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*WJO* is an annual biomedical research journal that focuses on orthopaedic-related surgery and engineering. *WJO* involves a two-step, double-blinded review process to ensure high quality of content: 1) review the submission and 2) review the authors’ responses to your suggestions. We provide you with a PDF of the submission, a Response Form, and an assessment guideline. We ask that you return your initial review within 2 weeks and include your overall assessment of the submission’s strengths and weaknesses, specific concerns for authors to address, and publication recommendation to the Co-Editors. You will not be asked to review more than two submissions for a given volume. We understand that your time is limited and valuable. If the request is not possible, or if you believe that the content does not align with your expertise, please let us know immediately. A prompt review helps encourage authors to submit future work and allows our team to meet printing and publication deadlines.

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WJO 2022; Volume 11

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ISSN 2687-7392 (print)
ISSN 2687-7406 (online)
The Western Journal of Orthopaedics (WJO) is a peer-reviewed (double blinded) publication of the UNM Department of Orthopaedics & Rehabilitation. WJO publishes annually in June and highlights original research relevant to orthopaedic-focused surgery and engineering, with the goal of MEDLINE indexing.

The submission deadline for WJO volume 11 is November 1, 2021. Manuscripts submitted afterward will be considered for volume 12. Email questions to WJO@salud.unm.edu.

Submit the Title Page, Blinded Manuscript, each table, and each figure to WJO@salud.unm.edu.

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Thank you for considering WJO as an avenue to feature your research.
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As Chair of The University of New Mexico (UNM) Department of Orthopaedics & Rehabilitation since 2005, I am pleased to present the 10th volume of the Western Journal of Orthopaedics (WJO).

2020 has been an overwhelming year of learning, tragedy, and understanding from an unexpected pandemic that made us rethink compassion, social justice, and how we live as families and citizens. My heart goes out to those who have lost loved ones and are challenged with recovery from COVID-19.

The senseless tragedies of George Floyd and Breonna Taylor brought to light our need for equality and fairness globally, especially in the United States. I compliment the outstanding work of all providers, front-line workers, and those who put themselves in harm’s way to make our lives livable and safe. Despite these COVID tragedies, we will be better as a nation and global member of this place we call earth.

The summer and fall of 2021 will hopefully begin to look like previous years. The second wave of COVID-19 was a bigger hit for New Mexicans than the first wave and has stretched thin all the hospitals in the state—something that happened across the nation. Our limited access includes fewer hospital beds per capita than most states. The number of COVID-sick patients, both on the floors and intensive care units, has been staggering. The possibility that our statewide hospitals “had no room at the inn” during this past holiday season was concerning and obviously stressful for all. Efforts for increasing capacity, advancing modern treatments (dexamethasone, remdesivir, monoclonal antibodies, and simple approaches, such as prone positioning and home oxygen), seeking additional step-down unit sites, repurposing operating rooms and intensive care unit beds, and reworking clinic sites have been huge tasks that have worked remarkably smoothly.

We enter 2021 with cautious optimism. Our response at UNM, with the first shipment of Pfizer/BioNTech’s mRNA-based COVID vaccine, has been remarkable. We have now inoculated over 70.0% of New Mexicans. The numbers of vaccinated continue to grow with the successful vaccination sites at UNM Hospital and The PIT alongside our colleagues in the private sector.

We are grateful to Johnson and Johnson for creating the classic single-dose vaccine that only requires refrigeration and can be easily distributed globally and will be started in the United States. These vaccine stories are great commentary to our caring ingenuity in the United States.

Thank you for the outstanding work from the WJO editorial board, with leadership from the collaboration of our editors Deana Mercer, Dustin Richter, and Christina Salas. They have made the publication an established entity within the department and university. We are grateful to the many peer reviewers who have volunteered their time to contribute to the quality of WJO.

Lastly, I would like to thank the entire UNM Orthopaedics family for making our space of work, academics, and research such a positive experience for all, especially during the time of COVID.

Sincerely,

R.C. Schenck Jr, MD
Professor and Chair
Department of Orthopaedics & Rehabilitation
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Lauren Radosevich  
Thaisa Swanson  
Mindy Alfaro-Trombely  
Beau Shelton  
Sarah Erb
2020 was a year like none other. It seems like just yesterday we set a deadline of May 1, 2020, as the time by which we would decide if we could hold our annual resident graduation event at Los Poblanos. It was March, and the COVID-19 pandemic was getting going—we had experienced elective surgical shutdowns. We had restructured our teams at the main hospital and Sandoval Regional Medical Center, but we figured things might be back to normal in a month or two. It didn’t take long to realize how wrong we would be.

We have had to adjust almost everything in 2020. We have adapted to learning via Zoom and have worked hard to maximize virtual platforms for meetings, conferences, and interviews. We have found that some things are better this way, such as faculty meetings. We found that there are great deficiencies as well. As orthopaedic surgeons, we must have hands-on motor skills training, and that simply cannot be replicated with a computer. More than anything, though, this forced isolation has shined a bright light on how much we depend on our personal interactions with our orthopaedic family members. Our program’s strength has long been the relationships we build with one another providing support, laughter, mentorship, and camaraderie that helps us navigate the challenges of orthopaedic practice and training and is also simply the lifeblood of our group.

This year, we celebrate the graduation of our five chief residents: Scott Plaster, Jordan Polander, Amber Price, Jory Wasserburger, and Matt Wharton. It has been an honor to participate in their growth as physicians, surgeons, and professionals for the last 5 years. We all appreciate their steadiness, leadership, and input as we have navigated the unknown this past year. It is clear that this is not how any of us pictured their last year of training; however, our chief residents have made the most of the year and provided exemplars to everyone in our program of what it means to persevere through this adversity.

We all hope to provide Scott, Jordan, Amber, Jory, and Matt the sendoff they deserve and have earned. We no longer take for granted these special events and opportunities to express our gratitude and appreciation to those close to us. We haven’t emerged from this mess, but we can see the end. We will miss these five graduates as we look to return to something more recognizable to us all. Congratulations to all of you and thank you for your time with us. It has been a true pleasure to work with and learn from each of you, and we are all proud to call you graduates of The University of New Mexico’s Orthopaedic program.

My very best regards.

Letter from the Residency Director

Gehron P. Treme, MD
Associate Professor and Residency Program Director
Department of Orthopaedics & Rehabilitation
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Chief Residents

Amber LaMae Price MD  
Medical School: Creighton University  
Fellowship: Spine

I am a native of the San Luis Valley in Southwestern Colorado. It is the world’s highest alpine valley and the headwaters of the Rio Grande. It is a remote area with a cold desert climate and is filled with small ranches and farms sandwiched between the Sangre de Cristo Mountains and the San Juan Mountains. As a child, my horses and family were the abiding passions of my life. I spent most of my days restoring old tack, building fences, and caring for the animals. I elected to pursue a career in medicine with a specific interest in surgery. During medical school, I was drawn to the field of orthopaedics. I was fortunate to be selected for an orthopaedic surgery residency at The University of New Mexico (UNM).

During residency, I have participated in several research projects. These include a biomechanical study on the effect of quad rods on rotational stability of different spine constructs; fusion rates in anterior cervical disectomy and fusion procedures backed by posterior spine fusion versus fusion of individual facet joints; cartilage damage in patients with multiple versus single patella dislocation; and several other arthroplasty and foot and ankle papers. My grand rounds focused on cranial cervical dissociation and the interplay between spinal fusion and the stability of total hip replacements. I will be pursuing a fellowship in spine after spending a year here at UNM as a general orthopaedic attending.

Outside of residency, my favorite activities include spending time with my family, horseback riding, wakeboarding, backpacking, and skiing. My husband Scott and I have been married for 8 years now, and during residency, we were blessed with the birth of our son, Liam. I want to thank Scott for the countless hours of encouragement during the last 5 years. His support allows me to be both a surgeon and a mother, and I cannot imagine getting through residency without him. I would also like to thank my parents for the years of guidance along the way. They instilled in me the resilience and hard work ethic that have been crucial in attaining all my goals. I want to thank my sister and brother for their comedic relief during the more difficult periods. To all my mentors and fellow residents, you are what make UNM a special place, and I thank you for the memories. I could not have asked for a better residency, and I am grateful I had the opportunity to train here.

Scott Plaster MD  
Medical School: OU College of Medicine  
Fellowship: Adult Reconstruction, Allegheny General Hospital

I was born and raised in Tulsa, Oklahoma, where I was the youngest of three kids. I grew up playing tennis and golf and trying to get to the lake as much as I could. I attended the University of Oklahoma in Norman, Oklahoma, for my undergraduate degree in chemical engineering. I had the quintessential college experience. I began working toward medical school about halfway through college and attended OU College of Medicine in Oklahoma City, Oklahoma.

After completing my orthopaedic surgery rotation, I couldn’t imagine doing anything else. My residency at The University of New Mexico (UNM) has been a dream come true, and I have honestly had some of the best times of my life here. The culture at UNM is truly unique. I am incredibly grateful to all of my attendings for providing an environment to learn and have fun. I cannot imagine a better orthopaedic residency.

I am very lucky to have the incredible support of my parents, who have always encouraged me to pursue my passions and given me the confidence to do so. My wife, Katie, has always been my biggest fan (and editor), and I cannot imagine this journey without her. She has worked incredibly hard to allow me to focus on residency while also making sure our free time is filled with friends, fun, and frequent road trips. Our family will be growing soon with twins on the way!

During our time in Albuquerque, we have taken advantage of the proximity to some of the country’s most beautiful landscapes. We have hiked and camped throughout New Mexico, as well as many of our neighboring states. I have really enjoyed being able to hop in the car with our dog on Friday after work and just head straight for the mountains for a weekend of skiing or car camping. I have also discovered a new hobby of running, thanks to the beautiful weather here.

I have been accepted to the Adult Reconstruction Fellowship at Allegheny General Hospital in Pittsburgh, Pennsylvania. While I am there, I hope to master the anterior approach to the hip and complex total hip and knee revisions. We have had an amazing time in Albuquerque and are looking forward to the next step in Pittsburgh!
I was born and raised on the black bayou in Bossier City, Louisiana. Growing up, I spent most of my free time on the water, skiing or fishing, when I wasn’t at football or baseball practice. I also spent many vacations snow skiing out west and backpacking. The plan was always Louisiana State University for undergrad, but then I chose to stay there for medical school, too. Once I chose the field of orthopaedics, I rotated at The University of New Mexico for a sub-internship. Between the high volume of trauma, talented attendings, and amazing culture of this program, I was hooked. I never imagined in my younger years that I would get the opportunity to live amongst the mountains and enjoy all of their offerings in sports and outdoors.

During residency, I had the opportunity to publish in journals on foot and ankle exam techniques and a national tibia fracture study. I am currently working on hip arthroscopy research as it relates to trauma and younger athletes. I was also lucky enough to spend a brief time in Lyon, France, studying under renowned sports and arthroplasty surgeons. Overall, I had a wonderful experience training here and enjoyed recharging in the great Southwest.

I couldn’t have done it without the amazing support of my friends, family, and mentors. I want to thank my parents, Michael and Kim, for always being there for me, even from across the country. I want to also thank my brother and sister, Kelly and Paige, for keeping me in check. Thank you to my significant other, Adison, who is amazing and has been more helpful than she’ll ever know. And last, to all of my coaches and mentors, thank you for your patience and guidance.

