinowi et al., 2017	49	32 (65)	Femur (86)	51%	2 (4)	Do not support
Xia et al., 2014*	3	2 (67)	Humerus (67)	67%	0	Support
Heaver and Marsh, 2011*	4	NR	NR	75%	NR	Support
Wronka et al., 2010*	1	1 (100)	Humerus (100)	NR	0	Support
Hassan et al., 2007	90	90 (0)	NR	65%	30 (33)	Do not support
Johnson and Kneisl, 2004*	2	1 (50)	Humerus/Femur	100%	0	Support
Clarke et al., 1993	17	NR	NR	100%	0	Support
Smith et al., 1988	27	17 (63)	Humerus (56)	92.5%	0	Support
Hebert et al., 1982	30	6 (20)	Femur (67)	71%	0	Support
Current study	16	5 (31.3)	Femur (88)	62.5%	4 (25)	Do not support

NR, not recorded. *technical note or technique not included in pooled diagnostic yield.

Technical notes or techniques

As mentioned above, four of ten articles described novel techniques in intramedullary tissue sampling. Johnson and Kneisl used an 18 to 22 French pediatric test tube inserted to the level of the targeted metastatic lesion for tissue retrieval after reamings.¹¹ They report adequate sampling in a proximal femoral lesion from breast cancer, and in a proximal humeral lesion secondary to myeloma. Final pathology was consistent with the known primary in each case using this technique. Heaver and Marsh used a Paterson or Lloyd Davis biopsy forceps to retrieve intramedullary reaming samples in four cases of MBD.⁸ This technique yielded a positive diagnosis in three (75.0%) instances. Similarly, Wronka et al. used esophageal forceps for intramedullary sampling in a patient with a pathological mid-shaft humeral fracture.⁹ This study did not report the diagnostic result, though mentioned a high-quality sample was obtained. Last, Xia et al. used either a laparoscopic forceps under image intensifier guidance or reamer-only in three cases (femur, n = 1; humerus, n = 2).¹⁰ A correct diagnosis was reached in two (66.7%) instances, and they reported the samples collected with the grasper were better for histological quality and volume of tissue than those scraped from the reamer.

Yield

Study data are listed in Table 2. Among the six retrospective reviews, a total of 266 MBD lesions underwent IF, and 267 intramedullary tissue samples were sent.^{4-6,12-14} For the studies that recorded operative characteristics, therapeutic and prophylactic IF were performed for 173 (67.0%) pathological fractures and 75 (26.0%) impending fractures, respectively. Intramedullary tissue was also sent on one case of a proximal femoral fracture nonunion that was internally fixated.¹⁴ Four of the six studies recorded location of MBD.^{5,6,12,14} The femur was the most

common site (74.3%, n = 119), followed by the humerus (23.8%, n = 38) and tibia (1.9%, n = 3). One humeral lesion had reamings sent twice, which equated to a total of 267 samples.¹⁴ Five (1.8%) of the original 267 tissue samples were excluded.⁴ Among the six retrospective studies, the pooled positive rate was 63.0% (n = 165). Thus, a negative result was recorded 37.0% (n = 97) of all samples sent. Of the six studies analyzed for overall yield, three also included a note on the quality of tissue received for pathological interpretation. Among these notes, 18.0% (n = 47) were inadequate due to crushing or necrosis of the tissue.⁴⁻⁶ For those studies that looked at use of a reamer only, the positive rate was 49.5% (n = 101) with a negative rate of 50.5% (n = 103).^{4-6,13} Last, after careful review of each of the ten included studies, there were no data or description as to whether the yield from intramedullary sampling changed the clinical management.

Institutional cohort

In the current institutional series, a total of 16 cases met the inclusion criteria. There were nine (56.3%) females and seven (43.8%) males. The predominant location of the lesion was the femur (n = 14, 87.5%), followed by one case each in the tibia (6.3%) and humerus (6.3%). The most frequent primary tumor was renal cell carcinoma (n = 5, 31.3%), followed by breast (n = 4, 25.0%), lung (n = 3, 18.8%), prostate (n = 2, 12.5%), lymphoma (n = 1, 6.3%), and neuroendocrine cancer (n = 1, 6.3%). Impending pathological fracture was present in 11 (68.8%) cases, and an actual fracture was recorded in five (31.3%) cases. Overall, the diagnostic yield was 62.5% (n = 10); 37.5% (n = 6) of samples gave negative results. Each of the ten positive samples was consistent with the patients known primary tumor. Furthermore, there were zero (0.0%) instances in which the clinical aspects of care including medication or adjuvant therapy were changed as a result of the positive reaming sample.

DISCUSSION

The most important finding of this review is that the majority of the included studies emphasized the inadequacy of intramedullary tissue sampling during IF. Notably, the pooled positive rate was 63.0% regardless of the technique used. For the retrospective studies that looked at conventional reamings only (i.e., tissue retrieved from the reamer itself), the cumulative positive rate was even lower at 49.5% (negative, 50.5%). The current institutional data, which analyzed 16 cases of intramedullary reamings, similarly recorded a positive result only 63.0% of the time. Together, these data confirm that the efficacy of intramedullary reamings is less than optimal given the high rate of negative results. Furthermore, the systematic review suggests intramedullary sampling is inadequate according to current literature, and future research is likely needed to confirm this finding.

Fixation of long bones for MBD is often accomplished by intramedullary nailing (IMN) after reaming the canal. Some authors have discussed performing sampling (referred to as intramedullary biopsy) at the time of IMN to obtain tissue samples for histological analysis.^{4,6,14} Hebert et al. were among the first to describe this technique using a forceps instrument to retrieve reamed tissue.¹⁴ Around the same time, it was also thought that diagnosing an unsuspecting primary via intramedullary sampling or biopsy may lead to a change in adjuvant therapy.³ Hebert et al. (using a forceps) reported a positive rate of 71.0%, and subsequent studies by Clarke et al. (reamings) and Smith et al. (catheter) noted 100% and 92.5% positivity rates of samples sent for histopathology, respectively.^{12,13} Contrary to historical reports, the primary tumor is now mostly known at the time of fixation, and tissue is usually sampled to look for additional disease. However, aside from recent technical notes or small (< 5) series, most large reviews fail to find a positive rate of this technique greater than 67.0%, which was confirmed from the data in the current institutional study.⁴⁻⁶

Various techniques have been suggested for intramedullary sampling, some of which are thought to obtain better quality and volume of tissue after reaming than when the tissue is scraped from the reamer itself. These techniques include flexible and wide-bore plastic catheters, bronchial-type or esophageal forceps, pediatric chest tubes, laparoscopic graspers with or without imaging guidance, Lloyd Davis or Paterson biopsy forceps, and Charnley spoons.^{6,8-12} In this systematic review, intramedullary sampling in reamings-only studies had a negative rate of 50.5%, and the current institutional data seem to confirm the inadequacy of this method as well as we found a high negative rate.^{4-6,13} In contrast, more direct methods of obtaining tissue such as with a grasper, pediatric chest tube, or forceps after reaming appear to

improve the positive rate.^{8-12,14} However, these data are limited to small case series or technical notes, and there are no direct comparisons to conventional intramedullary reaming. There was also no description of whether this improved method led to a clinical change in management. Furthermore, when these reviews are combined with reaming-only studies, the cumulative rate of all the included studies shows a positive rate of only 63.0%.

This systematic review, along with the included institutional data, fail to demonstrate a clear role for intramedullary sampling during IF. While the positive cases from each of the included studies were noted to be consistent with the patient's known primary tumor, there was no inclusion of histology which would have allowed for confirmation. Therefore, the institutional cohort was included to provide a histopathological supplement. In each of the ten positive results from our institution, the reamings were histologically confirmed as metastasis from the patient's known primary disease. However, it is also important to consider the clinical implications of tissue retrieval during IF for MBD. Patients with MBD are often managed collaboratively with medical and radiation oncologists, as well as other specialists depending on the location of the primary tumor. For example, the patient may see a hepatologist if the primary tumor originates from the liver. Thus, there is a clinical aspect to consider, and presently there is a lack of data to inform whether tissue sampling during IF for MBD changes the clinical management following surgery. Notably, each of the ten cases that were consistent with the patient's primary were reviewed for subsequent medical management. However, there was no instance in which any aspect of the clinical management was changed as a result of the positive intramedullary tissue sample.

Reaming the intramedullary canal theoretically allows for a large area of the bone to be sampled without prolonging the operation. However, the side effects are disadvantageous with respect to tissue preservation. In the six retrospective review studies, 18.0% of tissue sent was inadequate for histological analysis, all of which came from reamer-only studies. Conventional reaming results in direct mechanical damage to the tissues, resulting in crushing or necrosis.¹⁰ Second, there is no precise method to target the lesional tissue with a reamer, which may lower the positive rate if the level of the lesion is not reached with instrumentation. Reaming is also non-specific, and it may be impossible to differentiate gross lesional tissue from healthy tissue, which can dilute the sample sent for histological analysis. These side effects along with the relatively high rate of negative testing during intramedullary sampling, seem to question the role of this method of tissue retrieval, and this review provides systematic evidence of its inadequacy.

It appears there is no clear consensus regarding which technique may be superior to reaming given the limited evidence for other techniques, though among these studies, a recommendation for forceps, graspers, and/or catheters has been made. While these additional methods may improve tissue sampling, the question still remains about whether even these more accurate methods of sampling change the subsequent clinical management. In these technical notes as well as in our cohort, there were no identifiable changes in adjuvant treatment. Though ultimately a discussion with a multidisciplinary team is of critical importance. If the consensus of the team is that there is a possibility of a change in treatment, then perhaps obtaining tissue is warranted. Additionally, if there is concern for a primary sarcoma of long bones, this tactic would be inappropriate altogether. Thus, we feel that sampling during intramedullary fixation for MBD is of relatively low yield, and perhaps should be reconsidered in many cases. Future studies should investigate how often the treatment courses change based on the findings of this tissue sampling to better understand its clinical utility. These future efforts might be expanded to include any tissue that is sent for pathology during MBD cases, such as bone resected specimens for more complex MBD surgeries.

LIMITATIONS

This study is limited by the small number of articles available for review, as well as the heterogeneity of tissue sampling techniques and the small number of samples available for pooled analysis. The small number of available articles also highlights the paucity of data on sending tissue during MBD cases. A second limitation of this review is that the cumulative positive rate of all included studies may be lower due to the inclusion of the reamer-only studies. It has been demonstrated that mechanical removal of tissue from reamer blades is inferior to other techniques with regards to tissue preservation or volume of tissue obtained, and thus the overall estimated positive rate may be higher when looking at non-reaming cases only. Ultimately, more information is needed regarding the efficacy of these techniques, especially when comparing outcomes to tissue retrieval using just a reamer. Despite these implications, however, the majority of the included articles fail to indicate the feasibility intramedullary tissue sampling in this setting.

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SKELETAL RELATED EVENTS ARE RARE AFTER RADIATION TREATMENT FOR METASTATIC DISEASE OF THE FEMUR

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ABSTRACT

Background: Pain is a common presenting symptom in patients with metastatic disease to the femur (MDF), and it is often difficult to differentiate pain from the tumor itself versus pain from an impending pathologic fracture. Radiation therapy (RT) is commonly used in the management of pain secondary to MDF but is not adequate in isolation when the underlying bone is structurally compromised.

Questions/Purposes: The purposes of this study were to determine 1) the incidence of skeletal related events (SREs) following RT to the femur, 2) the frequency and implications of orthopedic evaluation prior to RT, and 3) the frequency of patients presenting with a pathologic fracture.

Methods: A retrospective, single-institution review of 86 patients with MDF treated with RT from 2005 to 2018 was performed. Patient demographics, primary cancer type, pathologic fracture, orthopedic interventions, and RT details were assessed. Patients were followed to evaluate the occurrence of skeletal related events of the femur until death or time of last recorded clinical follow-up.

Results: In our cohort of 86 patients, the mean RT dose was 22.3 Gy (8-55.8 Gy) delivered over 6.5 fractions (1-31 fractions). Fifteen patients (17%) received RT less than one month, 30 (35%) less than three months, and 49 (57%) less than six months prior to death. Prior to RT, 42 patients (48.9%) had an orthopedic evaluation, 16 of which (38.1% of those evaluated) received prophylactic stabilization with an intramedullary nail (IMN). Ten patients (11.6%) presented with a pathologic

fracture. Following RT, five patients (5.8%) had at least one SRE. Three patients sustained a pathologic fracture, three required repeat RT, and three required further surgical intervention.

Conclusion: Metastatic disease of bone is a common condition that affects many cancer patients. In our institution's series of MDF treated with RT, we only found one patient who sustained a pathologic fracture after RT treatment with an unrecognized impending fracture. As only half of the patients were referred for an orthopedic evaluation prior to RT, continued education of medical and radiation oncologists regarding the signs and symptoms of impending pathologic fracture is warranted.

Level of Evidence: IV

Keywords: femur, radiotherapy, pathologic fracture, bone metastasis

INTRODUCTION

Metastatic bone disease is a highly prevalent condition that impacts as many as 80 percent of patients with solid tumors during the course of their disease.¹ Metastatic disease to the femur (MDF) is one of the most frequent sites of bone involvement, with pain and reduced mobility being common presenting symptoms. The appropriate management of MDF is crucial as treatment may provide pain relief, functional restoration, and prevention and treatment of pathologic fractures. At presentation, it is often difficult to differentiate pain from the tumor itself versus pain from an impending pathologic fracture. Determining the etiology of pain is critical as those with an impending fracture require prophylactic surgical stabilization while those without concern of structural compromise may be treated by non-surgical means. Radiation therapy (RT) is commonly used in the management of pain secondary to MDF and several fractionation schedules may be used. Although radiation provides pain relief and preservation of function in a majority of patients, it is not adequate in isolation when the underlying bone is structurally compromised. There is limited information on the occurrence of skeletal related events (fracture, surgery, repeat RT) following treatment of MDF with radiation therapy.^{2,6}

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

Sources of Funding: No sources of funding declared.

Table 1. Baseline Patient Characteristics and Treatment Details

Patient	Number (%)
Age (years)	
Median (range)	59 years (18-90)
Male	50 (58.1%)
Female	36 (41.9%)
Tumor Histology	
Lung	32 (37.2%)
Kidney	15 (17.4%)
Breast	9 (10.5%)
Head & Neck	6 (7.0%)
Prostate	5 (5.8%)
Sarcoma	5 (5.8%)
Melanoma	4 (4.7%)
Gastrointestinal	4 (4.7%)
Cutaneous SCC	2 (2.3%)
Gynecologic	2 (2.3%)
Myeloma	1 (1.2%)
Unknown	1 (1.2%)
Pathologic fracture	
Yes	10 (11.6%)
No	76 (88.4%)
Treatment	
Orthopedic evaluation	
Yes	42 (48.8%)
No	44 (51.2%)
Prophylactic surgery prior to RT	
Yes	16 (18.6%)
No	70 (81.4%)
Radiation dose (Gy)	
Median (range)	20 Gy (8-55.8 Gy)

The purpose of this report was to determine 1) the incidence and factors associated with skeletal related events (SREs) following RT to the femur, 2) the frequency and implications of orthopedic evaluation prior to RT, and 3) the proportion and outcomes of patients presenting with a pathologic fracture.

METHODS

This study was an Institutional Board Review approved single-institution retrospective chart study of 96 potentially eligible patients with metastatic cancer to the femur treated with radiation therapy from 2005 to 2018. Patients were identified using the Elekta MOSAIQ (Elekta AB, Stockholm, Sweden) database from the University of Iowa Department of Radiation Oncology.

We included all cancer histologies. Patients with both femurs involved were counted as separate observations. Patients were excluded if they were < 18 years of age, were without follow-up or death within one year of treatment, received < 800 cGy total dose due to incomplete RT course, or had metastatic sarcoma with unknown primary site of disease.

Using the Electronic Medical Record, we recorded patient specific characteristics (age, sex, race, body mass index, Age-Adjusted Charlson Comorbidity Index, smoking history), tumor characteristics (primary cancer type, location of femur metastasis, systemic metastatic burden), surgical details (orthopedic consultation, neo-adjuvant RT, adjuvant RT, type of surgical procedure) and radiation treatment details (total dose, number of fractions). Following the completion of RT, patients were followed to evaluate for the occurrence of skeletal related events of the femur until death or time of last recorded follow-up. Skeletal related events included the development of a post-RT fracture, progressive pain or instability requiring surgical intervention, or re-irradiation.

We performed a descriptive analysis to report the prevalence of orthopedic evaluation, prophylactic stabilization, and pathologic fracture prior to the initiation of radiation therapy. Fisher's exact testing and t-tests were used to investigate the relationship between SREs and patient, tumor, or treatment related factors.

The final cohort consisted of 79 patients with 86 femur lesions (Table 1). The median age of our cohort was 59 years (range 18-90) with a median length of follow-up of 3.0 months (range 0-151.6 months) from the completion of radiation (Table 1). Fifty patients were male and 36 were female. Primary tumor types included lung (32), renal (15), breast (9), head and neck (6), prostate (5), sarcoma (5), melanoma (4), cutaneous squamous cell carcinoma (2), hepatocellular (1), rectal (1), ovarian (1), vulvar (1), pancreatic (1), neuroendocrine (1), multiple myeloma (1) and unknown primary (1). The mean radia-

Table 2. Details of 5 Patient with Post-Radiation Therapy SRE

Patient	Sex	Age	Primary site	Pre-RT orthopedic evaluation	Pre-RT prophylactic surgery	Pre-RT procedure	Radiation details (total dose / fractions)	SRE	Time to first SRE (days)
1	M	54	Lung	No	No		20 Gy / 5	Repeat RT	159
2	M	59	Renal	Yes	Yes	IMN	30 Gy /10	Fracture	69
3	M	59	Renal	Yes	No		20 Gy / 4	Fracture Surgery Repeat RT	777
4	M	62	Pancreatic	No	No		20 Gy / 5	Fracture Surgery	24
5	M	45	Cutaneous squamous cell	No	No		8 Gy / 1	Surgery Repeat RT	327

tion dose was 22.3 Gy delivered over 6.5 fractions (8 Gy in a single fraction to 55.8 Gy in 31 fractions).

RESULTS

Frequency of skeletal related events following RT

Following the completion of radiation therapy, five patients (5/86, 5.8%) had at least one SRE (Table 2). Three patients (3.5%) sustained a pathologic fracture, three (3.5%) required repeat RT, and three (3.5%) required further surgical intervention. In the three requiring surgical management, one had a pathologic fracture and repeat RT, one had a fracture only, and one had repeat RT only and later had an impending fracture that was managed surgically. The mean radiation dose in those with a post-RT fracture was 23.3 Gy (range 20-30 Gy) and in those without fracture was 22.5 Gy (8-55.8 Gy). Median time to fracture was 69 days (range 24-777) and median time of last follow-up from time of RT completion was 88 days (range 0-4578).

Frequency of death following RT

Overall, 79 patients (91.9%) died. Median time to death was 126 days (range 1-2368 days). Fifteen patients (15/86, 17.4%) died within one month of RT, 30 patients (30/86, 34.9%) within three months, 49 patients (49/86, 57.0%) within six months, and 65 patients (65/86, 75.6%) within one year of radiation completion.

Frequency of orthopedic evaluation and pathologic fracture at presentation

Prior to radiation therapy, 42 patients (42/86, 48.9%) had an orthopedic evaluation. Sixteen of the evaluated patients (16/42, 38.1%) received prophylactic stabilization with an intramedullary nail (IMN). Ten patients (11.6%) presented with a pathologic fracture, with eight undergoing subsequent ORIF (seven IMN and one plate) and two undergoing replacement prior to RT. None of the patients presenting with a pathologic fracture had an SRE following surgery and radiation therapy.

Risk factors associated with skeletal related events

In our cohort, a total of five patients (5/86, 5.8%) developed a skeletal related event following the completion of radiation therapy. On univariate analysis we did not identify any risk factors that were predictive of a skeletal related event or fracture (Table 3).

DISCUSSION

As many as 80 percent of patients with solid tumor malignancies will develop bone metastases during the course of their cancer.¹ Metastatic disease of the femur is one of the most common sites of osseous involvement and patients will typically present with pain or reduced mobility. When MDF is identified, it is crucial that appropriate evaluation is performed as impending pathologic fractures require prophylactic surgical stabilization followed by radiation therapy while metastases without concern for structural instability may be treated non-operatively. Prophylactic stabilization plays an important role in the management of impending pathological fractures as fixation may prevent significant pain and loss of function. In the setting of a pathologic fracture, fixation improves fracture healing compared to cast immobilization and radiation alone.⁷

Radiotherapy plays an important role in the management of metastatic bone disease with 60% of patients experiencing at least partial pain relief following treatment.⁸ Though radiation therapy is an integral and well-studied component in the management of metastatic bone disease, there is limited information of its role in MDF and SREs following the completion of radiation therapy. Townsend et al. compared the outcomes of surgery with post-operative RT to surgery alone in 64 cases requiring orthopedic stabilization of weight bearing bones with impending or complete pathologic fracture and found on MVA that functional status is significantly improved with the addition of radiation therapy.⁹ Wedin et al. and Wolanczyk et al. evaluated the re-operation rates

Table 3. Risk Factors for SREs or Fracture

	SRE	No SRE	p value	Fracture	No Fracture	p value
Male	5	45	0.0717	3	47	0.2613
Female	0	36		0	36	
Proximal	4	55	1	2	57	1
Other	1	26		1	26	
Other organ mets	4	51	1	2	53	1
No other organ mets	1	30		1	30	
Orthopedic eval	2	40	1	2	40	0.6118
No orthopedic eval	3	41		1	43	
Pathologic fracture	0	10	1	0	10	1
No path fracture	5	71		3	73	
Renal cell	2	13	0.2077	2	13	0.0773
Not renal cell	3	68		1	70	
Lung	1	31	0.6467	0	32	0.2908
Not lung	4	50		3	51	
Prophylactic surgery	1	15	1	1	15	0.4651
No surgery prior	4	66		2	68	
Survival < 3 months	1	29	0.6538	1	29	1
Survival > 3 months	4	52		2	54	
Survival < 6 months	1	49	0.1562	1	49	0.5691
Survival > 6 months	4	32		2	34	
Survival < 1 year	2	63	0.0912	1	64	0.1464
Survival > 1 year	3	18		2	19	
RT dose < 20 Gy	1	15	1	0	16	1
RT dose ≥ 20 Gy	4	66		3	67	
RT dose < 30 Gy	4	43	0.3713	2	45	1
RT dose ≥ 30 Gy	1	38		1	38	

of fracture sites treated with surgery alone vs surgery with radiation and found no difference in re-operation but a significantly lower rate of tumor progression in the group treated with radiation.^{10,11} The main purpose of our study was to report the incidence and factors associated with skeletal related events following radiation therapy to the femur. Other goals of our study were to report the incidence and importance of orthopedic evaluation and pathologic fracture at the time of MDF diagnosis.

Though the outcome of radiation for metastatic bone disease is well studied, few reports have investigated the impact of radiation on metastatic disease of the femur specifically and its association with fracture, re-irradiation, or the need for further surgical intervention. In our study, 5.8% of patients (5 of 86) had at least one skeletal related event, with three patients (3.5%) sustaining a pathologic fracture, three patients (3.5%) requiring repeat radiation, and three patients (3.5%) requiring further surgical intervention (Table 2). Of those with a post-RT fracture, one had been treated with a curettage and bone grafting, one patient had a fracture around a prophylactically-placed intramedullary nail and did not require further surgical intervention, and one patient had an impending fracture that was unrecognized prior to RT and was likely preventable had the risk of fracture been recognized.

The incidence of fracture rates in other studies vary, from 7.7% in Shimoyama et al. report to as high as 21.2% in the study by Tatar et al.^{2,6} The largest of these studies by Shimoyama analyzed 428 femur metastases treated with radiation, where 33 of 428 lesions developed a post-radiation therapy femur fracture at a median 4.4 months. In the current study, we investigated several patient and treatment related factors and their impact on skeletal related events and fracture following RT and did not identify any significant risk factors associated with an SRE. Prior reports have shown that femur fractures occur more often in proximal femur metastases, and in our cohort four of five SRE were located in the proximal femur, though this was not statistically significant.^{3,5,6} We also investigated whether radiation dose played a role on outcomes (≥20 Gy vs <20 Gy, ≥30 Gy vs <30 Gy) and did not find any statistical difference in line with prior studies.^{3,4} The median time to fracture in our group was 69 days (range 24-777), falling in the range of previously reported times of 8.5 weeks to 10 months.^{3,5,6} None of the patients in our study presenting with a pathologic fracture developed an SRE.

The distinction of tumor pain versus pain from impending pathologic fracture is also an important consideration as it plays a key role in a patient's pain relief and functional outcome. In our current study, we found that half of patients were referred for an orthopedic evaluation prior to the start of radiation therapy, and one patient with an unrecognized impending fracture at the time of presentation was not referred and ultimately required surgical intervention following radiation therapy. This single case demonstrates the need of educating medical and radiation oncologists on the signs and symptoms of an impending pathologic fracture at time of diagnosis, such as use of Mirels' criteria.¹² Of the patients that were referred to orthopedic oncology, 61.9% (26 of 42)

received surgical intervention to prevent or manage a pathologic fracture, demonstrating the importance of the orthopedic oncologist in the multi-disciplinary care of MDF.

Our study does have limitations that deserve mention. First, this is a small retrospective study with few overall skeletal related events which limits analysis. While the small number of observable events limits the power of any statistical conclusions, it does imply the benefits of multidisciplinary care of metastatic disease of bone. Specifically, there is a selection bias in the cohort, as all of these patients were treated at a comprehensive cancer center with co-localization of orthopedic oncology and radiation oncology in the same facility. All subtypes of cancer at our institution are managed with input from multidisciplinary tumor boards, so communication regarding complex patients is routine and expected. Therefore, it is likely that the number of unrecognized impending pathologic fractures (only one in the entire cohort) may be unrepresentatively low compared to smaller community hospitals where orthopedic consultation is not common or expected. This observation may serve as a suggestion that the best method to prevent post-RT fracture is to educate all the involved providers (radiation oncology, medical oncology, and orthopedic surgery) to recognize the signs and symptoms of impending pathologic fractures and obtain pre-RT surgical consultations when appropriate. Second, we did not investigate the use of bone modifying agents such as bisphosphonates.

In conclusion, our single institution retrospective study evaluating the impact of radiation therapy on MDF found no statistically significant risk factors that increase a patient's risk of developing a skeletal related event following treatment. We found that nearly half of patients with MDF were evaluated by an orthopedic oncologist, nearly 2/3 of whom received operative stabilization or reconstruction, and only one patient who sustained a pathologic fracture after RT treatment with an unrecognized impending fracture prior to treatment. As MDF is a common site of osseous disease with the potential for high morbidity, it is important that medical and radiation oncologists be educated on the signs and symptoms of impending pathologic fracture that warrant further evaluation.

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IS THE IMPLANT IN BONE? THE ACCURACY OF CT AND FLUOROSCOPIC IMAGING FOR DETECTING MALPOSITIONED PELVIC SCREW AND SI FUSION IMPLANTS

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ABSTRACT

Background: Spine fusions to the pelvis have been associated with increased strain to the sacroiliac joint (SI) and possibly continued postoperative low back pain. To minimize this, concomitant SI joint fusion at the time of lumbopelvic fixation has been advocated. This requires concomitant placement of sacral alar iliac screws (S2AI) for lumbopelvic fixation and triangular titanium rods (TTR) for the SI joint fusion. Traditionally, surgeons have mostly relied on fluoroscopic images to confirm final implant position and patient safety after pelvic instrumentation, although computer tomography (CT) has also been used.

Methods: We wanted to know which imaging modality, if any, was superior in helping to identify malpositioned implants during concomitant lumbopelvic fixation and SI joint fusion. We instrumented pelvic sawbones models with S2AI screws, TTR's, or both in the correct anatomic positions or malpositioned variants that led to known cortical breaches. Pelvic models were then imaged with fluoroscopy and CT, and the images assessed by blinded reviewers (spine surgeons and a musculoskeletal radiologist) for the presence of cortical breaches, the identity of the breached implant, and its direction. The responses of the blinded reviewers were then compared to the known position of the implants and Kappa coefficient calculated to determine agreement.

Results: We found that thorough evaluation of implant position with multiple fluoroscopic views (κ 0.641) or CT imaging (κ 0.906) al-

lowed reviewers to assess implant position, identity, and breach direction

Conclusion: These findings suggest that intraoperative CT imaging allows surgeons to make the best decision regarding implant position prior to leaving the operating room, thus potentially improving patient safety and unplanned returns to the operating room.

Level of Evidence: V

Keywords: spinopelvic fixation, SI joint fusion, intraoperative CT, sacral alar 2 iliac screws, triangular titanium rods

INTRODUCTION

Pelvic instrumentation is a common practice amongst spine surgeons. Most commonly, this is pursued during lumbopelvic fixation to increase construct rigidity and fusion rates in fusion surgeries extending to the sacrum.¹⁴ Extension of spine fusions to the sacrum has been associated with increased strain of the SI joint and continued postoperative low back pain.¹⁷ To minimize the pain from SI joint irritation after long fusions to the sacrum, surgeons have advocated performing concomitant SI joint fusion at the time of spinopelvic fixation. This technique involves placement of a triangular titanium rod (TTR) across the SI joint, just cephalad to an S2-Alar-Iliac (S2AI) pelvic screw. A prospective, randomized clinical trial is underway in order to investigate the clinical efficacy of this technique (SILVIA Study, clinicaltrials.gov, #NCT04062630). However, this emerging technique poses new challenges for spine surgeons, one of them being how to best determine implant containment within the narrow supra-acetabular bony corridor during concomitant lumbopelvic fixation and SI joint fusion (Figure 1). Pelvic anatomy is complex and its proximity to vital structures makes its instrumentation challenging. Traditionally, surgeons have relied on intraoperative fluoroscopic imaging for correct placement of implants. However, adequate imaging is not always possible and the difficulties with intraoperative fluoroscopic pelvic imaging are well documented in the orthopaedic literature.^{6-8,12} Obesity, bowel gas, and sacral dysmorphism have all been identified as negative predictors for obtaining useful fluoroscopic images that would allow for correct and safe placement of implants.⁹ In an effort to

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Disclosures: David Polly, MD lists a consultancy with SI Bone, the manufacturer of the triangular titanium implant, as a conflict with the current study. The other authors report no potential conflicts of interest related to this study.

Sources of Funding: This project was supported by the Clinical Research Fund maintained by the University of Minnesota Orthopaedic Research Department.

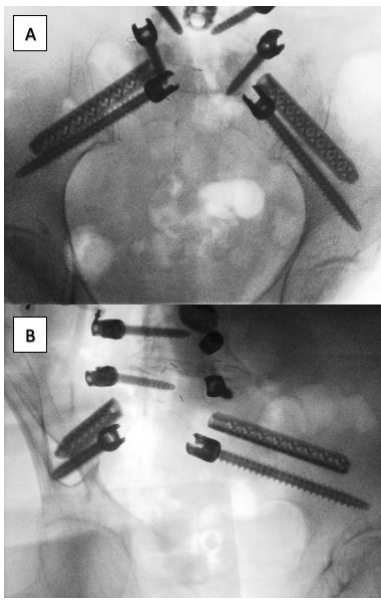


Figure 1. Intraoperative radiographs of open SI joint fusion with TTR in conjunction with S2AI spinopelvic fixation. (A) Inlet and (B) teardrop view, showing containment of implants within the supraacetabular bony corridor.

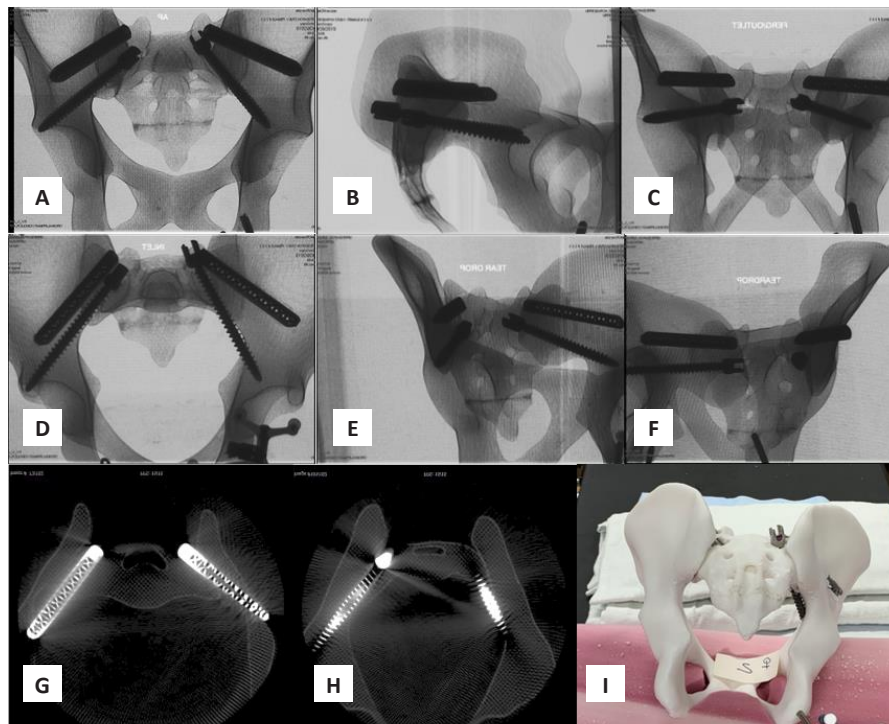


Figure 2. Example of instrumented pelvic model used for analysis. Fluoroscopic views: (A) Ap, (B) lateral, (C) outlet, (D) inlet, (E) Right iliac oblique, (F) right teardrop view. CT axial cuts showing (G) TTR's and (H) S2AI screws. (I) Picture of the imaged model showing the lateral TTR and medial S2AI screw breaches.

improve accurate implant placement and patient safety, some surgeons have adopted the use of intraoperative CT-based imaging. This has been shown to decrease the number of malpositioned implants, return to the operating room for revisions, as well as improving the safety of surgical interventions.^{10,8} The benefits of intraoperative CT imaging are not foreign to spine surgeons, where it has also been shown to reduce returns to the operating room to revise malpositioned pedicle screws.¹¹

Concomitant lumbopelvic fixation and SI joint fusion is a promising technique to help minimize continued postoperative back pain. Adequate visualization of the S2AI screw and TTR in the narrow supra-acetabular bony corridor is a technical challenge. Specifically, the presence of a second implant can cast radiographic shadows and obscure visualization, thus complicating imaging verification of implant position. To this date there is no published study on the ideal imaging modality, if any, to ensure accurate implant placement during this procedure and, thus, patient safety. With this in mind, we instrumented pelvic sawbones models with both S2AI and TTR's both in ideal positions, as well as various breached malpositions. We then used both fluoroscopy and computer tomography (CT) to image these pelvic models and asked blinded reviewers to determine the position of the implants and breaches, if any. The results

of this study will provide surgeons with guidance as to which intraoperative imaging modality, fluoroscopy versus CT, is superior at detecting malpositioned pelvic implants, particularly during concomitant lumbopelvic fixation and SI joint fusion.

METHODS

The design of this study was submitted and approved by the Institutional Review Board at our institution. Three female human sawbones pelvic models (SI Bone, Santa Clara, CA) were used for this study. S2AI Screws were placed into sawbones models in one of the following positions: 1) optimal anatomic placement in which the screw is entirely in bone, (2) violation of the sciatic notch, (3) hip joint violation, (4) medial wall violation, and (5) lateral wall violation. We then obtained anteroposterior (AP), lateral, inlet, outlet, iliac oblique, and teardrop fluoroscopic views of each specimen, and followed this with a CT scan (O-Arm, Medtronic, Minneapolis, MN). Next, TTR's (I-Fuse 3D, SI Bone, Santa Clara, CA) were placed cephalad to the S2AI implants trajectory in the same specimens in one of the following positions: (1) Optimal anatomic position, (2) medial wall violation, (3) lateral wall violation, (3) superior violation. The imaging was then repeated, as previously. Lastly, we then removed the S2AI implants, and imaged the

Table 1. Kappa Values of Single and Multiple Image Analysis for Fluoroscopy Versus CT Imaging

	Breach vs. No Breach	Identity of breached implant	Direction of breached implant
Fluoroscopy single view	-0.0987 (P = 0.9505)	0.0981 (p value not available)	N/A
Fluoroscopy multiple views	0.641 (0.344 - 0.923, p< 0.001)	0.521 (0.259 - 0.804, p<0.001)	0.576 (0.372 - 0.802, p<0.001)
CT imaging multiple views	0.906 (0.646 - 1.0, p<0.001)	0.776 (0.563 - 0.947, p<0.001)	0.7 (0.529 - 0.901, p<0.001)

Confidence interval and p value in parentheses.

TTR implants alone in a similar fashion. In all cases, the breached implant extended from the cortical margin by approximately 5mm, which is a distance shown to exceed tolerable anterior breaches into the abdominal or thoracic cavity from pedicle screws.¹³

Images from the CT scans and fluoroscopy were de-identified, randomized, and mounted in a PowerPoint presentation (Microsoft Office, Redmond WA). The fluoroscopic image analysis was performed in two different ways: single view and multiple view approach. In the single view analysis two reviewers, J.S and T.T, were asked to screen 41 individual images and make a determination on implant position based on a single fluoroscopic view (AP, lateral, inlet, outlet, iliac oblique, or teardrop view); one set of images was missing an AP view. In the multiple view fluoroscopic analysis, three reviewers (J.S.N, T.T, and D.P) were asked to screen seven sets of images with AP, lateral, inlet, outlet, iliac oblique, and teardrop view for any given pelvis model and implant combination. (Figure 2). The same pelvic models were reviewed in the single and multiple view analyses. Lastly, the reviewers evaluated the same pelvic models with CT scans, which included axial, sagittal, and coronal reconstructions. For the single view analysis, reviewers were provided with 21 axial, sagittal, or coronal stack images in video format for the given pelvic model and implant combination. For the multiple view analysis, the reviewers were provided with 7 different axial, sagittal, and coronal image stack for the same implant in video format. For each individual CT view or set of views, the reviewer was asked to state if there was an implant breach, and if so, which implant was breached, and lastly, which direction it was breached in.

For each analysis, agreement between the master key and the reviewer’s responses was quantified with the kappa statistic using Stata software (College Station, TX) for three categories: 1) cortical breach or no cortical breach, 2) identity of breached implant (none, S2AI, TTR), and 3) breach direction (medial, lateral, superior, inferior). When significant (greater agreement than that due to chance, P < 0.05), the classic interpretation

of kappa as given by Landis and Koch was used as a guide: <0 = poor, 0-0.2 slight, 0.2-0.4 fair, 0.4-0.6 moderate, 0.6-0.8 substantial, 0.8-1 almost perfect.¹⁴ The kappa statistics were then averaged across the reviewers, and our results are presented as the mean.

RESULTS

Analysis of individual fluoroscopic images

When asked to analyze individual fluoroscopic views and determine if there was a breach, the reviewers’ assessment of implant position yielded a mean kappa value of -0.0987 consistent with poor agreement. When there was a breach, their assessment of breach direction yielded a mean kappa value of 0.0981 (Table 1). When the analysis of single images was further broken down to assess if particular views (e.g: AP versus Inlet) were associated with a higher level of agreement with the master key, no view was found to help reviewers achieve a higher level of agreement with the master key.

Analysis of grouped fluoroscopy images

When asked to perform the analysis with the complete set of fluoroscopic images (AP, lateral, inlet, outlet, iliac oblique, and teardrop view), the reviewers’ mean kappa value was 0.641, consistent with moderate agreement with the master key. Identification of implant identity, S2AI screw or TTR, yielded a mean value at 0.521, consistent with a fair agreement with the master key. Finally, determining breach direction yielded a mean kappa value of 0.576, consistent with fair agreement with the master key (Table 1).

Analysis of computed tomography images

Determination of presence of cortical breach yielded a mean kappa value of 0.906, consistent with an almost perfect agreement with the master key. Identification of implant identity yielded a mean kappa value of 0.776 consistent with substantial agreement with the master key. Finally, direction of implant breach yielded a mean kappa value of 0.7, consistent with substantial agreement with the master key (Table 1).

DISCUSSION

Pelvic anatomy is complex and intra-operative imaging can be difficult to interpret, making instrumentation technically challenging, particularly in patients with high BMI, large amounts of bowel gas, and dysmorphic pelvic anatomy. The aim of this study was to evaluate fluoroscopy and CT imaging as modalities to determine the accuracy of pelvic instrumentation intraoperatively. To this end, we instrumented pelvic sawbones models with S2AI screws, TTR's, or a combination of these, which were then imaged with both fluoroscopy and CT-based imaging. These images were then evaluated by blinded reviewers to determine whether there were cortical breaches, and if so, the identity of the breached implant and its direction.

When reviewers were provided with single fluoroscopic images, determination of implant position was poor with a kappa value of -0.0987. On the other hand, when reviewers were provided with a complete set of fluoroscopic images for the implant in question, their assessment improved significantly for both determination of implant breach and identity, kappa value of 0.641 (moderate agreement) and 0.521 (fair agreement), respectively.

These findings highlight one of the caveats of fluoroscopic imaging of complex three-dimensional structures such as the pelvis, namely the superimposition of anatomy. For example, when placing implants in the supra-acetabular region of the pelvis, a lateral view of the pelvis is appropriate to assess for breach into the sciatic notch; however, a lateral breach would not be necessarily apparent. Thus, by capturing a three-dimensional structure in a two-dimensional image, fluoroscopy can create the false impression that implants are located within bone, leading surgeons to make erroneous determinations about the location of placed implants. Along similar lines, this issue is compounded when more than one implant is placed into the supra-acetabular corridor. In the case of an S2AI screw and a TTR, the radiographic shadow casted by one implant can further obscure the anatomic landmarks that surgeons use to estimate the location, and thus safeness, of their implants. Based on our results. Based on our results, when using fluoroscopy surgeons need to obtain a complete set of views to ensure safe pelvic instrumentation during spinopelvic fixation, SI joint fusion, or both.

In contrast to fluoroscopy, CT imaging provides a high-resolution cross-sectional image, in different planes, of the target area, as well as its relationship to the implants placed. Our results are a testament of the power of CT at making anatomy more apparent, as it allowed reviewers to make the most accurate assessment when identifying cortical breaches (kappa 0.906),

the identity of the breached implant (kappa 0.776), and its direction (kappa 0.7). The cross-sectional nature of the images obtained with CT allows reviewers to have a higher resolution view of the relationship of implants to cortical anatomy. In turn, this would allow surgeons to minimize injury to nearby critical structures by leaving malpositioned implants. These findings are particularly relevant when performing concomitant spinopelvic fixation and SI joint fusion. During this procedure, a TTR (average implant size 7mm x 90 mm) and a S2AI screw (average implant size 9.5 mm x 90 mm) are placed in the supra-acetabular region of the pelvis. This bony corridor is very narrow, particularly along its cephalad aspect, and is bounded by critical neurovascular structures that can easily be injured by misplaced implants. As such, it is crucial that surgeons have the certainty that their implants are appropriately positioned before the patient leaves the operating room.

Our results echo those of most literature on intra-operative imaging during pelvic instrumentation. Recent studies have shown that surgeons tend to overestimate the accuracy of safe implant position when using fluoroscopy for pelvic instrumentation during orthopaedic trauma cases.¹⁵ Malpositioned screws during instrumentation for pelvic fractures have been documented to be as high as 15%, while neurologic injury has been as high as 7.7%.⁸ Obtaining quality fluoroscopic imaging is not always possible, and as such, some trauma surgeons have adopted intraoperative CT imaging for instrumentation of pelvic fractures, which has led to improvement in the accuracy of placed implants.⁸ Similarly, spine surgeons have shown that intraoperative CT imaging is associated with lower pedicle screw malposition rates, when compared to fluoroscopy, particularly in the thoracic spine.^{11,16}

This study provides guidance to surgeons during imaging of pelvic implants; however, some limitations should be noted. First, this is an in-vitro study using pelvic sawbones models. The sawbones models, although a reproduction of a human pelvis, do not replicate human bone density in magnitude or distribution. This factor could have affected the identification of anatomical landmarks used by reviewers to assess the position of their implants. CT imaging, with its higher resolution, can compensate for this and make identification of landmarks easier. In the future, an alternative to this would be to replicate the study with cadaveric pelvises. Second, we have a homogeneous group of pelvic sawbones models. Pelvic dysmorphisms is a known factor that complicates imaging and instrumentation of the pelvis, as such it is possible that our results and interpretation may be skewed towards non-dysmorphic pelvises. If this was the case and given the known difficulties with imaging

and instrumentation of dysmorphic pelvises, we would expect this to further widen the accuracy gap in favor of CT imaging at identifying malpositioned implants. As such, we felt that the small differences in morphology between normal and dysmorphic pelvic models were unlikely to change the core conclusion of this project, which is that CT was superior to fluoroscopy in detecting small breaches. And finally, how clinically relevant is the 5mm breach chosen for this study? We could not find a study addressing this question for pelvic instrumentation, yet during placement of pedicle screws in the thoracic spine a 5mm breach was considered to be clinically relevant.¹³ The supra-acetabular bony corridor where the S2AI screw and the TTR are placed is bounded by critical structures that can lead to death or severe disability, if injured. As such, we felt that the 5mm threshold was appropriate, particularly inferiorly and medially.

In summary, when fluoroscopy was used, single radiographic views in isolation were not useful in identifying breached implants or their direction. However, a complement of radiographs including AP, lateral, inlet, outlet, iliac oblique, and tear drop views improved the accuracy of reviewers' assessment significantly. Nonetheless, CT-imaging proved far superior for detection of malpositioned implants when performing open SI joint fusion in conjunction with S2AI screws for spinopelvic fixation.

CONCLUSION

When performing open SI joint fusion with TTR in conjunction with spinopelvic fixation using S2AI screws, CT-based imaging allows for the most accurate assessment of malpositioned implants. Fluoroscopy can also identify breaches, but if chosen it would be beneficial to have a complete radiographic review, including AP, lateral, inlet, outlet, iliac oblique and teardrop images.

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INTRAOPERATIVE SPINAL CORD MONITORING DOES NOT DECREASE NEW POSTOPERATIVE NEUROLOGICAL DEFICITS IN PATIENTS WITH CERVICAL RADICULOPATHY OR SPONDYLOTIC MYELOPATHY UNDERGOING ONE OR TWO LEVEL ANTERIOR CERVICAL DISCECTOMY AND FUSION

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ABSTRACT

Background: Intraoperative neurological monitoring (IONM) is commonly used in spine surgery. However, the utility of IONM in anterior cervical decompression and fusion (ACDF) remains a topic of debate. The purpose of the study was to investigate the utility and cost of IONM (both Somatosensory evoked potentials (SSEPs) and Motor Evoked Potentials (Tc-MEPs)) in reducing postoperative neurological deficits in myelopathic and non-myelopathic patients undergoing ACDF.

Methods: Retrospective chart review was performed to include only patients with cervical radiculopathy or myelopathy undergoing one or two level ACDF over a 7-year period at a busy academic center. SSEP and Tc-MEP tracings were reviewed for all monitored patients and significant changes and inconsistencies were noted. IONM billing codes (SSEP/Tc-MEP) were reviewed and summed to evaluate the average procedural cost. Medical records were reviewed for preoperative physical exam and for new postoperative neurological deficits on postoperative day one and again at six weeks and matched to the monitored tracings.

Results: There were 249 total patients (48 Non-monitored, 201 monitored). There was no difference in gender, age, or BMI between monitored and non-monitored groups. There was no difference in new neurological deficits in monitored compared with non-monitored patients with radiculopathy ($p=0.1935$) or myelopathy ($p=0.1977$). However, when radiculopathy and myelopathy patients were combined, there was an increased incidence of new

neurologic deficits in monitored patients (8.0%) versus non-monitored patients (0%) ($p=0.0830$). All new neurological deficits occurred in patients with normal IONM tracings. There were no new neurological deficits in the non-monitored radiculopathy or myelopathy groups. The average IONM procedure charge was \$6500.

Conclusion: Our results indicate that intraoperative spinal cord monitoring did not reduce new neurological deficits in our cohort of patients. The higher incidence in new neurological deficits despite no IONM changes in our monitored group suggests a lack of utility of IONM in ACDF. Furthermore, at an average of \$6500 per IONM procedure, the present study underlines the importance of prudence when choosing to use IONM in the era of cost containment.

Level of Evidence: III

Keywords: intraoperative spinal cord monitoring, acdf, postoperative neurological deficit

INTRODUCTION

Intraoperative neurophysiologic monitoring (IONM) has become a useful technique in assessing the neurologic status of the anesthetized patient. Giving a wide variety of uses, IONM allows for real-time information regarding the cortex, brainstem, spinal cord, nerve roots, and peripheral nerves.^{1,2} Ideally, IONM works to identify neural injury at a time where the surgical team can intervene to reverse an otherwise permanent deficit. The effectiveness of IONM in many aspects of spine surgery is undisputed. Most notably, utilization of Simultaneous Somatosensory Evoked Potentials (SSEPs) in scoliosis surgery successfully reduced new post-operative neurological deficits from 0.7-4.0% to less than 0.55%.³⁻⁷ With an estimated pedicle screw breach or fracture rate of 5-6%,⁸ a loss of amplitude or increased latency discovered by IONM could prompt the surgeon to remove, adjust or ultimately decide against a certain screw placement—theoretically preventing spinal cord or nerve root damage. However, not all spine operations carry this same risk. In fact, complications in ACDF surgery are well documented and spinal cord or nerve

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

Sources of Funding: No sources of funding declared.

root injury is very rare.⁹⁻¹¹ More common complications are dysphagia, recurrent laryngeal nerve palsy, post-operative hematoma, vascular injury, pharyngeal or esophageal injury, and thoracic duct injury.¹²⁻¹⁶ We hypothesized that there would be no difference in new postoperative neurological deficits in monitored (SSEPs and Tc-MEPs) versus non-monitored groups of patients with myelopathy or radiculopathy undergoing one or two level ACDF. Secondarily, given that IONM is a potential added cost, to determine IONM charges at our institution.

METHODS

After obtaining IRB approval (IRB ID #201604773), a retrospective chart review was performed at a single institution to include all ACDF procedures over a 7-year period. Patient charts were then sorted by ICD-9 codes to include only patients undergoing one or two level ACDF with a diagnosis of cervical radiculopathy (723.4) or cervical spondylotic myelopathy (721.1). Patients from five orthopedic spine surgeons were included. Although patho-physiologically there are significant differences between radiculopathic and myelopathic patients, IONM compares intraoperative readings to a preoperative or pre-induction baseline—essentially zeroing the scale for each patient regardless of pathophysiology or preexisting deficits. Therefore, we elected to combine both radiculopathic and myelopathic patients into the same group. Patients with acute fracture, epidural abscess/infection, or tumor requiring ACDF were excluded from the study.

Patient demographic data including age, BMI and gender were recorded for each patient. Variables for age and BMI were compared between the monitored and non-monitored groups using student T-test. Gender was compared between the two groups using chi-square analysis. Significance was set at P-value less than 0.05.

Neurophysiological monitoring

The monitored group included SSEPs and Tc-MEPs using cortical and subcortical recordings in response to interval stimulation of median/ulnar and tibial/peroneal nerves. Baseline SSEPs and Tc-MEPs were obtained after induction of anesthesia and before opening incision in all cases. Continuous upper and lower extremity stimulation and transcranial motor stimulation was performed concurrently throughout the surgical procedure. The appropriate upper extremity nerve to be stimulated was selected according to the level of cervical decompression and accessibility dictated by anesthesia needs.

Peripheral Nerve SSEPs (Median/Ulnar/Peroneal/Tibial)

Peripheral nerves were stimulated bilaterally in an alternating fashion using self-adhesive surface electrodes

in pairs with proximally placed cathodes and the anode placed ~1 cm away. Recordings were obtained from the scalp using sub-dermal needle electrodes. Scalp electrodes used were CP3, CP4, Cz, Fz, C1, C2, A1 and A2 (according to the international 10-20 system). Constant voltage stimulators using adequate intensity to evoke a reliable response produced evoked sensory potentials. Stimulation frequency was 3.07 Hz with duration of 0.2-0.3 ms. Bandpass filters were set at 30–500 Hz with a gain of 2uV/division for cortical recordings. A 1000 trial average was used. Averages were computed from incision to closing.

Transcranial motor evoked potentials (Tc-MEPs)

The motor area of the cortex was stimulated using sub-dermal needle electrodes with anodal stimulation over the left and right area of the cortex in an alternating fashion. Stimulating electrodes were initially placed in the F3/F4 (according to the international 10-20 system) positions. Electrode position was adjusted until reliable baseline responses were obtained. Stimulation consisted of square wave electrical pulses of 75us duration in a train of up to 8 pulses with an inter stimulus interval of 1msec. Stimulation intensities of up to 800V were used; the lowest intensity at which reliable compound motor action potentials (CMAPs) were recorded was used. Bandpass filters were set at 30-3000Hz with a gain of 500uV/division. CMAPs were recorded from the deltoid, flexor carpi ulnaris, brachioradialis, and either abductor pollicis longus or abductor digiti minimi, depending on access to the hand, in the bilateral upper extremities. CMAPs were recorded from the tibialis anterior and abductor hallucis in the bilateral lower extremities.

Alarm Criteria

Baseline tracings for both SSEPs and Tc-MEPs were taken from the initial recordings obtained after induction of anesthesia and before incision. SSEPs were continuously collected (~1 every 5 minutes) throughout the procedure. Neurophysiological changes requiring surgeon notification included a greater than 50% reduction in primary somatosensory cortical amplitude in the recorded response or a prolongation of response latency by greater than 10% unrelated to changes in anesthesia. Tc-MEPs were collected continuously (~1 every 5 minutes) throughout the procedure. A reduction in the CMAP amplitude of greater than 50% unrelated to changes in anesthesia was viewed as being significant and the surgeon was informed. Alarm criteria was based upon optimal sensitivity and specificity for detecting iatrogenic injury in the spinal cord as agreed upon in the literature.^{1,17}

Table 1. Monitored and Non-Monitored Groups by Diagnosis

	Cervical Radiculopathy	Cervical Spondylotic Myelopathy
Monitored	117	84
Non-monitored	39	9
Total	156	93

Neuromonitoring Charges

IONM billing data was pulled for each case using Current Procedural Terminology (CPT) codes for both short-latency somatosensory evoked potentials (CPT 95938) and central motor evoked potentials (CPT 95939). A third code (CPT G0453) is also used for continuous intraoperative neurophysiology monitoring, from outside the operating room (remote or nearby), per patient, per unit time (1 unit=15 minutes), and was included in total charge summation. Billing codes were then reviewed and summed to evaluate average total procedural charges. All procedural charges were calculated using 2016 billing data.

Medical records were then reviewed for both monitored and non-monitored groups for development of new postoperative neurological deficit. New postoperative neurological deficit was defined as any new sensory deficit, or any new reduction in motor strength by greater than or equal to one level on the standardized motor examination rating scale. Patients were evaluated pre-operatively and then again on postoperative day one

Table 2. Patient Characteristics by Group

Patient Characteristics			
	Monitored	Non-monitored	P Value
Age (Mean)	50.53	49.78	0.69
BMI (Mean)	30.13	29.8	0.77
Gender			
Male	99	25	
Female	102	23	0.655

and at 6 weeks follow-up. Neurological deficits were subsequently matched to their respective monitored tracings. The Fisher exact test was used to compare groups.

RESULTS

A total of 249 patients, 50% female, were included. The control group consisted of 48 non-monitored and 201 monitored patients (Table 1). There was no difference in gender, age, or BMI between monitored and non-monitored groups (Table 2). There was no difference in new neurological deficits in monitored compared with non-monitored patients with radiculopathy (p=0.3377) or myelopathy (p=0.2044). However, when radiculopathy and myelopathy patients were combined, there was an increased incidence of new neurological deficits in monitored patients (8.0%) versus non-monitored patients (0%) that trended toward significance (p=0.0830) (Table 3). There were 15 patients with new neurological deficits (6 radiculopathy, 9 myelopathy). Four of fifteen (26.7%) patients had complete resolution of neurological deficit by

Table 3. New Neurologic Deficits in Monitored Versus Non-Monitored Groups

Radiculopathy				
	Neurologic Change +	Neurologic Change -		p=0.3377
Monitored +	6 (5.1%)	111 (94.9%)	117	
Monitored -	0 (0.0%)	39 (100%)	39	
		Total Patients	156	
Myelopathy				
	Neurologic Change +	Neurologic Change -		p=0.2044
Monitored +	9 (11.9%)	75 (88.1%)	84	
Monitored -	0 (0.0%)	9 (100.0%)	9	
		Total Patients	93	
Radiculopathy and Myelopathy Combined				
	Neurologic Change +	Neurologic Change -		p=0.0830
Monitored +	15 (8.0%)	186 (92.0%)	201	
Monitored -	0 (0.0%)	48 (100.0%)	48	
		Total Patients	249	

Table 4. New Postoperative Neurological Deficits

Patient	Gender	Age	Radiculopathy or Myelopathy?	ACDF Level	Monitoring Changes?	Preoperative Deficit?	New Postoperative Neurological Deficit?	Deficit resolved by 6-week follow-up?
1	M	60	Radiculopathy	C6/7	*Inconsistency	No	Decreased sensation 1-3 digits right hand	Yes
2	F	56	Radiculopathy	C4/5	*Inconsistency	No	4/5 Left deltoid weakness	no
3	F	47	Radiculopathy	C5/6	No	No	Decreased sensation right C6 dermatome	No
4	M	46	Radiculopathy	C5/6	No	No	4/5 right deltoid weakness	No
5	M	33	Radiculopathy	C5/6	No	No	4/5 Bilateral triceps weakness	Yes
6	F	58	Radiculopathy	C5/6, C6/7	No	No	Decreased sensation left middle finger	No
7	F	49	Myelopathy	C5/6	No	No	4/5 Left triceps weakness	No
8	F	58	Myelopathy	C5/6, 6/7	No	4/5 R grip/interossei	3/5 right hand grip/interossei weakness	No, but improved to 4/5 right grip/interossei weakness
9	F	44	Myelopathy	C5/6, 6/7	No	No	4/5 Bilateral upper extremity weakness	Yes
10	M	60	Myelopathy	C3/4	No	4/5 bilateral quads	Decreased sensation left upper and lower extremity	No
11	M	61	Myelopathy	C4/5, 5/6	No	4/5 bilateral biceps	3/5 left biceps, 4/5 right biceps weakness	No
12	F	41	Myelopathy	C5/6	No	No	4/5 BUE weakness	No
13	M	54	Myelopathy	C6/7	No	3/5 BLE	2/5 BLE weakness	Yes
14	F	58	Myelopathy	C4/5, 5/6	No	4/5 R intrinsic hand	4/5 bilateral wrist extensors.	No
15	F	45	Myelopathy	C4/5	No	No	4/5 right triceps weakness	No

*Inconsistency: Fluctuation in signal tracings not meeting threshold for Alarm Criteria.

Table 5. Patients with Intraoperative Monitoring Changes Meeting Alarm Criteria

Patient	Gender	Age	Radiculopathy or Myelopathy?	# of ACDF Levels	Monitoring Changes?	Intraoperative Tactic Leading to Signal Change Resolution	New Postoperative Neurological Deficit?
1	Female	64	Radiculopathy	2	Loss of Tc MEP in R tibialis anterior while closing wound	None, spontaneous \ resolution	No
2	Female	48	Radiculopathy	2	Loss of SSEP with Sevoflurane increase	Reduction in inhaled anesthetic	No
3	Male	46	Myelopathy	2	Loss of all Tc-MEPs on incision	Reduction in inhaled anesthetics	No
4	Male	50	Myelopathy	1	Loss of upper and lower extremity SSEPs	Increasing stimulation intensity	No
5	Female	48	Myelopathy	1	Loss of upper and lower SSEPs	Increasing stimulation intensity	No
6	Male	59	Myelopathy	1	Loss of Tc-MEPs in bilateral abductor pollicis	Did not resolve	No

Table 6. Breakdown of IONM Facility and Provider Charges for One or Two Level ACDF

	SSEPs CPT 95938 (Fixed charge)	Tc-MEPs CPT 95939 (Fixed charge)	Continuous Monitoring CPT G0453 (Charged per unit time. 1 unit=15 min)	Total Charges
One-level ACDF (120 min)	\$983.00 Facility + \$551.00 Staff	\$1646.00 Facility + \$320 Staff	\$214 x 8 units (Facility) + \$159 x 8 units (Staff)	\$6484.00
Two-level ACDF (180 min)	\$983.00 Facility + \$551.00 Staff	\$1646.00 Facility + \$320 Staff	\$214 x 12 units (Facility) + \$159 x 12 units (Staff)	\$7976.00

6-weeks; the remaining 11 had persistent deficits at six-week follow-up. Motor deficits occurred in 11 patients, while 4 patients had isolated sensory deficits (Table 4).

Intraoperative monitoring changes meeting alarm criteria requiring surgeon notification occurred in 3% of cases (6/201)—two changes in radiculopathy patients and four in myelopathy patients. Monitoring changes resolved intraoperatively in two cases with reduction of anesthetic, two by increasing stimulation intensity, one resolved spontaneously, and one did not resolve at all (Table 5). Intraoperative monitoring inconsistencies (ie. alterations in monitoring waveforms that did not meet alarm criteria) occurred in 21% of cases (43/201) with equal occurrence in patients with myelopathy or radiculopathy. None of the intraoperative monitoring changes meeting alarm criteria developed a postoperative deficit. All new neurological deficits occurred in patients with normal tracings as confirmed by the staff neurophysiologist’ final read. There were no new neurological deficits noted in the non-monitored radiculopathy or myelopathy groups (Table 3).

The estimated average time for a one and two level ACDF was 120 and 180-minutes respectively. Fixed facility and provider charges for upper and lower SSEPs were \$983.00 and \$551.00 respectively. Fixed facility and provider charges for upper and lower Tc-MEPs were \$1646.00 and \$320 respectively. Charges for continuous intraoperative neurophysiology monitoring were \$214 and \$159 per 15-minute interval for facility and provider respectively. The average total IONM charges for a 120-minute (billed as 8 units) single level ACDF or 180-minute (billed as 12 units) two-level ACDF, including Tc-MEPs and SSEPs was \$6484.00 and \$7976.00 respectively (Table 6). Facility charges accounted for 73.4% of total IONM charges.

DISCUSSION

Our results support our hypothesis that there is no difference in new postoperative neurologic deficits in monitored versus non-monitored groups of patients with radiculopathy or myelopathy undergoing one or two level ACDF. While IONM has been shown to decrease post-operative neurological deficits in scoliosis surgery, our retrospective review of seven years of data do not indicate a benefit for utilizing IONM in our patient popu-

lation. To our knowledge, this is the first non-database study to evaluate the utility of SSEPs, Tc-MEPs and assess IONM facility and staff charges in radiculopathy and myelopathy patients undergoing ACDF.

There continues to be ongoing debate as to the use of SSEP’s alone or in combination with Tc-MEPs. Surgeons using an anterior cervical approach are rightly reluctant to use primarily SSEP monitoring given documented high false-negative results and sensitivity of 25%.^{9,18-22} For this reason, Hilibrand et al. compared Tc-MEPs and SSEPs in cervical spine surgery, including myelopathic patients, and concluded Tc-MEPs to be superior to conventional SSEPs showing 100% sensitivity and specificity of Tc-MEPs. Interestingly, they also showed that SSEP changes, if captured, lagged behind Tc-MEPs changes by up to 33 minutes—highlighting the need for both Tc-MEPs and SSEPs.²⁰

However, the fundamental question remains, “does IONM reduce new postoperative neurological deficits in ACDF surgery?” This is a difficult question to answer as the incidence of new neurological deficits in ACDF procedures is exceedingly small, ranging from 0-0.9%.^{9-11,22} Because of this, utilization of both SSEPs and Tc-MEPs have been recommended^{20,23,24} to independently verify spinal cord integrity by two independent, but parallel systems. However, in the current study, the incidence of new neurological deficit was 8% in the monitored cohort despite using both SSEPs and Tc-MEPs. Furthermore, no new neurological deficits occurred in the non-monitored cohort.

Ultimately, the 8% deficit rate in our study is substantially higher than previously reported⁹⁻¹¹ and is fundamentally perplexing—especially when considering all new deficits occurred in the monitored group. This discrepancy is likely attributed to several factors. First, it could be argued that more severe; at risk patients were selected for monitoring. However, in our cohort, monitoring was the rule rather than the exception with 78% of patients utilizing IONM. Nevertheless, all deficits were in the setting of normal IONM tracings—indicating a low sensitivity of IONM to detect neurologic change. The discrepancy could also be attributed to our stringent definition of new neurologic deficit combined with the inherent variability in inter-observer examination. Surgeon experience could also play a factor. Indeed,

surgeon 5 carried the highest deficit rate, but ironically, was the only surgeon to exclusively use IONM. Perhaps there is a less obvious foe—a false sense of security? A corollary exists in joint arthroplasty in which laminar flow and spacesuits are almost exclusively used to hypothetically reduce the risk of postoperative infection. However, Hooper et al.²⁵ in 2011 showed no benefit of laminar flow or spacesuits in reducing postoperative infection—calling to question the added cost of their use in joint arthroplasty. Ultimately, spacesuits and laminar flow did not decrease infection, and IONM in our cohort did not prevent new neurological deficits—adding to the literature questioning the utility of IONM in one or two level ACDF.

Economic impact must also be considered in surgical decision-making. Cost-effectiveness in spine deformity has been well documented estimating ~200 cases must be performed to prevent a persistent, major neurological defect.^{3,26,27} Studies evaluating cost-effectiveness in ACDF surgery are sparse and many studies recommend against routine use of IONM.^{9,28,29} Investigation into IONM billing charges revealed three major CPT codes and six separate charges for each case (Table 6). Previous studies have estimated SSEP and SSEP/Tc-MEP costs of \$600-800⁹ and \$1423²⁸ respectively, but did not specify inclusion of both facility and provider charges. The current study, accounting for both facility and provider charges, indicates that previous studies may have underestimated total costs of IONM in ACDF procedures.

We recognize that no price can be placed on human suffering and that in the case of a neurologic deficit leading to paraplegia or quadriplegia, costs could far exceed \$1 million. However, the published rates of neurologic injury in ACDF are very low with severe neurologic injuries even less common. Given this, physicians also have a financial responsibility to our patients and society. Assuming the neurologic injury rate is 0.1%, 1000 procedures would be needed to prevent one new neurologic deficit. Estimating an average cost as stated by Traynelis et al.²⁸ of \$1423 for combined SSEP/Tc-MEP monitoring, the cost to prevent one deficit would be ~\$1.4 million. Exploiting the same equation and to our study, the cost to prevent one new neurological deficit approaches \$6.5-\$8 million. These costs are not insignificant and should invite prudence when deciding on IONM use.

There are several limitations to the current study. First is the retrospective study design. Second, is the variability in physical exam findings as midlevels, resident and staff physicians all contributed to the medical record. However, it is standard practice for multiple providers to document exam findings at different time periods and the variability likely aligns closely with true practice. Additionally, given the low incidence of

iatrogenic injury during ACDF, a larger sample size, specifically in non-monitored myelopathic patients would further strengthen our study. Furthermore, with no set criterion for use of IONM at our facility, selection bias could be introduced as currently IONM use is based solely on attending preference. Finally, our institution does not currently incorporate a set anesthesia protocol and inhaled anesthetics were routinely used. Inhaled anesthetics are well documented to cause abnormalities in IONM, most specifically MEPs²—potentially introducing confusion to the results of IONM. An ideal study would include specific criteria in choosing when to use IONM and then proceeding under Total Intravenous Anesthetic Techniques (TIVA).² Given the complexity of anesthesia and variations from patient to patient, however, strict adherence to TIVA can be difficult.

IONM seems like a “no brainer”—who wouldn’t want to use all measures to potentially decrease postoperative complications? But, you must objectively look at the data. Our results indicate that intraoperative spinal cord monitoring does not reduce new neurological deficits in patients with radiculopathy or spondylosis with myelopathy undergoing one or two level ACDF. Conversely, the results imply the opposite, showing higher incidence of new neurological deficits in the monitored cohort. The reasons for increased deficit rates in the IONM group are not entirely clear, but do highlight the reality that IONM should not provide the operating surgeon with a false sense of security. Furthermore, at an average added IONM charge of \$6500-\$8000 per one or two level ACDF case, the present study underlines the importance of prudence when choosing to use IONM in the era of cost containment.

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THE ROTATIONAL POSITIONING OF THE BONES IN THE MEDIAL COLUMN OF THE FOOT: A WEIGHTBEARING CT ANALYSIS

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ABSTRACT

Background: Malrotation of medial column bones of the foot has been advocated as an important factor in foot conditions such as hallux valgus and progressive collapsing foot deformity. Although stated as a deformity component, variances of normality in the general population are not completely understood. This study intended to describe the rotational profile of all medial column bones using weightbearing computed tomography (WBCT) images in a cohort of patients with different foot and ankle problems.

Methods: In this retrospective study, 110 feet of 95 consecutive patients that received a WBCT for assessment of different foot and ankle pathologies were included. Measurements were performed by a blinded fellowship-trained orthopedic foot and ankle surgeon. Rotation of the navicular, medial cuneiform, proximal and distal first metatarsal as well as proximal phalanx of the first toe were recorded. Positive values were considered pronation and negative values were considered supination. Rotational profile of each bone/segment was assessed by ANOVA and comparison between each segment was performed using Wilcoxon Each-Pair analysis. P-values of less than 0.05 were considered significant.

Results: On average, a rotational positioning in pronation (internal rotation) was observed for all medial column bones. The navicular (43.2°, CI

41.1°-45.3°) and the proximal metatarsal (33.9°, CI 31.8°-36.0°) showed the highest mean rotation values. The medial cuneiform presented the lowest mean pronation (6.1°, CI 4.0°-8.3°). Comparison between each bone segment demonstrated statistically significant differences of rotational alignment for the different bones ($p < 0.0001$), with the exception of the distal metatarsal and proximal phalanx, that had similar amounts of pronation. A zig-zag rotational pattern of alignment was observed from proximal to distal, with relative supination/pronation of adjacent medial column bones.

Conclusion: The overall rotational profile of medial column bones was found to be in absolute pronation, most pronounced at the navicular and proximal first metatarsal, with significant differences in the amount of pronation when comparing most of the medial column bones. The presented data may be utilized as reference/baseline values of medial column rotation, supporting future prospective, comparative and controlled studies.

Level of Evidence: IV

Keywords: rotation, medial column, pronation, rotational deformity, hallux valgus, flatfoot, progressive collapsing foot deformity, WBCT

INTRODUCTION

Malrotation of tarsal bones, particularly the bones of the medial column of the foot (navicular, medial cuneiform, first metatarsal and proximal phalanx of the first toe), has long been associated with several foot and ankle deformities. Rotation as a component of deformity has been described in diseases such as Progressive Collapsing Foot Deformity (PCFD),^{1,2} Cavovarus Deformity,^{3,4} and Hallux Valgus (HV).⁵⁻⁷ For each one of the conditions, different parameters and values are described in the literature.

In PCFD patients, collapse of the longitudinal arch associated with increased pronation of the first metatarsal, talonavicular and talocalcaneal joints was reported when compared to healthy control subjects.⁸⁻¹⁰ In hallux valgus, first ray rotational deformity with increased pronation has been linked to the pathogenesis and progression of the disease.¹¹⁻¹³ Failed recognition of this aspect of the deformity was also found to be related to recurrence and

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Disclosures: Cesar de Cesar Netto-CurveBeam: Paid consultant; Stock or stock Options, Foot and Ankle International: Editorial or governing board, Nextremity: Paid consultant, Ossio: Paid consultant, Paragon 28: IP royalties; Paid consultant, Weightbearing CT International Study Group: Board or committee member, Zimmer: Paid consultant. Daniel Soares Baumfeld-Arthrex, Inc: Paid presenter or speaker, Merck: Paid presenter or speaker. John E. Femino Arthrex, Inc: Research support, Integra: Paid consultant, OnconRegen: Unpaid consultant. The other authors report no potential conflicts of interest related to this study.