I look forward to my fellowship in sports and shoulder surgery next year in Boulder, Colorado. I’ll have the opportunity to hone my skills in team coverage, different surgical techniques, and clinical exams while developing more lifelong relationships with the great people in this field. Geaux Lobos!
Chief Residents

Mathew Wharton MD
Medical school: University of Arizona College of Medicine
Fellowship: Trauma, University of Kentucky

Hailing from a small town in Arizona, Apache Junction, I left the state to attend the University of Notre Dame for my undergraduate degree before returning to Arizona to work as an engineer for 5 years at Raytheon Missile Systems. I had a chance of heart in terms of career choice and was fortunate to attend medical school at the University of Arizona. I chose to train at The University of New Mexico (UNM) because of the phenomenal and supportive people. I rotated here as a medical student and was blown away by the excellent operative experience. It is hard to name just one favorite experience, but I would have to say the annual graduation dinner and golf tournament honoring the outgoing chiefs were absolute blasts. Albuquerque has been a great, affordable place to train. You are close to the mountains but have every city amenity you could want. My wife was born and raised in Albuquerque and has been happy to be back. My daughter loves living here, and we’ve been happy with the schools and extracurricular activities offered to her. Outside of medicine, my hobbies and interests include family, bourbon, hiking, running, and biking. Albuquerque has been a great place to partake in these hobbies.

I would like to, first and foremost, thank my wife, Katie, for being the most incredible wife and mother that I could ever imagine. You have put up with more over the past 5 years than anyone should have to deal with in a lifetime. Where others would have been crushed, you flourished. To my daughter, Hayley, I am so proud of the wonderful person you are growing up to be. You have inspired me to be a better person as I have gone through this journey. To Seth, you are forever loved and missed. To my and Katie’s parents, thank you for all the support to our family. You have provided so much help over the past nine years. To my fellow residents, you have challenged me every day to be a better person and surgeon.

To UNM Orthopaedics, thank you for taking a chance on me. Following my orthopaedic residency, I will be pursuing an orthopaedic trauma fellowship at the University of Kentucky in Lexington.

Fellows

Trevor Crean DO
Fellowship: Trauma
Residency: McLaren Oakland Hospital
Medical School: Michigan State University
College of Osteopathic Medicine

Lizzie Gibson MD
Fellowship: Hand
Residency: Orlando Health
Medical School: University of Texas Health Science Center at Houston

Nathan Menon MD
Fellowship: Hand
Residency: Georgetown University
Medical School: University of Maryland
Medical System

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Richard Wardell MD
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Letter from the Chief of the Division of Physical Therapy

Beth Moody Jones, PT, DPT, EdD, MS
Board-Certified Orthopaedic Clinical Specialist
Certified in Dry Needling
Associate Professor
Division Chief

In 2000, the American Physical Therapy Association held a strategic planning meeting leading to the adoption of “Vision 2020.” For years, the physical therapy community talked of Vision 2020—the principles of this vision guided the growth of physical therapy education and patient care.

This past year, the Division of Physical Therapy has learned to bend, change direction, negotiate, and reinvent itself as the world locked down. Patient care and physical therapy education changed due to COVID-19. While changing course and direction was not easy, the Physical Therapy Division did this with swiftness and agility. We found the silver lining of change that will forever alter our path. Here are a few of those lessons learned:

We can successfully teach in alternative ways, which has improved our teaching. With the pandemic upon us, we switched in-person lectures to asynchronous recordings, held small group discussions via Zoom, and limited our in-person class time to include only hands-on psychomotor techniques. Students reported that these changes allowed for learning at their own pace and improved productivity. Recorded lectures allowed students to re-listen to content that may have been confusing, and small lab groups gave them better access to instructors.

Our curriculum and faculty are fluid. With little notice, the faculty sought out resources and instruction for best online learning practices. We creatively adopted many education templates and rearranged the curricular path to flex with the tide of the pandemic. We increased our presence in labs during a dip in cases for the summer and finished hands-on labs early in the fall with the prediction of the fall surge.

We stayed healthy. With transparent town halls, the adoption of a social agreement, and a tiered approach to using the appropriate PPE for our face-to-face hands-on instruction, we reported only one COVID-positive case among our physical therapy community. Our community, faculty, staff, and students followed all safety practices put forward, limiting the spread of COVID within our learning community.

It is possible to celebrate achievement in a pandemic. To celebrate our graduating class of 2020, we had a drive-by celebration with all faculty and students. It was socially distanced outdoors, with noisemakers in hand and graduating students collecting their gown, cap, and hood. We created a video that included speeches, academic awards, congratulatory remarks, conferring of degrees, and students reading the Physical Therapy Oath. We live-streamed the video on graduation day, and graduates sent pictures of them being hooded by their families.

After preparing and teaching the entire fall in this new hybrid model, we found preparing for the spring semester in 2021 a much easier process. We will continue to teach in this hybrid mode until the summer. Our students are being vaccinated and are returning to the clinic again. We lost only 2 months of progress with one cohort, the class of 2021, who will be delayed because of the lack of clinical sites during the height of the pandemic.

We have a better understanding and appreciation of health measures and the need for health equity to help sustain global health and the future of health professionals. No one could have made all this work alone. Each member of our community kept this program moving. For that, we are incredibly thankful.

Respectfully,
Beth Moody Jones, PT, DPT, EdD, MS
Letter from the Co-Editors

It is hard to believe that WJO is now in its 10th year of publication. I would like to take this opportunity to thank everyone involved. The support and interest to get this project off the ground and improve the quality of the journal annually is a testament to the dedication of our authors, reviewers, and editors.

Ten years of WJO has been a challenging year for everyone. Our Orthopaedic Biomechanics and Biomaterials Laboratory (OBBL) researchers were particularly affected by the lab closures from March through August. As with all challenges, there were opportunities to step up and help solve problems, and our team rose to those challenges. Starting in April 2020, our team led a 24/7 university-wide effort to 3D print medical-grade, respirator-like masks for those in need in this year-long effort on May 6, 2021, with a distribution of 4500 masks and 750 pounds of shields across the Navajo Nation and multiple pueblos around the state. We wrapped up laboratory work at the end of August and are excited to continue this work moving forward.

Laboratory productivity in 2021 and 2022 will easily make up for any lost time due to COVID. I am very proud of our team who volunteered their time for this effort even while juggling remote and in-person classes and keeping our orthopaedics research projects moving forward. I expect that OBBL productivity in 2021 and 2022 will easily make up for any lost time due to COVID. I am very proud of our team who volunteered their time for this effort even while juggling remote and in-person classes and keeping our orthopaedics research projects moving forward. I expect

Our residents published 17 articles. We would like to take this time to highlight The University of New Mexico (UNM) Orthopaedic Medicine Residency Program. In 2020, UNM has made new connections with our friends in the sports medicine division at Yale, and increased our visibility as a premier academic research institution. The STaR Trial, under the direction of the University of Pittsburgh, is a multimillion dollar Department of Defense-funded study evaluating the timing of surgery and rehabilitation for the treatment of multi-ligament knee injuries in the civilian and military population. UNM is fortunate to participate in this study and is the lead site across the United States and Canada in study enrollment. We are also excited to become a study site for the multi-center Stability II trial that will evaluate the effect of graft choice and lateral extra-articular tenodesis on minimizing anterior cruciate ligament failure rates and donor site morbidity in an athletic population. This is an exciting opportunity to thank everyone involved. The support and interest to get this project off the ground and improve the quality of the journal annually is a testament to the dedication of our authors, reviewers, and editors.

Research and innovation at UNM are continuing to grow, and I am so happy to see that we are going strong! Due to COVID-19, this WJO is now in its 10th year of publication. I would like to take this opportunity to thank everyone involved. The support and interest to get this project off the ground and improve the quality of the journal annually is a testament to the dedication of our authors, reviewers, and editors. The support and interest to get this project off the ground and improve the quality of the journal annually is a testament to the dedication of our authors, reviewers, and editors. The support and interest to get this project off the ground and improve the quality of the journal annually is a testament to the dedication of our authors, reviewers, and editors.

Thank you once again to all my friends and colleagues for the outstanding support. A special thank you to the scientific advisory board and to the members of the editorial board for their continued leadership and support.

Christina Salas PhD

Welcome to the 10th volume of the Western Journal of Orthopaedics (WJO), featuring odd numbers. Each manuscript receives at least two reviewers per submission. We continually strive to facilitate quality control for reviewers and authors alike in our goal to nationally and internationally expand the audience and impact of this journal.

Christina Salas PhD
Letter from the Co-Editors

Deana Mercer MD
Welcome to the 10th volume of the *Western Journal of Orthopaedics (WJO)*, featuring efforts of faculty, alumni, fellows, residents, and students. This is the fifth volume to feature a double-blinded, external peer-review process for *WJO*. Each manuscript receives at least two reviewers per submission. We continually strive to facilitate quality control for reviewers and authors alike in our goal to nationally and internationally expand *WJO* audiences. We would like to take this time to highlight The University of New Mexico (UNM) Orthopaedic accomplishments in research over the past year as 2020 was a year of learning and adjusting. Our team adapted in a time of ZOOM conferences and digital presentations throughout the pandemic. In total, our faculty and residents have published 76 articles, with the number on track to increase in 2021. Of these, our residents published 17 articles. We would like to acknowledge Dr. Robert Schenck Jr., UNM Orthopaedic Chair, and Gail Case, administrative supervisor, for their continued leadership and support. We would also like to thank Angelique Tapia and Joni Roberts, managing editors, and Arianna Medina, copyeditor, for their effort in producing this volume of *WJO*.

Dustin Richter MD
It is hard to believe that *WJO* is now in its 10th year of publication. I would like to take this opportunity to thank everyone involved. The support and interest to get this project off the ground and improve the quality of the journal annually is a testament to the dedication and strength of our research staff, editors, authors, reviewers, department, and many more. Although COVID-19 has taken a mental and physical toll on so many, research and collaborations has been an area that has thrived with the enhanced virtual platform. This year, UNM has made new connections with our friends in the sports medicine division at Yale, worked on multi-ligament publications with colleagues from South Africa, Brazil, and India, and increased our visibility as a premier academic research institution. The STaR Trial, under the direction of the University of Pittsburgh, is a multimillion dollar Department of Defense-funded study evaluating the timing of surgery and rehabilitation for the treatment of multi-ligament knee injuries in the civilian and military population. UNM is fortunate to participate in this study and is the lead site across the United States and Canada in study enrollment. We are also excited to become a study site for the multi-center Stability II trial that will evaluate the effect of graft choice and lateral extra-articular tenodesis on minimizing anterior cruciate ligament failure rates and donor site morbidity in an athletic population. This is an exciting time at UNM. Thank you once again to all my friends and colleagues for the outstanding support.

Christina Salas PhD
Ten years of *WJO*, and I am so happy to see that we are going strong! Due to COVID-19, this has been a challenging year for everyone. Our Orthopaedic Biomechanics and Biomaterials Laboratory (OBBL) researchers were particularly affected by the lab closures from March through August. As with all challenges, there were opportunities to step up and help solve problems, and our team rose to those challenges. Starting in April 2020, our team led a 24/7 university-wide effort to 3D print medical-grade, respirator-like masks for those in need in New Mexico. We distributed more than 15,000 masks, food, water, hand sanitizer, and face shields across the Navajo Nation and multiple pueblos around the state. We wrapped up this year-long effort on May 6, 2021, with a distribution of 4500 masks and 750 pounds of supplies to the New Mexico Migrant Education Program, who will be providing these items to students and families in more than 10 school districts across Southern New Mexico. I am very proud of our team who volunteered their time for this effort even while juggling remote and in-person classes and keeping our orthopaedics research projects moving forward. I expect that OBBL productivity in 2021 and 2022 will easily make up for any lost time due to COVID. I look forward to building and growing our new research facility at the Center of Excellence!
Division of Research

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Considerations in Surgical Timing for Femoral Shaft Fractures

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Funding The authors received no financial support for the research, authorship, and publication of this article.