Sources of Funding: No sources of funding declared.

worse outcomes.¹⁴⁻¹⁷ By using radiographic and tomographic measurements, it was found that 87% of patients with hallux valgus had significantly increased metatarsal pronation.^{12,18} Prior data also observed increased malrotation at the tarsometatarsal, naviculocuneiform and talonavicular joints.¹¹ These ideas led different authors to propose new surgical techniques based on correcting the rotational aspect of the deformity.¹⁹⁻²²

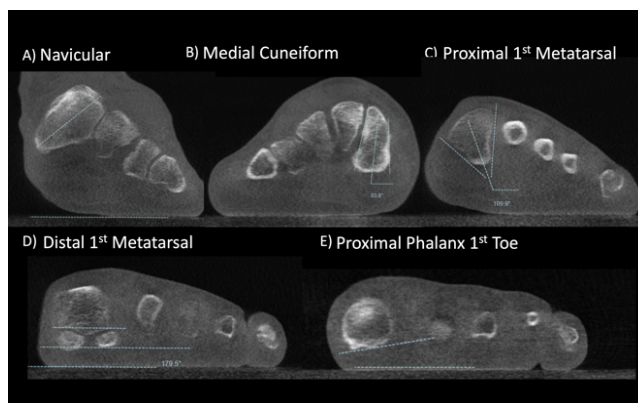
Notwithstanding the robust data regarding these two disorders, findings were mostly obtained by gait analysis, indirect radiographic signs and non-weight-bearing instruments, and conventional radiographic imaging.^{23,24} These assessments may present numerous biases and prejudice to the true three-dimensional positioning and rotation of the medial column bones during physiological standing and weight bearing. Weightbearing Computerized Tomography (WBCT), an image modality already established for the study of PCFD and HV,^{6,7,25,26} has risen as a potentially more complete and accurate three-dimensional assessment of rotational positioning of the tarsal bones during normal standing weight bearing load and standing conditions.²⁷⁻³⁰

Undoubtedly, a better understanding of both the normal and abnormal patterns of rotational positioning of the medial column bones during weight bearing would be crucial in the assessment of the role of medial column malrotation in the genesis and overall outcomes of common foot and ankle pathologies. Unfortunately, the current available data in the literature in regard to the three-dimensional rotational profile of the medial column bones during normal weightbearing is scarce.^{31,32} The objective of this study was to evaluate the 3D rotational weight bearing position of the navicular, medial cuneiform, first metatarsal and proximal phalanx of the first toe using WBCT images in a large cohort of patients with different foot and ankle disorders. Our hope was to provide the literature with baseline averaged data concerning rotational positioning of each bone of the medial column, that could serve as baseline/threshold values, fostering future prospective, controlled, and comparative studies.

METHODS

This IRB-approved retrospective study observed the Health Insurance Portability and Accountability Act (HIPAA) and the Declaration of Helsinki. It reviewed medical records of consecutive patients with various foot and ankle disorders that underwent WBCT examination as part of the standard of care at a single institution between February 2017 and February 2020.

Patients included were 18 years of age or older. They were excluded if they had a history of any realignment or fusion procedure of the foot and ankle, as well as if



Figures 1-A to 1-E Rotation measurement methods of the medial column bones.

they had significant arthritic findings of the metatarsophalangeal joints, midfoot or hindfoot.

WBCT scans were performed with a cone-beam (CB) computed tomography (CT) extremity scanner (PedCAT™; CurveBeam, LLC, Warrington, PA, USA). Patients were instructed to stand upright with their feet pointing forward at approximately shoulder width apart and instructed to distribute weight evenly on both lower extremities.

Raw multiplanar data was converted into sagittal, coronal, and axial plane images and evaluated using dedicated software (CubeVue™, CurveBeam, LLC, Warrington, PA, USA). One fellowship trained Orthopedic Foot and Ankle Surgeon with more than 10 years of experience performed the measurements. As standard, supination (external rotation) was defined as negative values and pronation (internal rotation) was defined as positive values.

The rotational profile of the medial column bones was assessed in coronal plane WBCT image and was defined as follows (Figure 1):

The navicular rotation was measured as the angle between the floor and the widest mediolateral distance of the bone, at a level just distal to the most distal aspect of the talonavicular joint (Figure 1-A).

The medial cuneiform rotation was assessed just proximally to the most proximal aspect of the first tarsometatarsal (TMT) joint,^{26,33} and was defined as the angulation between the floor and a bisecting line of an angle formed by tangent lines to the medial and lateral surfaces of the medial cuneiform (Figure 1-B).

As a long bone, the first metatarsal was measured both at its proximal and distal ends. For the proximal first metatarsal, the rotational profile was measured similarly to the medial cuneiform, at a level just distal to the most distal aspect of the first TMT joint. The angulation was defined as the angle between the floor and a bisecting line of the angle formed by tangent lines

Table 1. Summary of Diagnosis for Weight Bearing CT Imaging of Patients

Diagnosis for Weight Bearing CT Imaging	Number of Patients (%), Number of Feet (%)
Progressive Collapsing Foot Deformity	39 Patients (41%), 46 feet (41.8%)
Hallux Valgus Deformity	21 Patients (19.1%), 25 Feet (22.7%)
Anterior Ankle Impingement	13 Patients (13.7%), 13 Feet (11.8%)
Mild Cavovarus	9 Patients (9.5%), 13 Feet (11.8%)
Metatarsalgia/Hammertoe Deformity	6 Patients (6.3%), 6 Feet (5.5%)
Metatarsal Stress Fractures	3 Patients (3.2%), 3 Feet (2.7%)
Follow-up Ankle Fracture	2 Patients (2.1%), 2 Feet (1.8%)
Chronic Plantar Fasciitis	1 Patient (1%), 1 Feet (1%)
Bunionette Deformity	1 Patient (1%), 1 Feet (1%)

Included in the study (95 patients, 110 feet)

to the medial and lateral surfaces of the proximal first metatarsal (Figure 1-C). For the distal aspect of the first metatarsal, the rotational profile was assessed at the level of best visualization of the first metatarsal sesamoid grooves, and was defined as the angulation between the floor and a line connecting the most medial aspect of the medial sesamoid groove and the most lateral aspect of the lateral sesamoid groove in the plantar aspect of the first metatarsal head, similar to prior description in the literature (Figure 1-D).^{7,12,34}

Lastly, the rotational profile of the proximal phalanx of the first toe was defined by the angulation between the floor and a tangent line to the plantar aspect of the proximal phalanx, at a level just distal to the most distal aspect of the first metatarsophalangeal joint (Figure 1-E).

For each measurement, raw data was evaluated for normality using the Shapiro-Wilk test, and descriptive statistics was obtained including mean, median, interquartile range (IQR), 95% confidence interval (CI) values and Hodges-Lehmann Expected Differences. The Hodges-Lehmann value is an estimator of the location shift. For this measurement, all paired differences consisting of observations in the first level minus observations in the second level are constructed. The Hodges-Lehmann estimator is the median of these differences. For comparison of rotational profiles of the different medial column bones/levels, we used the one-way ANOVA/Wilcoxon, as well as paired Student's T-test/ Paired-Wilcoxon for comparisons of each pair. P-values of ≤ 0.05 were considered significant.

RESULTS

In total, 110 feet were included (95 patients, 38 male and 57 female), with a mean age of 56 years (range from 19 years to 87 years). A summary of the diagnoses of patients that underwent WBCT and were included in the study is presented in Table 1.

All bones of the medial column were found to have

an average rotational profile alignment in pronation (internal rotation). A summary of the results is presented in Table 2.

A zig-zag pattern of rotational positioning of the medial column bones was observed (Figure 2), with statistically significant differences found when comparing the rotational profile of most adjacent bones/segments (all p-values < 0.0001), except in the relation between the distal first metatarsal and the proximal phalanx, which demonstrated similar amounts of pronation (expected Hodges-Lehmann mean difference 2.40, CI -1.2 to 6.2, $p=0.19$) (Table 3). The navicular bone was found to have an average pronation of 43.2° (CI, 41.1° to 45.3°). A significant relative supination of the medial cuneiform in relation to the navicular was observed, with a mean rotational profile of 6.1° pronation (CI, 4.0° to 8.3°). A significant relative pronation of the proximal first metatarsal in relation to the medial cuneiform was found, with an average rotational positioning of 33.9° of pronation (CI, 31.8° to 36.0°). More distally, a significant relative supination of the distal metatarsal regarding the proximal aspect of the metatarsal was noticed, consistent with intrinsic internal torsion of the bone, with an average rotational alignment of 18.5° (CI, 16.4° to 20.6°). As previously mentioned, the rotational alignment of

Table 2. Measured Rotational Profiles of the Medial Column Bones

Medial Column Bone	Rotational Profile Mean Value (Degrees)	Lower 95% CI	Upper 95% CI
Navicular	43.2°	41.1	45.3
Medial Cuneiform	6.1°	4.0	8.3
Proximal First Metatarsal	33.9°	31.8	36.0
Distal First Metatarsal	18.5°	16.4	20.6
Proximal Phalanx Rotation	21.6°	19.5	23.7

Mean values (degrees and 95% Confidence Intervals (95% CI)

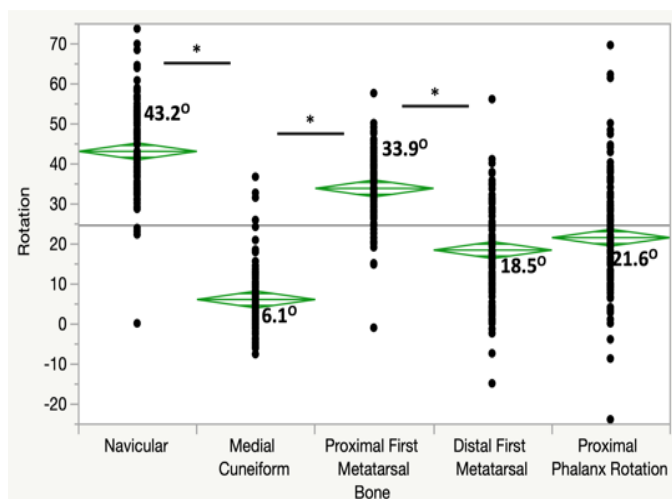


Figure 2. Mean rotation values for medial column bones, all in pronation.

the proximal phalanx was found to be 21.6° on average (CI, 19.5° to 23.7°), with no statistically significant differences in rotation when compared to the distal first metatarsal.

DISCUSSION

The present study was the first to describe in detail the rotational profile of bones of the medial column using standing WBCT images. We assessed a relatively large cohort of patients with different foot and ankle problems, providing baseline values for expected rotational positioning of medial column bones of the foot. We found that even though the average positioning of all bones of the first ray is in pronation, there is a zig-zag pattern of relative supination/pronation positioning of adjacent bone segments of the medial column from proximal to distal, including a significant amount of internal torsion of the first metatarsal.

WBCT images allow for a more complete and three-dimensional assessment of the alignment of tarsal bones, including in the coronal plane of the foot, that is not accurately assessed using conventional 2D radiographs.³⁵⁻³⁷ Even though the bulk of literature concerning the use of WBCT in the assessment of foot and ankle pathologies has been exponentially growing, little has been studied about rotational profile of the medial column.^{28,37,38}

Collan et al. were the first to report on the use of standing WBCT in the rotational profile of foot bones in HV patients.³² They found that the mean rotation of the distal first metatarsal bone was on average 8° (4 to 12°) and 2° (-4 to 8°), respectively in HV and controls, with no significant differences between the groups. Considering the rotational profile of the proximal phalanx of the first toe, they observed a mean pronation of 33° (27 to 39°) and 4° (-5 to 13°) in HV and control patients, respectively, with statistically significant differences between the groups. The authors have not assessed rotational profile of the other bones of the medial column. We observed overall more pronounced values of pronation of the distal first metatarsal (average, 18.5°) and proximal phalanx (average, 21.6°). Potential explanations for the observed differences could rely on the fact that our cohort does not include true asymptomatic controls, but patients with foot pathologies including HV and PCFD, where medial column instability and rotational malalignment of the medial column bones would be expected. Another factor that could have influenced the results is that in their study, the authors utilized single-leg stance WBCT rather than bilateral physiological stance WBCT, and during single leg stance the dorsiflexion/plantarflexion positioning of the first metatarsophalangeal joint could potentially change for adequate balance of the patient during image acquisition. Dorsiflexion/plantarflexion position of the

Table 3. Comparison of Rotational Profile Measurements (Wilcoxon Each-Pair) of the Bones of the Medial Column

Bone 1	Bone 2	Score Mean Difference	Z	p-Value	Hodges-Lehmann	Lower 95% CI	Upper 95% CI
Proximal First Metatarsal	Medial Cuneiform	104.845	12.2163	<.0001*	28.6	26.6	30.5
Proximal Phalanx Rotation	Medial Cuneiform	72.455	8.4429	<.0001*	14.6	11.5	17.8
Distal First Metatarsal	Medial Cuneiform	69.600	8.1097	<.0001*	12.7	10.0	15.4
Proximal Phalanx Rotation	Distal First Metatarsal	11.182	1.3028	0.1926	2.4	-1.2	6.2
Proximal First Metatarsal	Navicular	-57.091	-6.6519	<.0001*	-8.7	-11.2	-6.1
Proximal Phalanx Rotation	Proximal First Metatarsal	-59.773	-6.9644	<.0001*	-13.5	-16.7	-10.1
Distal First Metatarsal	Proximal First Metatarsal	-79.618	-9.2765	<.0001*	-15.6	-18.4	-12.8
Proximal Phalanx Rotation	Navicular	-82.727	-9.6388	<.0001*	-22.4	-25.7	-18.9
Distal First Metatarsal	Navicular	-97.836	-11.3991	<.0001*	-24.5	-27.6	-21.5
Medial Cuneiform	Navicular	-107.309	-12.5034	<.0001*	-37.0	-39.4	-34.7

Mean Differences, Z-values, P-values, Hodges-Lehmann Expected Differences, and 95% Confidence Intervals (95% CI).

joint was previously demonstrated to influence rotational position of the first toe and first metatarsal.³⁹

Our results are however in line with prior conventional radiographic studies that demonstrated pronation of the first metatarsal to be between 10° and 30° in patients with progressively increased intermetatarsal angle, consistent with worsening HV deformity.⁴⁰ The same group also demonstrated that collapse of the longitudinal arch was also directly correlated with an increase in the amount of first metatarsal pronation,¹¹ which may further support the reasoning for our results demonstrating relatively high numbers of pronation of the first metatarsal and proximal phalanx, given the prevalence of HV and PCFD patients in our cohort.

An interesting finding of our study was the observed intrinsic relative torsion in supination of the first metatarsal bone. While the proximal first metatarsal was found to be pronated with an average of 33.9°, the distal metatarsal demonstrated an average pronation of only 18.5°, with an overall significant difference of 15.6°, consistent with intrinsic torsion of the bone from proximal to distal. This intrinsic torsion of the first metatarsal was also demonstrated by Ota et al. when assessing hallux valgus patients and controls.³¹ They found the torsional angle of the first metatarsal from proximal to distal to be on average 17.6° in HV patients and 4.7° in controls, and the difference in torsion was significant between the groups. The amount of torsion observed in their study for HV patients is similar to the one found in our study, what would again be consistent with the increased prevalence of PCFD and HV patients in our cohort.

The most pronounced amount of pronation of the medial column bones in our study was noted in the navicular, followed by the proximal aspect of the first metatarsal, distal first metatarsal and proximal phalanx, and was minimal in the medial cuneiform. Our interpretation of these findings is mechanical and based on the need of the foot to be in a plantigrade position for an appropriate gait, as well as the fact that the rigidity and stability of the longitudinal and transverse arches of the foot is higher proximally at the level of the hind-foot/midfoot than distally at the level of the forefoot.^{41,42} With the rotational profile of the medial column bones starting at an average of 43° of pronation proximally in the navicular bone, a considerable amount of derotation is needed from proximal to distal so that the forefoot can be in relative plantigrade and positionally aligned for normal stance and toe off. Since the metatarsal and phalanx are considerably more mobile than the medial cuneiform, it would make sense that during evolution of primate feet, the derotation would be less evident in the medial cuneiform.^{41,43}

We also observed that the rotational profile of the dis-

tal metatarsal and proximal phalanx was similar, which would be consistent with the proximal phalanx of the first toe following the alignment/malalignment of the distal metatarsal or vice-versa. This concept was already explored and demonstrated by other authors in the scenario of HV deformity,^{11,40,44} and would be explained by the tight connections between the two bones by a complex tendinous, capsular and ligamentous apparatus, including the sesamoid bones, plantar plate and collateral ligaments. These structures ensure preservation of the rotational relationship between the bones, even in the scenario of severe HV.^{5,32}

Previous studies focused on PCFD have also investigated the rotational deformities of midtarsal joints as important components of collapse of the longitudinal arch and increased peritalar subluxation.^{45,46} Wang et al., Yoshida et al., and Kido et al. reported significant pronation at the talonavicular and talocalcaneal joints in PCFD patients when compared to controls.^{9,10,47} Even though the individual rotational profile of each medial column bone was not directly assessed in these studies, only the relationships between the bones, the findings of these authors corroborate those presented by this study.

There are several limitations in this study. The first is the fact that it is retrospective in nature, which could have introduced different biases to our study results. Secondly, our cohort of patients is made up of patients with different foot and ankle pathologies, including a considerable amount of PCFD and HV patients, which are both known causes of medial column instability and increased rotational deformity of the medial column bones. The interpretation of the data should take this fact into strong consideration. The third is the absence of a control group as well as the absence of healthy volunteers with no foot problems as these individuals would have potentially more normally aligned medial column bones. Finally, we used only one reader to assess the rotational profile of the bones and measurement reliability was not calculated, however, the reader of the WBCT images had considerable experience.

CONCLUSION

To the best of the author's knowledge, this is the first study that individually assessed the rotational profile of each bone of the medial column of the foot using standing bipedal WBCT in patients with different foot and ankle pathologies. We found that navicular, medial cuneiform, proximal and distal first metatarsals as well as the proximal phalanx of the first toe are all positioned in different degrees of pronation, most pronounced at the navicular bone and at the proximal aspect of the first metatarsal. There is an apparent zig-zag compensatory supination/pronation regarding the rotational profile and

relative positioning between the bones from proximal to distal.

We expect that the rotational profile data of the medial column bones reported in this study can be used as baseline reference values and can foster additional studies on this subject in the future, particularly comparative, controlled, and prospective studies.

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WEIGHTBEARING COMPUTED TOMOGRAPHY FOR ASSESSMENT OF FOOT AND ANKLE DEFORMITIES: THE IOWA EXPERIENCE

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ABSTRACT

Background: Weightbearing computed tomography (WBCT) is a reliable and precise modality for the measurement and analysis of bone position in the foot and ankle, as well as associated deformities. WBCT to assess three dimensional relationships among bones allowed the development of new measurements, as the Foot and Ankle Offset (FAO), which has high inter and intra-rater reliability. This study reports the University of Iowa's experience utilizing WBCT for the care of foot and ankle patients by describing its utility across different orthopedic diseases in improving diagnostic assessment, aiding surgical planning, and expanding the use for objective clinical follow-up.

Methods: The medical records of consecutive patients with various foot and ankle disorders that underwent WBCT examination as part of the standard of care at a single institution between November 2014 and August 2020 were retrospectively reviewed. Patient factors, including body mass index (BMI), sex, and patient comorbidities were collected. 3D coordinates for calculation of FAO were harvested using the Multiplanar Reconstruction (MPR) views were calculated from the obtained exams. Descriptive statistics were performed with Shapiro-Wilk test and the Anderson-Darling tests.

Results: 1175 feet and ankles (820 patients) had a WBCT performed over the studied 68 months. 53% of the subjects were male and 47% female. 588 of the acquisitions were from the right side

(50.04%) and 587 from the left side (49.96%). Diabetes was present in 15.47% of, Rheumatic diagnoses in 4.52% and smoking habits in 44.10% of patients. Mean BMI of the sample was found to be 32.47 (32.03-32.90, 95% CI). The mean Foot and Ankle Offset (FAO) encountered in the study's population was 2.43 (2.05-2.82, 95% CI; min -30.8, max 37.65; median 2.39).

Conclusion: This study contains the largest cohort of WBCTs with accompanied FAO measurements to date, which can aid with establishing a new baseline FAO measurement for multiple pathological conditions. Acquiring WBCTs resulted in a variety of more specific diagnoses for patient with foot and ankle complaints. The ability to utilize WBCT for presurgical planning, the capability to provide a 3D reconstruction of patient anatomy, and its use for assessment of advanced relational foot and ankle measurements, such as FAO, demonstrate how WBCT may serve as a remarkable utility in clinical practice and has become a standard of care in our practice at the University of Iowa.

Level of Evidence: IV

Keywords: weight-bearing ct, foot ankle offset

INTRODUCTION

Previous studies have identified the weightbearing computed tomography (WBCT) is a reliable and precise modality for the measurement and analysis of bone position in the foot and ankle, as well as associated deformities.¹⁻⁴ WBCT offers assessment and visualization of the true relative positioning between bones of joints under loading conditions, which cannot be assessed by standard CT scans.⁴ Traditional weight bearing radiographs for assessment of bone orientation under loading are more susceptible to technological errors, such as rotational malalignment, which leads clinicians to obtain inaccurate measurements of pathological deformities.⁵ Moreover, WBCT has already demonstrated high utility for various foot and ankle deformities ranging from Progressive Collapsing Foot Deformity (PCFD) and Hallux Valgus (HV) to Periprosthetic Cysts and Ankle Osteoarthritis (AO).⁶⁻¹⁰ This imaging modality allows for a more accurate three-dimensional deformity assessment

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Disclosures: JF-Arthrex, Inc: Research support, Integra: Paid consultant, OnconRegen: Unpaid consultant. CDCN-CurveBeam: Paid consultant; Stock or stock Options, Nextremity: Paid consultant, Ossio: Paid consultant, Paragon 28: IP royalties; Paid consultant, Zimmer: Paid consultant; PP-Arthrex, Inc: IP royalties, Crossroads: Paid consultant; Stock or stock Options, Novastep: Paid consultant, Smith & Nephew: Paid consultant. SL-Foot and Ankle Clinics of North America: Editorial or governing board, Foot and Ankle Orthopedics: Editorial or governing board. NSBM-Brazilian Foot and Ankle Society: Board or committee member. The other authors report no potential conflicts of interest related to this study.

Sources of Funding: No sources of funding declared.

and a higher spatial resolution, providing the physician with a more complete armamentarium for treatment planning.^{1,2} The evaluation of measurements and signs extracted from WBCTs demonstrate both high intra-rater reliability and inter-rater reliability among varying levels of clinicians and for different conditions.^{2,11,12}

The capability in the WBCT to assess three dimensional relationships among bones allowed the development of new measurements, as the Foot and Ankle Offset (FAO).¹³⁻¹⁵ This assessment describes the relationship between the relative position of the ankle joint's mechanical axis (center of the talus) and the foot tripod (first metatarsal, fifth metatarsal and calcaneus).^{1,13,14} It is a semiautomatic three-dimensional assessment tool, providing a percentage of ankle deviation from the foot vector. In other words, it corresponds to the level arm of the torque produced in the ankle by bodyweight and ground reaction forces during physiological weight bearing ambulation.^{1,13,14} Previous studies showed a value of 2.3% (+2.9) in normal patients, -11.6% (+6.9) in varus and 11.4% (+5.7) in valgus alignment.¹⁴ Moreover, the use of the FAO has validated in the assessment of PCFD, Cavovarus Deformities and Ankle Arthritis, providing a reliable value for diagnosis and deformity prognosis.^{10,16,17}

New indications and clinical utilities are being described for WBCT over the last decade.^{18,19} Syndesmotic instability, lateral ligament instability, Lisfranc ligament injury, hallux rigidus and post-traumatic conditions are gaining attention from the scientific community as the WBCT portrays a natural and physiological stress to the evaluated region.²⁰⁻²³ Research focusing in WBCT applicability in knee and hip disorders are also increasing while new devices gain the capability of a more proximal evaluation.^{24,25} As such, this study aims to report the University of Iowa's experience utilizing WBCT for the care of a large cohort of foot and ankle patients. We intend to show its utility across different orthopedic diseases as an instrument that improves diagnostic assessment, aids knowledge to surgical planning, and expands the use for objective clinical follow-up, as well as describe the overall foot alignment of the patients assessed, by measuring FAO

METHODS

Study Design

This is a retrospective epidemiological observational IRB-approved study that complied with the Declaration of Helsinki and the Health Insurance Portability and Accountability Act (HIPAA) and it reviewed medical records of consecutive patients with various foot and ankle disorders that underwent WBCT examination as part of the standard of care at a single institution between November 2014 and August 2020.

Sample

The University of Iowa Department of Orthopaedics and Rehabilitation introduced a WBCT scanner in November 2014 for use by the foot and ankle clinicians. All patient WBCTs obtained from activation of the WBCT scanner in November of 2014 until August of 2020 were collected. For the purposes of this report, each WBCT is defined as a single foot/ankle CT with unique laterally, left or right, obtained with the patient bearing weight through the imaged extremity. Any bilateral WBCTs obtained were split into individual scans to maintain consistent reporting. Patient data and their associated WBCT scans were compiled into a single study database under the supervision of the principal investigator.

Retrospective chart review was utilized to collect all patient demographics including age, body mass index (BMI), sex, and patient comorbidities (diabetes, rheumatoid diseases, and smoking status). The main diagnosis related to the need for WBCT imaging was also evaluated.

All the patients had their diagnoses reviewed and the WBCT images were assessed for measurement of the Foot and Ankle Offset (FAO).

WBCT Imaging

WBCT studies were completed with a cone-beam CT extremity scanner (PedCAT™, CurveBeam LLC, Warrington, PA, USA). Participants were instructed to bear weight in a normal and physiological standing upright position, dispensing the body weight uniformly between the lower limbs and with the feet set at shoulder width and measurements.

The raw 3D data was converted to sagittal, coronal, and axial image slices that were then transferred digitally into dedicated software (CubeVue™, CurveBeam, LLC, Warrington, PA, USA). Image marks were removed, and studies were given a unique and random number. One fellowship-trained foot and ankle surgeons independently and blindly assessed FAO.

The 3D coordinates for calculation of FAO were harvested using the Multiplanar Reconstruction (MPR) views. The first point marked is the most distal voxel of the first metatarsal head, followed by the most distal voxel of the fifth metatarsal head and most distal voxel of the calcaneal tuberosity. Finally, the most central and proximal aspect of the talar dome was marked, and the automatic calculation of the FAO was given by the software (Figure 1).

Statistical Analysis

The variables were initially evaluated for normality using the Shapiro-Wilk test and the Anderson-Darling test. Mean, median, interquartile range (IQR), and 95%

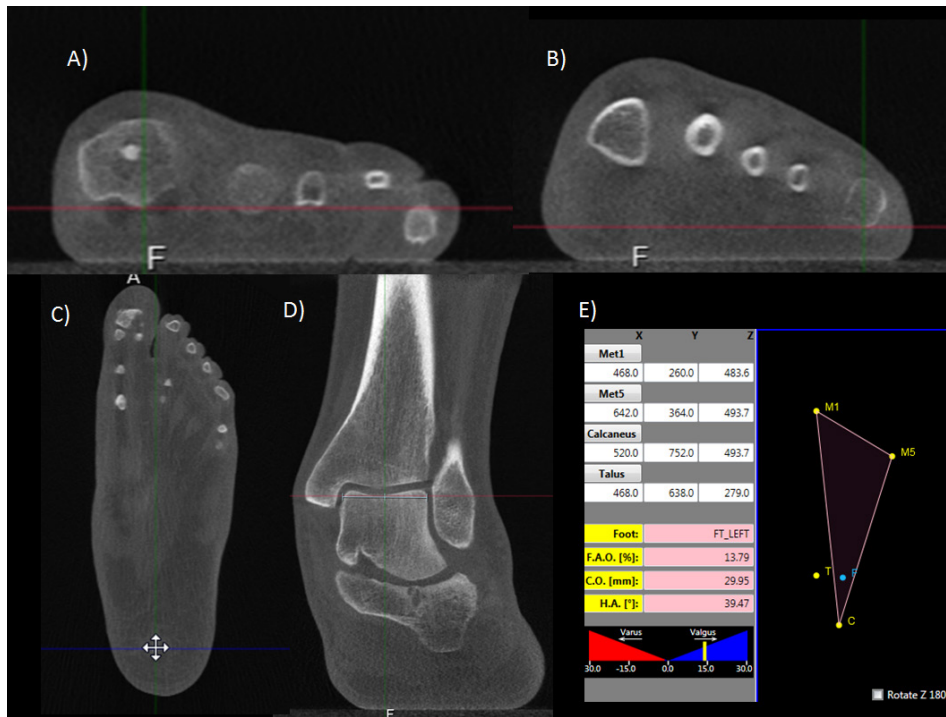


Fig1. Foot and Ankle Offset (FAO) semiautomatic measurement. Using the three planes (x; y; z), the most plantar voxel of the first metatarsal is found (A) in the three planes, followed by the most plantar voxel of the fifth metatarsal (B), the most plantar voxel of the calcaneus (C) and the most proximal and central voxel of the talus (D). The software calculates (E) positioning of the foot tripod (M1-M5-C) and the expect position of the ankle joint center (F). The percentage of displacement in subject's talus position (T) in relation to this axis (M1-M5-C-F) is determined as the FAO.

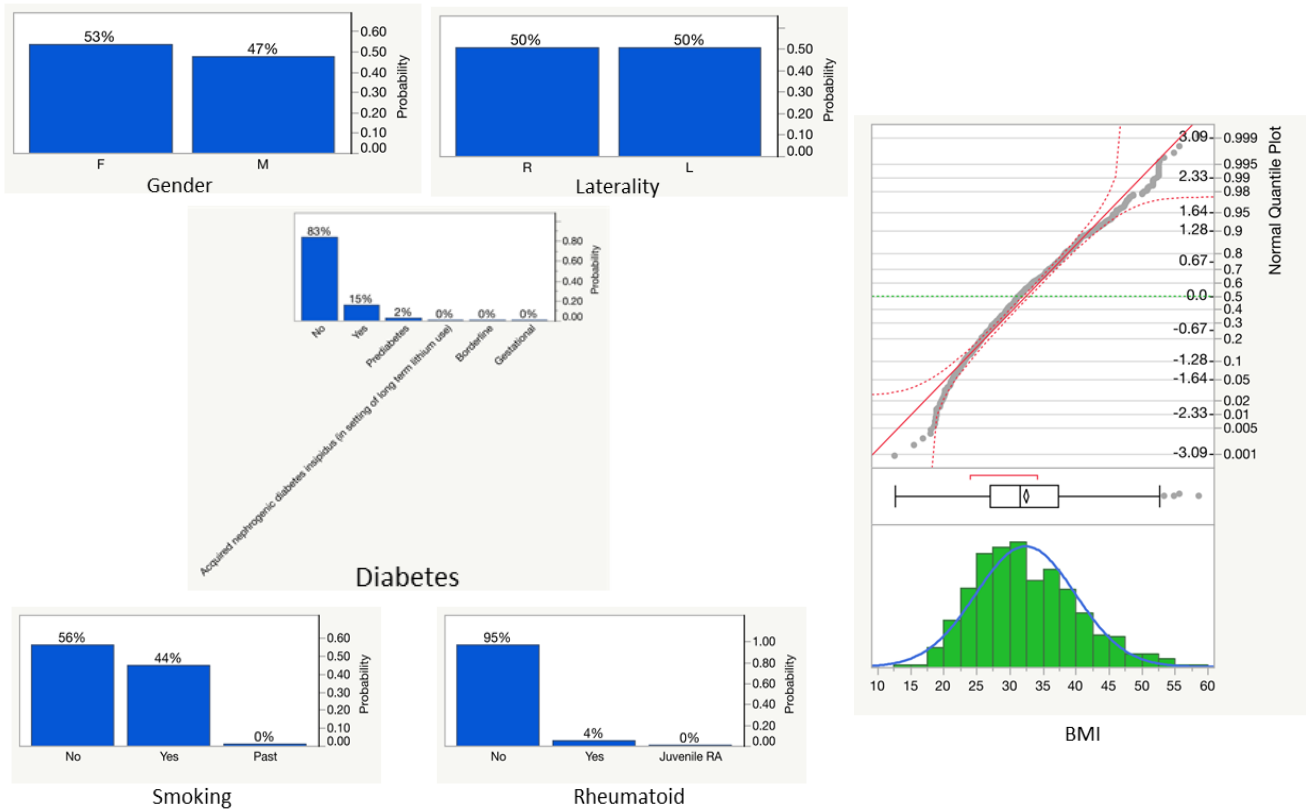


Figure 2. Demographic distribution for gender, laterality, comorbidities, and body mass index (BMI).

Table 1. Summary of the Most Common Foot and Ankle Disorders that Underwent a WBCT Over the Studied Period

Diagnosis	Count	Prob
Flatfoot	175	0.15009
Ankle Arthritis	154	0.13208
Control	152	0.13036
Hallux Valgus	43	0.03688
Subtalar Arthritis	42	0.03602
Ankle Impingement	41	0.03516
Cavus Foot	37	0.03173
Previous Calcaneus Fracture	34	0.02916
Midfoot Arthritis	27	0.02316
Previous Pilon Fracture	25	0.02144
Previous Ankle Fracture	25	0.02144
Clubfoot	24	0.02058
Syndesmosis Instability	23	0.01973
Previous Tibia Fracture	21	0.01801
Subtalar Impingement	20	0.01715
Previous Subtalar Arthrodesis	19	0.01630
Charcot Foot	15	0.01286
Previous Fracture	14	0.01201
Previous Flatfoot Reconstruction	14	0.01201
Tarsal Coalition	12	0.01029
Talonavicular Arthritis	12	0.01029
Previous Ankle Replacement	11	0.00943
Hallux Rigidus	11	0.00943
Toe Deformity	9	0.00772
Achilles Insertional Tendinopathy	8	0.00686
Foot Ulcer	8	0.00686
Previous Midfoot Arthrodesis	7	0.00600
Talus Osteochondral Lesion	7	0.00600
Peroneal Tendinopathy	7	0.00600
Previous Talonavicular Arthrodesis	7	0.00600
Previous Lisfranc Lesion	6	0.00515
Lisfranc Lesion	6	0.00515
Subtalar Nonunion	6	0.00515

confidence interval (CI) values for each measurement were reported.

Demographic data and diagnoses were assessed by frequencies distributions and quantile plots. P values of less than 0.05 were considered significant. Estimate of the likelihood of the model to estimate future was performed by Akaike information criterion (AIC) and Bayesian information criterion (BIC).

RESULTS

A total of 1175 feet and ankles (820 patients) had a WBCT performed over the studied 68 months. 53% of the subjects were male and 47% female. 588 of the acquisitions were from the right side (50.04%) and 587 from the left side (49.96%). Diabetes was present in 15.47% of patients, Rheumatic diagnoses in 4.52%, and smoking habits in 44.10% of patients included. Mean BMI of the sample was found to be 32.47 (32.03-32.90, 95% CI). A summary of demographics findings can be found in Figure 2.

The main obtained diagnoses were PCFD (Flatfoot) with 15.01% of occurrences and Ankle Arthritis with 13.21%. A considerable number of controls (13.04%) was shown, mainly the contralateral side of affected limb. Hallux valgus (3.7%), subtalar arthritis (3.6%), ankle impingement (3.5%), Cavovarus (3.1%), previous calcaneus fracture (2.9%), midfoot arthritis (2.3%), previous pilon fracture (2.1%), previous ankle fracture (2.1%), clubfoot (2%) and syndesmosis instability (1.9%) follow the sample incidence. A complete list of diagnoses may be found on Table 1 and Figure 3.

The mean Foot and Ankle Offset (FAO) encountered in the study's population was 2.43 (2.05-2.82, 95% CI; min -30.8, max 37.65; median 2.39). Figure 4 and Table 2 displays FAO distribution.

DISCUSSION

Weight-bearing computed tomography (WBCT) is a reality in current orthopedic care and become a standard study in the assessment of foot and ankle patients at the University of Iowa. The use of this method is helping physicians and orthopedic surgeons to better diagnose, assess and treat patients. To the author's knowledge, this is the first study to portray a substantial population of individuals that received a WBCT as standard clinical care, specifying diagnoses and demographics. Additionally, we demonstrated the largest collection of FAO in the literature across multiple diagnoses, and with accompanied control measurements that previous prospective investigations have utilized to establish possible patterns for symptomatic foot and ankle injuries.¹⁷ Within the study a total of 23 diagnoses had a sample size greater than 10, and 11 diagnoses had sample sizes of at least 25, which provided a greater diversity in clinical data than many of the prospective studies analyzing FAO for various pathological conditions.^{15,26} The calculated mean FAO of 2.43 (2.05-2.82, 95% CI) within our large, diverse population based on diagnoses, may represent a more accurate or true baseline measurement than what has been previously reported. Along the same lines, the present work provides diagnoses that are specific to each individual imaging study obtained. This is particularly



Figure 3. Diagnoses distribution.