Conflict of Interest The authors report no conflicts of interest.

ABSTRACT
Femoral shaft fractures are a common orthopaedic injury. They are generally treated with intramedullary nailing. The optimal timing of operative treatment is variable and debated. Relatively simple femoral shaft fractures can be successfully treated in less than 24 hours in most health care systems. Femoral shaft fractures can be more complicated owing to various factors, such as multiple traumatic injuries, associated conditions, etc. These more complicated femoral shaft fractures benefit from stabilization within the first 6 hours to minimize complications. Stabilization of the long bones helps achieve an upright chest position and improves pulmonary, circulatory, and musculoskeletal function. Some patients with multiple severe traumatic injuries may suffer worsening of their general condition and pulmonary status. This article reviews concepts for selecting optimal timing of intramedullary fixation of femoral shaft fractures and reviews relevant current literature.

Keywords: Femur, Intramedullary, External Fixator, Diaphyses

INTRODUCTION
The timing of fracture fixation in patients with multiple traumatic injuries is complex. Many factors play a role in the trauma team’s decision-making process, specifically for the operating surgeon. The trauma team must keep in mind the risks and benefits of definitive fixation of various fractures. Numerous studies have shown that relatively simple femoral shaft fractures can be treated successfully in less than 24 hours in most health care systems (Figure 1). The literature supports either early fixation or the damage control orthopaedics (DCO) approach depending on the overall severity of the patient’s presentation. Other factors influencing the optimal time for surgical fixation are the associated injuries that occur with femoral shaft fractures. This article aims to review the literature and provide guidance in the timing of fixation of femoral shaft fractures.

TIMING OF INTERNAL FIXATION
A large part of deciding the surgical timing of fixation of femoral shaft fractures depends on the associated injuries sustained during the patient’s mechanism of injury. The injury severity score (ISS) is a scoring system often used to quantify the overall severity of an individual’s total injury. ISS may be low in a patient with an isolated femoral shaft injury or very high (>25) in the critically injured patient with multiple traumatic injuries. The more severely injured patients have higher ISS scores. Multiple studies have attempted to examine the consequences and outcomes of early fixation of femoral shaft fractures in high and low ISS situations.

Cantu et al retrospectively examined the relationship between time to definitive fixation of femoral shaft fractures, ISS score, and in-hospital mortality. In patients with an ISS score of less than 25, they found a considerably increased risk of mortality if definitive fixation was delayed beyond 48 hours. This increased risk was especially evident in patients older than 65 years. Similarly, when looking at pulmonary complications and increased mortality of patients, the risk of mortality increased at the window of time between injury presentation and definitive fixation. This is a risk even in patients with an ISS score above 18.

DAMAGE CONTROL ORTHOPAEDICS
In the more critically injured patient, the focus needs to shift from definitive fixation, where the ultimate goal is to get patients mobilized as quickly as possible, to stabilizing the patient’s major injuries quickly to allow for aggressive resuscitation. It is with this mindset that the concept of DCO was developed. DCO can often be applied when treating femoral shaft fractures in patients with higher ISS scores. This strategy aims to balance various means of fixation while respecting the patient’s total level of systemic inflammation. It also aims to avoid what is often referred to as a “second-hit phenomenon,” where lengthy surgical intervention introduces additional inflammatory mediators to the patient’s already compromised system. A DCO approach often involves acute application of external fixation and rapid temporary stabilization in the setting of femoral...
shaft fractures. When applied appropriately, outcomes have shown to be improved in these circumstances of critical trauma.

When comparing DCO and early definitive fixation for femoral shaft fractures in patients with multiple injuries, DCO groups have considerably shorter operative times and less estimated blood loss for initial surgeries. One study showed no significant difference in the incidence of acute respiratory distress syndrome (ARDS), pneumonia, various lung scores, and total time on mechanical ventilation.

Although the initial fixation is often temporized in the DCO setting, the patient can be optimized to return to the operating room at a later time when they are more stable. Delay in definitive fixation can allow time for aggressive resuscitation in the setting of more critical, systemic injury. It is difficult to quantify how much time between initial injury presentation to fixation is adequate. Morshed et al\(^4\) published a retrospective study of over 3000 patients using data from a United States national trauma bank. They showed significant benefit when fixation was delayed at least 12 hours when compared to more immediate surgical interventions.\(^4\)

**FEMORAL SHAFT FRACTURES AND HEAD INJURY**

Femoral shaft fractures often present with some degree of associated head injury owing to the high energy often associated with this fracture type. In more severe traumatic brain injury cases, surgical timing of the associated femoral fracture may be affected. A fine balance can be seen between early intervention and a delay in fixation to allow for a more adequate resuscitation. Wang et al\(^5\) studied trauma patients that sustained a head injury and various orthopaedic fractures, including femoral shaft fractures. They found surgical intervention within 24 hours may lead to better neuropsychological outcomes at 6 months postoperatively.

Similarly, Nau et al\(^6\) found that the presence of a head injury in patients with a femoral shaft fracture should not prevent surgical stabilization within the first 24 hours if the patient is otherwise cleared for surgery. Compared to patients with a head injury, patients without femoral shaft fractures received either a temporizing external fixator or an intramedullary nail within the first 24 hours did not have an increase in mortality, intensive-care unit stay, or total time requiring mechanical ventilation.

One thing that should be considered in this subset of patients is the possibility of increasing cerebral perfusion pressure if a reamed intramedullary nail is chosen as the mode of fixation for a femoral shaft fracture in the setting of an associated head injury. Anglen et al\(^7\) studied 17 patients from a single center treated with intracranial pressure monitoring and a reamed femoral nail during the patients' hospital stay. They found a slight increase in intraoperative and postoperative cerebral perfusion pressure. However, the amount of increase measured was widely variable.\(^7\) Intramedullary nailing of femoral shaft fractures has

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**Figure 1.** Graph depicting results from a number of studies examining how much time (in hours) to surgical fixation of femoral shaft fractures resulted in the “best outcome.” Note that a majority of the studies included had the best outcome with a time to fixation of less than 24 hours.
become the gold standard and can still be used in the setting of a head injury. It has been shown that there can be an increase in cerebral perfusion pressure when reaming the medullary canal. The insertion of an unreamed intramedullary nail can be considered a damage-control option if intracranial pressures are preoperatively elevated.

**FEMORAL SHAFT FRACTURES AND PULMONARY INJURY**

Patients sustaining femoral fractures because of higher energy mechanisms may also have some degree of thoracic/pulmonary injury. Physicians must also take this into account to not further worsen pulmonary inflammation in ARDS. They must also consider that not treating a femoral shaft fracture for an extended period poses its own pulmonary sequelae, including the risk of pneumonia and pulmonary embolism secondary to the patient being immobilized.

Nahm et al. retrospectively looked at 55 patients between 2010 and 2015 at a level-1 trauma center. They compared results of patients with femoral shaft fractures who received acute external fixator application versus skeletal traction application before being definitively fixed later. They found an overall shorter duration of mechanical ventilation required in the external fixation group and a 54.0% decrease in the incidence of ARDS. Likewise, Byrne et al. retrospectively looked at 17,000 patients with femoral shaft fractures across a national database of level-I and -II centers and found that centers that treated patients the earliest (<24 hours) had half the incidence of pulmonary embolism (1.3% versus 2.6%).

This relationship is further supported by a meta-analysis by Jiang et al., who looked at a total of seven retrospective studies investigating any relationships between early (<24 hours) and late (>24 hours) intramedullary nailing of femoral shaft fractures and associated pulmonary complications in patients with an ISS score above 18. They found that there was no difference in the results in the incidence of ARDS, Pulmonary Embolism, pneumonia, multi-organ failure or mortality.

**FEMORAL SHAFT FRACTURE PROTOCOL AND DAMAGE-CONTROL TECHNIQUES**

When dealing with femoral shaft fractures, both the variability in treatment options available and the various associated injuries can complicate the timing of surgical fixation. Numerous authors have suggested implementing standardized protocols and novel techniques to deal with these complex and potentially life-threatening injuries. A more uniform treatment algorithm may be helpful to limiting unnecessary delay to fixation while taking the necessary steps to optimize and resuscitate the patient adequately in light of associated injuries.

Vallier et al. tested an early appropriate care protocol in which patients were treated based on the level of metabolic acidosis. Their findings showed that fractures fixed within the first 36 hours after presentation were associated with lower complications, fewer episodes of sepsis, and shorter intensive care unit length of stay. Only patients with the most severe chest injuries showed greater incidence of pulmonary complications. Overall, patients with mild chest injury still experienced fewer complications. It should be noted that this specific cohort included pelvic ring, acetabulum or spine fractures in addition to femoral shaft fractures. Byrne et al. also suggested that a standardized protocol in trauma centers would be beneficial in stabilizing these fractures early to prevent the pulmonary complications associated with a delay in fixation and ultimately mobilization.

As previously mentioned, the goal of DCO is to safely and effectively stabilize orthopaedic injury as quickly as possible to allow for further resuscitation. Higgins and Horwitz suggested a novel attempt to combine DCO and definitive fixation with a suggested technique called “damage-control ailing.” The technique is described as inserting an unreamed nail in a retrograde fashion without proximally locking the nail. They executed this technique in five cases in which the patient was already making a trip to the operating room for accompanying injuries. They were able to stabilize the fracture in less than 30 minutes in all patients. When they deemed the patient as more stable, they returned to the operating room to either lock the proximal part of the nail or exchange the nail for a larger nail. Four of the five patients went on to heal without considerable limitation.

**CONCLUSION**

Femoral shaft fractures are a common orthopedic injury occurring in roughly 10 per 100,000 patients per year. Timing in surgical fixation of these fractures is complicated and influenced by many patient and institutional factors. It has been shown that early intervention should be the goal to minimize associated complications. However, multiple variables may direct the operating surgeon towards a damage-control approach, including associated head injuries, pulmonary injuries, and ISS scores. Standardized protocols similar to those already established for other injuries may aid surgeons and hospital systems to be more successful in treating femoral shaft fractures while minimizing complications as much as possible. When treated appropriately, most patients with femoral shaft fractures can be returned to mobilization within 24 to 48 hours, allowing them the best chance at a successful recovery.
REFERENCES


Seven Deadly Sins of Volar Distal Radius Fracture Fixation

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Funding The authors received no financial support for the research, authorship, and publication of this article.

Conflict of Interest The authors report no conflicts of interest.

ABSTRACT
Distal radius fractures are common injuries, accounting for 17.0% of all emergency department visits. Operative treatment is an option when indicated. Volar plating has become the most frequently used mode of fixation. Although fixed angle volar locking plates allow for reliable and stable fixation, complications have been reported. Complications include flexor and extensor tendon rupture, intra-articular screw penetration, malreduction, loss of reduction, carpal tunnel syndrome, implant failure, and complex regional pain syndrome. We propose seven principles to avoid these preventable outcomes and tips to succeed.