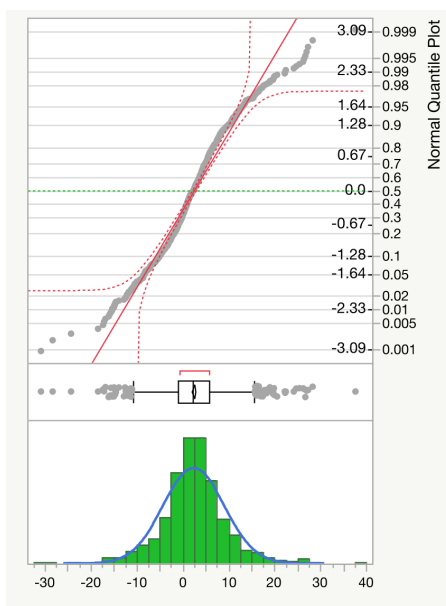


Figure 4. Foot and Ankle Offset (FAO) distribution over the analyzed population.

important as previous epidemiological studies of this kind have limited their data to anatomical location of disease (ankle, midfoot, hindfoot, etc), which provides low granularity for applying clinical data to individualized patient care.^{27,28}

Moreover, previous epidemiological studies utilizing large datasets of foot and ankle WBCTs have emphasized financial efficacy and radiation exposure relative to traditional weight bearing radiographs and standard CTs.^{27,28} A prior investigation by Richter et al. has demonstrated the superiority of WBCTs in comparison to traditional radiographs in the angle measures of the 1st – 2nd intermetatarsa, talo-metatarsal 1 (TMT) dorsoplantar and lateral projection, hindfoot angle, calcaneal pitch angle.²⁹ Improvements in angle measurements utilizing WBCT were due to the function of weight-bearing’s effect on alignment for imaging and subsequent three-dimensional reconstruction to eliminate many of the technical difficulties present with capturing high quality traditional radiographs.²⁹ The present work utilized WBCT for providing an accurate, reproducible measurement in FAO,

across multiple pathologies as part of standard patient care. FAO has been previously utilized as a standard measure in multiple prospective studies and correlation with disease severity have been assessed.^{10,16,17} These measurements may aid in the establishment of anatomical variants for predisposition to various foot and ankle pathologies that can be accurately utilized by clinicians with various degrees of experience as previous studies have already demonstrated high intra-rater and inter-rater reliability.^{2,11,12}

Likewise, the aim to establishing these type of measurements may also provide clinicians with the information necessary to accurately assess disease progression and need for surgical intervention by determining if patients demonstrate greater deviation from control measurement ranges, as previously presented for patients with syndesmotic injuries.^{21,30} Furthermore, the capability to utilize WBCT to demonstrate assess the three-dimensional relationship within the foot and ankle by calculating FAO cannot be understated. This measurement provides an accurate and readily reproducible biomechanical axis that can be correlated with severity of diseases in many instances and is highly reliable among different observers.^{1,13,14} For example, previous investigation on PCFD demonstrated a preoperative FAO of 9.8% (8.0-11.5, 95% CI) and FAO of 1.3% (-0.4-2.9, 95% CI) following surgical correction.³¹ This finding in small cohort of 19 patients (20 feet) was consistent with previous non-pathological values of an FAO of 2.3% (+2.9) in normal patients, -11.6% (+6.9) in varus and 11.4% (+5.7) in valgus alignment.^{14,15} More importantly, these corrections demonstrated statistically significant correlation with positive clinical outcomes as assessed by patient reported outcome measures (PROs) postoperatively, which have gained greater emphasis recently as healthcare systems seek to reimburse patient care based on PROs.^{15,32}

There are several limitations present within this work. First, the study was retrospective in nature and data was acquired from a single institution in the Midwest region of the United States. The single center aspect of data collection and possible lack of diversity

Table 2. Fitted Normal Distribution to Foot and Ankle Offset Readings

Parameter		Estimate	Std Error	Lower 95%	Upper 95%
Location	μ	2.4391278	0.1975659	2.0519056	2.8263499
Dispersion	σ	6.6559495	0.054185	6.5505916	6.6672228
Measures					
		-2*LogLikelihood	7522.8007		
		AICc	7526.8113		
		BIC	7536.8695		

in patient demographics may limit the generalizability of the findings from the assimilated dataset. Moreover, there was no standardization in the methodology for the time periods that the WBCTs were obtained that limits the reproducibility of building a database for comparison. Further, the study is descriptive and provides an epidemiological dataset that cannot directly compare different interventions or pathologies no protocol was established indicating the rationale for WBCT acquisition, follow-up studies, or intended utilization of the study. Additionally, no comparisons between the different conditions identified within the study were performed, which could have demonstrated that other factors within the study population, including specific patient demographics, could have influence on FAO measurements. Moreover, no clinical evolution and outcomes measures were studied, which might have supported WBCT capability in changing the course and care of diseases, however other works have established relationships between WBCT measures and PROs.^{15,26} Finally, the dataset utilized a single observer for assessment and measurement of FAO that could theoretically skew the results and introduce bias. However, previous works have already demonstrated that intra and inter-rater reliability for this measure is high and is sustained across varying levels of experience.¹¹

CONCLUSIONS

WBCTs from a total of 1175 feet and 820 unique patients were obtained over the study period. This study contains the largest cohort of WBCTs with accompanied FAO measurements to date, which can aid with establishing a new baseline FAO measurement for multiple pathological conditions. Acquiring WBCTs resulted in a variety of more specific diagnoses for patient with foot and ankle complaints. The ability to utilize WBCT for presurgical planning, the capability to provide a 3D reconstruction of patient anatomy, and its use for assessment of advanced relational foot and ankle measurements, such as FAO, demonstrate how WBCT may serve as a remarkable utility in clinical practice.

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POSTERIOR MALLEOLAR FIXATION REDUCES THE INCIDENCE OF TRANS-SYNDesmOTIC FIXATION IN ROTATIONAL ANKLE FRACTURE REPAIR

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ABSTRACT

Background: Inaccuracy of ankle syndesmotiC repair via reduction and trans-syndesmotiC fixation can occur during ankle fracture repair. The goal of this study was to determine whether reduction and fixation of the posterior malleolar fracture (PM) fragment in rotational ankle fractures reduces the need for independent syndesmotiC screw fixation.

Methods: A retrospective study was conducted using a consecutive series of patients treated operatively for a rotationally unstable ankle fracture with a PM fragment between 2011-2017. All ankle fractures underwent open reduction and internal fixation and divided into two groups: PM fixed or not fixed. An intraoperative stress evaluation of the ankle following bony fixation was performed in all cases to evaluate syndesmotiC instability. Patient and fracture characteristics, and intraoperative instability and trans-syndesmotiC fixation were compared between both groups.

Results: Eighty-five unstable ankle fractures that had a PM fragment were identified. Forty-three fractures underwent PM fixation and 42 did not. There were no differences between the PM fixation groups with regard to age, gender, body mass index or fracture pattern ($p > 0.183$ for all). On average, PM fragments in the fixed group were larger than those not fixed ($p < 0.001$). There were significantly lower odds of needing syndesmotiC fixation if the PM fragment was reduced and fixed ($p < 0.001$). Only 2 out of 43 ankles with a fixed PM fragment underwent syndesmotiC fixation compared with 34 out of 42 non-fixed PM fragments.

Conclusion: Posterior malleolar fixation imparts syndesmotiC stability and may obviate the need for

trans-syndesmotiC fixation for restoring dynamic ankle mortise congruence.

Level of Evidence: III

Keywords: ankle fractures, posterior malleolus, operative treatment

INTRODUCTION

Posterior malleolar (PM) fractures are a common component in rotational ankle fractures and occur in up to 44-46% of all ankle fractures.^{1,2} The presence of a PM fragment in ankle fracture is likely indicative of worse clinical outcomes.³ When planning for open reduction and internal fixation (ORIF) of a rotational ankle fracture, the decision to fix the PM fragment is highly variable among surgeons.⁴ Fragment size (percentage distal tibial articular surface), which is implicated in long-term arthritic changes,⁵ has been the main determining factor for most surgeons, with 25-33% of the articular surface as the cited threshold for fixation.⁶ However, there is generally no consensus on whether or not to fix smaller PM fragments.

The anatomic relationship between the PM fragment of the distal tibia and the ankle syndesmosis through the posteroinferior tibiofibular ligament (PITFL) is well established. Anatomic reduction and stable fixation of this fragment is technically feasible through the posterolateral approach⁷ and can restore the previously disrupted PITFL complex in addition to restoring the tibiotalar articular surface and contact area.^{8,9} Restoring the PITFL along with fibular fixation should confer stability to the syndesmosis, and may potentially limit the need for trans-syndesmotiC reduction and screw fixation.

Trans-syndesmotiC reduction and direct fixation of an unstable syndesmosis has been demonstrated to have a high rate of malreduction (30-40%) on computed tomography (CT) imaging.^{10,11} Furthermore, malreduction of the syndesmosis can alter ankle kinematics and has been associated with poorer functional outcomes.¹¹⁻¹³ Recent evidence suggests that syndesmotiC stabilization through PM fixation has outcomes that are at least equivalent to syndesmotiC screw fixation on follow-up.¹⁴ These findings merit further investigation to determine whether surgeons should be more aggressive about fixing PM fragments.

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

Sources of Funding: No sources of funding declared.

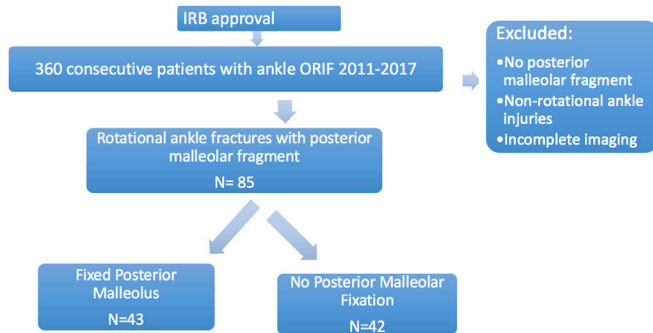


Figure 1. Flow Diagram illustrating the retrospective study sampling method and subject inclusion for analysis.

The primary aim of this study is to determine whether PM reduction and internal fixation reduces the need for trans-syndesmotism fixation in rotational ankle fractures. As a secondary aim, the effect of fragment size on this relationship will be examined. We hypothesize that fixation of the PM fragment, regardless of size, confers stability to the syndesmosis and obviates the need for trans-syndesmotism fixation.

METHODS

Study Design and Patient Population

A retrospective review was performed on an institutional review board-approved database of subjects who underwent ankle ORIF by any of 4 orthopedic trauma surgeons at one urban, academic institution from 2011-2017. Three hundred and sixty patients were identified. Patients 18 and older, with rotational ankle fracture patterns involving a posterior malleolar fragment were included in this study. Subjects with non-rotational ankle and distal tibia fractures, or fracture patterns without a posterior malleolar fragment, and subjects with incomplete pre-operative and fluoroscopic imaging were excluded. Using these criteria, 85 patients (23.6%) with 85 bi- or trimalleolar fractures make up our study cohort (Figure 1). The posterior malleolus fragment was reduced and fixed in 43 and not fixed in 42 subjects forming the two comparison groups in this study.

Surgical Technique

In either case, all fractures underwent open reduction and internal fixation using standard fixation principles with small fragment plates and screws. In cases in which the posterior malleolus was not fixed the patient was positioned supine. The decision on whether or not to fix the fragment was surgeon-dependent, but mainly predicated on fragment size and articular involvement. If the decision to fix the posterior malleolus was made it was done with an open approach if the fragment was displaced. In two cases where the fragment was not displaced, fixation in situ was performed with antero-



Figure 2. Post-operative images of a trimalleolar ankle fracture (a) AP, (b) lateral with a posterior malleolar fragment that was fixed with a posterior antiglide plate through a posterolateral approach.

posterior partially threaded cannulated screws. The patient was positioned depending on the pre-operative plan decided by the surgeon. A posterolateral approach between the flexor hallucis longus and the peroneal tendons was typically performed in the lateral or prone position. In this setting, the fibula was typically fixed first with a posteriorly placed anti-glide plate, followed by reduction of the posterior malleolar fragment and fixation with a plate and screws (Figure 2) or lag screws alone. Medial malleolar fixation was performed last, and done either in the prone position or after switching to supine position depending on surgeon preference.

It was our standard protocol to perform an external rotation stress test following fibular, posterior and medial malleolar fixation, to determine stability of the syndesmosis under fluoroscopy. Loss of tibiofibular overlap (<1mm) or increase in tibiofibular clear space (>5mm) on the stress view indicated syndesmotism instability, which was typically addressed using trans-syndesmotism fully-threaded cortical screws (Figure 3) or TightRope® (Arthrex, Naples Fla) transosseous suture and endo-button fixation. If trans-syndesmotism screw fixation was elected, the number of screws, and cortices of purchase varied depending on surgeon preference, and patient factors (diabetes, obesity). Reduction of the syndesmosis by anatomically aligning the fibula to the tibial incisura with or without the use of clamps was performed if needed depending on the extent of syndesmotism widening and disruption. All syndesmotism reductions were assessed on biplanar fluoroscopic imaging and accepted if adequate. Post-operatively all patients in this study were treated with a standardized protocol that included, non-weight bearing for a period of 6 weeks, and started early ankle range of motion with physical therapy. Venous thromboembolic disease prophylaxis was maintained in all cases with either low molecular weight heparin or an aspirin daily for 4 weeks.



Figure 3. Post-operative images of a trimalleolar ankle fracture (a) AP, (b) lateral with a posterior malleolar fragment that was not directly fixed, and trans-syndesmotic fixation with one fully threaded tri-cortical screw used to stabilize the syndesmosis.

Radiographic Review

Complete pre-operative radiographic imaging as well as intra-operative fluoroscopy were reviewed by two authors (OB, RN) to determine radiographic parameters such as posterior malleolar fragment size, as well as whether the syndesmosis was unstable to intra-operative external rotation stress examination. In patients requiring syndesmotic screw fixation, the reduction was assessed intra-operatively and judged to be adequate based upon standard image intensification views. On pre-operative radiographs, the ankle fracture pattern was classified as bi- or tri-malleolar, as well as the presence of medial clear space widening, and loss of tibiofibular overlap. The size of the posterior malleolar fragment as a percentage of the distal tibial articular surface was measured on the lateral view as historically described by Hartford⁸ utilizing the ruler function on the digital x-ray system (PACS, Siemens, Ehrlanger Germany). Despite the underestimate of fragment size on lateral x-ray views given the posterolateral orientation of the fragment, all measurements were performed with the same standard using x-ray imaging, as not all subjects had computed tomography imaging pre-operatively.

Statistical Analysis

Baseline patient demographics and characteristics were compared between the two groups of posterior malleolus fixation using independent samples t-test or Fisher's exact test as appropriate. To address the primary hypothesis, Fisher's exact test was used to compare both groups of posterior malleolar fixation on the proportions of syndesmotic instability requiring trans-syndesmotic fixation. This relationship was also tested using a binary logistic regression model controlling for posterior malleolar fragment size. All statistical analysis was performed using Statistical Package for Social Sciences (SPSS Version 23).

RESULTS

With the numbers available, there were no statistical differences in age, gender, body mass index (BMI) or fracture pattern (bi or trimalleolar) between both groups of PM fixation ($p > 0.183$ for all) (Table 1). The average age of patients in this study sample was 51 years and 62% were female. The mean BMI was 28, and the majority of ankle fractures in this sample were tri-malleolar (86%). The average size of the PM in the fixed group was $27\% \pm 9\%$ of the articular surface, whereas the size among those not fixed was $19\% \pm 8\%$ ($p < 0.001$).

Among all fixed PM fragments that were fixed, 39 (91%) were fixed with plates (T or 1/3 tubular plates) and 4 (9%) were fixed with anteroposterior partially-threaded screws. Thirty-four (94%) of all trans-syndesmotic fixations were performed using one or two fully threaded screws drilled and placed in a holding position, and 2 (6%) were performed using a suture over a button device (TightRope®, Arthex).

Only 2 (4.6%) syndesmotic complexes were found to be unstable following PM fixation, both requiring syndesmotic screw fixation, compared with 34 (80.9%) unstable syndesmotic complexes when the PM was not fixed (Figure 4) (Figure 2) ($p < 0.001$). The odds ratio of requiring syndesmotic fixation if the PM was fixed was 0.011 (95% CI: 0.002-0.058). The association between

Table 1. Baseline Patient Demographics and Ankle Fracture Characteristics by Group of Posterior Malleolar Fixation

		Group of Posterior Malleolar Fixation		
		Fixed (n=43)	Not fixed (n=42)	P-value
Baseline Characteristic	Age (years)	50 ± 17	51 ± 18	0.756
	Gender (M / F)	Females = 30 Males = 13	Females = 23 Male = 19	0.183
	Body Mass Index (kg/m ²)	28 ± 5	28 ± 7	0.641
	Bi- or Trimalleolar	Bi = 7 Tri = 36	Bi = 5 Tri = 37	0.757
	Posterior Malleolar Fragment (% of articular surface)	27% ± 9%	19% ± 8%	<0.001 *

Odds ratio: 0.011 (95% CI: 0.002 – 0.058), P-value <0.001

Binary Logistic regression model controlling for posterior malleolar fragment size: P-value <0.001

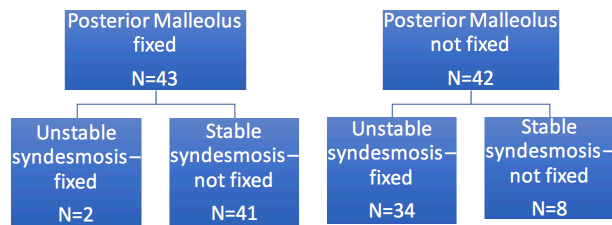


Figure 4. Flow Diagram demonstrating the number of cases which required trans-syndesmosis fixation secondary to syndesmosis instability between the two groups.

persistent syndesmosis instability and PM fixation remained significant in a binary logistic regression model controlling for PM fragment size ($p < 0.001$). Finally, when comparing posterolateral incisions and dissection for PM fixation ($n = 39$) to direct lateral fibular approaches in cases with percutaneous or without PM fixation ($n = 46$), there were only two cases of post-operative wound complications, one in either group ($p = 1.000$).

DISCUSSION

This clinical study confirms our belief that PM fixation increases syndesmosis complex stability and may reduce the need for independent trans-syndesmosis fixation. Reduction and fixation of the PM fragment anatomically restores the syndesmosis and may be anatomically and biomechanically more superior to trans-syndesmosis fixation. This explains why 95% of all of the fixed PM ankles in this study did not demonstrate residual instability on stress exam following PM fixation. A study of post-operative CT scans comparing ankles in which PM was fixed regardless of fragment size to those with syndesmosis screws only, demonstrated improved reduction of the syndesmosis articulation with PM fixation, than with direct trans-syndesmosis screw fixation.¹⁵ Furthermore, PM fixation has been demonstrated to restore 70% of syndesmosis stiffness compared with 40% with syndesmosis screws, in a cadaver study.¹⁶ This is concordant with other evidence demonstrating that PITFL injury has the highest predictive value for syndesmosis instability compared with the other syndesmosis ligaments.¹⁷ Moreover, PM fixation through an open, posterolateral approach was not associated with any increased risk of wound complications compared with a direct lateral fibular incision.

It is unclear why in 2 cases out of 43, the syndesmosis was found to be unstable after PM fixation, requiring separate trans-syndesmosis screws. One hypothesis is that there may have been significant stripping of the

PITFL iatrogenically during the identification of the fragment, such that restoring the PM fragment no longer restored the PITFL function.

Apart from restoring syndesmosis stability, PM fixation restores the distal tibial articular surface, which holds important implications for tibiotalar contact area and pressures. Size of the PM fragment has been inversely correlated with tibiotalar contact area,^{8,18} which forms the basis of using fragment size for surgical indication of fixation. Moreover, PM fragment size $> 5\%$ of the articular surface, and residual articular step off of $\geq 1\text{mm}$ have been correlated with development of tibiotalar arthritis.⁵ These findings are suggestive that PM fixation, even in small fragments, may impede degenerative changes of the tibiotalar joint. More long-term evidence is needed to investigate this relationship.

Trans-syndesmosis fixation, although widely used, is associated with high rates of malreduction which is associated with poorer functional outcomes. Davidovitch et al., found a 30-38% rate of syndesmosis malreduction whether standard fluoroscopy or intraoperative CT scan were used.¹⁰ Another study by Sagi et al., demonstrated a 44% rate of malreduction with closed reduction of the syndesmosis intraoperatively, compared with 15% malreduction rate with open reduction of the syndesmosis.¹¹ This high rate of malreduction is not inconsequential, and is associated with worse functional outcome scores.^{11,12} Direct comparisons between the clinical outcomes of trans-syndesmosis fixation and PM fixation are limited in the existing literature. Miller et al., found equivalent outcome scores between both methods in 1 year follow-up.¹⁴ Another study demonstrated worse clinical outcomes at 1 year in subjects who had syndesmosis fixation in addition to malleolar fixation, compared with malleolar fixation alone, but this included lateral and medial malleoli.¹³ Given the well-studied biomechanical and anatomic advantages of PM fixation compared with trans-syndesmosis fixation, more evidence is needed on the clinical outcomes between both, over long-term follow-up, to better guide surgical indications.

One limitation of this study is the lack of post-operative assessment of syndesmosis reduction for all treated ankles because post-operative CT scans were not obtained. Plain films have been shown to be significantly less accurate than CT at assessing syndesmosis reduction.¹⁹ Other limitations of this study include its retrospective nature, and therefore inherently prone to selection bias with case selection. Furthermore, the sample size was too limited to allow for further multi-variable control of other potentially confounding variables including patient demographics and ankle fracture characteristics. Finally, there are other potentially confounding variables that were not captured in this

database including the surgeon's indication to fix the PM fragment, PM reduction and fixation technique and energy and mechanism of injury, which may be related to syndesmotic stability after PM fixation. Finally, we have no patient reported outcomes to determine whether this approach to syndesmotic fixation makes difference in clinical outcomes.

CONCLUSION

The results of this study suggest that posterior malleolar fixation may be an alternative to trans-syndesmotic fixation for restoring ankle stability while potentially avoiding the risks of tibiofibular malreduction and compromised functional outcomes that result from direct trans-syndesmotic fixation. Further study is needed to validate these findings and compare the accuracy of syndesmotic reduction as well as clinical outcomes.

ACKNOWLEDGEMENTS

The authors would like to recognize the efforts of Abdullah Qatu, BSE in preparing the database that was ultimately used in this study.

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HIP ARTHROSCOPY PRIOR TO PERIACETABULAR OSTEOTOMY DOES NOT INCREASE OPERATIVE TIME OR COMPLICATIONS: A SINGLE CENTER EXPERIENCE

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ABSTRACT

Background: Periacetabular osteotomy (PAO) is a well-established procedure to improve function and reduce pain in the non-arthritic dysplastic hip. PAO and hip arthroscopy are often performed together; however, there is concern that hip arthroscopy increases difficulty of PAO due to arthroscopic fluid extravasation. The purpose of the current study was to examine the effect of performing hip arthroscopy prior to PAO under the same anesthetic on PAO operative time and postoperative complications.

Methods: A retrospective review of all PAO cases during a two-year period at a single academic institution was performed. Cases were stratified into two groups based on whether concomitant hip arthroscopy was performed. In the combined hip arthroscopy and PAO group, hip arthroscopy was performed prior to PAO under the same general anesthetic in all cases. Student t-test was utilized to compare the operative times between the two study groups and Chi Square was used to compare categorical variables.

Results: During the two-year study period, 93 total PAO cases in 86 patients (mean age: 23.5 + 8.7 years; 81.4% female) were performed. Of these, 67 PAO surgeries (72.0%) were performed following hip arthroscopy. The total complication rate was 2.2% with one postoperative complication occurring in each group. There was no difference in mean PAO operative time between the two study groups (PAO: 127.6 + 18.0 minutes; PAO with hip arthroscopy: 125.4 + 16.8 minutes; p=0.570).

Conclusion: Performing hip arthroscopy prior to PAO under the same general anesthetic does not significantly increase PAO operative time or postoperative complications.

Level of Evidence: IV

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

Sources of Funding: No sources of funding declared.

Keywords: periacetabular osteotomy, hip arthroscopy, operative time, complication

INTRODUCTION

Developmental dysplasia of the hip is a complex deformity of the femur and acetabulum that predictably results in cartilage degeneration and labral pathology.¹⁻³ The acetabulum is shallow and vertically oriented with variable patterns of deficiency.⁴ This condition results in significant hip pain, decreased physical function, and premature osteoarthritis in young and active individuals.^{5,6} Periacetabular osteotomy (PAO) improves coverage of the femoral head by reorienting the acetabulum leading to improved function and decreased pain.⁷⁻¹¹ More favorable results occur in young patients with hip dysplasia without radiographic evidence of hip osteoarthritis.^{8,9,12} PAO functions to increase the contact area of the hip, therefore distributing stress in articular cartilage and other soft tissue structures over a greater area.¹³⁻¹⁵ Femoral deformity and labral pathology is common in patients with hip dysplasia.¹⁶ Cam deformity or femoral dysplasia at the head-neck offset has been shown to accelerate osteoarthritis after PAO and is important to identify preoperatively, as unaddressed cam deformity is associated with inferior patient reported outcomes following PAO.¹⁶⁻¹⁸

Hip arthroscopy can address labral and femoral head/neck offset pathology in the dysplastic hip.^{19,21} Hip arthroscopy and PAO can be performed concurrently; however, increased difficulty during the approach for PAO after hip arthroscopy due to arthroscopic fluid about the joint is a concern.²² Additionally, there have been reports of life-threatening abdominal compartment syndrome following hip arthroscopy due to fluid extravasation.^{23,24} Some surgeons elect to stage the procedures in an effort to mitigate these concerns. The purpose of the current study was to examine the effect of performing hip arthroscopy prior to PAO under the same anesthetic on PAO operative time as well as postoperative complications.

METHODS

Patient Selection

After Institutional Review Board (IRB) approval, a retrospective medical record review was performed on

Table 1. Demographics of the Study Cohorts

	PAO n= 26; 28.0%	PAO with Hip Arthroscopy n= 67; 72.0%	p-value
Patients, n	25	61	
Age (years)			
Mean + SD	22.2 + 9.4	24.0 + 8.5	0.376
Sex (male)	7 (28.0%)	9 (14.8%)	0.152
Body Mass Index (kg/m ²)			
Mean + SD	27.2 + 5.1	24.8 + 4.7	0.035

PAO= periacetabular osteotomy; SD= standard deviation

patients who underwent PAO at a single, large, academic center, between September 2017 and September 2019. Only patients with a corresponding diagnosis of acetabular/hip dysplasia were included. Patients that underwent concomitant femoral derotational osteotomies or surgical hip dislocations were excluded. Cases were stratified into two groups based on whether concomitant hip arthroscopy was performed. In the combined hip arthroscopy and PAO group, hip arthroscopy was performed prior to PAO under the same general anesthetic in all cases. PAO was performed by a board-certified orthopedic surgeon (MCW) while hip arthroscopy was performed by a sports-medicine trained board-certified orthopedic surgeon (RWW). PAO was performed based on techniques described by the Bernese group.²⁵ Hip arthroscopy for correction of cam deformity and/or acetabular labral repair was performed as described by Byrd et al.²⁶ and Kelly et al.²⁷ Labral preservation and capsular repair/plication was performed in all cases. Patients were indicated for combined hip arthroscopy and PAO when there was clear labral pathology on MRI, previous failed hip arthroscopy, concern for possible cartilage loss that would contraindicate PAO,²⁸ or older age. During the study period one PAO procedure was canceled because of focal full thickness cartilage loss observed during hip arthroscopy. This 40-year-old patient underwent a planned total hip arthroplasty 3 months after canceling the PAO. Typically, hip arthroscopy was not performed in patients with more severe hip dysplasia, though this was not always a contraindication for hip arthroscopy in our series.

Patient charts were reviewed for demographic data including age, sex, and body mass index (BMI). Operative reports were examined for PAO operative time defined as time of incision to completion of final closure. For the combined PAO and hip arthroscopy group, nursing staff documented the time of preoperative time-out for the PAO portion of the case. This was only performed when the staff surgeon performing the PAO was scrubbed in and the patient sterilely prepped and draped. The time of

preoperative time-out for the PAO portion was deemed the start of the case in the combined PAO and hip arthroscopy group and completion of incision closure as the end of the case. Lastly, patient charts were reviewed for postoperative complications defined as surgical site infection requiring antibiotic treatment, deep infection requiring irrigation and debridement (I&D) in the operating room, neurovascular injury, venous thromboembolic event (VTE), emergency department (ED) visit within 6 weeks of surgery, hospital readmission within 6 weeks of surgery, abdominal compartment syndrome, and mortality.

Statistical Analysis

Student t-tests were utilized to compare patient demographics and operative times between the two study groups, and Pearson’s Chi-Square tests were used to compare categorical variables, with statistical significance defined as $p < 0.05$. All statistical analyses were performed on SPSS Version 9 (IBM Corp, New York, USA).

RESULTS

During the two-year study period, 93 total PAO cases in 86 patients (mean age: 23.5 + 8.7 years; 81.4% female) were performed, of which 67 (72.0%) were performed under the same anesthetic with hip arthroscopy. Seven patients (8.1%) underwent a staged contralateral surgery. There was no difference in age ($p=0.152$) or sex ($p=0.152$) between the two study groups; however, the isolated PAO group had significantly larger BMI ($p=0.035$) [Table 1]. The overall complication rate for the entire cohort was 2.2% with one postoperative complication occurring in each group. There was no difference in complication rates between the isolated PAO (3.8%) and PAO with hip arthroscopy (1.5%) groups ($p=0.483$). In the isolated PAO group, one patient suffered a PE, while there was one superficial surgical site infection that resolved with oral antibiotics in the combined PAO and hip arthroscopy group. There were no cases of deep surgical site infection requiring operative debridement,

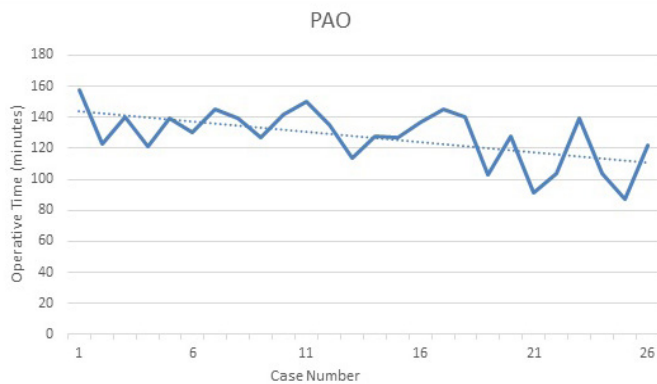


Figure 1. Line graph depicting operative times of isolated PAO cases during the two-year study period.

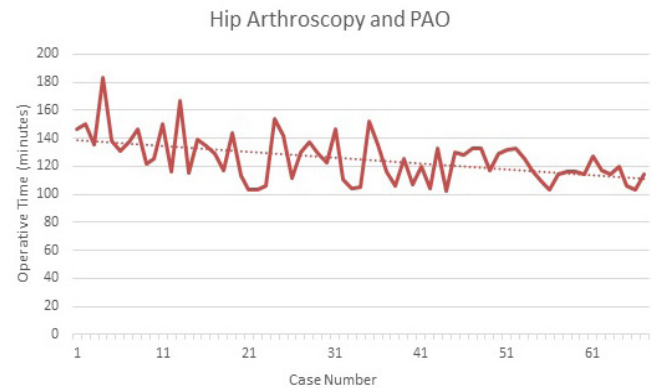


Figure 2. Line graph depicting operative times of combined PAO and hip arthroscopy cases during the two-year study period.

neurovascular injury, emergency department (ED) visits within 6 weeks of surgery, repeat hospital admission within 6 weeks of surgery, abdominal compartment syndrome, or mortality. There was no difference in mean operative time between the two study groups (PAO: 127.6 + 18.0 minutes; PAO with hip arthroscopy: 125.4 + 16.8 minutes; $p=0.570$) with a near identical trend in both groups towards reduced operative time later in the series. [Figures 1-2].

DISCUSSION

Hip arthroscopy is increasingly utilized concomitantly with PAO for patients with intra-articular pathology or femoral head-neck offset deformity.^{19,20} It has been suggested that hip arthroscopy prior to PAO would make the procedure more challenging and increase the risk of postoperative complications secondary to fluid extravasation and longer anesthesia time.^{29,30} Our retrospective review of a single center's experience over a two-year study period revealed that performing hip arthroscopy prior to PAO did not significantly increase PAO operative time. Furthermore, complication rates were similar with one postoperative adverse event observed in each study group.

The current study demonstrated no difference in PAO operative times performed with and without prior hip arthroscopy. There is concern that concomitant hip arthroscopy under the same general anesthetic makes the surgical approach for the PAO procedure more challenging. Although arthroscopic fluid is certainly encountered on the PAO approach, we feel any surgical delay is inconsequential. Although hip arthroscopy does not increase the surgical time for PAO, it certainly does increase total time in the operating room and time under general anesthesia. Beyond the specialized fellowship training required in these surgeries, attention must be paid to operating room logistics. Hip arthroscopy and PAO are performed on different operating room tables

with different specialized equipment necessitating transition of the patient to a new table and operative site 're-prep' and 're-drape'.³¹ Increased equipment needs alone may make performing these surgeries under the same general anesthetic not feasible in some centers. However, techniques have been described to perform these procedures without changing the operative table or re-prepping the extremity.³²

In our practice, hip arthroscopy is an important tool in the treatment of the young adult with a non-arthritic dysplastic hip. Intra-articular pathology in this patient subgroup is common and more easily appreciated with arthroscopic visualization than direct arthrotomy.³³ Previous studies have suggested that intra-articular central compartment pathology is a leading cause of revision surgery after PAO.³³⁻³⁵ In a cohort of patients who underwent combined hip arthroscopy and PAO, Maldonado et al. demonstrated improved patient reported outcomes which were sustained at a minimum five-year follow-up.³⁶ Additionally, in rare instances, previously unrecognized osteoarthritis is appreciated during arthroscopy and the PAO procedure aborted.²⁸

Complication rates following isolated PAO have been reported from 5-7%.^{11,37} There is concern that performing hip arthroscopy prior to PAO theoretically increases complication rates secondary to an increased total anesthesia time and soft tissue fluid extravasation. Sabbag et al. published a prospective case series of patients who underwent concomitant hip arthroscopy and PAO reporting a 3% rate of significant complications defined as Dindo-Clavien grade III or IV adverse events.³⁰ However, the previously mentioned study demonstrated a 2.5-time higher risk of postoperative complication per decade of advanced age at the time of surgery.³⁰ A study by Wells et al. also cited increased age as a risk factor for failure after PAO.³⁸ In the study by Sabbag et al., surgical time was not associated with postoperative complication on univariate analysis.³⁰ Our study cohort had a complication

rate of 3.8% following PAO and 1.5% following combined PAO and hip arthroscopy, consistent with the published literature. A single patient in the isolated PAO group developed a postoperative pulmonary embolism (PE) treated with rivaroxaban for 5 months. A superficial surgical site infection was observed in the hip arthroscopy and PAO group and was successfully treated with a ten-day course of oral cephalexin.

In the present study, there were no instances of abdominal compartment syndrome in the 67 cases of combined PAO and hip arthroscopy. In a recent study, Castel-Onate et al. examined intra-abdominal pressures during hip arthroscopy and found a significant increase during the first hour of surgical time and then a relatively steady state for the rest of the case.³⁹ Fluid extravasation leading to abdominal compartment is a life-threatening complication that must be carefully observed for intraoperatively. Additionally, hip arthroscopy should be performed before PAO to prevent extravasation of the arthroscopic fluid through the osteotomy into the abdominal cavity.⁴⁰ Additionally, the authors encourage caution when performing dissection over the anterior hip capsule for the ischial osteotomy. It is important to maintain integrity of the anterior capsule especially when dysplastic hip stability is a concern.⁴¹ Care should be taken to prevent disruption of the repaired hip capsule during the anterior dissection and placing the osteotome for the ischium osteotomy.

Limitations

The current study is limited by its retrospective design. Additionally, the cases examined were at a single center, which limits the generalizability of our findings to other surgeons. All operative time measurements were recorded from operating room logs which rely on prompt and accurate record keeping by operating room nursing staff. Our complication data only represents adverse events seen in our outpatient clinics. Therefore, complications such as surgical site infection treated by a primary care provider with oral antibiotics may have been missed. Furthermore, patient reported outcomes at follow up are not completed on this series of patients, so efficacy of performing hip arthroscopy prior to PAO cannot be assessed. Finally, given the relatively low number of cases, the statistical analysis may be underpowered to detect differences between groups.

CONCLUSION

Performing hip arthroscopy prior to PAO under the same general anesthetic, does not significantly increase PAO operative time or postoperative complications. Surgeons experienced in these operative techniques can perform these procedures under the same anesthetic without increased risk of complications or increased

the difficulty of the PAO. A randomized clinical trial is needed to fully assess the efficacy of adding hip arthroscopy to PAO for hip dysplasia.

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MID-TERM OUTCOMES OF COMBINED HIP ARTHROSCOPY AND LIMITED OPEN CAPSULAR PPLICATION IN THE NON-DYSPLASTIC HIP

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ABSTRACT

Background: Hip microinstability remains poorly-defined but increasingly diagnosed in the setting of borderline dysplasia (LCEA 20-25°), soft tissue laxity, or following unrepaired arthroscopic capsulotomy. While hip microinstability is commonly treated with arthroscopic capsular plication with short-term outcomes reported, this procedure has been performed open for some time. The purpose of current study was to assess the durability of outcomes of combined arthroscopy and open capsular plication in treating symptomatic hip microinstability at mid-term follow-up.

Methods: Hip microinstability remains poorly-defined but increasingly diagnosed in the setting of borderline dysplasia (LCEA 20-25°), soft tissue laxity, or following unrepaired arthroscopic capsulotomy. While hip microinstability is commonly treated with arthroscopic capsular plication with short-term outcomes reported, this procedure has been performed open for some time. The purpose of current study was to assess the durability of outcomes of combined arthroscopy and open capsular plication in treating symptomatic hip microinstability at mid-term follow-up.

Results: A total of 27 hips met criteria for inclusion and follow-up was obtained for 22 hips (81.5%) at a mean of 7.1 years. All patients were female with a mean age of 25.9 years and 7 (32%) hips had previous surgery. Patients undergoing the combined procedure improved from a mean baseline mHHS of 55.3±13 to a mean follow-up mHHS of 74.5±20.9 (p<0.001). At midterm follow-up, 54.5% of hips met criteria for PASS and 68.2%

of hips met criteria for MCID, with 72.7% of hips meeting criteria for either MCID or PASS. Overall, 10 hips (45%) were considered failures with 6 hips (27%) requiring reoperation and an additional 4 hips (18%) with clinical failure. Hips without previous surgery had a failure rate of 33.3% (5/15) while 71.4% (5/7) of those with previous surgery failed (P=.09).

Conclusion: Our study demonstrates a high (45%) rate of reoperations and persistent symptoms in hips with microinstability treated with combined arthroscopy and open capsular plication. Further mid- and long-term studies evaluating soft tissue plication are needed, as well as comparisons with bony procedures in the setting of microinstability are needed.

Level of Evidence: III

Keywords: microinstability, capsular plication, hip

INTRODUCTION

Hip microinstability is increasingly diagnosed and treated but remains poorly defined and understood.¹ This pathology has a multifactorial etiology and currently lacks strict radiographic parameters or definitive physical exam findings to establish a diagnosis.² Hip capsular plication, or capsulorrhaphy, is increasingly utilized for treatment of microinstability in the absence of major femoral or acetabular bony deformities.

In addition to bony structures, the hip capsule is a critical component of hip stability.^{3,4} Unrepaired capsulotomy during arthroscopy may be a source of iatrogenic microinstability.^{1,4-7} Although rare, cases of macroinstability or overt hip dislocation subsequent to capsulotomy have also been reported.^{3,5,8-11} Capsular hip repair following arthroscopy can potentially prevent iatrogenic microinstability and is now increasingly utilized. Capsular plication is increasingly utilized to address native microinstability in the non-dysplastic hip, but longer term studies are needed to establish the durability of outcomes.^{12,13}

Hip microinstability can occur with normal bony coverage in the setting of significant soft tissue laxity. More commonly, hip microinstability is seen with soft tissue laxity when combined with the presence of mild bony

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Disclosures: JJN reports personal fees from Responsive Arthroscopy LLC and Smith+Nephew, Inc; Research support from Stryker and Zimmer Biomet. JRR reports personal fees for Smith+Nephew, Inc. JCC reports personal fees for Wolters Kluwer Health, Microport Orthopedics, and Zimmer Biomet; Research support from Stryker, Zimmer Biomet, Department of Defense. The remaining authors report no potential conflicts of interest related to this study.

Sources of Funding: Curing Hip Disease Fund

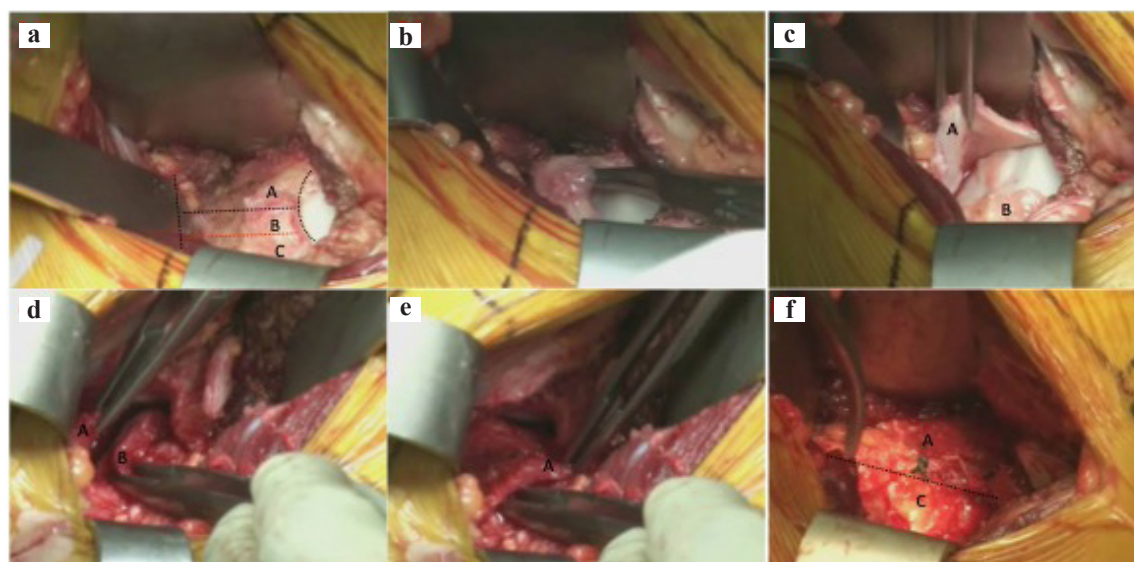


Figure 1. Intraoperative images demonstrating open capsular plication. For orientation, proximal is to right, distal to left, medial to top, and lateral to bottom of image.

- (a) Capsule is exposed with interportal capsulotomy from arthroscopy visualized (curved dotted line). The “I” shaped configuration of the planned capsulotomy and capsular plication is shown (black dotted lines). The medial capsule (A) will be advanced over the adjacent capsule (B) in a pants-over-vest configuration which approximated the medial capsule (A) to the lateral capsule (C).
- (b) An instrument demonstrates the laxity in the hip capsule prior to capsular plication.
- (c) The longitudinal portion of the capsulotomy is completed and then extended distally to complete the “I” shaped capsulotomy.
- (d) The laxity of the capsular limbs is assessed to determine the amount of capsular plication, which is typically 1 cm.
- (e) The medial hip capsule (A) is advanced over the intervening capsule (B) to reach the lateral capsule (C).
- (f) After completion of the open capsular plication with #2 Ethibond suture demonstrates the approximation of the medial capsule (A) to the lateral capsule (C) with 3-4 sutures.

deformities, such as borderline acetabular dysplasia,^{14,15} which is most commonly defined as a lateral center edge angle (LCEA) between 20 and 25 degrees. In this group, treatment decision-making between isolated hip arthroscopy with capsular plication versus periacetabular osteotomy (PAO) remains controversial.¹⁶⁻¹⁸

The senior author has performed open hip capsular plication prior to the more modern utilization of this procedure in an arthroscopic setting. In general, the open approach for capsular plication allows for more aggressive capsular plication compared to common arthroscopic techniques performed through an interportal capsulotomy.¹⁹ Short term outcomes of combined hip arthroscopy and capsular plication of the hip in the setting of microinstability are good, but a portion of patients report continued symptoms.^{16,17} Mid to long term outcomes of hip capsular plication are less established. Given the deteriorating results of capsular plication in other joints with soft tissue laxity the results of hip capsular plication may similarly deteriorate with time.²⁰ The purpose of current study was to assess the durability of outcomes of combined arthroscopy and open capsular plication in treating symptomatic hip microinstability at mid-term follow-up.

METHODS

This study was a retrospective assessment of patients enrolled with prospective baseline data collection in an institutional hip preservation database. We utilized this database to identify patients who underwent combined hip arthroscopy and open capsular plication between 2008 and 2013 by the senior author for treatment of symptomatic hip microinstability (secondary to soft tissue laxity or iatrogenic destabilization). This study was approved by our institution’s IRB. Hips with microinstability in the absence of increased femoral anteversion (femoral version > 35 degrees) or significant acetabular dysplasia (LCEA < 20°) were considered for this treatment, while bony reorientation was utilized for more severe deformities. Given the lack of clearly defined standards for diagnosing hip microinstability, this condition was diagnosed based on clinical assessment including the present of soft-tissue laxity, excessive hip range of motion, and patient-reported symptoms of giving out. The Beighton score was considered in this population but not routinely recorded in the medical record. A total of 27 hips met criteria for inclusion in our study with follow-up available for 22 (81.5%) hips from 20 patients at a mean of 7.1 years (range 4.9-13.1).

Table 1. Patient Characteristics

Number of patients	20
Number of hips	22
Sex, n (%)	
Female	22 (100%)
Age	25.9 ± 9.9 (13.4 to 45.1)
LCEA	26.7 ± 4.5 (20.2 to 39.2)
Acetabular inclination	3.8 ± 4.9 (-8.4 to 10.7)

Surgical Technique

All patients underwent central compartment hip arthroscopy to assess labral and cartilage pathology during the same anesthesia event. Capsular plication was then performed in the same surgical setting through a limited open Smith-Peterson exposure with an I-shaped capsulotomy (Figure 1). This limited open approach also allowed for proximal femoral osteochondroplasty when needed as previously described.²¹ This was followed by open capsular plication with greater than 1 cm of overlap obtained between the medial and lateral capsular leaflets proximally and distally. The integrity of the capsular flaps was variable depending upon the baseline tissue quality and whether capsular tissue was previously excised. After mobilization of the capsular flaps the vertical arthrotomy was secured with 3-4 interrupted # 2 Ethibond (EER, Ethicon, Inc., Cincinnati OH) sutures. The proximal aspect of the arthrotomy along the acetabular rim was then similarly secured in this advanced position with interrupted sutures.

Data Collection and Analysis

Patient-reported outcomes (PROs) were recorded at baseline and at a minimum of 5 years postoperatively through clinic or phone visits. During the study period, the modified Harris hip score (mHHS) was the primary PRO utilized. Any additional surgeries during the follow-up period were also recorded. The minimally clinical important difference (MCID) was defined as an

increase of 8 or more in the mHHS score from baseline to follow up of the index capsular plication procedure. For patients who underwent additional surgeries, scores prior to reoperation were used for analysis. The patient acceptable symptom state (PASS) has previously been defined as an mHHS of at least 74 at follow up.¹⁷ Clinical failure was defined as not meeting either MCID or PASS. The overall failure rate was composed of hips with reoperation or clinical failure. Additionally, chi-squared analysis (or Fisher's exact test) was utilized to compare the failure rates associated with the presence or absence of hip characteristics including previous surgery and borderline acetabular dysplasia. Student's t-test or paired t-test were utilized for comparison of continuous outcomes. P values less than 0.05 were considered significant.

RESULTS

Patient characteristics can be found in Table 1. All 22 hips were from female patients with a mean age of 25.9 years (Range 13.4-45.1 years). Seven hips (31.8%) had borderline dysplasia with an LCEA between 20 and 25 degrees. Seven hips (31.8%) had prior ipsilateral surgery, with six failed hip arthroscopies and one prior pelvic osteotomy at age 13. Three hips were from patients with Ehlers-Danlos Syndrome (EDS) and nineteen hips had hyperlaxity without the EDS diagnosis.

Clinical outcomes including mHHS and rates of clinical failure can be found in Table 3. The mean mHHS improved from 55.3±13 at baseline to 74.5±20.9 at midterm follow-up (P<.001). At midterm follow up, 54.5% of hips met criteria for PASS and 68.2% of hips met criteria for MCID, with 72.7% of hips meeting criteria for either MCID or PASS. There were no major postoperative complications from capsular plication. A total of 6 hips (27.3%) had additional surgeries. Details of additional surgeries and mHHS following reoperation, if available, can be found in Table 2. One hip that had an mHHS of 46.2 after capsular plication underwent subsequent PAO

Table 2. Reoperations at Mid-Term Follow-up after Open Capsular Plication

ID	Age at Surgery	Prior Surgery (Yes/No)	mHHS before Reoperation	Time to Reoperation (years)	Reoperation Surgery Type	mHHS after Reoperation
1	15.5	Yes-HS	74.8	1.4	PAO/HS	63.8
2	18.5	Yes-HS	N/A	5.5	Revision arthroscopy	84.7
3	38	No	N/A	7.0	Revision arthroscopy	61.6
4	18.4	Yes-HS	61.6	7.1	PFO	N/A
5	25.7	Yes-HS	74.9	4.4	PFO/HS	80.3
6	14.9	No	46.2	2.3	PAO	99.0

PAO-Periacetabular Osteotomy; HS-hip scope; PFO-Proximal femoral osteotomy; N/A-Not available
mHHS = modified Harris hip score

TABLE 3: Patient Reported Outcomes (PROs) and Failure Rates

	Overall (n=22)	No prior surgery (n=15)	Prior surgery (n=7)	LCEA>25 (n=15)	Borderline dysplasia LCEA 20-25 (n=7)
Baseline mHHS	55.3 (13.0)	55.6 (14.1)	54.8 (11.1)	54.9 (11.7)	56.3 (16.7)
Postop mHHS	74.5 (20.9)	73.7 (23.3)	76.5 (15.4)	74.3 (20.3)	75.2 (24.1)
Clinical failure* (%)	27.3%	26.7%	28.6%	26.7%	28.6%
Reoperation (%)	27.3%	13.3%	57.1%	26.7%	28.6%
Total failure rate (%)	45.5%	33.3%	71.4%	46.7%	42.9%

*Hips are considered as clinical failures if meeting neither MCID (≥ 8 increase in mHHS from baseline to follow up) nor PASS (mHHS ≥ 74 at follow up); mHHS = modified Harris hip score

with a final mHHS of 99.0 (Figure 2). Two hips did not have documented mHHS before the revision procedure occurred but were assigned as clinical failures. For the 16 hips that did not undergo additional surgery, the mean preoperative mHHS was 56.9 ± 12.0 and the mean mHHS at midterm follow up was 77.0 ± 21.9 (delta mHHS 20.1 ± 18.1). In addition to the six hips undergoing reoperation (27.3%), an additional four hips did not meet MCID or PASS (18.2%), resulting in a failure rate of 45.5% (10/22) for the index procedure.

Hips with prior ipsilateral surgery had a mean baseline mHHS of 54.8 ± 11.1 compared to 55.6 ± 14.1 for hips without prior surgery ($p=0.91$). At midterm follow up, hips with prior ipsilateral surgery had a mean mHHS of 76.5 ± 15.4 versus 73.7 ± 23.3 for hips without prior surgery ($p=0.76$). Five hips (71.4%, 5/7) with prior ipsilateral surgery were failures due to subsequent reoperation or failure to meet MCID or PASS, while 5 hips (33.3%, 5/15) without prior ipsilateral surgery were failures ($p=0.17$). Hips with borderline dysplasia (LCEA 20-25°) had a mean baseline mHHS of 56.3 ± 16.7 compared to 54.9 ± 11.7 for hip with an LCEA >25° ($p=0.84$). At midterm follow up, hips with borderline dysplasia had a mean

mHHS of 75.2 ± 24.1 compared to 74.3 ± 20.3 for hips with LCEA >25° ($p=0.93$). Overall, three hips (42.9%, 3/7) with borderline dysplasia were failures and seven non-borderline dysplastic hips (46.7%, 7/15) were failures ($p=1.00$).

DISCUSSION

Our study demonstrates variable improvement in pain and increased overall hip function in patients with hip microinstability treated with combined arthroscopy and open capsular plication in the absence of classic acetabular dysplasia or severe increased femoral anteversion. Although capsular plication resulted in significant improvement in pain, nearly half of hips had persistent symptoms or required reoperation, including arthroscopy, femoral osteotomy or PAO.

Our study's retrospective nature results in certain limitations with respect to data collection. The Beighton score is a measure of generalized hypermobility and has been correlated with hip capsular thickness.²² This score can be useful in characterizing microinstability but was not routinely recorded at the time when the surgeries in the current study were performed. All patients in the

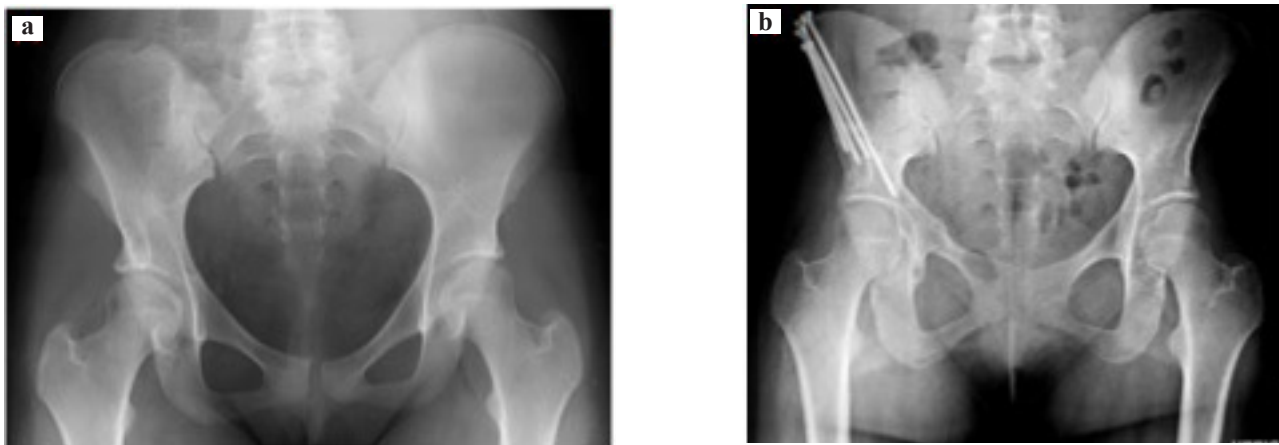


Figure 2. Case example (a) AP pelvis x-ray of patient that underwent hip arthroscopy with open capsular plication of right hip with mHHS of 46.2 after index surgery (b) AP pelvis x-ray from same patient after revision PAO with final mHHS of 99.0

current study were felt to have generalized hyperlaxity. We are also unable to evaluate the influence of femoral version on outcomes because it was not recorded in data during the study period based on clinical examination or three-dimensional imaging. Our surgeries utilized an open method of capsular plication, which is different from the arthroscopic technique more commonly used today. Although this enables more aggressive plication it is also more invasive, and it is not known whether results of the two approaches are truly comparable. Finally, our data is limited by the small size of the cohort. However, due to the limited literature on capsular plication (small case numbers and short-term follow-up) to address hip microinstability, the current study is comparable to existing literature but with a mean follow-up of over 7 years.

We found that patients with hip microinstability associated with borderline dysplasia (LCEA 20-25°) did not have worse outcomes compared to those without dysplasia (LCEA>25°), but the results remain highly variable in both groups. Our results are consistent with previous studies that have demonstrated clinical improvement in patients with borderline dysplasia and microinstability treated with arthroscopy and capsular plication, but with some patients reporting persistent symptoms.¹⁶⁻¹⁸ Although mean baseline and follow up mHHS were similar between hips with prior surgery and hips without, there is a higher composite failure rate with a trend towards significance ($p=.09$) in hips with prior surgery due to a high rate of reoperations in this group. This may indicate that bony procedures are more appropriate than capsular plication for hips with a history of prior failed surgery and persistent microinstability despite improvement in pain symptoms, although further studies are needed to make this determination.

Prior studies evaluating arthroscopic capsular plication in hips with borderline dysplasia have demonstrated clinical improvement but highly variable results. A study by Domb et al. of 22 hips with microinstability and borderline dysplasia (without previous surgery) treated with arthroscopy and capsular plication at a short-term minimum two year follow-up found that two hips (9%) required revision surgery and 23% of hips had a mHHS \leq 80 following capsular plication.¹⁶ A similar study of 123 hips (without previous surgery) and a minimum two year follow up by Maldonado et al. has a failure rate of 21%, with failure defined as secondary arthroscopy/THA or mHHS below PASS.¹⁷ Although these studies demonstrate lower rates of failure compared to our study, these studies only included primary procedures and minimum follow up was only two years compared to our minimum four year and average 7 year follow-up. In the current study, two-thirds (4/6) of the reoperations occurred after four years postoperatively. In another study by Domb et

al. of 21 hips treated with primary surgery and followed for a minimum of 5 years, 19% of hips had reoperation and an additional 14% had an mHHS<70, resulting in a 33% failure rate if failure had been defined using a composite outcome similar to our study.¹⁸ This failure rate is consistent with the 33% failure rate in the current study when assessing hips without previous surgery. The current study would have yielded a considerably higher composite failure rate of 54.5% if failure was similarly defined as reoperation or mHHS<70. Notably, the mean preoperative mHHS of hips in the Domb midterm cohort was 70.3 compared to a preoperative mean mHHS of 54.4 in the current study. So despite greater improvements in mean PROs, patients in the current study demonstrated higher rates of persistent symptoms. The higher rate of failure in our cohort despite a similar sizeable increase in mHHS following index surgery may indicate that capsular plication is more appropriate for patients with milder pain symptoms of microinstability at baseline.

The current study demonstrates a high rate of failure of capsular plication in hips with persistent symptoms in the setting of prior surgical intervention. A significant proportion (32%) of hips in the current study had undergone prior surgical intervention. The studies by Domb and Maldonado excluded hips with prior operations, which may contribute to the lower failure rates compared to the current study. Although these studies by Domb and Maldonado are limited to hips with microinstability in the setting of borderline dysplasia, we believe these results should be comparable to ours since our study seems to indicate that borderline dysplasia does not impact outcomes.

Studies evaluating combined arthroscopy and capsular plication strictly in non-dysplastic hips (LCEA>25°) with microinstability are limited. A study by Larson et al. of 16 hips in EDS patients without acetabular dysplasia demonstrated a mean improvement in mHHS of 42.9 following arthroscopy and capsular plication, with one hip requiring revision arthroscopy.²³ This study provides support for the utility of arthroscopy and capsular plication in treating microinstability in non-dysplastic hips with soft tissue laxity.

Despite clinical improvement in hip function and pain, the significant portion of hips achieving suboptimal outcomes is concerning at this mid-term time point. Reoperations occurred in 27% of hips in our current study. The time to reoperation ranged from 1.4 to 7.1 years indicating both early and late symptomatic failure may occur. The limited open approach enabled us to be particularly aggressive in tightening the hip capsule compared to an arthroscopic approach to plication. This should in theory provide the most robust attempt to address hip microinstability with capsular plication

that may be more protected from subsequent loosening over time compared to arthroscopic techniques. The relatively high failure rate despite aggressive tightening of the hip capsule has led the senior author to rarely indicate open plication since 2014 in favor of alternative modalities to correct underlying mild bony deformities. Currently, those with borderline dysplasia and significant microinstability are treated with combined PAO and arthroscopy. Those with microinstability and increased femoral anteversion are treated with proximal femoral osteotomy and arthroscopy. Patients with significant hip microinstability in the absence of bony abnormalities are treated with arthroscopy and arthroscopic capsular closure. Some patients with capsular insufficiency from previous surgery or severe hyperlaxity without bony abnormality would currently be considered for arthroscopy and capsular plication (arthroscopic or open).

Our study demonstrates a high (45%) rate of reoperations and persistent symptoms in hips with microinstability treated with combined arthroscopy and open capsular plication. Further mid- and long-term studies evaluating soft tissue plication are needed, as well as comparisons with bony procedures in the setting of microinstability are needed.

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DOES SMOKING CESSATION PRIOR TO ELECTIVE TOTAL JOINT ARTHROPLASTY RESULT IN CONTINUED ABSTINENCE?

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ABSTRACT

Background: Smoking tobacco is a known modifiable risk factor for complications in total joint arthroplasty (TJA) patients. Patients are commonly required to quit smoking prior to TJA. After the early postoperative period, little is known about the long-term implications of this preoperative behavioral change. Our aims were to 1) identify TJA patients that had negative anabasine screen prior to elective TJA and 2) determine the long-term rates of continued smoking abstinence.

Methods: At our institution, TJA patients identified as smokers undergo urine anabasine testing prior to surgery. Between 2009 – 2018 all patients that had elective primary TJA with pre-operative urine anabasine tests were queried. Patients were called post-operatively at mean 52 months (range 15 – 126 months) and surveyed regarding smoking status. Long-term smoking cessation rates were then analyzed along with relapse time frame. The use of quit aid and patient perspective on importance of quitting were also analyzed.

Results: 249 smokers that had elective TJA were identified. 124 (50%) participated in the survey, and 93 quit to facilitate surgery. 21 (23%) never resumed smoking, and 32 (34%) were currently abstinent. Just over half of the patients relapsed in the three-month post-operative period (55%). There were no differences in quit aid or patient perspectives between these groups.

Conclusion: With an increased focus on smoking cessation prior to elective TJA, orthopedics contributes to an important public health initiative. Although national quit rates are in the single digits, 23% of patients were able to quit permanently.

Level of Evidence: IV

Keywords: arthroplasty, smoking cessation, abstinence, total joint arthroplasty, total hip arthroplasty, total knee arthroplasty, smoking

INTRODUCTION

Despite declines in cigarette smoking over the past several decades, according to the Centers for Disease Control 2018 data approximately 34 million US adults (14% of the adult population) continue to smoke. To that end, tobacco use remains the leading cause of preventable disease, disability, and death in the United States, and smoking remains a large burden on the healthcare system with nearly \$170 billion spent on direct medical care for smokers.⁵ Smoking is well established as a modifiable risk factor for patient's undergoing elective primary total joint arthroplasty (TJA). Smokers are at an increased risk for wound complications, prosthetic joint infections (PJI), lower respiratory infections, myocardial infarction, and increased mortality rates.^{2,3,6,7,12,13,16,17,20} As a result, patients are routinely encouraged to quit smoking prior to TJA.

The preoperative period has been seen as a potential target for impacting smoking cessation efforts.¹⁴ This time frame is unique in that it offers a tangible incentive to quit smoking and the prospect for continuity of care with ongoing perioperative visits. Synergistically, research has demonstrated that hospitalized surgical patients express an increased motivation to quit smoking.¹⁸ With little known about the long-term implications of preoperative smoking cessation in TJA, we set out to deepen our understanding.

Our aims were to identify TJA patients that had a negative nicotine screen prior to elective TJA and determine the long-term rates of continued nicotine abstinence following their procedure. We further set out to identify unique patient characteristics that may impact successful abstinence. In those patients that relapsed, we completed a sub-group analysis seeking to better understand the timeframe to relapse.

METHODS

We performed a retrospective study looking at patients who underwent TJA at a single institution: University of Iowa Hospitals and Clinics between 2009 and 2018. At our institution, patients recognized as smokers

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

Sources of Funding: No sources of funding declared.

Table 1. Time to Relapse

Time to relapse	Number	Percent
</= 3 months	37	55
</= 6 months	17	25
</= 12 months	9	13
> 12 months	5	7
Total	68	100

undergo urine testing preoperatively to confirm smoking abstinence in order to be cleared for surgery. Laboratory analysis of urine nicotine metabolites is completed. Our protocol relies on urine anabasine levels. Urine anabasine is a minor alkaloid of the tobacco plant and is a marker of active tobacco use. Anabasine is unique in that it will not be falsely elevated in patients utilizing nicotine replacement therapy. A urine anabasine level < 3 ng/mL is accepted as a negative result. Only those patients with a negative urine anabasine result documented pre-operatively were included in our study. It should also be noted that no formal smoking cessation treatment or counseling is offered at our institution. Further inclusion criteria encompassed elective surgery and primary TJA.

Our database query identified 249 patients who met the inclusion criteria. Basic demographic information from the time of surgery was collected for each patient and included: age, sex, and BMI. Laterality and details relating to the procedure performed were also gathered. Patients who underwent staged bilateral TJA were asked specifically about smoking status as it related to the first of the procedures. Contact information was also acquired through chart review. Deceased patients or those with incomplete contact information were excluded.

Patients were contacted via phone call to participate in a short six question survey. Those patients who were unable to be reached after a minimum of three attempts were also excluded. Patients were asked about quit status prior to TJA, relapse time frame, current smoking status, if they used any quit aids, and whether they felt quitting was an important step to ensure the success of their surgery.

Univariate analysis was utilized to investigate the significance demographics, patient opinion, and the use of a quit aid played in achieving long-term successful smoking cessation. Chi-square or Fisher’s exact tests were used for categorical variables, and Wilcoxon rank sum test was used for continuous variables. Statistical analysis was performed with SAS 9.4 (SAS Institute Inc, Cary, NC). Significance level was defined as p value < 0.05. Post-operative smoking cessation relapse was categorized by time frame.

Table 2. Patient Demographics, Quit Aid Utilization, Opinion of Quitting

	Maintained smoking abstinence post - TJA	Resumed smoking post-TJA	
N	21	72	
Mean Age	55.53 +/- 8.69	51.78 +/- 10.12	
Median Age	57	52	p = 0.1026
Mean BMI	31.14 +/- 6.95	33.50 +/- 6.92	
Median BMI	30.11	32.78	p = 0.1249
Female	9	38	
Male	12	34	p = 0.4237
Used Quit Aid	4	26	
No Quit Aid	17	46	p = 0.1411
Quitting Important	19	55	
Quitting not important	2	17	p = 0.1589

RESULTS

We identified 249 patients who underwent TJA between 2009 – 2018. The inclusion criteria encompassed patients with a negative pre-operative urine anabasine screen, elective primary TJA. Mean follow-up was 52 months with a range of 15 – 126 months. Of the 249 patients identified, 26 had inaccurate contact information, 11 were deceased and 65 were unable to be reached despite multiple attempts. Of the 147 patients we were able to reach, 124 (84%) agreed to participate in the phone survey. Of those questioned, 93 (75%) quit with the explicit purpose to facilitate their TJA. Patients who quit smoking greater than 6 months prior to surgery were categorized as former smokers. The 10 patients (8%) subsequently identified as former smokers reported a median abstinence time of 8.5 years prior to surgery. Those who denied smoking cigarettes were categorized as non-smokers. This group included 8 non-smokers (7%) who instead endorsed smoking marijuana or chewing tobacco. Finally, 13 patients (11%) denied having successfully quit smoking despite a negative preoperative anabasine test. The most common response in this group was they were successful in cutting back significantly on the number of cigarettes smoked but were unable to quit.

The results of the phone survey revealed that 21 (23%) patients were able to maintain abstinence since surgery. Furthermore, 32 (34%) are currently abstinent. Sub-group analysis of the 68 patients who resumed smoking and could recall the time to relapse revealed that 55% of patients relapsed within 3 months. This number decreased to 25% at 6 months and 13% at 12 months. (Table 1) As may be expected, our results showed that those patients who relapsed were more likely to do so within the first 3 months following surgery. Of note, 63 (68%) patients

quit cold turkey, without the use of a quit aid product or medication and 74 (80%) expressed they felt quitting was important to the overall success of their surgery.

Age, sex, and BMI were not significant in this analysis. The use of a quit aid pre-operatively further demonstrated no significant impact. Subjective patient opinion regarding the importance of abstinence and the success of the TJA also failed to reach significance. (Table 2)

DISCUSSION

With such strong evidence linking smoking with post-TJA complications, pre-operative smoking cessation is highly encouraged. As a result, investigators have explored interventions targeted at helping smokers quit in anticipation of surgery.^{8,10,19,22,23} While a few groups have subsequently probed the lasting effects of pre-operative smoking cessation, there remains limited data on this topic with wide ranging results. To that end, our aim was to add to the field in hopes of better understanding the lasting impact smoking cessation prior to TJA has on our patient population in light of the ongoing public health crisis caused by smoking.

The relevance of this work stems from the sheer number of patients who contact healthcare through Orthopedic Surgery, and specifically for the purpose of joint replacement surgery. Greater than 1 million TJA procedures are performed annually and that number is anticipated to grow, projected to approach 2 million by 2030.²¹ The prevalence of smokers in TJA candidates is reportedly 10 – 24%.⁶ Furthermore, there is evidence to suggest surgical patients experience a boost in their motivation to quit smoking in the perioperative period.^{14,18} Putting this all together paints a picture that successful smoking cessation in the TJA patient population has the potential to significantly impact the smoking cessation public health initiative.

Sadr, et al. investigated the success of short and long-term smoking cessation following TJA. Their study was a prospective randomized clinical trial comparing a smoking cessation program to a control group. The program involved weekly meetings with patients and nicotine replacement therapy (NRT). Patients started the program 4 weeks pre-operatively and continued 4 weeks post-operatively. Of the 92 patients with 1-year follow-up, they reported 33% abstinence in the intervention group versus 15% abstinence in the control group.¹⁹ Lee, et al. reported on another randomized controlled trial comparing an intervention versus a control. The intervention arm in their study included brief counseling, a smoking cessation brochure, referral to a smoking quit line, and six-week nicotine replacement therapy. Of the 127 patients with 1-year follow-up, they reported 20% abstinence in the intervention arm versus 6% abstinence

in the control group.¹⁵ Akhavan, et al. investigated the impact various interventions had on successful smoking cessation pre-operatively. They completed a sub-group analysis and reported 64% long-term abstinence rates in 14 patients at 6 months.¹ Most recently, Hart, et al. reported long-term abstinence rates of 45% at 8 years in their cohort of TJA patients.¹¹

Unique to our study, we report long term smoking cessation rates intrinsic to the experience of quitting to facilitate a TJA procedure. Patients who are identified as smokers pre-operatively are instructed to quit and informed they will undergo urine anabasine laboratory analysis prior to approval for elective TJA. This is nearly uniformly enforced by all orthopedic surgeons in our institution. There is no common intervention or counseling offered pre-operatively to aid patients in their efforts. This is supported by 68% of patients in the current study endorsing quitting without the utilization of a quit aid. Moreover, our study offers objective evidence of pre-operative smoking cessation in the form of urine anabasine levels in all patients. The significance of our sub-group analysis investigating time to relapse is supported by Gilpin, et al. who investigated the impact duration of smoking abstinence has on successful continuous abstinence. These authors reported 83% successful continuous abstinence in those who quit for 6 months or longer. This number increases to 90% continued abstinence with 1 year or more of abstinence.⁹ One should consider that the smoking cessation prevalence is reported to be 6% in the general population.⁴

The results of this study reinforce the importance of encouraging smoking cessation in patients undergoing TJA. Quitting to facilitate TJA provides strong motivation to quit smoking and may lead to successful permanent smoking cessation for almost 25% of patients. Not only does this help to decrease complication rates, but it allows us to play an important role in improving the health of our patients while contributing to an important public health initiative.

There are several limitations in our study. Primarily, this is a retrospective study that relies on accurate patient recall. Moreover, we relied on analysis of the medical record which is prone to inaccuracies. The study could have been further strengthened by a better understanding of patient tobacco use levels. In the current study, we did not stratify patients by the number of cigarettes smoked prior to surgery. Finally, we had a significant number of patients, 37%, who were excluded from the study due to inaccurate contact information or an inability to reach them by phone call.

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INSURANCE COVERAGE CRITERIA FOR FEMOROACETABULAR IMPINGEMENT SURGERY: ARE THEY RESPONDING TO IMPROVING EVIDENCE?