Keywords: Radius, Wrist, Hand

INTRODUCTION
Distal radius fractures are common injuries, accounting for 17.0% of all emergency department visits.1,2 In people over the age of 50, the mechanism of injury is most often a fall onto an outstretched hand. Closed reduction and immobilization are options for stable, extra-articular fractures.1

In unstable, intra-articular distal radius fractures, surgical options include closed reduction and percutaneous fixation, external fixation, intramedullary nailing, open reduction internal fixation (ORIF) with volar or dorsal plating, and ORIF with fragment specific fixation.4 The goal of surgical fixation is to re-establish radial inclination, volar tilt, length, and articular congruity to improve range of motion, comfort, function, and potentially decrease the risk of post-traumatic arthritis.5,6 Volar plating has become the most frequently used mode of fixation in the treatment of unstable distal radius fractures.7 Fixed angled anatomic volar locking plates provide stable fixation in osteoporotic and comminuted fractures with the goal of avoiding extensor tendon and other soft-tissue injuries common in dorsal plating. Complications have been reported, including flexor and extensor tendon rupture, intra-articular screw penetration, malreduction, loss of reduction, carpal tunnel syndrome (CTS), implant failure, and complex regional pain syndrome.8-10

We have identified seven preventable outcomes, the seven “deadly sins,” in distal radius volar plating. We propose strategies for avoiding these potential outcomes.

I. Inadequate Exposure
Inadequate exposure can lead to difficulty with fracture visualization and may result in malreduction and difficulty with accurate implant placement. In subacute injuries, dorsal callus and hematoma formation can be considerable and make adequate reduction of fractures difficult.

The flexor carpi radialis (FCR) approach is often used to gain adequate exposure. The FCR tendon sheath should be released past the trapezial ridge distally (Figure 1A). The radial septum is delineated, and the first dorsal extensor compartment is released to free the radial styloid fragment. The brachioradialis is step-cut for later repair and also releases the radial styloid fragment. The pronator quadratus is elevated from the watershed line at the tuberosity just proximal to the lunate facet and elevated radial to ulnar to the level of the distal radial ulnar joint (DRUJ). The ulnar cortical border of the distal radius is visualized and used for adequate reduction of the distal fragment. The watershed line should be clearly visible at the proximal reflection of the carpal bursa (Figure 1B). After releasing the radial septum, including the first extensor compartment and brachioradialis, the next step is pronation of the proximal fragment. Pronation of the proximal fragment facilitates dorsal periosteal and callous release, which frees the distal fragment to facilitate reduction (Figure 1C). Adequate exposure facilitates visualization of the surrounding nerves, arteries, and tendons and decreases the force of retraction across these structures. This exposure provides excellent visualization and facilitates fracture reduction.11

II. Anatomical Structures within the Surgical Field
Anatomical structures to be aware of include the median nerve, palmar cutaneous branch of the median nerve, and radial artery. The surgeon should be aware

ABSTRACT
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The authors report no conflicts of interest.

Conflict of Interest

Funding

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Fracture Fixation

Seven Deadly Sins of Volar Distal Radius

Fracture reduction.11 Inadequate exposure can lead to difficulty with fracture visualization and may result in malreduction and complications such as flexor and extensor tendon rupture, intra-articular screw penetration, malreduction, loss of reduction, carpal tunnel syndrome, implant failure, and complex regional pain syndrome.8-10 We propose seven principles to avoid these preventable outcomes and tips to succeed.

We have identified seven preventable outcomes, the seven “deadly sins,” in distal radius volar plating. We propose strategies for avoiding these potential outcomes.

In unstable, intra-articular distal radius fractures, volar plating has become the most frequently used mode of fixation.1,2 In patients 50 years of age and older, the mechanism of injury is most often a fall onto an outstretched hand. Closed reduction and percutaneous fixation are contraindicated if patients present acutely with CTS symptoms that do not improve with closed fracture reduction. If there is a concern for compartment syndrome caused by accompanying severe forearm or hand injury, fasciotomies and carpal tunnel release should be performed. In patients who have underlying CTS, accompanying surgical release of the carpal tunnel may be considered. The median nerve is protected by applying retraction across the FCR tendon in the extended FCR approach (Figure 2A).

The palmar cutaneous branch of the median nerve typically branches off the radial side of the median nerve 5 cm to 6 cm proximal to the wrist crease, runs with the median nerve for 2 cm to 3 cm, and then runs parallel about 2 cm to 3 cm lateral to the median nerve to gain adequate exposure. The FCR tendon sheath to the scaphoid tuberosity distally. C) Complete exposure with final removal of pronator quadratus. Example of pronation of the proximal fragment in the extended FCR approach for volar fixation of distal radius fractures.

Figure 1. A) A photograph of dissection in the extended flexor carpi radialis (FCR) approach. B) Release of FCR sheath to the scaphoid tuberosity distally. C) Complete exposure with final removal of pronator quadratus. Example of pronation of the proximal fragment in the extended FCR approach for volar fixation of distal radius fractures.

Median nerve injury and CTS are known to occur acutely after distal radius fractures. An article describing postoperative median nerve injuries after distal radius fixation has been reported in the literature.13 Carpal tunnel release should be performed if patients present acutely with CTS symptoms that

Figure 2. Photographs of dissections in the extended flexor carpi radialis (FCR) approach. A) The arrow points to the median nerve that lies medial to the FCR tendon encased in fatty tissue. B) Tenotomies identifying a branch of the radial artery distal near the radial septum. C) Forceps identifying the palmar cutaneous branch of the median nerve ulnar to the FCR tendon.
along the ulnar border of FCR (Figure 2B). The anatomy of the palmar cutaneous nerve is variable. Care should be taken to sharply incise the volar ulnar aspect of the deep FCR sheath because the palmar cutaneous branch is typically deep to the sheath and lies ulnar.13

The radial artery branch that traverses the distal radius volarly is at risk during release of the radial septum distally in the extended FCR approach (Figure 2C). One case report in the literature reports a radial artery pseudoaneurysm after volar distal radius ORIF following postoperative collapse and dorsal displacement of the fracture.14

### III. Malreduction

Malreduction can lead to injury of the flexor tendons, particularly the flexor pollicis longus (FPL) and flexor digitorum profundus (FDP) of the index finger. In general, acceptable closed reduction parameters include radial height of 8 mm to 12 mm, radial inclination of 21° on anteroposterior view and a neutral tilt of 10° volar tilt on lateral, and intra-articular step-off of less than 2 mm.15 Many of the newer volar fixed angle plates are designed to fit on the volar surface of distal radii. The plate can be used to facilitate anatomical reduction because the fracture can be reduced to the plate contour. Plates may not fit well when anatomic reduction is not achieved, leading to problems such as intra-articular screw penetration and loss of fixation if the screws are not placed subchondral. Adequate reduction using fixed angle devices is key to fixation of distal radius fractures. The extended FCR approach provides excellent visualization of the volar distal radius and facilitates the reduction of complex distal radius fractures.

Loss of reduction is most often the result of inadequate fixation of the multiple distal fracture fragments. Malreduction of the fracture can also lead to inadequate fixation because the volar plates are designed to capture the fragments in near anatomical reduction. Loss of fixation presents most commonly with dorsal collapse, loss of reduction of the volar lunate facet, or radial shortening.8 A cadaveric study showed that radii with distal screws placed over 4 mm proximal to the subchondral bone had significantly more radial shortening than when fixed with screws closer to the subchondral bone.16 Fragment-specific fixation can be particularly useful in volar marginal fragment fractures, in which capturing the volar-ulnar corner is critical for radiocarpal stability.17 Using the anatomical plate as a guide followed by reduction and fixation into the proximal shaft, the distal fragment first technique can be used where distal locking screws are placed to capture the distal fragment. This technique helps correct volar tilt.18 Surgeons should aim for anatomic reductions with the subchondral placement of screws and should consider various reduction techniques such as using the plate as a reduction tool.

After treatment of distal radius fractures, DRUJ problems can be a considerable source of morbidity, often owing to the healing of the distal radius fracture in a malreduced position. Contra-lateral wrist radiographs can be helpful and used as a guide to re-establish anatomical ulnar variance, owing to the variability across individuals. The extended tangential view can help assess intra-articular reduction of the sigmoid notch, DRUJ alignment, and screw breakthrough into the DRUJ.19,20 Distal radius malunion can restrict forearm rotation and alter DRUJ kinematics, causing pain and instability.21,22

### IV. Plate Placement

Plate placement may lead to flexor tendon irritation. Rupture can lead to intra-articular screw penetration because the plates are anatomical. Improper plate placement can also contribute to the loss of fixation because the distal fragments are not well stabilized. One of the benefits of volar plating is the decreased risk of tendon irritation and rupture, unlike dorsal plating. The correct technique should be employed to maximize this benefit.

![Figure 3. A) In the extended flexor carpi radialis approach: Identification of the watershed line (1), flexor digitorum profundus (FDP) to the index finger, and flexor pollicis longus (FPL) in relation to a volar fixed-angle distal radius plate. B) FPL rupture in a patient who was taken back to the operating room for exploration after inability to extend their thumb after distal radius volar open reduction internal fixation.](image)
The watershed line is a ridge on the distal radius just distal to the pronator quadratus and proximal to the volar ligaments of the wrist. Plates placed distal to this line have been shown to have increased rates of flexor tendon injury, most commonly to the FPL and FDP of the index finger (Figure 3A and 3B).25,26 Screw-back out has also been reported to cause flexor tendon problems.19,27,28 Re-establishing adequate volar tilt and repairing the pronator quadratus may also aid in the protection of the flexor tendons because the pronator quadratus can be used to cover the entire distal portion of the plate. Anatomic fixed angle plates should be placed proximal to the watershed line. Care should be taken to restore volar tilt and repair the pronator quadratus to minimize the risk of flexor tendon injury.

V. Screw Trajectory/Placement

Screws can be placed with a trajectory that may lead to intra-articular breakthrough, loss of fixation if not placed subchondral, or rupture of the extensor tendons. Screws can inadvertently be placed into the joint (Figure 4), as reported in a series by Arora et al.20 The goal of fixed angle, volar locked plating is plate placement proximal to the watershed line and the subchondral placement of screws. The 30° lateral allows a tangential view of the radiocarpal joint and is the best method of assessing subchondral screw placement because it provides excellent visualization of the articular surface.23 Screw lengths should be checked and shortened if needed based on tangential lateral fluoroscopy. The extended tangential view can also be used to evaluate screw lengths. Collapse of intra-articular fractures can also result in penetration of the joint by screws.

Fixed angle anatomic distal radius plates rely on subchondral placement. Bicortical fixation of distal pegs or screws is not required. One technique to avoid tendon or intra-articular complications involves drilling distal screws unicortically instead of bicortically. In a biomechanical study, Wall et al29 showed unicortical locking screws of at least 75.0% length produced similar construct stiffness to bicortical screws. Pegs or screws will lock into the plate, minimizing the risk of projection past the dorsal cortex.

While extensor tendon rupture is much less common with volar fixation of distal radius fractures compared to dorsal fixation, extensor tendon rupture and synovitis have been reported.20,21 Prominent dorsal screws and drill tip penetration have been thought to contribute to extensor tendon rupture. Lister’s tubercle can make it challenging to identify dorsal screws that are prominent. Live fluoroscopy, the dorsal tangential, or the skyline view can aid in the evaluation of screw lengths dorsally.22 Fracture type has been shown to be associated with extensor pollicis longus (EPL) rupture risk. A retrospective review of patients with distal radius fractures treated at a single institution with volar locking plates found a 5.7% EPL rupture rate.22 EPL rupture was found to have a high association to patients with fracture extension into or through Lister’s tubercle.23 Similarly, Lee et al22 found a higher association of EPL rupture in patients with “displaced dorsal beak fracture of Lister’s tubercle.” Callus formation, even without screw or drill penetration, can narrow the EPL groove.

VI. Postoperative Management

Inadequate pain management and delayed rehabilitation can lead to poor outcomes after distal radius fracture fixation.

Mobilization and rehabilitation after distal radius ORIF have been studied, and most surgeons advocate for a period of postoperative immobilization.30 A recent randomized clinical trial of 133 adults found that immobilization of 1 to 3 weeks after ORIF resulted in superior function, range of motion, and pain management.28 Lozano-Calderón et al31 studied smaller groups of patients and found no significant differences in two groups of 30 patients who began wrist range of motion 6 weeks after volar plate fixation versus 2 weeks. While the exact length of immobilization is debated, we recommend up to 2 weeks of immobilization, depending on the fracture and surgeon preference. Hand therapy should be started soon after immobilization has been discontinued in patients with clinical stiffness. Finger and thumb range of motion needs to be emphasized whether or not the fractures are treated with surgery. Elevation of the hand and wrist can be helpful to minimize postoperative and post-injury swelling, which can adversely affect outcomes because swelling limits motion.

While distal radius ORIF and other orthopaedic bony procedures are known to be painful, the prescription of narcotic pain medications has become a large topic of debate in recent times. In a prospective series of patients undergoing upper extremity surgical procedures, Kim et al32 found that their surgeons were prescribing on average 24 opioid pills, and patients

Figure 4. A sagittal computerized tomography scan of volar distal radius plate with distal intra-articular extension of screw.
consumed on average 8.1 pills over an average of 3.1 days. Teunis et al.\textsuperscript{28} found that male sex and greater dorsal angulation of the articular surface on lateral radiograph were associated with requesting a second opioid prescription after locking plate fixation of distal radius fractures. We recommend prescription of no more than 20 opioid pills to patients after distal radius ORIF over 3 days to 2 weeks. Patients should be counseled to expect some postoperative pain and that additional narcotics are not recommended after the first 2-week postoperative visit.

Complex regional pain syndrome (CRPS) may occur after distal radius ORIF and can be difficult to treat.\textsuperscript{46} Various studies have suggested that if started on the date of injury, vitamin C supplementation for 50 days may decrease the risk of CRPS after distal radius fracture, while follow-up studies have shown no benefit.\textsuperscript{46,47} While the evidence is controversial, vitamin C supplementation is quite benign, and we recommend 500 mg daily to our patients for 50 days post-injury.

\textbf{VII. Removal of Implants}

Volar-locked plates rarely need to be removed, but if there is evidence of tendonitis or tendon rupture, one should not hesitate. Patients may describe a sudden loss of active range of motion of a finger, indicating tendon rupture. In tendonitis, patients often present with dorsal swelling proximal and distal to the extensor retinaculum. Early removal of symptomatic plates is important in preventing tendon rupture.

The rate of plate removal ranges from 3.0% to 10.0% in the literature, most commonly for flexor tendon rupture or irritation.\textsuperscript{48,49} Timeframe of rupture is on average 6 months to 26 months postoperatively. Patients should be counseled about warning signs of flexor tendon irritation, including difficult and painful flexion of the thumb, fingers, and volar wrist synovitis.\textsuperscript{46} If patients do present with any of these warning signs or symptoms, they should be offered removal of the implant.

\textbf{CONCLUSION}

Distal radius fractures are common. Fixed angle volar locking plates are the most common fixation method for distal radius fractures, with excellent outcomes if done technically well. Complications of volar plating include flexor and extensor tendon injury, malreduction, intra-articular screw penetration, nerve and artery injury, and pain and stiffness. The extended PCF approach can aid in visualization, reduction, and proper plate placement proximal to the watershed line, with the goal of anatomic reduction and distal screw placement subchondral and extra-articular. Tangential lateral, extended tangential, and live fluoroscopy can aid in the examination of screw lengths dorsally. A period of up to 2 weeks of immobilization should be followed by encouraged range of motion and hand therapy. Opioids should be prescribed for no more than 2 weeks. Patients should be counseled to expect some pain postoperatively. Vitamin C may be prescribed for 50 days after the initial fracture. If patients present with concerning signs of tendonitis or tendon rupture, plates should be removed, and patients with ruptures should be treated with appropriate tendon procedures. Avoiding the “seven deadly sins” proposed above can lead to fewer complications in the surgical treatment of distal radius fractures.

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A Systematic Review to Examine Functional Recovery After Total Knee Arthroplasty and Successful Physical Therapy Protocols

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Funding The authors received no financial support for the research, authorship, and publication of this article.

Conflict of Interest The authors report no conflicts of interest.

Acknowledgments The authors acknowledged Dr. Fox to initiate the data entry system and special thanks to Dr. Schilz for her supports on her initial works on developing Capstone Research Activities for DPT students.

ABSTRACT

Background: Total knee arthroplasty (TKA) continues to be the most common elective procedure performed every year, with the goal to reduce pain and improve return to functional activities. Recent studies have investigated new surgical techniques and therapeutic interventions to determine which protocols result in reduced pain and accelerate return to function.

Methods: We systematically reviewed 131 out of 301 studies between 1996 and 2019 to assess trends in patient functional performance and perceptive functional recovery after TKA from preoperative up to 2 years postoperative. We evaluated functional outcome measures recommended by the Osteoarthritis Research Society International. Results that considerably deviated from the established healthy values were reanalyzed to assess the effectiveness of postoperative therapeutic interventions.

Results: The general trend of patient functional recovery after TKA occurs from immediate to 6 months postoperatively, and some outcome measures highlight improvement after 1-year postoperatively. Some studies with successful outcomes contain intensive strengthening protocols for the quadriceps femoris and hip abductor muscle groups during physical therapy.

Conclusion: The results from this study provide insightful information for clinicians to use. These valid functional assessments establish effective and evidence-based interventions in physical rehabilitation after TKA.

Keywords: Total Knee Arthroplasty, Systematic Review, Functional Outcome Measures

INTRODUCTION

Total knee arthroplasty (TKA) is one of the most common elective orthopaedic surgical procedures in the United States. It is typically performed to alleviate pain secondary to osteoarthritis (OA). In the United States, the number of TKA procedures is projected to reach 1.68 million by 2030, and the demand is expected to increase by 855.0% between 2012 and 2050. Although arthritic pain reduction is the primary goal for patients electing TKA, reducing arthritic pain cannot always ensure a full return to the functional performance of a healthy person of the same age.

Patients often elect for a TKA procedure expecting decreased arthritic pain and increased range of motion for everyday functional activities. Surgical techniques for TKA have evolved to preserve the normal arthrokinematics of the knee and reduce the tissue damage associated with the standard surgical approach. These surgical protocols have been shown to effectively reduce postoperative pain, accelerate healing time, promote earlier discharge from acute care units, and provide earlier return to functional activity.

To reinforce the surgical outcomes, physical therapy (PT) is often the primary intervention to treat patients who have undergone TKA, with physical therapists focusing on managing postoperative pain, restoring knee range of motion, and promoting functional recovery. However, the current standard of care for postoperative physical rehabilitation has not been established. In June 2020, the American Physical Therapy Association (APTA) provided the first clinical guideline for TKA rehabilitation. Although this guideline recognizes the considerable effects of PT on functional recovery, there is a lack of evidence describing the clinical validity of functional outcome measures.

The APTA clinical guideline states that PT is a clinically significant intervention to improve recovery. Such interventions include motor function training and intensive quadriceps strengthening using neuromuscular electrical stimulation. Available evidence has proven that increased quadriceps strength of the operated limb can improve physical function in patients after TKA at the level of age-matched cohorts with native knees. There lacks a consensus regarding the key aspects of
therapy and whether these outcomes can be evaluated using valid functional outcome measures.

The purpose of this systematic review was to examine the general trend of functional recovery for TKA. As an exploratory analysis, we conducted additional reviews for studies with successful functional outcomes by examining whether PT had been used and which therapeutic interventions were used. We hypothesized that 1) the general trend of functional recovery can be established by the recommended functional outcome measures, and 2) the best outcomes are strongly associated with intensive PT focused on quadriceps strengthening exercises. This study will help clinicians select proper measurements for evaluating functional recovery after TKA, and it will help establish an effective plan of care for patients who have undergone TKA.

**METHODS**

A systematic review was conducted by searching the MEDLINE database for publications between 1996 and 2019. We evaluated the physical component score (PCS) from the Short Form-36 (SF-36), which evaluates patient perception of functional recovery in PT. We also evaluated performance-based functional outcome measures recommended by the Osteoarthritis Research Society International (OARSI), including the stair climbing test (SCT), 40-m fast gait speed (40-m GS) test, 30-second chair rise test (30SCRT), and the 6-minute walk test (6MWT). The search terms used were total knee AND stairs AND seconds OR total knee AND stairs AND time, fast gait speed OR fast AND gait AND total knee, total knee AND 30 AND second AND chair AND seconds, and six minute OR 6 minute OR six minutes AND walk AND total knee as well as (((((((((Short Form 36[Text Word]) OR The Short Form 36[Text Word]) OR SF-36[Text Word]) OR SF-36[Text Word])) AND (((physical[Text Word]) AND score[Text Word]) OR pcs[Text] AND))) AND total knee[Text Word]). The search strategy used Boolean Operators “and” or “or” to search key terms. A total of 301 articles were populated through our keyword search. The articles were manually and separately screened by at least two individuals and reviewed for exclusion and inclusion criteria. Exclusion criteria included lack of data, systematic review articles, pediatric studies, if the patient underwent bilateral TKA or uni-compartmental TKA, and if the patient presented with other pathology like rheumatoid arthritis. Of the 301 articles populated from our initial database to search key terms, 170 articles were excluded and 131 articles were included for further analysis (Figure 1).

To maintain data quality representing the common functional recovery of patients who have undergone TKA, we recorded medical and therapeutic information such as surgical procedures, PT duration, and exercises. We presented the data plots with heterogeneous distribution due to the data being limited for each outcome measure. A retrospective analysis was applied to articles with results considered to be at the level of established healthy values (ie, SF-36 PCS = 50, fast gait speed = 1.74 m/s) or with excellent functional recovery.

*Figure 1. Literature screening showing that 301 articles were initially populated through the keyword search. The exclusion criteria are shown, displaying the number of articles included within each functional outcome and the total number of articles used for further review and data collection.*
To investigate quality of care, we analyzed 11 studies about PT interventions and postoperative rehabilitation protocols. Non-parametric descriptive statistics, median, and percentile were used to describe the general tendency of primary outcomes after TKA. Data from all articles were plotted by time: preoperative, 2 weeks postoperative, 1-month postoperative, 3 months postoperative, 6 months postoperative, 1-year postoperative, and 2 years postoperative.

### Table 1. Non-parametric Descriptive Statistics for Functional Outcome Measures

<table>
<thead>
<tr>
<th></th>
<th>Preoperative</th>
<th>2 Weeks</th>
<th>1 Month</th>
<th>3 Months</th>
<th>6 Months</th>
<th>1 Year</th>
<th>2 Years</th>
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<tr>
<td>SCT (Time: seconds/step#)</td>
<td>Median [25th, 75th percentile]</td>
<td>0.84 [0.74,0.88]</td>
<td>1.28 [1.07,1.48]</td>
<td>1.16 [0.87,1.35]</td>
<td>0.67 [0.48,0.78]</td>
<td>0.60 [0.59,0.66]</td>
<td>0.47 [0.42,0.52]</td>
</tr>
<tr>
<td>40m Gait Speed (meters/second)</td>
<td>Median [25th, 75th percentile]</td>
<td>1.28 [1.04,1.34]</td>
<td>0.71 [0.71,0.72]</td>
<td>0.85 [0.84,0.85]</td>
<td>1.13 [1.13,1.23]</td>
<td>[n/a]</td>
<td>1.67 [n/a]</td>
</tr>
</tbody>
</table>

SF-36 PCS, Short Form 36 Physical Composite Score; SCT: Stair Climb Test; 30sCRT, 30 Second Chair Rise Test; 6MWT, 6 Minute Walk Test

*The table indicates the median values and the 25th and 75th percentiles in the bracket for each testing time. Data are shown for each functional outcome assessed.