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ABSTRACT

Background: With the rapidly growing body of FAI literature in the last decade, improved evidence exists to support FAI surgery. However, it remains unclear how well third-party insurance company's FAI policies have adapted over time to improved evidence. The purpose of this study was (1) to compare the 2020 FAI surgery criteria of four major insurance companies utilizing a multi-center cohort of FAI patients undergoing surgery to identify rates and causes of ineligibility, and (2) to compare the rates of approval based on changes in policy from 2012 to 2020.

Methods: Four major insurance companies' coverage policies with specific criteria for the surgical treatment of FAI were applied to this population at two time points (2012 and 2020). The policies listed various combinations of age, symptom duration, radiographic signs of FAI, radiographic signs of osteoarthritis, and physical exam findings. A prospective, multi-center cohort of 712 patients (including 45.5% males and 54.5% females with a mean age of 28.7 years) undergoing surgical treatment of FAI was utilized for analysis of insurance policies.

Results: Based on 2020 FAI policies across 4 insurers, 22.5% (range 18.4-28.4%) of FAI patients would be deemed ineligible. In 2012, the average percent exclusion of the four companies was 23.7%. The most likely reason to be excluded

was either failure to meet imaging criteria (alpha angle $>50^\circ$ or positive cross-over sign) [13%, n=94] or the absence of an impingement sign (9%, n=65). Other causes of exclusion were <6 -month symptom duration (6%, n=44), age <15 years (4%, n=28), or skeletally immaturity (3%, n=23).

Conclusion: Our study shows that despite a six-year span of growing literature and updated policies, nearly 1 in 5 patients diagnosed with FAI would still potentially be denied coverage. This highlights a continued divide between surgeons and insurance companies. There is a major need for improved consensus regarding the diagnosis of FAI and appropriate indications for surgical intervention.

Level of Evidence: IV

Keywords: femoroacetabular impingement, insurance, fai, insurance coverage criteria, surgical treatment, surgery

INTRODUCTION

Femoroacetabular impingement syndrome (FAI) is a clinical entity describing the symptomatic premature contact between the femoral neck and the anterior acetabulum during movement, causing restricted range of motion and pain. Patients frequently present with groin or hip pain exacerbated by hip flexion or difficulty sitting.¹ The cause of this impingement has been attributed to specific hip morphology such as cam, pincer, or a combined cam/pincer.^{2,3} Cam morphology refers to osseous deformity of the femoral head-neck junction while pincer morphology describes an acetabular-based overcoverage that can cause impingement through. In addition to short term pain and restricted movement, FAI is associated with progressive damage to the labrum and cartilage and eventual osteoarthritis (OA) development.^{3,4} FAI surgery attempts to halt the ongoing damage and delay or avoid the progression to OA, which remains to be clearly demonstrated.

There are many treatment options for FAI, ranging from initial conservative options such as physical therapy aimed at strengthening hip muscles, to operative correction using arthroscopic or open methods. Surgical intervention focuses to reshape the bony morphology of femur and/or acetabulum to relieve the associated

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Disclosures: JJN reports personal fees from Responsive Arthroscopy LLC and Smith+Nephew, Inc; Research support from Stryker and Zimmer Biomet. JRR reports personal fees for Smith+Nephew, Inc. JCC reports personal fees for Wolters Kluwer Health, Microport Orthopedics, and Zimmer Biomet; Research support from Stryker, Zimmer Biomet, Department of Defense. ANCHOR Study Group Members reports research support from Zimmer Biomet and ANCHOR Research Fund. The remaining authors report no potential conflicts of interest related to this study.

Sources of Funding: No sources of funding declared.

Table 1. Insurance Company FAI Surgery Criteria

			2012 Criteria	2020 Criteria
Aetna™	Age		18-50 years	>15.0 years old or skeletally mature
	Symptom Duration		> 6 months	> 6 months
	Positive Impingement Sign		No	Yes
	Any of these radiographic findings:*	Alpha angle Acetabular retroversion Lateral center edge angle	Alpha angle > 50° Present –	Alpha angle >50° Present >40°
Joint Space		≥ 2 mm	≥ 2 mm	
Tönnis Grade		0 or 1	0 or 1	
United HealthCare™	Positive Impingement Sign		Yes	Yes
	Any of these radiographic findings:*	Alpha angle Acetabular retroversion	Alpha angle > 50° Present	Alpha angle >50° Present
	Tönnis Grade		0 or 1	0 or 1
Blue Cross Blue Shield™	Age		15-55 years	Skeletally mature
	Symptom Duration		> 3 months	> 3 months
	Positive Impingement Sign		Yes	Yes
	Any of these radiographic findings:*	Alpha angle Acetabular retroversion	Alpha angle > 50° Yes	Alpha angle >50° Yes
	Tönnis Grade		0 or 1	0 or 1
Joint Space		≥ 2 mm	≥ 2 mm	
Cigna™	Symptom Duration		-	> 3 months
	Restricted Internal Rotation		-	Yes
	Positive Impingement Sign		Yes	
	Any of these radiographic findings:*	Alpha angle Acetabular retroversion	Alpha angle > 50° Yes	Alpha angle > 55° Yes
	Tönnis Grade		0 or 1	0 or 1

3rd-party payer inclusion criteria of four major insurance companies from 2012 and 2020 for FAI surgical intervention. Unless otherwise indicated, patients must meet all criteria to qualify. Bolded text indicates changes from the 2012 to 2020 policy criteria. * indicates that there may be more radiographic findings accepted as evidence of FAI by this insurance provider. These can be found in the methods section.

impingement, as well as treat the labral and cartilage damage that has already occurred. Hip arthroscopy has gained popularity over open methods due to shorter recovery times,^{5,6} although outcomes of the two approaches appear to be similar.⁷ A recent metanalysis of randomized control trials comparing hip arthroscopy and physical therapy has established that hip arthroscopy conveys significantly better hip-related quality of life outcomes, meeting the minimal clinically important difference (MCID), compared to conservative treatment of FAI.⁸ Furthermore, the failure rates of hip arthroscopy have been relatively low in the literature, cumulatively at 5.5% undergoing reoperations.⁹ Finally, surgical correction of cam-type FAI has showed stabilization of cartilage degeneration and more uniform stress distribution, potentially decreasing the risk of osteoarthritis development.¹⁰

While surgical management of FAI has been shown to be beneficial overall, there are still often difficulties getting insurance approval for intervention and significant variability in the insurer’s criteria. This is can be attributed to a lack of consensus regarding FAI and criteria for surgery. Sankar et. al described five elements that should

be present to diagnose FAI: abnormal femoral and/or acetabular morphology, abnormal contact between the two, collision and contact from activity, repetitive motion causing continuous insult, and finally presence of soft tissue damage due to impingement.¹¹ While these elements help define some aspects of FAI, they are not detailed enough to alleviate the gap in diagnostic definition and surgical candidacy. Therefore, other radiographic and physical exam criteria have been used to examine the need for diagnosis and surgery of FAI by both physicians and insurance companies. The purpose of this study was (1) to examine the 2020 FAI surgery criteria of four major insurance companies utilizing a multicenter cohort of FAI patients undergoing surgery to identify rates and causes of ineligibility and (2) to compare the rates of approval for 2012 and 2020 policies across insurers.

METHODS

The current study applied the FAI surgery policies of four major insurers to an established prospective multicenter cohort of FAI patients undergoing hip preservation surgery to determine rates of approval and

disapproval. Additionally, we characterized the items leading to ineligibility across policies.

Four national health insurance companies were selected as a representative sample: Aetna™, UnitedHealth Group™ (United), Blue Cross Blue Shield Association™ (BCBS), and Cigna™. Aetna is a subsidiary of CVS health and Cigna is a subsidiary of Anthem Inc. Medical policies specifically addressing criteria for FAI treatment from 2012 and 2020 were found on each companies' respective websites (Table 1).¹²⁻¹⁵ Necessary data points were obtained and included: age at time of surgery, skeletal maturity, symptom duration, Tönnis osteoarthritis grade, impingement sign, minimum joint space width measurement on anteroposterior pelvic radiographs, hip internal rotation in flexion range of motion, and radiographic findings such as alpha angle, lateral center edge angle, and cross-over sign. The Cigna 2020 policy required restricted internal rotation without a specific threshold. Given this lack of specificity, we analyzed the data with two thresholds representing restricted internal rotation: (a) less than or equal to 20 degrees; (b) less than or equal to 30 degrees. Several criteria included in the medical policies were excluded in our analysis. First, every policy required the presence of moderate to severe symptoms with flexion activities (eg squatting or prolonged sitting). All of our patients were symptomatic pre-operatively. Secondly, the Outerbridge score (United, BCBS) was excluded from the analysis as it is a surgical assessment that is not possible to know preoperatively and has not been validated for use on preoperative MRI. This score is an intraoperative assessment that isn't feasible preoperative. Additionally, Aetna requires that none of the patients have osteogenesis imperfecta or generalized joint laxity (Marfan syndrome or Ehlers-Danlos). While no patients in the current study had osteogenesis imperfecta, data on Marfan syndrome and Ehlers-Danlos was not available on this cohort. Finally, we utilized the most commonly used FAI imaging findings listed above (alpha angle, acetabular retroversion, and lateral center edge angle), some insurance providers also accepted other radiographic findings to confirm the diagnosis of FAI. All third-party payers accepted coxa profunda or pistol-grip deformity as evidence. BCBS additionally had posterior wall sign, acetabular rim damage, or coxa protrusio. Cigna had decreased femoral head-neck offset as another accepted parameter.

A prospective multicenter cohort of FAI patients undergoing primary FAI surgery was assessed relative to the insurance policies. Exclusion criteria included previous open or arthroscopic hip surgery, prior hip/acetabular fracture or dislocation, Perthes disease, or slipped capital femoral epiphysis. The study cohort was established for the ANCHOR FAI-1 cohort of 760 hips

undergoing surgical treatment between May 2007 to April 2012. Through physical examination and radiographic findings, these patients have been diagnosed with FAI and deemed appropriate for surgical treatment of FAI by experienced surgeons. All patients within this database initially underwent conservative non-operative treatments such as physical therapy, activity modification, and occasionally corticosteroid injections, as such minimum symptom duration before surgery in these patients is 3 months. This study was performed under an institutional review board-approved protocol obtained at all participating sites. Hips were included in the current study only if they had complete data for all clinical and radiographic criteria evaluated above (Table 1). A total of 712 hips remained in the final cohort after the exclusion of 48 hips for incomplete data.

Preoperative radiographs included an anteroposterior (AP) pelvis and either a frog-lateral, 45° Dunn lateral, or cross-table lateral radiograph based on the preference of the treating surgeon. Osteoarthritis was classified on the AP pelvis plain radiographs using the Tönnis classification system.¹⁶ The minimum joint space thickness was also determined on the AP pelvis view, in addition to the lateral center edge angle (LCEA) and presence or absence of a "cross-over-sign" (COS) as an indicator of acetabular retroversion despite its limitations.^{17,18} The alpha angle was measured on all available lateral radiographs. Skeletal maturity was determined as closure of the proximal femoral physis. Each of these radiographic measurements and classifications were performed by the treating surgeon.

Statistical Analysis

Statistical data were analyzed utilizing SPSS (version 22.0, IBM Corp, Chicago, IL). Descriptive statistical analysis was performed to determine the mean and standard deviation of the patients ages.

RESULTS

A total of 712 hips comprised the cohort for the current study. These patients comprised of 324 men (45.5%) and 388 females (54.5%) with a mean age of 28.7 years (range 11.0-57.0). The clinical diagnosis of FAI subtype was isolated cam in 42.3%, isolated pincer in 7.4%, and combined cam/pincer in 50.3% of patients.

2020 Insurer Policies

Each insurance provider had a different set of criteria as seen in Table 1, with 7 major items represented: Age, symptom duration, Tönnis OA grade, impingement sign, joint space distance, internal rotation in ninety degrees of hip flexion (IRF) range of motion, and imaging findings (alpha angle, crossover sign, etc.). The average number of criteria per policy was 7 categories with only 4 catego-

Table 2. Frequency of Not Meeting Individual Insurance Criteria

Criteria Group	Sub-criteria	Percent of cohort (n)
Age	<15 years	3.9% (28)
	Outside 18-50 years range	24.4% (174)
	Outside 15-55 years range	5.1% (36)
	Skeletally Immature	3.2% (23)
	<15 years and Skeletally Immature	1.5% (11)
Symptom Duration	< 3 months of symptoms	0% (0)
	< 6 months of symptoms	6.2% (44)
	> 6 months	93.8% (668)
Impingement Test	Negative	9.1% (65)
	Positive	90.9% (647)
Internal rotation with knee in 90° flexion	>20°	10.4% (74)
	>30°	3.5% (25)
Imaging Findings	Alpha angle <50° and COS negative	8.1% (54)
	Alpha angle <55° and COS negative	13.2% (94)
	Alpha angle <50°, COS negative, LCEA <40°	7.4% (53)
Tönnis Grade	Grade 0 or 1	98.0% (698)
	Grade 2 or 3	2.0% (14)
Joint space	< 2 mm	0% (0)
	≥ 2 mm	712 (100%)

Cohort information who underwent primary surgical treatment for FAI in this study. Different categories represent how many met or did not meet certain insurance criteria from 2012 and 2020. All criteria that would result in exclusion under a policy is bolded. COS = cross over sign, LCEA = lateral center edge angle.

ries consistent across all insurance providers (failure of conservative treatment, pain with flexion activities (eg squatting or prolonged sitting), positive impingement test, and low-grade osteoarthritis).

Age and skeletal maturity were utilized in two of the four 2020 policies (Aetna, BCBS). Aetna allowed for patients to be skeletally mature or greater than 15 years old while BCBS required documented skeletal maturity. There was no age requirement for United or Cigna. In total, 3.9% of patients (n=28) were less than 15 years old while the rest (96.1%, n=684) were 15 or older (Table 2). Of the patients that were <15 years old, 39% (n=11/28) had open physes. Twelve patients over the age of 15 were skeletally immature.

A symptom duration requirement was utilized in all of the 2020 policies. A minimum 3-month symptoms duration was required by United, BCBS, and Cigna. All patients in the study cohort met this criterion. However, one company (Aetna) requires >6 months of symptoms, resulting in exclusion in 6.2% of patients (n=44) with symptom duration less than 6 months (Table 2).

Physical examination findings were included in most criteria, including impingement sign (4 of 4) and restriction of internal rotation (1 of 4). All insurance companies required the presence of a positive impingement sign, which was absent in 9.1% (n=65) of patients (Table 2). Cigna has a requirement of restricted internal rotation,

which can be described by either 20- or 30-degree thresholds. At 30 degrees or less, 4.5% of patients (n=25) met this criterion. At 20 degrees or less, 7.6% less patients (n=49) failed to meet this criterion (Table 2).

Imaging requirements were present in all policies to meet the criteria of FAI diagnosis. All policies had a list of criteria that the patient must meet at least one of which to qualify, including alpha angles, acetabular retroversion (as assessed by the COS), and LCEA as marker of overcoverage. An alpha angle cutoff of greater than 50° were required by 3 insurers (Aetna, United, BCBS), while an alpha angle greater 55° was required by 1 insurer (Cigna). Overall, 16.6% (n=118) of patients did not meet the 50° cut-off, while 29.8% (n=212) of patients were not above 55°. A COS was absent in 42.4% (n=302) of the patients in this cohort. Bringing these features together, 8.1% (n=54) did not have an alpha angle >50° or a positive COS, while 13.2% (n=94) did not have an alpha angle >55° or a positive COS. Only one insurer (Aetna) listed the LCEA of >40° as an acceptable imaging finding to qualify as FAI. 93.3% of patients (n=664) met this criterion. When combined with other criteria, 7.4% (n=53) of patients did not meet any of the tested imaging requirements (positive COS, alpha angle >50°, or LCEA of >40°).

Finally, all policies required an assessment of the presence of OA either through the Tönnis OA grade or

Table 3. Rates of FAI Surgery Criteria Rejection by Insurers in 2012 and 2020

Identifier	Insurance Company	Rejection Percentage	
		2012 Policy	2020 Policy
A	Aetna	35.5%	24.3%
B	United	18.4%	18.4%
C	Blue Cross Blue Shield	22.5%	21.3%
D	Cigna*	18.4%	23.9-28.4%
	Average	23.7%	22.5%

Percentage of patients that would've been rejected was calculated using the 2012 and 2020 criteria. * designates that Cigna required restricted internal rotation which can be defined by 20 and 30 degrees and thus a range was given for percentage of patients rejected in 2020.

joint space distance ≥ 2 mm. 98% of patients had a Tönnis grading of 0 or 1 (n=698) and only 2% (n=14) had grades of 2 OA (Table 2). All patients studied had a joint space ≥ 2 mm (n=712).

Overall, the 2020 rate of rejection when applied to FAI cohort resulted in an average of 22.5% (range 18.4-28.4%) of patients being rejected (Table 3). Specifically, the rates for the four companies were 24.3%, 18.4%, 21.3%, and 23.9-28.4% (depending on IRF cutoff used of 20° and 30°, respectively). The third-party criterion that the most patients failed was either an imaging sign (alpha angle $>50^\circ$ or positive COS) (13%, n=94) or the presence of an impingement sign (9%, n=65).

Comparison of 2020 and 2012 Policies

Overall, 2012 insurance policies would have rejected an average of 23.7% (range; 18.4-35.5%) of the FAI cohort (Table 3). This was a 1.2% higher than the 2020 policy average (22.5%). The rates for the four companies were 35.5%, 18.4%, 22.5%, and 18.4%. One policy (Aetna) that contained age as a requirement became more inclusive with an age of 15 years or older, which would include 23% of the subject cohort (n=174 v. 11) that the 2012 guidelines would've excluded. Unfortunately, the addition of a positive impingement test as a requirement largely negated this increase in patients included – without the impingement test requirement, 7% of the subjects would have been included (116 v. 169 excluded). Another policy (Cigna) added a minimum symptom duration criterion of >3 months, but this did not affect the number of patients covered in this cohort. The most significant changes came from one particular policy (Cigna). First, they increased their alpha angle requirements to 55° from 50° , resulting in an exclusion of 13.2% more of the study cohort (118 to 212) (Table 2). Additionally, Cigna added a physical exam stipulation of restricted internal rotation, which can be described by either 20 or 30 degrees. These requirements resulted in 3.5-10.4% patients rejected depending on definition used, respectively (n=25 or 74).

DISCUSSION

Surgical treatment of FAI is a well-accepted treatment option for patients that have failed conservative treatment and has demonstrated good outcomes with relatively low complication rates.^{3,19,20} Recent level one evidence from randomized controlled trials also supports improved outcomes of surgical treatment compared to physical therapy.²¹ Despite these results, surgeons have anecdotally noted continued barriers for obtaining approval for FAI surgery from third-party payers. The current study evaluated 712 patients that had FAI surgery by experienced surgeons and only 71.6-81.6% would have been considered appropriate by insurance providers' criteria. On average, these rates of rejection were largely unchanged 8 years prior in 2012. One company's policy changed resulted in significant less ineligibility (decreasing from 35.4% to 24.3%), while another company's policy led to increased rates of ineligibility (increasing from 18.4% to 23.9-28.4%). These disagreements in surgical criteria between the various third-party payer policies and surgeons can create delays in treatment or even result in the inability to treat some patients with symptomatic FAI. Early intervention is crucial in these patients, as some studies have demonstrated that these delays are clinically significant and may result in progression of articular cartilage changes.^{22,23} Ultimately, surgical criteria set forth by insurers and used independently by surgeons should be evidence-based. While it is possible that the policies are behind the most current literature due to the restraints of annual revisions, trends showing continued disparity between insurers and surgeon practice begs further investigation as some policies remain unchanged from 2012 to 2020. This current study, therefore, reviews the literature with respect to each of the individual third-party payers' surgical criteria for coverage of FAI surgery.

Imaging findings for FAI are varied and dependent on the type of FAI, with cam-type impingement associated with a larger alpha angle²⁴ and pincer morphology with both the COS²⁵ and LCEA.²⁶ The COS is generally viewed as an indicator of acetabular retroversion and is defined as the anterior acetabular wall lying lateral to the posterior acetabular wall as it approached the lateral sourcil. In this study, we utilized the COS as a proxy for acetabular retroversion, but it is increasingly recognized that this is an oversimplification.^{17,18} Three-dimensional imaging is now routinely utilized in this assessment, but was not at the time of this multicenter FAI cohort. Furthermore, there is significant debate as to the best cutoff for the alpha angle with a recent systematic review finding thresholds ranging from 50° to 83° .²⁷ One insurer utilized a 55° cutoff, while the other three utilized the more common 50° threshold.

This five-degree difference in threshold results in ineligibility of approximately 5% of the current FAI study cohort. The authors believe alpha angles of 50-55° can contribute to symptomatic FAI in some patients, particularly when combined with decreased femoral version or activities requiring large amount of hip flexion. Insurers also include the pistol-grip deformity in criteria, but such a finding would indicate an elevation of the alpha angle anyway. Insurers also continue to include some criteria with poor evidence. Coxa profunda, as defined by the acetabular fossa being medial to or touching the ilioischial line was once viewed as representing pincer morphology, but has been shown to not be valid and largely abandoned.²⁸ Another insurer includes a positive posterior wall sign, indicating posterior acetabular undercoverage. While this finding is indeed present in the setting of significant acetabular retroversion, in combination with positive crossover sign, this finding indicates a more severe deformity that may actually be a less ideal candidate for hip arthroscopy compared to anteverting periacetabular osteotomy. Unfortunately, setting cutoffs as exclusionary criteria when there exists much controversy over threshold values may mean that some patients are improperly excluded.

Defining an age or skeletal maturity as a cut-off for surgical treatment of FAI is challenging. FAI is being increasingly recognized in developing adolescents between 11 and 19 years of age²⁹⁻³¹ and a number of studies demonstrating significant clinical improvements after arthroscopic FAI correction in younger adolescent patients.^{29,31,32} In a FAI cohort composed of adolescent patients with open physes (n=37 hips), Larson et al. had excellent results using a non-physal-sparing arthroscopic approach – 93% (n=34) of patients returned to preinjury level of sports participation and 81% (n=30) exceeded the minimally clinically important difference for patient reported outcomes.³¹ Despite this study and several others demonstrating safety and efficacy in the skeletally immature population, this patient population remains excluded by two of the four insurers. Even among patients older than 60 years old, surgical intervention has been shown to be beneficial in selected patients without OA.³³⁻³⁵ Honda et al. found that arthroscopy is still effective treatment for FAI, as their cohort of patients over the age of 70 had significant improvement of PROs and no evidence of progressive osteoarthritis following hip arthroscopy.³⁵ For these reasons, limiting the age groups or skeletal maturity that can undergo treatment clearly excludes patients that have been shown to derive benefits from intervention. Of note, two insurance companies have expanded age criteria (from 18-50 and 15-55-year-old cut-offs) to 15 years of age or skeletally mature, have clearly done so alongside expansion of the

literature. However, the current policies remaining limiting from populations that still appear to benefit from FAI surgery and would have excluded 1.5-3.2% of patients in this cohort. Given the positive results in the literature of treatment at varied stages of maturity and age, expanding or eliminating these cutoffs is recommended.

The optimal timing for treatment of FAI relative to symptom onset is not well delineated in the literature. While conservative treatment is beneficial and may avoid the need for surgery in some cases, a recent study found that patients who undergo surgery within 3-6 months of symptom onset have significantly better patient reported outcomes and are more likely to achieve a minimal clinically important difference compared to those who wait longer than 6 months for intervention.³⁶ This directly questions an insurer excluding patients with 3 to 6 months of symptoms from FAI surgery. Other studies have also found that those who had symptoms for >12 months have worse outcomes and are more likely to undergo additional intervention.³⁶⁻³⁹ Additionally, given the high incidence of grade 3 and 4 chondromalacia noted at the time of surgery in some studies, one could argue that FAI corrective surgery might be more beneficial if performed earlier in some instances.⁴⁰ In our study, 93.8% of the patients that underwent FAI surgery had at least 6 months of symptoms prior to surgery. Interestingly, despite these reports in the literature, third-party payers do not seem to be adjusting their time requirements. One company (Aetna) has kept their >6 months requirement constant over the past 8 years. These requirements would have rejected 6.2% (n=44) of our study cohort. While a time requirement of at least 3 months of symptoms is fairly well accepted, this highlights the lack of any evidence supporting a 6-month requirement and concern that delays could result in disease progression.

Physical examination findings play a major role in the diagnosis of FAI, but no single test alone remains absolutely sensitive and specific. A positive impingement test is required by all of the insurance policies (without alternative), but is well documented to not be positive in all patients with FAI (not 100% sensitive). Originally described by Klaue et al. to identify hip labrochondral pathology,⁴¹ studies have reported mixed results regarding this test's sensitivity with anywhere from 88.6% to 100% of symptomatic FAI patients having a positive anterior impingement test.^{22,29,42} Hananouchi et al. evaluated the accuracy of the anterior impingement test and, despite the reported high positive predictive value (100%), the impingement test had a low sensitivity (56%).⁴² Finally, a systematic review of the diagnostic accuracy of clinical tests for FAI found similar results – the anterior impingement test had one of the lowest sensitivity of the tests assessed (0.11).⁴³ In this study, 9.1% (n=65) of patients

did not have a positive impingement test. Thus, this suggests that the application of this test as strict criteria by a third-party payer may result in exclusion of a subgroup of patients from surgical treatment despite having symptomatic FAI. In these patients, alternative physical examination findings (painful straight leg raise, pain with deep hip flexion), as well as positive responses to intra-articular injections may still isolate the hip as the source of pain despite a negative impingement test. Insurance policies would be better served to utilize a broader approach to elucidate exam findings consistent with an intra-articular source of pain. Restricted internal rotation range of motion was added by one policy in 2020 (Cigna), which seems to be an appropriate marker of FAI. Fortunately, no strict restrictions were provided, which allow the clinician to consider other patient factors that may affect what would be considered restricted (sex, soft tissue laxity, activity).

Plain radiographic findings play an important role in identification of patients with early OA who are less likely to benefit from FAI surgery.^{37,44-46} Early case series of surgical treatment of FAI noted that patients with worse clinical outcomes or higher rates of conversion to total hip arthroplasty (THA) had Tönnis grade II or III changes on preoperative radiographs.⁴⁵⁻⁴⁹ The presence of Grade II Tönnis OA remains fairly well accepted as a contraindication to hip preservation surgery and was reflected in all 4 policies. While some patients may still observe short-term benefit, the high risk of progression to THA and variable results in this population are well established.^{50,51} However, minimum joint space width measurements may be more sensitive to early OA and offer better inter-observer reliability.⁵² Studies have demonstrated higher rates of THA and significantly lower postoperative modified Harris Hip Scores in patients with ≤ 2 mm joint space or $> 50\%$ joint space narrowing on plain radiographs.^{44,53,54} In a 10 year follow up study, Travis et al. found that joint spaces of < 2 mm had significantly higher rates of failure – 89% (n=34/38) of FAI patients with < 2 mm joint space required a THA compared to just 15% (n=16/107) of patients with larger joint spaces.⁵⁵ Two of the insurance providers included a criteria of > 2 mm of joint space remaining. Of note, none of the study population had a joint space width less than 2 mm.

While not explicitly addressed in our results section, two out of four of the insurance providers had Outerbridge classification requirements (either $<$ Grade III and IV or only $<$ Grade IV) that the patient must meet prior to surgical intervention approval. We do not know how to interpret these requirements given that the Outerbridge scale is an intraoperative scale that requires direct visualization of the cartilage. Assuming that these third-

party payers are referring to pre-operative evaluation of cartilage, even advanced and expensive MR imaging modalities (such as dGEMRIC techniques) have lower sensitivity and specificity ranges (63-88% and 37-63%, respectively) for the detection of chondral lesions^{56,57} and don't allow application of this scale anyway. Finally, although the authors agree that FAI surgery should be limited in patients with significantly advanced chondral disease, Grade IV chondral lesions of the acetabulum are commonly present in the setting of FAI and do not preclude successful treatment.^{55,58,59} Thus, full-thickness acetabular cartilage lesions should not exclude patients from FAI surgery.

Limitations

The present study is not without limitations. The diagnosis of FAI in our cohort is based on the surgeons' diagnosis. While it is possible that the patients within the study may have the incorrect diagnosis, we believe that the criteria of the database are appropriate and accurate when analyzing patients with hip pathology. It is important to note that these insurance policies are a starting point in the approval process, and an appeal process for denials is also available. However, in many cases the appeals are still evaluated strictly relative to the existing criteria. Furthermore, the cohort of patients in this study all underwent surgery with many not meeting some criteria, so presumably these patients were eventually approved. This does show that while not perfect, these policies do appear to have some flexibility in regard to approval and physician appeal. Additionally, the insurance providers selected may not be fully representative of all insurance providers in the market. These third-party payers were selected because they and their parent companies are the top four largest US health insurers.⁶⁰ We did not examine criteria for insurers outside of the United States or governmental insurance. Finally, our study looked only at a limited number of imaging findings for confirmation of FAI (alpha angle and acetabular retroversion via COS). In reality, there are many other imaging findings (coxa profunda, posterior wall sign) that are included but actually felt not to be indicative of FAI in isolation. For the sake of clarity, we chose to use three of the most commonly used diagnostic indicators present in both the literature and in our study cohort, while using other criteria may slightly decreased the rates of ineligibility.

CONCLUSION

Between 2012 and 2020, there has been a growing body of evidence supporting the utility of FAI surgery and appropriate patient populations. While some insurance providers have changed their initial approval criteria during that eight-year interval to allow for a wider age

range, approximately 1 in 5 patients with FAI would still be rejected even with updated policies. This highlights a discrepancy in the indications used by experienced surgeons and third-party payers. While the spectrum of disease is wide and includes a diverse patient demographic, the need for consensus regarding surgical treatment of FAI is critical for early and appropriate intervention in preventing progression to OA.

NOTE

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ASSESSMENT OF SPLINTING QUALITY: A PROSPECTIVE STUDY COMPARING DIFFERENT PRACTITIONERS

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ABSTRACT

Background: Splinting is routinely performed in the emergency department (ED), and follow-up visits of improperly placed splints are commonplace in orthopaedic clinics. As open reduction and internal fixation (ORIF) of fractures has become the preferred treatment for many injuries, orthopaedic surgeons and emergency physicians have received less instruction on splinting technique. Limited literature exists regarding error/complication rates of splint application. The purpose of this study is to determine: (1) Is there a difference in splinting complication rates between orthopaedic and non-orthopaedic services, and low versus high volume emergency room and urgent care centers? (2) What are the most common technical errors and complications in splint application?

Methods: Patients presenting to orthopaedic clinic with any extremity splint were enrolled in this IRB approved prospective study. Splint characteristics collected included: type of provider placing the splint, duration of wear, type of splint, and material used (i.e. plaster or fiberglass). Errors included inappropriate length, circumferential placement, and direct contact between the ACE bandage and the skin; while complications included swelling, blistering, ulceration, heat injury, and other issues on a case-by-case basis.

Results: 203 patients were enrolled in this study. 98 (48%) were splinted by the Orthopaedics service, 69 (34%) were splinted in the trauma hospital ED, and 36 (18%) were treated at an

outside hospital. 123/203 (61%) had an error/complication related to the splint. Error/complication rates for orthopaedics, the trauma hospital ED, and outside hospitals were 46% (45/98), 65% (45/69), and 92% (33/36) respectively. The most common errors were inappropriate length, present in 58/203 (29%) patients, and direct contact between the ACE bandage and skin, present in 50/203 (25%) patients.

Conclusion: The appropriateness and complication rates of splints applied in the ED differ based on the type of provider and the institution. Outside hospitals were found to have the highest complication rates, while the lowest rates were associated with splints placed by Orthopaedics. These findings support the importance of education of proper splinting technique in non-trauma hospitals.

Level of Evidence: III

Keywords: emergency department, trauma, education, splint

INTRODUCTION

Splints are lightweight, noncircumferential immobilizers that accommodate extremity swelling, making them ideal for the management of acute musculoskeletal conditions.^{1,3} Common indications for splinting include sprains, initial fracture stabilization, and postoperatively. In these situations, splinting serves to immobilize and protect the extremity, aid in healing, and lessen pain.

Splinting has potential complications including skin breakdown, ischemia, heat injury, infection, pressure sores, neurological injury, compartment syndrome, and fracture malreduction or non-union.^{1,2,4,8} Further, errors in splint placement can place unnecessary restrictions on patient movement, limiting participation in work, exercise, and other activities. These complications can affect patients regardless of patient age or the duration of treatment.⁶ Patients at increased risk of complications include those who are obtunded or comatose, anesthetized, young, developmentally delayed, spastic, and/or with pre-existing neuropathy.^{2,3}

Plaster splints have been used to treat fractures for greater than 150 years.⁹ However, as open reduction and internal fixation (ORIF) of fractures has become the preferred treatment for many orthopaedic injuries,

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

Sources of Funding: No sources of funding declared.

Table 1. Patient Demographic and Splint Characteristic Data

Splint Characteristics	Number (%)
Service placing splint	
Orthopaedics	98 (48)
Trauma Hospital ED	69 (34)
Other ED	36 (18)
Splint type	
Long arm	34 (17)
Sugar tong	21 (10)
Short arm	22 (11)
Short arm thumb spica	10 (5)
Short arm to fingers	9 (4)
Radial gutter	2 (1)
Ulnar gutter	15 (7)
Long leg	11 (5)
Short leg	78 (38)
Removable finger splint	1 (0.5)
Splint material	
Plaster	171 (84)
Fiberglass quickset	32 (16)
Average number of days from placement to removal	9

orthopaedic surgeons and emergency physicians have received less instruction on proper splint application. In a recent study examining what procedures were considered necessary for graduating medical school students, only 31% of faculty and 26% of resident physicians rated splinting as a “must know” skill.¹⁰ Decreased instruction on proper technique due to this perception may increase the likelihood of erroneous application, thereby increasing the risk of complications. For example, a recent article assessing splinting in the emergency department found that prior to an educational intervention on proper technique the rate of correctly applied splints for hand injuries was 49%.¹¹

Improving splinting practice could lead to improved quality of care, decreased healthcare costs, and decreased societal costs (e.g. lost work hours, lost employment, and excess medical and drug costs). The current study aims to ascertain (1) is there a difference in splinting complication rates between orthopaedic and non-orthopaedic services, and low versus high volume emergency room and urgent care centers; and (2) what are the most common technical errors and complications in splint application.

MATERIALS AND METHODS

Our Institutional Review Board approved this prospective study. An a-priori power analysis suggested that a total sample number of 155 patients would be necessary to detect a difference between groups based on the assumption of a 30% complication rate, a power of 80% (beta), and a significance level of 0.05 (alpha).

A single researcher evaluated all patients entering the orthopaedic clinic from May-June 2015 and November-December 2015. Patients were selected using a purposive sampling method based on the presence of any extremity splint. The researcher was not involved in patient care, and prospectively documented and observed patients with splints who presented to the general orthopaedic, pediatric orthopaedic, and hand clinics. Splint characteristics and the underlying skin and soft tissues were assessed for technical errors and complications, as described below. Injury type, splint characteristics (e.g. type and material, placing provider, dates of placement and removal, and days before evaluation), patient demographics (e.g. age and gender), and errors/complications were recorded.

Definitions of proper splinting technique and errors utilized in this study were drawn from the text “Casts, Splints, and Support Bandages – Nonoperative Treatment and Perioperative Protection” for each injury and splint type.¹² Technical errors addressed included appropriateness of splint type for injury, splint length relative to anatomic landmarks, range of motion limitations, circumferential nature, and neutral positioning of the extremity. Complications assessed included numbness/tingling, swelling secondary to the splint compression of an extremity, blistering, ulceration, heat injury, and compartment syndrome. Additionally, several errors and complications not discussed in the referenced text were addressed in an “Other” category, which included: direct application of the ACE bandage to the skin, excessive splint loosening, tissue maceration, and splint compression compromising positioning of the fingers or toes. Although ACE contact with the skin may be considered acceptable in some circumstances, it is not recommended on a general basis and has been utilized as an error criterion in other studies.^{1,2,13}

At the time of data collection, the trauma hospital was the only Level I trauma center in the region. In order to minimize bias, all data regarding date of placement, fracture or injury type, and service was obtained from the patient’s electronic medical record (EMR) after assessment. Data was divided into three groups for final analysis based on provider training and practice environment: “Orthopaedics” (orthopaedic surgery residents or attending physicians in the operating room or on consultation in the emergency department), “Trauma

Table 2. Errors and Complications Associated with Splints

Errors and Complications	All Services N = 203 (%)	Orthopaedics N = 98 (%)	Trauma Hospital ED N = 69 (%)	Outside Hospitals N = 36 (%)	P-value
Any error or complication	123 (61)	45 _a (46)	45 _b (65)	33 _c (92)	<0.0001 _a
Inappropriate splint type	14 (7)	0 _a (0)	6 _b (9)	8 _b (22)	<0.0001 _a
Inappropriate splint length	58 (29)	22 (22)	20 (29)	16 (44)	0.164
Crossing joint/Limiting ROM	49 (24)	21 (21)	16 (23)	12 (33)	
Too Short	9 (4)	1 (1)	4 (6)	4 (11)	
Circumferential (>2/3)	10 (5)	5 (5)	5 (7)	0 (0)	0.264
Swelling	7 (3.4)	2 (2)	2 (3)	3 (8)	0.199
Blistering	6 (3)	2 (2)	2 (4)	2 (3)	0.685
One	3 (1)	1 (1)	1 (1)	1 (3)	
Multiple at one end	3 (1)	1 (1)	1 (1)	1 (3)	
Multiple scattered blisters	0 (0)	0 (0)	0 (0)	0 (1)	
Ulceration(s)	17 (8)	3 _a (3)	8 _{ab} (12)	6 _b (17)	0.021 _a
Stage I: Non-blanchable erythema	14 (7)	3 (3)	7 (10)	4 (11)	
Stage II: Partial thickness	1 (0.5)	0 (0)	1 (1)	0 (0)	
Stage III: Full thickness skin loss	2 (1)	0 (0)	0 (0)	2 (6)	
Stage IV: Full thickness tissue loss	0 (0)	0 (0)	0 (0)	0 (0)	
Heat injury	0 (0)	0 (0)	0 (0)	0 (0)	-
Other	74 (37)	25 _a (26)	20 _a (29)	29 _b (81)	<0.0001 _a
Bandage directly contacting skin	50 (25)	18 _a (18)	10 _a (15)	22 _b (61)	<0.0001 _a
Inappropriate flexion/extension	10 (5)	3 (3)	5 (7)	2 (6)	0.460

Subscripts denote subsets of categories that do not differ significantly from one another at the 0.05 level. For “Any error or complication” Orthopaedics (a) is significantly different from both Trauma Hospital ED (b) and Outside Hospitals (c). For “Inappropriate splint type” Orthopaedics (a) is significantly different from Trauma Hospital ED (b) and Outside Hospitals (b), which do not differ from one another. For “Ulcerations” Orthopaedics (a) is significantly different from Outside Hospitals (b), but Trauma Hospital ED (a,b) does not differ significantly from either group. For “Other” Orthopaedics (a) and Trauma Hospital ED (a) do not differ from one another, but both are significantly different from Outside Hospital ED (b). For “Bandage directly contacting skin” Orthopaedics (a) and Trauma Hospital ED (a) do not differ from one another, but both are significantly different from Outside Hospital ED (b).

Hospital ED” (emergency physicians, emergency medicine resident physicians, or cast technicians), and “Outside Hospitals” (any practitioner performing the procedure at another facility).

This study was granted a waiver of written consent by the IRB. All patients eligible to participate in this study received a verbal description of the study methods, research question, and their involvement prior to their voluntary enrollment. Patients excluded from this study included those who declined to participate, those who had been previously enrolled in the study for another injury, and those who had altered the splint before its final documented removal.

Statistical analysis was performed using SPSS statistics version 23.0 (IBM, Armonk, New York). A two-tailed unpaired t-test was used to compare the splints placed by Orthopaedics in the operating room versus the emergency room. A chi-squared test with a post-hoc Bonferroni correction was used to assess if the error/

complication rate differed between services. With the Bonferroni correction a P value of less than 0.017 was deemed significant.

RESULTS

A total of 203 patients were enrolled in the study. 98/203 (48%) were splinted by Orthopaedics, 69/203 (34%) were splinted by the Trauma Hospital ED, and 36/203 (18%) were treated at an Outside Hospital. There were 85 females (42%) and 118 males. The average age and standard deviation of patients enrolled in the study was 34 ± 22 years. Splint characteristics are listed in Table 1.

The overall error/complication rate was 61% (123/203), with specific issues listed in Table 2. The combined error/complication rates for Orthopaedics, the Trauma Hospital ED, and Outside Hospitals were 46% (45/98), 65% (45/69), and 92% (33/36) respectively. Splints placed by Orthopaedics in the operating room



Figure 1a-b: Examples of inadequate splints. (a) Short arm thumb spica splint covering elbow proximally and MCP joints of 2nd through 5th digits distally. Additionally, the ACE bandage is in direct contact with the skin both proximally and distally. (b) Short arm thumb spica splint placing wrist is in volar flexion rather than a mild amount of dorsiflexion. Fiberglass quickset material overlapping from the mid-forearm distally over the thumb, creating a fully circumferential splint. Inappropriate proximal and distal length of splint again demonstrated.

versus the emergency room did not differ significantly ($P=0.31$), and were combined into a single group. There was a significant difference in incorrectly placed splints and/or complications between the three groups, with Orthopaedics having the fewest errors or complications ($P<0.001$). The average ages for patients splinted were 38.8 ± 19.2 , 30.8 ± 24.7 , and 23.8 ± 17.7 years for Orthopaedics, the Trauma Hospital ED, and Outside Hospitals, respectively. A chi-squared test with post-hoc Bonferroni correction showed that the Trauma Hospital ED was not significantly different from either group with regard to age ($P(\text{Orthopaedics}) = 0.03$ and $P(\text{OSH}) = 0.1$); however, the patients splinted by Orthopaedics were on average older than those patients seen at Outside Hospitals ($P<0.001$). Nevertheless, the calculated odds ratio indicated that patient age was not a significant predictor of splinting complications or errors ($P=0.86$, 95% confidence interval 0.99-1.01).

The most common error was inappropriate length, which occurred in 58/203 (29%) patients (Figure 1), but did not occur at different rates between the groups. In the category of "Other" the most common error was direct contact between the ACE bandage and patient's



Figure 2a-b: Examples of ulceration after splinting. (a) Ulceration at second MCP joint secondary to an inappropriately tight splint. (b) Ulceration and ecchymosis at fifth MCP joint due to splint tightness and insufficient padding.

skin, which occurred in 50/203 (25%) of patients overall. Other common complications were ulcerations and/or blistering (Figure 2), which occurred in a total of 23/203 (11%) cases. The second most common issue in this category was failure to immobilize the limb in an appropriate position based on the injury, instead positioning it in inappropriate flexion, extension, or with torsion. This occurred in 10/203 (5%) of patients overall. The most common issue was excessive plantarflexion at the ankle when the patient was placed in a short or long leg splint, which accounted for 7/10 (70%) cases (Figures 3). Circumferential coverage of the extremity was observed in 10/203 (5%) patients (Figures 1B and 4). Additional problems included splint loosening requiring the patient to use additional supportive tape (1), need for a patient to pad the proximal end of splint due to abrasion (1), tissue maceration (1), and splint compression causing phalanges to be crossed (1).

Although application of the ACE bandage directly to the skin has previously been cited as an error, ACE bandages are often directly applied to the skin in the absence of a splint or cotton padding, causing the authors to question this criterion as a true "error." With this criterion removed, the overall complication rate decreased to 51% (105/203). Thus, 64% (32/50) of splints with the ACE directly contacting the skin had some other error. Group-specific error and complication rates with this criterion removed for Orthopaedics, the Trauma Hospital ED, and Outside Hospitals were 34% (33/98), 61% (42/69), and 83% (30/36) respectively. A repeated chi-squared test confirms that the significant difference in incorrectly placed splints and/or complications between the three groups is maintained with the



Figure 3. Short leg fiberglass splint with ankle placed in inappropriate equinus.

elimination of this criterion, with Orthopaedics having the fewest issues ($P < 0.001$).

DISCUSSION

The mantra, “There are no hypochondriacs in casts” is essential to remember for both casted and splinted patients.² Incorrectly applied splints can cause complications ranging from mild issues such as blisters or partial thickness ulceration to limb- or life-threatening complications such as ischemia or infection.^{1,2,4-8}

Our findings of an overall complication rate of 61% (123/203) and direct application of bandage to the skin in 25% (50/203) are comparable with prior studies and show that the rates of technical errors and complications of splint placement are alarmingly high. A recent study of pediatric extremity injuries noted complications in 93% of the patients evaluated, with the most prevalent complication being direct application of bandage to the skin, seen in 77% of patients.⁴ Another study examining the outcomes of treatment of mallet finger injuries identified skin complications in 38/84 (45%) patients, with 3 cases of skin necrosis secondary to direct application of the strap fastener to the skin.⁷ A study comparing outcomes of pediatric distal radius fracture immobilization found that 24% of patients had sores, and 14% experienced pain from the splint.¹³

Similar to previous studies, this study utilized blanket criteria for technical errors in splint placement including contact of ACE wrap with the skin and malpositioning



Figure 4. Short leg splint. Plaster of the proximal portion surrounds greater than two-thirds of leg and is nearly touching at the anterior tibia.

of joints. Although deviations may be appropriate in specific situations, these actions are not advisable on a global basis, and for the purposes of rigorous study they were all considered errors. Generally, one would expect purposeful deviations from guidelines to be employed more often by the Orthopaedics group, which would artificially inflate the error rate for this group – nonetheless Orthopaedics had the lowest error/complication rate.

A prior study of non-operative treatment of mallet fracture injuries found that skin complication rates are seven times as likely when prefabricated fiberglass are used instead of custom-made orthoses.⁹ While fiberglass is not inherently problematic, it does have the potential for complications when applied incorrectly. In this study 89% (32/36) of splints placed by an OSH were fiberglass, and a greater percentage of splints placed by an OSH were complicated by ulcers 17% (6/36) than those placed by the Trauma Hospital ED (12%) or Orthopaedics (3%) ($P = 0.021$).

The three study groups were divided based on the training and practice environment. The average age of patients enrolled in the study was 34 ± 22 years. The Orthopaedics cohort was older on average (39 ± 19) than either the Trauma Hospital ED (31 ± 25) or OSH (24 ± 18). This difference likely reflects the inclusion of post-operative patients in the Orthopaedics group, many of whom were elderly. Given the lack of any association between age and complication rate in our study, we felt that the age difference between cohorts was acceptable.

The differences in error and complication rates between ED physicians in our trauma hospital versus OSH may also be secondary to volume of experience versus physician and physician extender instruction by the orthopaedics service in our hospital.

Orthopaedic training programs often utilize surgical skills labs for teaching and practicing techniques and skills on simulators, models, and/or cadaveric specimens.¹⁴⁻¹⁶ In contrast to many other skills, splinting can be practiced on other trainees and instructors with no ill effects, need for special equipment, or a significant cost to the institution. Further, videos illustrating proper splint placement could be utilized to instruct practitioners at OSH as a review of the previously learned skill. The literature indicates that minor curriculum changes could have significant effects on splinting practice.^{17,18} For example, a recent study demonstrated that training paramedic students in a 3-hour course on a cadaveric model increased comfort and proficiency in application of traction splints for femoral shaft fractures.¹¹ In another study evaluating the effectiveness of instructional videos on improving physicians' procedural skills, pediatric residents were taught to place a volar splint in a small workshop setting and then evaluated on a 5-point scale 2-12 months later by a researcher either without (control) or with (intervention) a review of the technique by means of a 3-minute instructional video prior to performing the procedure. This study found that those who watched the video score 1.87 points higher than those who did not without any increase in the overall time needed to complete the procedure.¹⁷

The present study is best interpreted within the context of its strengths and limitations. All patients were enrolled and evaluated by a single researcher, helping to decrease inconsistency in assessment. Further, all data was collected in a single orthopaedic clinic staffed by a consistent group of attending surgeons, residents, nurses, orthopaedic technicians, and physician assistants who aided in identifying patients and limiting attrition bias. One limitation was the lack of standardization in patient education regarding appropriate splint care. Many patients were excluded from the study because they had removed and replaced the splint prior to evaluation, and it was impossible to tell in many cases if errors such as the bandage directly contacting the skin were secondary to improper technique or poor splint care, as splints were not evaluated at initial application. Another limitation to this study was a lack of control of the type of splinting material utilized. Pre-fabricated devices were used almost exclusively by outside hospitals, and may have negatively impacted measures of technique and patient follow-up as these are more easily removed, and ease of removal has been linked to poor follow-up.¹⁹ Lastly, while the

role of all providers in the Trauma Hospital ED and Orthopaedics groups is known, no information is available regarding the training of the providers in the Outside Hospital group, limiting the generalizability of the study.

In summary, this study found significant differences between splint quality when placed by the orthopaedics service, the emergency room staff in our trauma hospital, and outside hospital emergency room staff. The relatively high overall error and complication rates emphasize the importance of meticulous attention to splint quality, and the progressively increased rates in our trauma hospital emergency room versus outside hospital emergency rooms suggests potential benefit of outreach and education of emergency room staff on proper splinting technique.

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INCREASED MEDIAL DISPLACEMENT OF THE HUMERAL SHAFT OF AT LEAST 40% CORRELATES WITH AN INCREASED INCIDENCE OF NERVE INJURY IN PROXIMAL HUMERUS FRACTURES

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ABSTRACT

Background: Peripheral nerve and infraclavicular brachial plexus injury following proximal humerus fractures are commonplace, but diagnosing a concomitant nerve injury in the acute setting is challenging. Fracture displacement has been identified as a qualitative risk factor for nerve injury, and additional attention should be paid to the neurologic exams of patients with proximal humerus fractures with significant medial shaft displacement. However, a quantitative relationship between the risk of nerve injury and medialization of the humeral shaft has not been shown, and additional risk factors for this complication have not been assessed. The aim of this study was to identify the risk factors for a neurologic deficit following a proximal humerus fracture, with particular interest in the utility of the magnitude of medial shaft displacement as a predictor of neurologic dysfunction.

Methods: A retrospective chart review was performed on all proximal humerus fractures in a 3-year period (2012-2015) at a level one trauma center. Isolated greater tuberosity fractures (OTA 11-A1) were excluded. Fracture displacement was measured on initial injury AP shoulder radiograph and expressed as a percentage of humeral diaphyseal width. All orthopedic inpatient documentation was assessed to identify clinical neurologic deficits.

Results: We identified 139 patients for inclusion. There were 22 patients (16%) with new neurologic deficits at presentation (8 axillary nerve, 2 radial nerve, 12 infraclavicular brachial plexus or multiple nerve injuries). The average shaft medial displacement in patients with neurologic injuries was 59% vs. 21% without nerve deficits ($p=0.03$). Using a 40% medial displacement threshold, the

odds ratio for a nerve injury was 5.24 (95% CI 1.54 – 17.77, $p=.008$).

Conclusion: Increased medial displacement of the humeral shaft following proximal humerus fracture is associated with an increased incidence of nerve injury at the time of initial presentation. This finding is not meant to be a surrogate for a high-quality neurologic exam in all patients with proximal humerus fractures. However, improved knowledge of the specific risk factors for an occult neurologic injury will improve the clinician's ability to accurately diagnose and properly treat proximal humerus fractures and their sequelae.

Level of Evidence: III

Keywords: proximal humerus fracture, infraclavicular brachial plexus injury, axillary nerve injury, humeral shaft displacement

INTRODUCTION

Peripheral nerve and infraclavicular brachial plexus injury following proximal humerus fractures are commonplace.¹⁻⁹ Unfortunately, evidence of a concomitant nerve injury in the acute setting after a fracture is often not easily discernible. Pain often precludes accurate assessment of the motor and sensory function of the injured extremity, and subtle deficits may be missed. Concomitant nerve injury may prolong the recovery of the fractured extremity, and may have a negative effect on functional outcomes after fracture healing.⁴ Identified risk factors for nerve injury after a proximal humerus fracture include underlying cervical spine disease, low BMI, diabetes mellitus, increased time from injury to operation, and fracture displacement.^{4,10} Medial displacement of the humeral shaft has the potential to disrupt neurologic function secondary to direct injury or stretch.¹¹ However, no studies have quantified the risk of peripheral nerve or infraclavicular brachial plexus injury with increasing medialization of the humeral shaft.

The aim of the current study is to investigate the rate of neurologic injury in patients with proximal humerus fractures and medial shaft displacement. While prior studies have qualitatively suggested an increased frequency of nerve injuries with proximal humerus fracture displacement, to our knowledge no study has quantitatively evaluated this relationship. We hypothesized

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

Sources of Funding: No sources of funding declared.

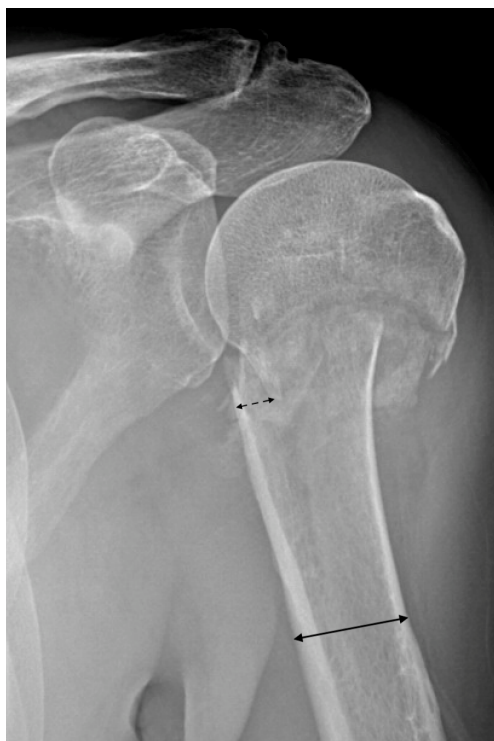


Figure 1: Humeral shaft displacement X-ray measurements. The dashed arrow represents fracture displacement. Medial or lateral fracture displacement was measured and expressed as a percentage of humeral diaphyseal width (solid arrow). Diaphyseal width was measured just proximal to the deltoid tuberosity.

that the incidence of peripheral nerve or infraclavicular brachial plexus injuries would increase with medial displacement of the humeral shaft fragment.

METHODS

We retrospectively identified patients who presented to a single academic level one trauma center with a proximal humerus fracture between 2012 and 2015. Patients were identified via a search of the electronic health record (EHR) for the term “proximal humerus fracture.” Patient factors were reviewed, and the injury was categorized according to the Orthopaedic Trauma Association (OTA) fracture classification. As the central aim of the study was to assess if shaft medialization is associated with neurologic injury, patients with isolated tuberosity fractures (OTA Class 11-A1) were excluded. Further, fracture-dislocations (OTA Class 11-C3) were excluded as these injuries are notorious for causing concomitant neurologic damage. Additionally, polytraumatized patients with concurrent fractures of the ipsilateral upper extremity were excluded to reduce the possibility of a confounding nerve injury from the other fracture.

The relative displacement of the shaft fragment from the anatomic position was calculated as demonstrated in Figure 1 on AP radiograph. Evidence of peripheral

Table 1. Demographics and Injury Characteristics of 139 Proximal Humerus Fractures

Parameter	Value
No. Fractures	139
Sex	
Male	43
Female	96
Age (Range)	67.2 (18-98)
Fracture Classification (OTA)	
11A (excluding 11-A1)	77
11B	50
11C (excluding 11-C3)	12
Nerve Injury	22
Axillary	8
Radial	2
Infraclavicular Brachial Plexus +/- Peripheral Nerve Injury	12

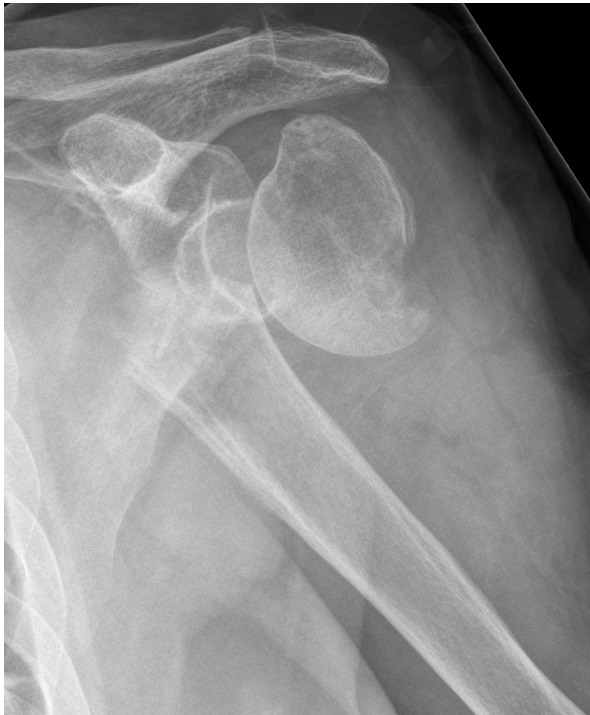
nerve injury or infraclavicular brachial plexus injury was recorded from retrospective chart review. Any clinical neurologic deficit noted on orthopedic examination was recorded and categorized by the distribution of the affected nerve.

Statistical analysis was completed using Prism version 8.3 (GraphPad, LaJolla CA). Measurements were made by orthopaedic surgery residents (PLM and MSF). Continuous variables were compared using an unpaired Student’s t-test. Categorical variables were compared using Fisher’s Exact Test. P-values < .05 were considered significant. Data is presented as mean ± standard deviation.

RESULTS

One hundred thirty-nine patients were identified for inclusion (43 male, 96 female). Results are summarized in Table 1. The patient age ranged from 18-98 years (mean 67.2 ± 17.6). Of the 139 fractures, 37 were non-displaced and 102 were displaced at the head-neck junction. Of the displaced fractures, the humeral shaft was displaced laterally in 30 cases, and medially in 72.

New neurologic deficits in the affected extremity were observed in 22 patients (16%). The most frequent isolated nerve injuries were the axillary nerve (n=8) and the radial nerve (n=2). Of those patients with nerve injuries, 3 (3/22, 14%) occurred in fractures with a laterally displaced humeral shaft. The remaining 19 (19/22, 86%) nerve injuries occurred in fractures with a medially displaced humeral shaft. In patients with a nerve injury, the average degree of shaft displacement was 59% medially, versus 21% medial displacement for the entire cohort. (p = 0.03). Figure 2 shows a representative case of a patient presenting with a widely displaced proximal humerus fracture resulting in an infraclavicular brachial plexus injury.



A 73-year-old female presented after a ground level fall with a widely displaced proximal humerus fracture with shaft medialization (measured as 194% medialization according to the method presented in Figure 1). She was diagnosed with an infra-clavicular brachial plexus injury on clinical examination.

Using the method described in Figure 1, the overall average displacement of the humeral shaft was 21% medial. For the 72 medially displaced fractures, the average displacement was 39.6%. For simplicity, we rounded this value to 40% to establish a proposed “displacement threshold”. We then compared those fractures that were displaced more than 40% medially to those that were not (including those displaced less than 40% medially, non-displaced, or laterally displaced). In the greater than 40% medially displaced group, the odds ratio for nerve injury was 5.24 (95% CI 1.54-17.77, $p=0.008$).

DISCUSSION

The current study was designed to determine whether medial shaft displacement was an independent risk factor for peripheral nerve and/or infraclavicular brachial plexus injury after a proximal humeral fracture. The authors found evidence that nerve injury is in fact related to the degree of medial displacement of the humeral shaft. Of the 22 nerve injuries identified, the humeral shaft was displaced medially in 19 (86%). Further, the degree of displacement was found to be significantly greater in patients with a nerve injury compared to those without. After setting a threshold of $\geq 40\%$ to define significant displacement, displaced fractures had an increased risk of nerve injury when compared to non-displaced fractures.

Proximal humerus fractures are very common, and the incidence of these fractures continues to rise.^{12,13} However, few studies have investigated risk factors associated with neurologic injury following a proximal humerus fracture. Visser et al.⁴ found that the risk of nerve lesions was four times higher in patients with displaced proximal humerus fractures (Neer II, III, and IV) when compared to those with nondisplaced (Neer I) fractures. The authors suggest that fracture displacement is a considerable risk factor for nerve injury, but fail to examine if varying degrees of displacement result in different rates of nerve injury. Other authors have commented on intraoperative findings of nerve compression or impalement by the proximal aspect of the humeral shaft during fixation of proximal humerus fractures,^{5,14} providing further evidence that medial displacement of the humeral shaft can directly damage proximal peripheral nerves and/or the brachial plexus. Again, no quantitative measures were proposed to identify “at risk” patients. In their study of 37 patients, Warrender et al.¹⁰ identified risk factors for intraoperative nerve alerts, which they defined as sustained neurotonic activity on electromyography or a greater than 50% decrease in the amplitude of transcranial electrical motor evoked potential, during the fixation of proximal humerus fractures. These included a history of underlying cervical spine disease, low BMI, diabetes mellitus, and an increased delay from injury to operation. The authors also compared rates of nerve alerts with fracture classification,¹⁵ but were unable to find any significant association.

The current study attempts to assist clinicians in accurately predicting the risk of peripheral nerve or infraclavicular brachial plexus injury using readily obtainable radiographic parameters. Our threshold for shaft displacement may be indicative of direct damage or traction injury by the humeral shaft, suggesting that surgical intervention to relieve the pressure on these nerves may be beneficial.⁵ By developing concrete measurements based on quantitative evidence we hope to guide clinicians in estimating the risk of occult neurologic injury, thereby guiding the ultimate treatment plan and predicting outcomes. The findings of this work do not seek to replace physician judgement or relieve concern for neurologic deficit in the setting of a proximal humerus fracture. However, we do hope that fractures with radiographic displacement $\geq 40\%$ medially may give clinicians pause and motivate more detailed and frequent neurologic examinations.

Limitations of this study include its retrospective nature, which is dependent upon analyzing entries in the electronic health record. The authors must rely on accurate documentation to calculate the incidence of nerve injury. Nerve injuries presumably could have been

missed, over-diagnosed, or simply omitted from clinical documentation. Further, electrophysiologic studies were not consistently collected for these patients except in cases of overt neurologic deficit, leading to a reliance on clinical examination alone to identify mild cases. Lastly, a prospective validation of our proposed threshold is necessary prior to any recommendation for broad clinical use. Measurements were made on radiographs and these parameters may be influenced by patient positioning or general quality of these studies.

The strengths of this study include the development of a simple, yet reproducible radiographic, measurement to provide clinicians with a tool to predict the risk of nerve injury following proximal humeral fracture. This study is the first of its kind to provide quantitative evidence that medial displacement of the humeral shaft in proximal humerus fractures increases risk of nerve injury. With greater than 40% medial displacement of the humeral shaft, one's risk of neurologic injury increases over five times that of one sustaining a less-displaced fracture. With the knowledge that medial shaft displacement has greater association with injury to peripheral nervous structures, we hope to provide clinicians with another tool to best guide treatment and determine prognosis of these common injuries.

CONCLUSION

The results of this study demonstrate a significant relationship between medial displacement of the humeral shaft and infraclavicular brachial plexus and/or peripheral nerve injury following a proximal humerus fracture. These results highlight the importance of careful neurovascular examination at the time of presentation, particularly in patients with medially displaced fractures. Improved knowledge of specific risk factors for occult neurologic injury in these cases will improve the clinician's ability to accurately diagnose and properly treat these fractures.

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IN SITU STRAIGHTENING OF A BENT TIBIOFEMORAL INTRAMEDULLARY NAIL: CASE REPORT AND REVIEW OF THE LITERATURE

Alan Shamrock, MD¹; Steven Leary, BS¹; James Kohler, MD¹; Matthew Karam, MD¹; Christopher Carender, MD¹; David DeMik, MD¹, PharmD; James Nepola, MD¹

ABSTRACT

Background: Intramedullary nailing is considered the gold standard for the surgical management of diaphyseal long bone fractures of the lower extremity. A rare complication following intramedullary nailing of a femur or tibia fracture is peri-prosthetic fracture following secondary trauma with deformation of the nail itself. We present a case of a 51-year-old male with a long history of prior left knee arthrodesis with a tibiofemoral nail who sustained a work injury resulting in a proximal tibia fracture and bent tibiofemoral nail. Clinically, he presented with significant varus and procurvatum limb deformity and a six-centimeter limb length discrepancy. The patient was successfully managed with in situ straightening of the tibiofemoral nail under a general anesthetic with return to work three months following manipulation.

Level of Evidence: IV

Keywords: tibiofemoral nail, bent, deformation, limb deformity, in situ straightening

INTRODUCTION

Intramedullary nailing is considered the gold standard for the management of diaphyseal long bone fractures of the lower extremity given its high union rates and low risk of complication.^{1,2} Rarely, secondary trauma to the same extremity with a retained intramedullary nail may lead to refracture with bending of the nail. The existing literature on this complication primarily consists of case reports describing techniques to extract and exchange the bent femoral or tibial nail such as partial or complete nail sectioning at the level of refracture or at the point of nail insertion.³⁻¹⁰ Of these reports, few describe in situ bending to correct the deformity prior to extraction^{4,8,9} and none either describe the management of a bent tibiofemoral nail or closed manipulation of a bent

intramedullary nail without exchange nailing. Here, we describe the case of a 51-year-old male who presented with a bent long tibiofemoral nail following secondary trauma treated definitively with manipulation under anesthesia and in situ bending 33 years following the index procedure.

CLINICAL CASE SUMMARY

A healthy 51-year-old male presented to our clinic for evaluation of left lower extremity deformity and knee pain following a work injury. Notably, in 1985, the patient was involved in a motorcycle accident resulting in a left lower extremity injury that was treated with knee arthrodesis with a long tibiofemoral nail. The exact nature of this injury and initial radiographs were, unfortunately, not available for our review. Postoperatively, the patient states he recovered well from this injury and returned to work without restriction performing manual labor at an iron factory. He had essentially no functional limitations for several decades following the initial injury.

In July 2018, the patient was at work when he fell approximately 5 feet from an embankment onto his left lower extremity. He noted immediate onset of lateral knee pain and significant deformity of the extremity. He was unable to bear weight following the injury.

Clinically, the patient was noted to have a six-centimeter leg length discrepancy, left shorter than right. He had an obvious varus and procurvatum deformity at the knee and was unable to ambulate secondary to pain as well as the leg length discrepancy. Otherwise, the patient was found to be neurologically intact. Radiographic evaluation demonstrated an acute fracture line involving the lateral aspect of the proximal tibia and a bent tibiofemoral intramedullary nail with 21° varus deformity in the coronal plain and 26° procurvatum deformity in the sagittal plane (Figures 1-3).

Following a long discussion with the patient regarding treatment options, the decision was made to proceed with manipulation of the extremity to straighten the intramedullary nail and correct the deformity under a general anesthetic. If unsuccessful, the nail would then be removed through an open approach with revision intramedullary nailing of the lower extremity. Open hardware removal would involve cutting the nail at the level of the knee to facilitate removal.

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

Sources of Funding: No sources of funding declared.

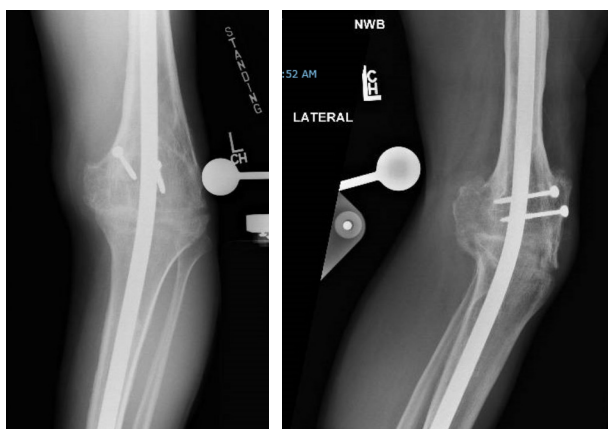


Figure 1. Standing anteroposterior (AP) and lateral radiographs of the left knee demonstrating the periprosthetic proximal tibia fracture through prior fusion mass.

Under general anesthesia, the patient was placed supine on a Cappello board. Posts were placed lateral to the knee and immediately proximal to create a fulcrum during manipulation. With significant effort, the nail the successfully bent in situ and the extremity straightened. This was confirmed with intraoperative fluoroscopy. Clinically, the patient's leg length discrepancy had decreased to only one centimeter and the alignment was improved in both the sagittal and coronal planes (Figure 4). Given the maintained integrity of the nail and improved alignment, the decision was made to not revise the hardware. Postoperatively, the patient was permitted to be weightbearing as tolerated and discharged home uneventfully the following day.

At successive follow-up visits, the patient reported sustained improvement in both pain and alignment of his left lower extremity. He was cleared to return to work three months after manipulation of the extremity and subsequently released to perform full activities as tolerated.

DISCUSSION

The bending of an intramedullary nail due to secondary trauma represents a difficult complication to manage given the challenging nature of nail removal and revision fixation.¹¹ The most common clinical presentation in the literature consists of a young male with an apex anterior and varus bent intramedullary nail following secondary high-energy trauma. The first report of a bent intramedullary nail was by Bielejeski and Garrick in 1970.¹² In their report, a deformed 12-millimeter stainless steel intramedullary femoral nail was sectioned in half with a dental drill and extracted through the fracture site. Additionally, Patterson and Ramser first described using a perineal post a fulcrum to straighten a bent femoral nail prior to removal.¹³

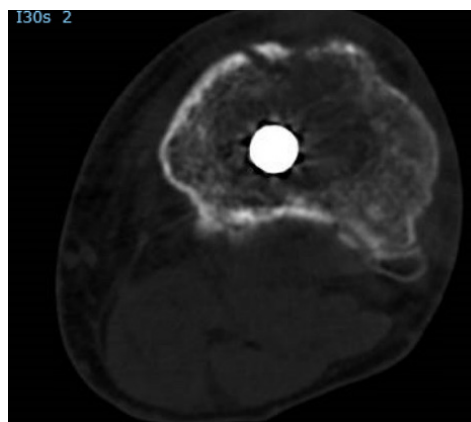


Figure 2. Axial computed tomography (CT) sequence at the level of the proximal tibia fracture.

Much of the prior literature has described various surgical techniques to extract the bent intramedullary nail including different methods to straighten the nail in situ prior to removal. Shen et al. facilitated removal by first straightening the nail with a dynamic compression plate and two bone-holding forceps.⁸ Banerjee et al. progressively sectioned the anterior aspect of a deformed nail before straightening the affected leg against a perineal post acting as a fulcrum and subsequently removing the nail.⁴ The report by Banerjee was similar to the presented case, however, the current case was definitely managed with hardware retention given the maintained integrity of the nail and minor nature of the proximal tibia fracture. Suh et al. also described two bent intramedullary

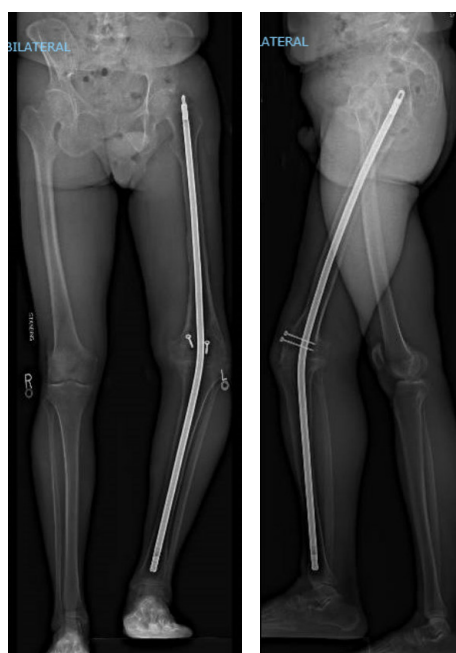


Figure 3: Standing anteroposterior (AP) and lateral long leg radiographs demonstrating the bent tibiofemoral intramedullary nail. Note the leg length discrepancy.