### Figure 2. Longitudinal analysis of the mean SF-36 physical component score at each of the follow-up intervals in the various studies. The boxplot indicates the heterogeneous distribution of data at each testing time. The x-axis indicates the testing time, from baseline to 2 years. Each boxplot is color-coded, with the appropriate testing time on the x-axis. The y-axis indicates the gait speed, measured in meters per second. The higher bar indicates the maximum values, while the lower bar indicates the minimum values. The top of the box indicates the 75th percentile, and the bottom of the box indicates the 25th percentile. The line within the box indicates the median value. The circles aligned over the boxplot indicate the data points from individual studies. Abbreviations: SF-36, Short Form-36; PCS, physical component score; Pre-Op, preoperative; WK, week; MO, month

### RESULTS

In total, we analyzed 131 articles from the database and included 12,954 patients with a mean age of 66.5 years old.

Patients’ perception of functional recovery using the plotting testing times, as measured by SF-36 PCS, showed a steady increase of the mean PCS over time with significant improvement of PCS at final follow-up when compared to the preoperative scores. The highest mean of the PCS was noted at 1-year...
**Figure 3.** Data points of the stair climbing test from preoperative to 2 years postoperative. The boxplot indicates the heterogeneous distribution of data at each testing time. The x-axis indicates the testing time, from baseline to 2 years. Each boxplot is color-coded, with the appropriate testing time on the x-axis. The y-axis indicates time to complete the stair climbing test, and the time is represented in seconds/step number. The higher bar indicates the maximum values, while the lower bar indicates the minimum values. The top of the box indicates the 75th percentile, and the bottom of the box indicates the 25th percentile. The line within the box indicates the median value. The circles aligned over the box plot indicate the data points from individual studies. Abbreviations: Pre-Op, preoperative; WK, week; MO, month.

**Figure 4.** Data points of the 30 second chair rise test (30sCRT) from preoperative to 6 months postoperative. The boxplot indicates the heterogeneous distribution of data at each testing time. The x-axis indicates the testing time, from baseline to 2 years. Each boxplot is color-coded, with the appropriate testing time on the x-axis. The y-axis indicates the number of sit-to-stands completed within 30 seconds. The higher bar indicates the maximum values, while the lower bar indicates the minimum values. The top of the box indicates the 75th percentile, and the bottom of the box indicates the 25th percentile. The line within the box indicates the median value. The circles aligned over the boxplot indicate the data points from individual studies. Abbreviations: Pre-Op, preoperative; WK, week; MO, month.
postoperatively (Table 1 and Figure 2). The scores were
taken preoperatively and up to 2 years postoperatively
for some studies. The mean PCS postoperatively was
32, and the mean PCS at 2 years postoperatively was
46 (Figure 2). The highest recorded mean PCS was
observed 1-year postoperatively with a mean score of
49, which is equivalent to established healthy values.

Four performance-based functional outcome
measures recommended by OARSI showed a similar
recovery pattern in physical function. There was an
overall gradual decrease in performance time for
SCT; however, time increases occurred at 2 weeks
postoperatively and 1-month postoperatively (Table 1
and Figure 3). For SCT, we assessed “time in seconds/
the number of steps ascended and descended” because
each facility has a different numbers of steps. The
preoperative SCT time was 0.84, which increased to
1.28 and 1.16 at 2 weeks postoperatively and 1-month
postoperatively, respectively. The recovery of SCT
time appeared to plateau at 6 months postoperatively.
Following the increase at 2 weeks, there was a continual
decrease in performance time up to 2 years. Results for
30sCRT were shown for up to 6 months postoperatively
with no data for the 1- and 2-year marks (Table 1 and
Figure 4).

30sCRT was 10.95 preoperatively and decreased
to 4.35 at 2 weeks postoperatively. The difference
exceeded the minimally clinically important difference
(MCID) of a 2.60 sit to stand score. The results then
increased up to 6 months postoperatively (1 month,
10.93; 3 months, 6.20; and 6 months, 13.80), which
remains lower than the established healthy values
(ie, 15.5). The results of 40-m GS were assessed from
preoperative to 1 year. However, we had limited-to-
no data for most of the plotted testing times. There
was an overall increase in gait speed from 2 weeks
postoperatively to 1-year postoperatively, with a drop-in
speed at 2 weeks (Table 1 and Figure 5). No difference
in gait speed was shown until 1-year postoperatively,
with 1.23 preoperatively and 1.67 at 1 year. This recovery
trend is similar to the established healthy gait speed (ie,
1.74 m/s) when considering the MCID of 0.3 to 5 m/s.
Results from the 6MWT showed an overall increase
in the distance ambulated in 6 minutes observed
from 2 weeks to 2 years postoperatively, with a large
decrease in the distance at 2 weeks (Table 1 and Figure
6). Preoperatively, the walking distance was 376 m,
which decreased to 282 m at 2 weeks. Walking distance
gradually increased to 542 m at 2 years, which is similar
to the established healthy values (ie, 555 m).

**DISCUSSION**

PT is essential to rehabilitating patients after TKA.
It is often implemented as a standard of care since
the bundled payment system was established. Many
clinical studies support the effectiveness of using PT
to improve physical function. However, more research
is needed to measure the effectiveness of PT using
valid functional outcome measures. This systematic
review aimed to investigate the general tendency of
Our findings showed that the functional outcome measures SF-36 PCS, SCT, 30sCRT, 40-m GS, and 6MWT, demonstrated a gradual improvement in the functional recovery of patients after TKA during a 2-year period with an expected decrease at 2 weeks postoperatively and 1-month postoperatively. These observations are similar to the results previously reported. At 2 years postoperatively, some functional outcome scores reached the level of the established healthy values, including SF-36 PCS, 40-m GS, and 6MWT. The results of 30sCRT were observed to be lower than established healthy values. This finding shows that 30sCRT is associated with quadriceps strength, which is consistently weak in patients 3 years after TKA.

In their retrospective review, Marcus et al. reported that articles with a PCS score of 50 or greater focused on increasing specific activity after TKA. Exercise protocols that challenged the quadriceps and hip musculature with eccentric contractions through resistance training and activities like tai-chi improved knee strength, flexibility, and range of motion. The excellent functional outcomes in the more challenging tests (eg, 30sCRT) were associated with progressive strengthening of the quadriceps, hip abductors, and hamstrings. By incorporating specificity into physical rehabilitation protocols, PT will better improve the strength and functional performance of patients after TKA. Other studies emphasize the significant contributions of intensive hip abductor and hamstring strengthening for functional improvement. Significant quadriceps strengthening contributes to successful rehabilitation for patients who have undergone TKA. Progressive strength training of the quadriceps, hip abductors, and hamstrings can be easily incorporated into the plan of care and performed in the clinic and at home with home exercise programs to increase exercise frequency.

Aquatic therapy is often discussed as a form of therapy after TKA due to short-term effects such as functional recovery and reduced pain. However, the long-term effectiveness after 6 months after TKA is controversial because of the increased risk of falling due to weight bearing. It has been suggested that altering interventions to shift the focus of treatment from the intensity of muscle strengthening to activity alone can address this risk. Increasing physical activity is clinically recommended, yet the evidence of outcomes is insufficient. Low impact activities like aquatic therapy and tai-chi may particularly help patients who enjoyed these activities preoperatively.

Limitations of this study include the limited number of reviewed articles per functional outcomes by using only MEDLINE as our search database. Another functional recovery using functional outcome measures recommended by OARSI.

Figure 6. Data points of the 6-minutes walk test (6MWT) from preoperative to 2 years postoperatively. The boxplot indicates the heterogeneous distribution of data at each testing time. The x-axis indicates the testing time, from baseline to 2 years. Each boxplot is color-coded, with the appropriate testing time on the x-axis. The y-axis indicates the distance in meters which was ambulated in 6 minutes. The higher bar indicates the maximum values, while the lower bar indicates the minimum values. The top of the box indicates the 75th percentile, and the bottom of the box indicates the 25th percentile. The line within the box indicates the median value. The circles aligned over the boxplot indicate the data points from individual studies. Abbreviations: Pre-Op, preoperative; WK, week; MO, month.
Despite strong evidence helping clinicians use valid functional assessments and of the operated limb. The evidence from this study can including hip abductor strengthening and eccentric outcomes contain intensive strengthening protocols, 1-year postoperatively. Our retrospective systematic measurements show the potential improvement after month to 6 months after undergoing TKA, and some functional recovery for patients occurs from 1 This systematic review showed that significant functional recovery for patients occurs from 1 month to 6 months after undergoing TKA, and some measurements show the potential improvement after 1-year postoperatively. Our retrospective systematic review indicates that the studies with successful outcomes contain intensive strengthening protocols, including hip abductor strengthening and eccentric contraction strengthening for the quadriceps muscle of the operated limb. The evidence from this study can help clinicians use valid functional assessments and establish effective interventions after TKA. OARSI-recommended measures are currently used as a general practice and not part of an established and consistent standard of care; therefore, further research with a more extensive database is needed.

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40m Gait Speed

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Effect of Patient-Surgeon Orientation on Plunge Depth During Plate Fixation of Clavicle Fractures

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Funding The authors received no financial support for the research, authorship, and publication of this article.

Conflict of Interest The authors report no conflicts of interest.

ABSTRACT

Background: Operative management of clavicle fractures indicated for open reduction internal fixation poses significant risk to critical anatomic structures. The associated risks to the underlying neurovascular structures during clavicle fixation as a result of plunge depth for patients in the supine position in comparison to patients in the beach-chair position is currently unknown. The purpose of this study was to compare plunge depth measurements between the supine and beach-chair positions during plate fixation of clavicle fractures.

Methods: The participant population at this single institution was comprised of residents, fellows, and fellowship-trained, attending orthopaedic surgeons. The participants drilled three bicortical holes into the bone model. The arm was then adjusted and positioned at 45° to simulate beach-chair positioning. The participant drilled three additional holes into the bone model. After allowing each clay mold to harden, the clay was removed, and the plunge depth was measured with a depth gauge by two independent researchers with a standard depth gauge.

Results: A total of 9 attending surgeons, 9 fellows, and 12 residents participated in this study. Including all levels of training, it was found that the beach-chair position had an average plunge depth of 2.9 mm, which was lower than the average supine position plunge depth of 3.2 mm. This difference was not found to be significant ($P = 0.116$).

Conclusions: We found no significant difference in plunge depth measurements during clavicle fixation in the supine versus beach-chair position. However, the importance of safely executing clavicle fracture fixation is critical to prevent avoidable morbidity and potential mortality of orthopaedic patients. The plunge depths recorded, if produced from a larger sample, should motivate deep reflection of the current liberal indications of clavicle fracture fixation.