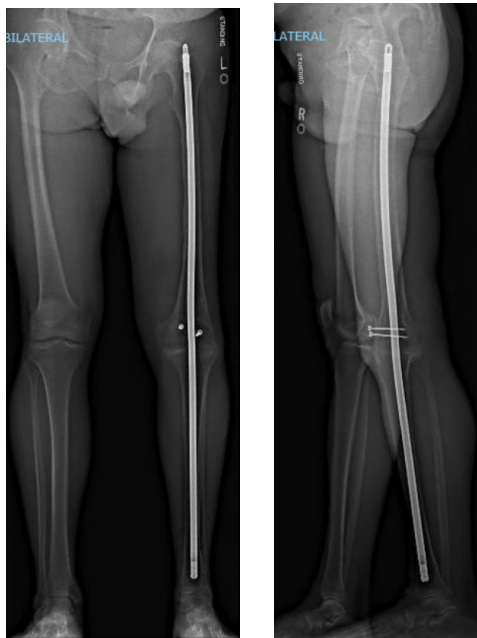


Figure 4: Post-manipulation standing anteroposterior (AP) and lateral long leg radiographs demonstrating interval straightening of the tibiofemoral intramedullary nail and correction of coronal and sagittal plane deformity.

nail cases treated with attempted closed manipulation.⁹ One case still required removal of the femoral nail after successful straightening due to compromised integrity with revision intramedullary nailing, while the other was not successfully straightened in situ and required open sectioning of the nail with a burr to fully correct the deformity.

The characteristics of the intramedullary nail itself plays an important role in determining whether or not in situ bending alone will successfully correct the deformity. Bong et al. recently reviewed the biomechanics of intramedullary nails and discussed four properties which affect a nail's bending resistance. First, its inherent resistance to bending is directly proportional to the diameter of the nail to the third power. Second, the metal composition of the nail affects its bending resistance. The two most common metals used for intramedullary nails, titanium alloy and stainless steel, have similar strengths but differ in their respective elastic modulus. Stainless steel nails have an elastic modulus two times greater than that of titanium alloy and are, therefore, more rigid with an increased resistance to deformation forces. Lastly, the authors noted that the cross-sectional shape of the nail affects both torsional rigidity and medullary canal contact which allows transmission of forces to the bone and greater construct stability.

While the above properties can be used to guide decision making regarding the management of bent intramedullary nails, further consideration should be paid

to the tibiofemoral joint during closed manipulation of a bent tibial or femoral nail. Considerable force is often required to correct angular deformity and the knee can be subject to these forces leading to bony or ligamentous injury if not carefully protected. The current case was felt to be particularly amenable to closed manipulation as the long tibiofemoral nail was originally placed for the purpose of knee arthrodesis. This not only created a natural fulcrum point for straightening, but it also permitted a greater force to be applied without increasing the risk for iatrogenic fracture or ligamentous injury.

Though a rare complication, angulated femoral and tibial nails have been documented in multiple case reports, however a bent long tibiofemoral intramedullary nail has yet to be reported. Here, we present the case of a 51-year-old male who presented with a bent long tibiofemoral nail following secondary trauma treated definitively with manipulation under anesthesia and in situ bending 33 years following the index procedure. Notable benefits of closed manipulation include reduced morbidity with the avoidance of a surgical incision and potential for immediate weight-bearing with prompt return to activities as tolerated.

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THE RURALITY OF UPPER EXTREMITY FIREARM INJURIES

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ABSTRACT

Background: To highlight the unique spectrum of hand and upper extremity firearm injuries seen at a rural, Midwestern level 1 trauma center and identify modifiable factors that contribute to firearm injuries of the hand and upper extremity.

Methods: A retrospective review of upper extremity firearm injuries from a rural, Midwestern level 1 trauma center was collected from January 2002 to December 2019. Data acquired included injury description, demographics, injury mechanism/description/location, firearm used, toxicology, and information regarding hospitalization. Data was analyzed using Chi-squared analysis and Fisher's exact test for categorical data and the Wilcoxon rank sum test for continuous data.

Results: 55 patients with upper extremity firearm injuries were identified. Average age was 33.3 ± 13.0 years, 81.8% were males, and zero fatalities were identified. 58% (38) of these injuries were unintentional firearm injuries, followed by assaults at 34.6% (19). Law enforcement-related and self-inflicted injuries contributed minimally. Handguns were the most common type of firearm, used in 43.6% of cases. 7.3% (4) of injuries occurred while hunting, with 21.8% (12) total during November or December, the active deer hunting months. 92.7% (51) of all firearm injuries presented with fracture, among which 92.2% (47) met a Gustilo-Anderson classification score of at least 3A. Alcohol was detected in 20% (11) of the patients, while other drugs of abuse were detected in 36.4% (20).

Conclusion: Our data suggests that upper extremity firearm injuries in a rural population are unique from urban injuries in that they are predominantly unintentional, isolated, and non-fatal. We identify a distinct rural cohort that may benefit

from better directed interventions to prevent firearm injuries and ultimately guide firearm education and public policy.

Level of Evidence: III

Keywords: firearm, rural, trauma, unintentional, upper-extremity

INTRODUCTION

In 2016, the American College of Surgeons (ACS) issued a consensus statement recommending addressing firearm injury prevention as both a trauma system and public health problem.¹ Hand surgeons have an important role to play in reducing the burden of unintentional firearm injuries through treatment, prevention, and patient education. The foundational components and long-term consequences of unintentional firearm injuries are often not recognized from a public policy perspective, however upper extremity surgeons can provide a valuable perspective when assessing these issues. Surgeons, working closely with public health officials, can advance informed, targeted interventions, ultimately having greatest impact on society.

Firearm injuries have taken center stage in political debates, the media, and in households across the United States. However, these discussions regularly focus on violent crimes or related to law enforcement, and often fail to recognize unintentional injuries commonly seen in rural communities. Correspondingly, much of the epidemiological research on firearms follow the same pattern. Although one may expect firearm death rates in urban areas to dwarf those of rural areas, multiple studies demonstrate that population-adjusted mortality rates are nearly equivalent in both urban and rural settings.^{2,3} This finding is not limited to the adult population; similar trends are also seen within the pediatric population.⁴

The purpose of this study was to assess hand and upper extremity firearms injuries presenting to a rural, Midwestern level 1 trauma center. We aim to provide insight into prevalence, mechanism of injury, outcome expectations, and to identify modifiable factors that contribute to firearm injuries of the hand and upper extremity in the rural setting.

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

Sources of Funding: No sources of funding declared.

Table 1. Subgroup Analysis Demographics

	Unintentional	Assault	OR 95% CI	P-value
Sex	N=32 (58.2%)	N=19 (34.6%)		
Male	27 (84.4%)	15 (79.0%)		p= 0.7114
Female	5 (15.6%)	4 (21.1%)		
Race				p= 0.0106
Caucasian	27 (84.4%)	9 (47.4%)	OR=13.50 95CI(2.45-74.48)	
African American	2 (6.3%)	9 (47.4%)	Ref	
Other	3 (9.4%)	1 (5.3%)		
Firearm Type				p=0.0085
Handgun	18 (56.3%)	4 (21.1%)	OR=10.50 95%CI (2.48 -44.55)	
Shotgun	5 (15.6%)	1 (5.7%)	OR=11.67 95% CI (1.11 122.38)	
Rifle	3 (9.4%)	-		
Other	6 (18.8%)	14 (73.7%)	Ref	
Extent of Injury				p=0.0099
Isolated Injury	31 (96.9%)	12 (63.2%)	OR=18.08 95%CI (2.01- 162.88)	
Non-Isolated injury	1 (3.1%)	7 (36.8)	Ref	
Gustilo-Anderson Classification				
1	1 (3.1%)	-		p=0.4606
2	2 (6.3%)	-		
3A	24 (75.0%)	14 (73.7%)		
3B	3 (9.4%)	1 (5.3%)		
3C	2 (6.3%)	4 (21.1%)		
ED GSC	2 (6.3%)	8 (42.1%)	Odds Ratio 10.901 95%CI(2.00 59.51))	p=0.0032
Toxicology				
Alcohol	3 (9.4%)	7 (36.8%)	Odds Ratio 5.64 95%CI (1.25-25.54)	p=0.0278
Illicit Drugs	4 (12.5%)	13 (68.4%)	Odds Ratio 15.17 95%CI(3.64 63.12))	p=0.0001

METHODS

After Institutional Review Board approval, retrospective data was collected through electronic medical record review from a rural, Midwestern tertiary care institution. The study population included patients who sustained upper extremity firearm injuries from January 2002 through December 2019. All patients with firearm injuries were identified via a search of this hospital’s trauma registry and then filtered using the International Classification of Disease, (ICD) ninth and tenth revision (ICD-9,10) diagnosis codes to isolate firearm-related injuries to the hand and upper extremity only, defined as including the shoulder girdle and distal. Exclusion criteria included military members and incarcerated patients.

Patient demographics, including race, age, sex, and date of birth, and date of injury were obtained. Descriptive information pertaining to the injury included mechanism of injury, type of firearm used, associations to seasonal hunting, toxicology, and injury anatomical location. The firearm injuries were classified as either isolated, in which case the patient presented with a single lesion, or non-isolated, presentation with multiple lesions. The Gustilo-Anderson (GA) classification system was utilized in classifying cases associated with fractures. Treatment details including date of admission, discharge, and first

operation, as well as length of stay, injury to operation time, total number of surgeries, non-unions and reoperations were identified. Re-operation was considered if any subsequent operation was performed within 6 months from discharge of initial hospital presentation.

Our total cohort consisted of 55 patients, 32 of which were unintentional injuries and 19 assaults. The remaining four cases were attributable to other mechanisms such as law enforcement related or self-inflicted, and were not included in the statistical analysis. Chi-squared analysis and Fisher’s exact test were used for categorical data, while continuous data was assessed via the Wilcoxon rank sum test. All statistical analysis were conducted by software SAS 9.4 (Cary, NC, USA), and statistical significant level was set at $p < 0.05$.

RESULTS

Demographics

55 patients were identified with upper extremity firearm injuries from January 2002 through December 2019, none of which resulted in fatality. 81.8% (45) of the injuries occurred in male patients. Ages ranged from 3 to 73 years with a mean of 33.3 ± 13.00 years. 70.9% (39) of patients were Caucasian, 21.8% (12) were African-American, and 7.3% (4) were other (Table 1).

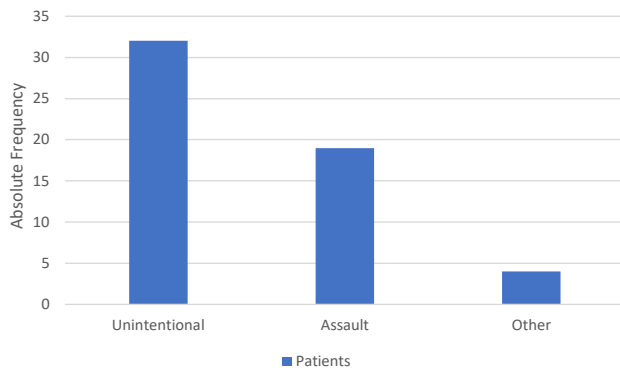


Figure 1: Mechanism of Injury (55 patients)

Caucasian individuals accounted for 84.4% (27) of the unintentional firearm injuries, while African Americans and other contributed 6.3% (2) and 9.4% (3), respectively.

Mechanism of Injury

The mechanism of injury was unintentional in 58.2% (32) of the cases, assault in 34.6% (19), and Other in 7.3% (4) of cases (Figure 1). Males accounted for 85.4% (27) of the unintentional firearm injuries. Alcohol involvement was 5.64 times as likely in assault cases versus unintentional cases. Assaults were 15.16 times more likely to involve illicit drugs than unintentional injuries (Table I).

Of the cases in which the firearm was identified, handguns were the most common type, contributing to 40% of cases (22). Shotguns contributed to 10.9% (6) of injuries, and rifles in 7.3% (4) (Figure 2). Handguns were the cause of injury in 56.3% (18) of unintentional cases. 73.7% (14) of assault cases lacked identification of firearm type (Table 1).

85.5% (47) of all presentations were isolated injuries. 96.9% of the unintentional firearm injuries were isolated (Table 1). When compared to assaults, unintentional injuries were 18.08 times more likely to result in an isolated injury. Correspondingly, assault injuries were 10.91 times as likely to get a GCS applied upon presentation (Table 1).

Of the 51 cases that presented with fracture, 92.2% met GA classification score of at least 3A (Table 1). Nonunion of the fractured bones was more frequently seen in cases of assault (16.7%) than cases unintentional injury (6.9%). This finding directly correlated with the GA classification based on mechanism on injury, with the average GA classification of assault cases being of higher grade than that of unintentional firearm injuries. Re-operations were performed in 56.4% (31) of cases. There were similar rates of re-operation among the assault and unintentional subgroups, 52.6% and 65.6% respectively, with frequent indications being irrigation & debridement and open-reduction internal fixation (Table 1).

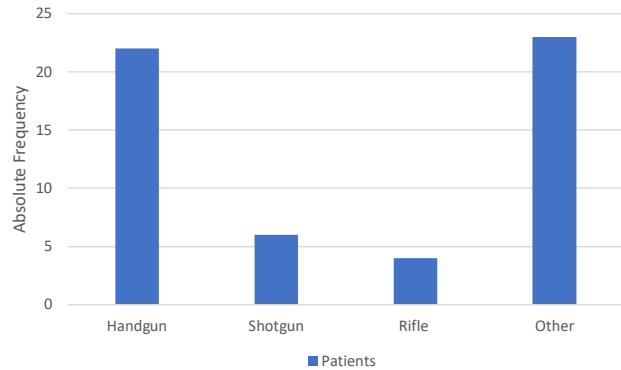


Figure 2: Firearm Type (55 patients)

Seasonal Associations

Of the 55 total presentations, 4 (7.3%) of them were documented as hunting accidents, all of which occurred as unintentional firearm injuries among Caucasian men. Of these confirmed hunting incidents, 2 (50%) of them were due to rifles. It may be that additional cases were hunting-related with inadequate documentation, thus additional correlations to hunting season were pursued. 12 (21.8%) of the total 55 firearm injuries occurred in months of November and December, the active deer hunting months in the community of study (Figure 3). This association to hunting season becomes more powerful when focusing only on unintentional injuries, where 25% took place during November or December, 50% of which were due to handguns.

DISCUSSION

Our findings demonstrate that upper extremity firearm injuries in a rural, Midwestern cohort are most frequently unintentional, isolated, non-fatal injuries occurring to Caucasian men. With the goal of prevention in mind, the unintentional mechanism should receive more attention than currently devoted when defining

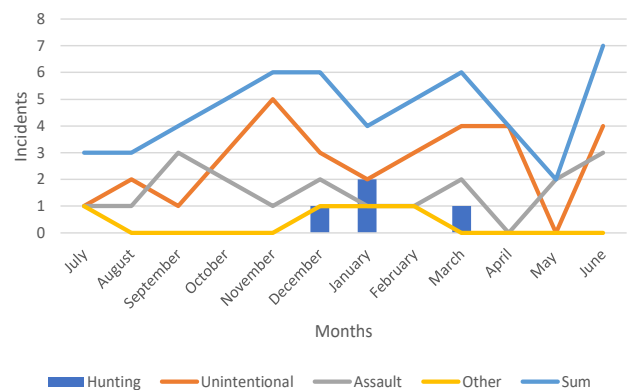


Figure 3. Upper Extremity Firearm Injuries by Month

gun policies and safety precautions. In support of this notion, a previous report from 2012 found that rates of unintentional firearm death in the United States generally increased with increasing rurality, quantified as 2.16 times higher after adjusted for confounders, in most rural counties when compared with most urban counties.⁵ Miller et al. further supported this data, proving there to be a positive correlation between unintentional firearm mortality and the percentage of a states' population that resided in rural counties.⁶

Though the previously referenced studies do highlight the discrepancies of unintentional firearm injuries based on rurality-urbanicity, they represent at large all firearm injuries, irrespective of anatomy, with emphasis on mortalities.^{5,6} The aim of our study was to more directly focus on an underrepresented population, being that of firearm injuries affecting the upper extremity sustained in a rural setting, irrespective of mortality. Although our study consisted of no fatalities of any mechanism, Guetschow et al. reported that unintentional firearm injuries had the smallest fatality rate among all mechanisms that they studied.⁷ Extrapolating from their results, in conjunction with our results, one can anticipate that a large portion of the frequently seen unintentional firearm injuries from a rural setting will be non-fatal.

Upper extremity injuries represent a substantial portion of overall firearm injuries, with estimations as high as 30% of firearm injuries involving the upper extremities.^{8,9} Furthermore, upper extremity firearm injuries present a unique challenge as they are often combined injuries, classified as having more than one tissue type involved, e.g., bones, tendons, nerves, and/or blood vessels.¹⁰ Several studies have demonstrated that nearly 50% of upper extremity firearm injuries are combined injuries.^{11,12,13} Provided this information, we see value in analyzing rural firearm injuries by anatomy to add depth to our understanding of these injuries and how to most effectively prevent/treat them.

While fatality is unlikely among this cohort, fractures certainly are not. With 90.6% of our fracture cohort meeting GA classification of at least 3A, complicated operations oftentimes requiring bridge-plating or bone-grafting can be anticipated.¹⁴ Upper extremity firearm wounds in rural environments may be further complicated by limited access to a team of highly experienced hand surgeons, oftentimes having to transfer a patient to the nearest trauma center fitted for this type of injury, which can be many miles away. This experience and raw number of cases provides means to begin strengthening our understanding/documentation of firearm injuries.

Guetschow et al. correlated a temporal association of rural firearm injuries with seasonality, finding that rates of firearm injuries in their rural setting increased in the

winter months of deer hunting season, most frequently attributable to use of shotguns.⁷ Of note, long guns of high caliber, such as shotguns, are frequently used when hunting large animals including deer. Although our data did not statistically support a temporal association to hunting season, it begins to show early trends of similar patterns, though more frequently involving handguns rather than shotguns. While sample size may, in part, explain the difference in firearm type observed between the two studies, we also hypothesize that focusing only on upper extremity firearm wounds may have excluded many long gun injuries to the lower extremity from our sample. Handguns are easily maneuvered within the confines of our hands, which may increase the likelihood of an upper extremity injury due to handguns as opposed to longer guns. Additionally, the fluctuating seasons of our Midwestern state offer cold winters, an optimal time to clean/maintain firearms which may also contribute to the seasonality of firearm injuries.

Limitations of our study include a relatively small sample size, in part due to the isolated focus on upper extremity, but also due to lack of identification of every firearm injury in the state. Further limitations include a retrospective study design with non-standardized data collection from a single center. Furthermore, upon extensive chart review, we were unable to identify the firearm type in 23 of the 55 cases. While this is an acceptable reality in assault cases, we hypothesize that failure of providers to inquire about firearm type also contributed, which highlights an additional area of improvement.

CONCLUSION

Firearm injuries in rural settings are primarily unintentional as compared to interpersonal violence seen in more urban environments. When focusing on the upper extremity, firearm injuries most commonly occur among males sustaining unintentional, isolated, and non-fatal wounds. From the perspective of a level I trauma center serving a predominately rural state, a need for improving data collection of rural-based injuries exists. Further study must be done to assist with guiding public policy specific to rural communities. Rural and urban environments face different risk factors, and ubiquitous policy is likely not the most effective way to reduce firearm injuries.

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SAFETY AND EFFICACY OF FOREARM TOURNIQUET COMPARED TO UPPER ARM TOURNIQUET FOR LOCAL INTRAVENOUS REGIONAL ANESTHESIA IN HAND SURGERY: A RANDOMIZED CLINICAL TRIAL

Alexander J. Volkmar, MD¹; Molly A. Day, MD¹; Ignacio Garcia Fleury, MD¹; Ericka A. Lawler, MD¹; Melinda Seering, MD²; Lindsey S. Caldwell, MD¹

ABSTRACT

Background: Forearm tourniquets may offer decreased doses of anesthetic, shorter procedure times, and less pain compared to upper arm tourniquets. There is limited data comparing the clinical efficacy of forearm Bier blocks to conventional upper arm Bier blocks. The purpose of this study was to assess the effectiveness, complications, duration, cost, and patient satisfaction between forearm and upper arm Bier blocks during surgery.

Methods: Sixty-six carpal tunnel release, ganglion excision, or trigger finger procedures were performed. Patients were randomized to 3 groups: upper arm tourniquet for 25 minutes, forearm tourniquet for 25 minutes, or forearm tourniquet with immediate deflation following the procedure (<25 minutes). The efficacy of surgical anesthesia, tourniquet discomfort, and supplementary local anesthetic administration were recorded. Pain was assessed intraoperatively and postoperatively. Patient satisfaction was assessed on the first post-operative day.

Results: No difference was observed between groups with respect to pain, satisfaction, or administration of supplemental medication. The tourniquet time for the group with immediate deflation following procedure was shorter by an average of 9.3 minutes. Total hospital charges were 9.95% cheaper with immediate tourniquet deflation compared to procedures where the tourniquet remained inflated for at least 25 minutes.

Conclusion: The forearm Bier block is a safe, efficient, cost-effective technique for intravenous regional anesthesia during hand surgery, and tourniquet deflation immediately following the procedure (<25 minutes) does not increase incidence

of complications. The forearm tourniquet reduces the dose of local anesthetic and therefore risk for systemic toxicity, with similar effectiveness as compared to the upper arm technique.

Level of Evidence: II

Keywords: carpal tunnel, anesthesia, bier block

INTRODUCTION

Intravenous regional anesthesia (IVRA), otherwise known as a “Bier block”, is a well-known anesthetic technique introduced by Karl August Bier in 1908.¹ A Bier block involves exsanguination of an upper extremity and inflation of a tourniquet, followed by intravenous injection of anesthetic agent distal to the tourniquet. Traditionally, a dose of 50 mL of 0.5% lidocaine is infused intravenously.^{2,3} Analgesia is achieved by direct diffusion of the anesthetic locally in the operative extremity with a tourniquet to block systemic circulation.

Local anesthetic systemic toxicity remains one of the most feared complications of Bier blocks. The risk of local anesthetic systemic toxicity includes seizures, cardiac arrhythmias⁴ or even rarely death.⁵ To minimize the risk of toxicity, by convention a double-cuff tourniquet has been used and remains inflated for a minimum of 30 minutes.^{6,8} Prolonged tourniquet inflation time can also result in significant discomfort for the patient and extend surgical procedures that are otherwise shorter than 30 minutes. More recently, newer techniques of smaller-dose forearm Bier blocks have been introduced to minimize risks.⁹

The forearm tourniquet may offer advantages over the conventional upper arm tourniquet, including decreasing the risk of lidocaine toxicity by using a smaller dose of lidocaine (thereby enhancing the safety margin for the patient), decreasing the tourniquet time, shortening surgical procedures, and minimizing patient discomfort intraoperatively. Forearm Bier block has been described and demonstrated to be an effective method of anesthesia in literature with a success rate of 93-96%.¹⁰⁻¹² Although previous research has not demonstrated an increased complication rate with a shorter tourniquet duration,⁷ no clear guidelines exist as to a minimum “safe” tourniquet time for Bier blocks.

The purpose of this study was to assess the effectiveness, complications, duration, cost, and patient satisfac-

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

Sources of Funding: No sources of funding declared.

Table 1. Study Design Characteristics

Study Group	Cuff Placement	Lidocaine Dose	Inflation Time
Group 1	Upper arm	50 mL (0.5%)	25 minutes
Group 2	Forearm	25 mL (0.5%)	25 minutes
Group 3	Forearm	25 mL (0.5%)	Immediate deflation

All patients premedicated with 2 mg of midazolam and 50 mg of fentanyl

tion between forearm and upper arm Bier block during hand surgery. To our knowledge, there is little prior data comparing the efficacy, costs, and complications of a low-dose forearm Bier block technique with a standardized, shorter tourniquet time to the conventional upper arm Bier block.

METHODS

After obtaining institutional review board approval, we performed a randomized controlled study from adult patients undergoing hand surgical procedures at our institution. Patients over the age of 18 undergoing carpal tunnel release, ganglion excision, or trigger finger release were consented and enrolled in the study. Exclusion criteria included: patients with a contraindication to tourniquet use on the operative extremity (i.e. AV fistula), patients unable to cooperate with a visual analogue score, and patients with contraindications to Bier block (e.g. Raynaud’s phenomenon, homozygous sickle cell disease).

Patients were randomized to one of three study groups through computer-generated group randomization prior to the procedure (Table 1). All 3 study groups involved inflation of a pneumatic tourniquet inflated to 125 mmHg above systolic blood pressure, with a maximum of 300 mmHg. Group 1 used a double cuff tourniquet with only one cuff inflated at any given time, and groups 2 and 3 used a single cuff tourniquet. Patients assigned to group 1 had the cuff placed proximal to the elbow joint, with a minimum inflation time of 25 minutes. Patients randomized to group 2 had the cuff placed distal to the elbow joint, with a minimum inflation time of 25 minutes. Patients randomized to group 3 had the cuff placed distal to the elbow joint, with immediate deflation following completion of the procedure regardless of tourniquet time. The protocol for the upper arm technique (group 1) was intravenous injection of 50 mL of 0.5% lidocaine, and for the lower arm technique (groups 2 and 3) 25 mL 0.5% lidocaine was injected. For all groups, patients were premedicated with up to 2 mg of midazolam and 50 mcg of fentanyl.

During the procedure, the anesthesia provider monitored and recorded any adverse events including abnormalities in the EKG, systolic blood pressure fluctuations,

Table 2. The Iowa Satisfaction with Anesthesia Scale (Dexter, et al.)

Statements	Response choices
I threw up or felt like throwing up	-3 = Disagree very much
I would want to have the same anesthetic again	-2 = Disagree moderately
I itched	-1 = Disagree slightly
I felt relaxed	
I felt pain	1 = Agree slightly
I felt safe	
I was too cold or hot	2 = Agree moderately
I was satisfied with my anesthetic care	3 = Agree very much
I felt pain during surgery	
I felt good	
I hurt	

The 11 statements that make up the Iowa Satisfaction with Anesthesia Scale alternate between “negative” and “positive” statements. Responses to statements are given an individual score ranging from -3 to +3, the scores for the “negative” statements are multiplied by -1, and the cumulative scores are averaged to determine a final composite score. A final score of +3 represents the most satisfied a patient can be with their anesthesia experience, while a final score of -3 represents the least satisfied a patient can be with their anesthesia experience.¹³

symptoms of local anesthetic toxicity including tinnitus, perioral tingling, visual disturbances, and dizziness. Tourniquet inflation time, total procedure time, and any need for supplementary local anesthetic or anxiolytic were recorded, as well as verified through review of the electronic medical record. Patients also reported an intraoperative pain score using the visual analogue scale (VAS) score from 0 to 10; 0 representing no pain and 10 for the worst pain. Postoperatively, patients were monitored for adverse events in the post-anesthesia care unit (PACU), and another VAS score was reported 30 minutes after the conclusion of the procedure. On the first postoperative day, patients were administered the Iowa Satisfaction with Anesthesia Scale (ISAS) via phone survey. The ISAS is comprised of 11 questions, and it has been shown to be a reliable and valid primary study end point in multicenter clinical trials (Table 2).¹³ Each question is given an individual score ranging from -3 to +3, and the cumulative question scores are averaged to determine a final composite score. A final score of +3 represents the most satisfied a patient can be with their anesthesia experience, while a final score of -3 represents the least satisfied a patient can be with their anesthesia experience. Total hospital charges associated with each procedure were obtained from the billing department and were subcategorized into anesthesia charges, charges for operating room services, drug charges, and charges associated with the use of the recovery room.

Table 3. Study Group Characteristics

	Group 1	Group 2	Group 3
Participants	21	23	22
Average Age (SD)	53.7 (15.4)	50.3 (14.3)	53.6 (11.4)
Intra-op VAS (SD)	1.60 (2.50)	1.10 (2.57)	1.23 (2.16)
Post-op VAS (SD)	0.55 (1.23)	0.83 (2.14)	0.35 (1.57)
Tourniquet Time (SD)	26.2 (2.41)	24.9 (2.59)	16.2 (3.38)
Complications	0	0	0
Additional Local	9.5%	13.0%	18.2%
Additional Benzo/ Opioid	23.8%	34.8%	18.2%

A statistical power analysis was performed for sample size estimation to determine the number needed to detect a significant statistical difference between groups. Because of the paucity of studies that compare complications of Bier block techniques, the power analysis was performed based on data from a similarly-designed study by Chaio et al. comparing the use of a forearm versus arm upper arm tourniquet.¹⁴ In that study, for an effect size of greater than 30% on pain ratings per group ($\alpha = 0.05$, power = 0.90), 54 patients were required. Using the same sampling ratio, the projected sample size needed for this study was a minimum of 20 patients per group. We analyzed the total hospital charges associated with each encounter as well as each of the subcategories individually using a Student's t-test. Group analysis was by parametric analysis for continuous variables and chi-squared test for categorical variables. P-values less than 0.05 were considered significant.

RESULTS

A total of 66 procedures were included in the study (Table 3). Fifty-five patients were enrolled in the study, and 11 of these patients had bilateral procedures performed on separate dates. There were seven patients who declined to be included in the study, with no apparent trends in age or gender. Surgeries in each group were similar and included 63 carpal tunnel releases (95.5%), 2 ganglion excisions (3.0%), and 1 trigger finger release (1.5%). There were no intraoperative or postoperative complications in any group. Intraoperative ($p=0.518$) and postoperative ($p=0.926$) VAS pain scores were similar between all groups. There were no significant differences between groups in patient satisfaction measured on the first postoperative day using the ISAS ($p=0.556$) (Figure 1). The average tourniquet time for group 3 was 16.2 minutes (standard deviation 3.4 mins), shorter by an average of 9.3 minutes ($p<0.001$) (Figure 2). The use of supplementary analgesic and anxiolytic interventions was recorded, and there were no differences in the fre-

quency or amount of supplemental medication between groups. Total hospital charges were 9.95% less for group 3 compared to groups 1 and 2.

DISCUSSION

The purpose of this study was to compare the overall efficacy and safety of the upper arm and forearm Bier block in hand surgery, as well as assess cost savings using the forearm technique. Our data indicates that compared with traditional methods, a forearm Bier block technique with immediate tourniquet deflation following conclusion of the procedure is a safe, efficient, and cost-effective strategy to provide intravenous regional anesthesia during hand surgery. There was no statistical difference between groups in terms of complications, pain scores, patient satisfaction, or additional medication given during the procedure. We were able to demonstrate that the safety and efficacy of the forearm technique with immediate tourniquet deflation following the procedure is comparable to the upper arm technique and, additionally, led to a decrease in total hospital charges by 9.95% at our institution secondary to a shorter amount of time spent in the operating room and decreased medication costs.

Our results compare favorably with previous studies assessing the safety of forearm tourniquet placement for local intravenous anesthesia in hand surgery. Since its original description in 1978 by Rouso, it has been noted that the major advantage of using a forearm tourniquet is the potential to use a lower dose of local anesthetic to achieve satisfactory anesthesia.^{9-12,15,16} Hesitation for implementing the forearm tourniquet has occurred due to the theoretical risk of leakage of local anesthetic through interosseous vessels in the forearm.¹⁷ However, no study has demonstrated that the forearm tourniquet produces an increased risk of venous or arterial leaks.^{4,7,11,18} Specifically, Coleman et al. provided a quantitative comparison of leakage under the tourniquet in forearm versus upper arm IV regional anesthesia and found no difference between the two techniques.¹⁸

In one of the first studies to evaluate the anesthetic dose required for adequate pain control, Plourde et al. showed that 1.5 mg/kg of 0.5% lidocaine solution is sufficient to produce satisfactory analgesia.¹¹ The standardized anesthetic dose (25 mL of 0.5% lidocaine) used for the forearm technique in our patient population was based on the retrospective review of 105 patients conducted by Arslanian et al. that was published in 2014. The study demonstrated that using 25 mL of 0.5% lidocaine with a forearm tourniquet and an average tourniquet time of 10.1 minutes resulted in no complications and adequate intraoperative analgesia.⁷

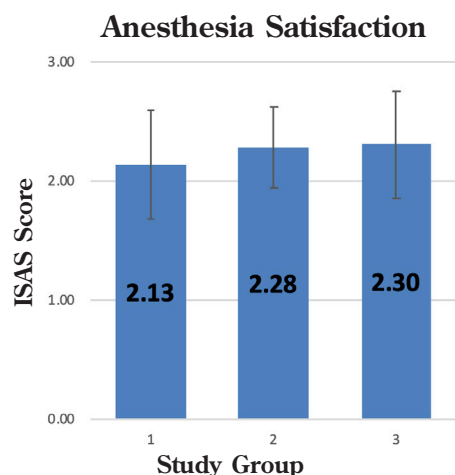


Figure 1. There was no significant difference between groups in terms of patient satisfaction measured on the first postoperative day using the ISAS ($p=0.556$). All 3 groups were satisfied overall with their anesthesia experience.

We sought to compare the overall effectiveness of the forearm technique compared with the upper arm technique in terms of pain scores during and immediately following the procedure, as well as patient satisfaction with their anesthesia experience. To date, there have been 3 randomized controlled trials investigating the analgesic efficacy of the upper arm tourniquet in IVRA compared to the forearm tourniquet.^{14,19,20} These studies span a variety of distal upper extremity procedures performed on a total of 129 patients, and their results were analyzed in a 2018 systematic review and meta-analysis performed by Dekoninck et al. The authors' concluded that IVRA using a forearm tourniquet technique is as efficient as using an upper arm tourniquet. In addition, the authors noted that use of a forearm Bier block comes with the advantages of a lower need for sedation due to less tourniquet pain, faster onset of sensory block, better tourniquet tolerance, and a drier surgical field.²¹

This study demonstrates that there is no statistical difference in intraoperative or postoperative pain using a forearm Bier block versus an upper arm Bier block, which agrees with the previous studies mentioned previously. Additionally, there was also no difference in patient satisfaction measured using the ISAS (Figure 1). Although scores trended toward increased satisfaction with forearm tourniquet placement, this difference was not statistically significant. The 3 groups included in this study had final scores ranging from 2.13 to 2.30, indicating that all groups were very satisfied overall with their experience.

Our average tourniquet time for study group 3 was 16.2 minutes, shorter than the average for groups 1 and 2 by 9.3 minutes (Figure 2). This reduction in time demonstrates that procedures amenable to Bier Block anes-

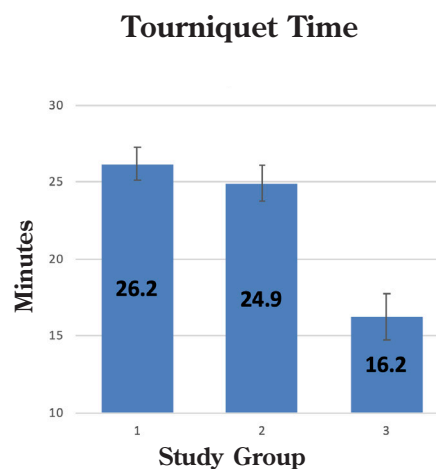


Figure 2. Immediate deflation of the tourniquet at the conclusion of the procedure led to a significant decrease in tourniquet time (9.3 minutes) for group 3.

thesia are typically quicker than the conventional 25-30 minutes of tourniquet time, and that the ability to deflate the tourniquet at the end of the procedure decreases the amount of operating room time and increases efficiency. At our institution, the mean of the total hospital charges for study group 3 was reduced by 9.95% compared to study groups 1 and 2 (10.4% reduction compared to study group 1, and 8.5% reduction compared to study group 2) by immediately releasing the tourniquet following the completion of the procedure ($p<0.001$). This cost reduction is a direct result of spending a shorter amount of time in the operating room as well as decreased medication costs. Considering the regularity at which these types of procedures are performed¹⁹ any potential cost-saving measure merits further investigation.

Limitations to this study include the fact that the majority of the surgeries included in this study were performed by a single surgeon, and all surgeries were performed at a single institution. The vast majority of procedures performed in this study were carpal tunnel releases, a relatively short procedure with a focal area requiring anesthesia. We cannot conclude from our study that the forearm Bier block method would be as efficacious with a more invasive procedure. Furthermore, although guidelines were provided regarding amount and specific sedative medications to utilize, different anesthesia providers had different styles and approaches to analgesia, leading to some subtle variability in the supplemental sedatives administered to supplement the Bier block.

CONCLUSION

This study demonstrates that the use of a forearm Bier block is a safe and efficient method of analgesia for intravenous regional anesthesia during hand surgery. While there is no clear benefit in terms of post-operative pain scores or patient satisfaction, the forearm Bier block with tourniquet deflation at the end of the procedure provides several other advantages including a reduction in required operating room time and associated decrease in hospital charges.

ACKNOWLEDGEMENTS

A portion of this work was presented at the Mid-America Orthopaedic Association (MAOA) 2019 Annual Meeting and the 74th Annual Meeting of the American Society for Surgery of the Hand (ASSH). Other than the abstract, there are no directly related manuscripts or abstracts, published or unpublished, by any authors of this paper.

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