Keywords: Clavicle Fracture, ORIF, Trauma

INTRODUCTION

Clavicle fractures typically occur in young, active individuals and account for about 3.0% of all fractures. Approximately 80.0% of clavicle fractures occur in the middle third of the clavicle. Due to this relationship, there is a considerable risk to the clavicle’s critical anatomical structures when these fractures are treated with open reduction internal fixation (ORIF). Robinson et al reported a 4.8 mm distance between the subclavian vein and the clavicle, with a standard deviation of 2.6 mm from the medial clavicle.

Safely drilling for bicortical fixation is of paramount importance during the operative treatment of clavicle fractures. One of the most fundamental skills of an orthopaedic surgeon is minimizing the depth of drill-bit penetration when drilling for bicortical fixation. Drill-bit penetration through the far cortex is terminologically described as “plunging” or “past-pointing.” A greater depth of plunging poses an increased risk of surgical complications, such as injury to neurovascular structures like the subclavian vein, subclavian artery, brachial plexus, and lung parenchyma.

Clavicle fracture fixation is performed with the patient in either the supine or beach-chair position or with the head of the bed between the two positions. To our knowledge, the effects and associated risks of plunge depths on the underlying neurovascular structures during clavicle fracture fixation relative to patient positioning are currently unknown. We believe that plunging is more likely to occur when patients are positioned in the beach-chair position because this position requires surgeons to extend their arms away from their center of mass, resulting in a longer lever arm during drilling.

The purpose of this study was to evaluate potential differences in plunge depth measurements during clavicle fracture fixation according to patient-surgeon positioning and level of surgical training. We hypothesized that one-third of the plunge depths would exceed
the previously reported distance of 4.8 mm between the far cortex of the clavicle and the closest neurovascular structure, regardless of patient-surgeon positioning and level of training.

METHODS
After obtaining Institutional Review Board approval (HRPP #HSC-MS-18-0620), participant recruitment occurred from January to August 2019. The participant population at this institution was comprised of residents, fellows, and fellowship-trained, attending orthopaedic surgeons. Demographic information collected for each subject included level of training (resident year, fellow, and attending) and the approximate number of clavicle ORIF procedures performed.

Sawbone models of human radii were chosen for this study because they can be more appropriately contained in the mounting construct and allow for repeatable measurements (Sawbones USA, Pacific Research Laboratories; Vashon, Washington). Molding clay was affixed to the undersurface of each bone model to simulate the physical structures present on the undersurface of the clavicle. The bone and affixed clay were then placed in a bivalved 2.5-inch diameter polyvinyl chloride pipe secured to an adjustable arm on a custom aluminum frame with a 9.5-inch wooden base. This design allowed for the simulation of clavicle fixation in supine and beach-chair positions. The height from the ground to the top of the aluminum frame was 57.5 inches. From the ground to the arm of the platform, the height was 44.0 inches. The base was removable to accommodate for height differences between participants. The arm was adjusted to 10° for the supine position and 45° for the beach-chair position (Figures 1 through 3). A board-certified orthopaedic surgeon selected the height and degree of rotation based on measurements obtained in simulated supine and beach-chair positions in the operating room.

In each simulation, the arm of the completed construct was first positioned at 10° to simulate supine positioning. The participant drilled three holes into the bone model after adjusting their body position, as appropriate, for technical execution. The arm was then adjusted and positioned at 45° to simulate beach-chair positioning. The participant then drilled three additional holes into the same bone model. Participants were not given practice attempts or additional training. A Stryker System 7 drill with a 2.5-mm drill bit was used. A new drill bit was issued after every two participants, along with a charged battery to ensure consistency with respect to drill bit blunting and drill speed. After each clay mold was removed, the plunge depth was measured with a depth gauge by two independent researchers.

Table 1. Mean plunge depths for each training level

<table>
<thead>
<tr>
<th>Training Level</th>
<th>Total, n</th>
<th>Supine, n</th>
<th>Beach-Chair, n</th>
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<td>Residents</td>
<td>36, 8 (22.2)</td>
<td>17 (47.2), 19 (52.8)</td>
<td>0 (0.0), 0 (0.0)</td>
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<td>Fellows</td>
<td>13, 8 (61.5)</td>
<td>4 (30.8), 6 (46.2)</td>
<td>3 (23.1), 10 (76.9)</td>
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<td>Attending</td>
<td>74, 8 (47.2)</td>
<td>36, 9 (25.0), 27 (18.6)</td>
<td>38 (26.7), 36 (25.0)</td>
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Table 2. Mean plunge depths for each training level and beach-chair versus supine positioning

<table>
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<tr>
<td>Supine</td>
<td>0 to 8 mm</td>
<td>0 to 8 mm</td>
<td>0 to 8 mm</td>
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<tr>
<td>Beach-Chair</td>
<td>0 to 8 mm</td>
<td>0 to 8 mm</td>
<td>0 to 8 mm</td>
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Figure 1. Aluminum frame to simulate supine (left) and beach-chair (right) positioning.

Figure 2. Sawbone model in supine position.

Figure 3. Sawbone model in beach-chair position.
RESULTS
A total of 9 attendings, 9 fellows, and 12 residents participated in this study. The average number of ORIF clavicle cases for residents, fellows, and attending surgeons was 7, 15, and 74, respectively. Including all levels of training, it was found that the beach-chair position had an average plunge depth of 2.9 mm, which was lower than the average supine position plunge depth of 3.2 mm. This difference was not found to be significant ($P = 0.116$). The range of plunge depth by attending surgeons was 1 to 6 mm in the supine position and 1 to 6 mm in the beach-chair position. The range of plunge depth by orthopaedic fellows was 1 to 5 mm in the supine position and 1 to 4 mm in the beach-chair position. For residents, the plunge depth range was 0 to 8 mm in the supine position and 1 to 6 mm in the beach-chair position. The differences between groups were not statistically significant. Attending surgeons and fellows had measured depths greater than or equal to 3 mm significantly ($P < 0.05$) more often than the residents (Tables 1 and 2).

DISCUSSION
The purpose of this study was to compare plunge depth measurements between supine and beach-chair positions during clavicle fracture fixation and to simultaneously evaluate differences in plunge depths based on the surgeon’s level of training. The importance of drill control and the consequences of plunging is well known to the orthopaedic surgeon. However, to our knowledge, the effect of patient positioning on plunge depth during clavicle fracture fixation has not been described. We hypothesized that a significantly lower plunge depth would occur when this procedure is performed in the supine position when compared to the beach-chair position. Although the opposite was true, the difference was not statistically significant, which we believe is due to a combination of factors. First, the surgeon is drilling nearly colinear to the direction of gravity, allowing them to appreciate the breach in the far cortex more effectively than with the patient in the supine position, where drilling is nearly perpendicular to the direction of gravity. Second, perpendicular drilling allows for more friction, potentially preventing the surgeon from appreciating the breach in the far cortex, which may result in a deeper plunge depth.

Similar to Clement et al.\(^b\) and opposite Stillwell et al.\(^a\) we found no significant difference in our evaluation of plunge depths in relation to the surgeon’s level of training. Safe bicortical drilling is a skill that can be rapidly acquired and retained by orthopaedic surgeons early in their career, but even experienced surgeons place the critical structures at risk. The range of plunge depth for all participants at all positions was 0 to 8 mm. Given that the conical tip of the drill bit measures 1 mm, it is understood that plunging of 1 mm is required to completely drill a bicortical path. Although this is the case, Mulder et al.\(^a\) reported the relationship of the subclavian vein to be located as close as 0 mm from the clavicular cortex in both intact and fractured clavicles. Theoretically, any plunging past 1 mm from the far cortex places patients at risk.

Sinha et al.\(^a\) have suggested superior plates in medial fractures and anterior plates in lateral fractures to avoid the subclavian vessels. However, as with all surgical procedures performed by orthopaedic surgeons, regional anatomy knowledge and expected technical skill are critical to safely expose, reduce, and provide fixation to fractures, regardless of the patient positioning and level of experience.\(^a\)

There were potential limitations in our study. Similar to an operative setting, multiple people were in the room while the participants performed drilling. Thus each participant was aware their performance was being measured and compared to their peers and colleagues, possibly creating biased results. We believe the Hawthorne effect was equal for all groups and played a minimal role in the results. Other limitations included a small number of attending surgeons recruited for the study and that the study did not occur in a surgical setting.

The importance of safely executing clavicle fracture fixation is critical to prevent avoidable morbidity and potential mortality of orthopaedic patients. Our study did not show a statistically significant difference in plunge depths between supine and beach-chair positioning. However, knowing they were being watched and compared to their peers, the participants in this
REFERENCES

Gunshot Wounds to the Foot and Ankle: Review of Cases from a Level-1 Trauma Center

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Funding The authors received no financial support for the research, authorship, and publication of this article.

Conflict of Interest The authors report no conflicts of interest.

ABSTRACT

Background: Gunshot injuries frequently involve the foot and ankle. The standard of care for treatment of gunshot injuries to the foot and ankle is not clear. To better understand these injuries, we completed a retrospective review of foot and ankle gunshot injuries at a level-1 trauma center seen as orthopaedic consults over a 2-year period.

Methods: Orthopaedic consults for foot and ankle gunshot injuries from June 1st, 2018, through May 31st, 2020, were reviewed. Patient characteristics, zone of injury, mechanism of injury, associated injuries, treatment, follow-up, and outcomes were recorded.

Results: Forty-eight foot and ankle gunshot injuries were identified, encompassing 16.0% of all gunshot consults in that period. Most patients were men and, on average, 30 years old. Most injuries were due to alterations and self-inflicted injuries. Most injuries were distal to the tarsometatarsal joint (zone one). There were three arterial injuries, five nerve injuries, and one tendon laceration. Three infections occurred, and 18 patients did not follow-up after their initial consultation. Most patients (68.8%) were treated as outpatients with a dose of intravenous antibiotics, bedside irrigation and debridement, and immobilization followed by a short course of oral antibiotics.

Conclusion: In this series, most gunshot injuries to the foot and ankle occurred in men approximately 30 years of age owing to alterations. Most were treated nonoperatively with a 6.0% rate of infection. From our review, nonoperative treatment was found to be successful in the majority of gunshot injuries to the foot and ankle.

Keywords: Foot, Ankle, Wounds, Injuries

INTRODUCTION

Injuries due to gunshot wounds are common in the United States. In 2017, there were 39,773 firearm-related deaths, with 12,2 firearm-related deaths occurring per 100,000 population. Although gunshot injuries are

common in the United States, there is a paucity of literature about firearm injuries to the foot or ankle. Using data from the Firearm Injury Surveillance Study, Cosco and King reviewed the epidemiology of self-inflicted gunshot injuries to the foot in the United States from 1993 to 2010. They found that these 667 incidents represented 1.0% of the reported gunshots. In this study, 90.0% of the patients were male, and 52.0% were between ages 15 and 34 years. Husain et al. published a retrospective case series evaluating 27 civilian patients over 8 years with low-velocity gunshot injuries to the foot and ankle. Most injuries in their series were distal to the midtarsal joint, and 96.3% of injuries involved fractures. They reported that 37.0% of these patients underwent fracture surgery, and one patient later developed osteomyelitis.

Several unique features of the foot and ankle may impact gunshot injuries. There is minimal soft tissue coverage of the bones. Owing to this minimal coverage, injury from lower velocity guns may lead to more frequent fractures and difficulties with wound healing. There are multiple bones and joints in the foot, making intra-articular fractures more likely. More than 80.0% of gunshots to the foot and ankle have been found to cause fractures. Shoe and sock material can be forced into the wound by the projectile, which has been found to increase the risk of developing pseudomonas osteomyelitis. Infection rates after gunshot injuries to the foot specifically are higher than in other locations. Foot mobility, weight bearing, and the ability to comfortably wear shoes may also be negatively impacted by the gunshot injury. Given the lack of literature evaluating foot and ankle gunshot injuries, we sought to understand better our experience with the presentation and treatment of these injuries. We hypothesized that most foot and ankle gunshot injuries at our institution were treated nonoperatively with bedside irrigation and debridement, immobilization, and antibiotics. A retrospective review of all patients who had an orthopaedic surgery consultation at a level-1 trauma center was completed over a 2-year period.
The location of the injury was divided into four zones (Figure 1). Zone one was distal to the tarsometatarsal joint and included the metatarsals and phalanges. Zone two was between the transverse tarsal joint and the tarsometatarsal joint, including the cuneiforms, navicular, and cuboid. Zone three was the hindfoot with the talus and calcaneus. Zone four was above the ankle joint, including the distal tibia and distal fibula.

**METHODS**

After obtaining Institutional Review Board approval (HSC #20-410), we reviewed the daily orthopaedic consult list from June 1st, 2018, to May 31st, 2020. This list contains the identifying information of every patient whom the orthopaedic on-call service was asked to see in consultation at our institution. The consult list from June 1st, 2018, to May 31st, 2020. This list contains the identifying information of every patient who was requested from the emergency department, urgent care, or other inpatient services. Patients diagnosed with gunshot injuries were noted, and their charts and radiographs were reviewed to determine which patients had been shot in the foot or ankle. A chart and radiographic review of patients shot in the foot or ankle was performed for this study.

**Chart Review**

The electronic chart was reviewed for patients who had sustained a gunshot to the foot or ankle. Age, sex, and side of injury were noted. We recorded the mechanism of injury, the presence of other injuries, screening of alcohol and drugs if applicable, and the length of orthopaedic follow-up. The type of treatment and complications developed were also reviewed. Prisoners, patients who were pregnant, children under 18 years, and cognitively impaired patients were excluded.

**Radiographic Review**

We reviewed radiographs to determine the location of the injury and which bones, if any, were fractured. The location of the injury was divided into four zones (Figure 1). Zone one was distal to the tarsometatarsal joint and included the metatarsals and phalanges. Zone two was between the transverse tarsal joint and the tarsometatarsal joint. This zone included the cuneiforms, navicular, and cuboid. Zone three was the hindfoot with the talus and calcaneus (Figure 2). Zone four was above the ankle joint, including the distal tibia and distal fibula.

![Figure 1. Lateral radiographic view of the zones of injury. 1: distal to the tarsometatarsal joint, including the metatarsals and phalanges. This radiograph shows an example of a zone one injury. Two: between the transverse tarsal joint and the tarsometatarsal joint, including the cuneiforms, navicular, and cuboid. Three: hindfoot with the talus and calcaneus. Four: ankle joint and proximal, including the distal tibia and distal fibula.](image)

![Figure 2. A and C) Lateral and B and D) Harris/axial radiographic views of zone three calcaneus fracture gunshot injury. C and D) represent radiographs at 6-months follow-up. The bullet fragment had been removed.](image)

**Table 1. Demographic information for patients with foot and ankle gunshot wounds**

<table>
<thead>
<tr>
<th>Sex</th>
<th>40 Male</th>
<th>8 Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laterality</td>
<td>23 Left</td>
<td>25 Right</td>
</tr>
<tr>
<td>Mean Age (years)</td>
<td>29.75</td>
<td>--</td>
</tr>
<tr>
<td>Age Range (years)</td>
<td>16 to 80</td>
<td>--</td>
</tr>
</tbody>
</table>
The location of the injury was divided into four zones: the ankle joint, including the distal tibia and distal fibula; the talus and calcaneus (Figure 2). Zone three was the hindfoot with the ankle joint, including the metatarsals and phalanges. Zone one was distal to the tarsometatarsal joint and included the cuneiforms, navicular, and cuboid. Zone three was the hindfoot with the ankle joint and included the metatarsals and phalanges. Zone four was above the navicular, and cuboid.

RESULTS

We reviewed a total of 309 orthopaedic consultations involving gunshot injuries. Forty-eight of these were foot- or ankle-related injuries, accounting for 16.0% of gunshot injuries. There were 48 foot and/or ankle gunshot injuries identified. Demographic information is listed in Table 1.

Of the 48 patients, 14.6% sustained only soft-tissue injuries, and 85.4% had bony involvement (Table 2). Zone one was most commonly affected (41.7%). All but one zone four injuries involved the ankle joint or syndesmosis. All but one of the bony injuries within zone four were intra-articular or within the syndesmosis. The one exception was an isolated fibula fracture, which occurred 4 cm above the ankle joint. The bones most affected were metatarsals (29.2%), followed by the calcaneus (18.8%) (Table 3). Non-foot and ankle injuries also occurred in seven patients, and one of these patients was shot in the spinal canal.

The mechanism of injury was most often altercations (39.6%), followed by self-inflicted injuries (29.2%) (Table 3). In the chart review, we were unable to distinguish between intentional and accidental self-inflicted injuries. In 13 patients, the mechanism was unknown or not recorded. Twenty-nine of the 48 patients were tested for alcohol or drugs. One or more of these substances were found in 21 patients (72.4%). Three patients were noted to have been wearing shoes or socks at the time of injury. Most patient charts did not note whether bullet(s) went through shoes or socks. Fifteen of the 48 patients were admitted to the hospital (31.3%), primarily due to other injuries. The remaining 33 patients were treated as outpatients.

Eighteen patients did not show up for their orthopaedic follow-up after the initial consultation. Of these patients, 11 patients were not tested for drugs and alcohol or tested negative, and the remaining seven patients tested positive for one or more substances. Of the remaining 30 patients, the average follow-up length was 102.7 days (±151.4). There were three infections, two patients with residual nerve pain and one patient with a symptomatic foreign body that was later removed. There was one extensor hallucis longus rupture, one anterior tibial artery injury, one dorsalis pedis artery injury, one superficial femoral artery injury, and one femoral vein injury. Nerve injuries included two deep peroneal nerve neuropraxias, one tibial nerve neuropraxia, one patient with second and third toe numbness presumed to be digital nerve neuropraxias, and one patient with clinical allodynia with signs of neuritis in the foot.

Ten patients had operative procedures to the foot and ankle, five inpatients and five outpatients. The reasons for operative treatment are listed in Table 4. Two patients presented to the emergency department after their wounds had healed. The remaining 36 patients presented with open wounds and were treated

<table>
<thead>
<tr>
<th>Bone Fractured</th>
<th>Number of Injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tibia</td>
<td>6</td>
</tr>
<tr>
<td>Fibula</td>
<td>7</td>
</tr>
<tr>
<td>Talus</td>
<td>7</td>
</tr>
<tr>
<td>Calcaneus</td>
<td>9</td>
</tr>
<tr>
<td>One or more tarsals</td>
<td>6</td>
</tr>
<tr>
<td>One or more metatarsals</td>
<td>14</td>
</tr>
<tr>
<td>One or more phalanges</td>
<td>8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mechanism of Injury</th>
<th>Number of Injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self-inflicted</td>
<td>14</td>
</tr>
<tr>
<td>Altercations</td>
<td>19</td>
</tr>
<tr>
<td>Unknown</td>
<td>13</td>
</tr>
<tr>
<td>“Looking at gun and went off”</td>
<td>1</td>
</tr>
<tr>
<td>Bullet through wall</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Toxicology Screen</th>
<th>Substances</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not tested</td>
<td>19</td>
</tr>
<tr>
<td>Negative</td>
<td>8</td>
</tr>
<tr>
<td>ETOH</td>
<td>8</td>
</tr>
<tr>
<td>Amphetamine</td>
<td>7</td>
</tr>
<tr>
<td>Opioids</td>
<td>6</td>
</tr>
<tr>
<td>Benzodiazepines</td>
<td>4</td>
</tr>
<tr>
<td>Cannabinoids</td>
<td>7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Structures Injured</th>
<th>Number of Injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>39</td>
</tr>
<tr>
<td>Artery</td>
<td>3</td>
</tr>
<tr>
<td>Vein</td>
<td>1</td>
</tr>
<tr>
<td>Nerve injury</td>
<td>5</td>
</tr>
<tr>
<td>Tendon</td>
<td>1</td>
</tr>
</tbody>
</table>

ETOH, Alcohol
with bedside irrigation, debridement, antibiotics, and immobilization. Bedside irrigation and debridement were performed with two liters of normal sterile saline directly into the wound(s). If the wound was small, it was dressed with petroleum gauze or xeroform and allowed to granulate. If the wound was large, it was loosely sutured with nylon or prolene. Intravenous cefazolin was most commonly given initially, followed by 5 to 14 days of oral cephalexin antibiotics. Ciprofloxacin was given to three patients per provider choice.

### DISCUSSION

This study is a retrospective chart and radiographic review of 48 foot and/or ankle gunshot injuries identified by orthopaedic surgery consultations at a level-1 trauma center. The patients represent 16.0% of all orthopaedic consults involving gunshot injuries seen in consultation over 2 years. Our review covers more patients than the 2016 study by Husein et al,3 who reviewed foot and ankle gunshot injuries over 8 years. Similar to their review, most injuries were distal to the midtarsal joint, with most patients being male. In their series, 70.0% of patients underwent operative irrigation and debridement within 1 hour of presentation. Only 31.3% of the patients in our study were admitted to the hospital, and most admissions were for injuries other than the foot and ankle. Indications for admission for isolated gunshot wounds to the foot or ankle included vascular injury or skin compromise requiring immediate open reduction. Most of our patients did not require internal or external fixation of their fractures.

In a review of lower-extremity gunshot injuries, including the foot and ankle at a level-1 trauma center in Jamaica by Abghari et al,9 there were 148 gunshot injuries over 2 years. The Abghari et al study found that these patients had worse functional scores at final follow-up than the general population.

The velocity of the gunshot was rarely recorded on our patient charts. Most patients with low-velocity gunshot injuries can be treated as outpatients with surgical indications as appropriate.10-11 Many high-energy injuries require formal operative debridement with fracture fixation and wound coverage techniques if considerable soft-tissue damage occurs.12

Many of the patients in our series tested positive for illicit substances or alcohol. Alcohol misuse has been shown to be associated with firearm violence and risk behaviors.13 Controlled substances have also been associated with gun violence, interpersonal violence, and suicide.13

Three of our patients (6.3%) had arterial injuries, one to the dorsalis pedis, one to the tibialis anterior, and one to the superficial femoral artery owing to a separate gunshot injury to the thigh. Only one of these patients required a revascularization procedure. It has been reported that in the lower extremities, gunshot injuries more frequently lead to arterial injury than in the upper extremities.14 Sadjadi et al15 recommends obtaining ankle brachial indices (ABIs) on all hemodynamically stable patients with lower-extremity gunshot injuries. If initial ABIs are over 0.9, patients can be safely discharged home with 100.0% positive predictive value and 98.0% negative predictive value in their study.16 In our series of patients, ABIs were not routinely recorded. Since most gunshot injuries in our series were distal to the ankle, ABIs may not always be necessary. They should be considered in more proximal injuries.

Various studies have supported the use of antibiotics in lower-extremity gunshot injuries to prevent infection.16-22 We had three infections in our series, all bony injuries without neurovascular or other considerable injuries. All three patients received intravenous cefazolin in the emergency department and bedside irrigation and debridement. One patient was brought to the operating room for formal irrigation and debridement and required two further operative irrigation and debridements with wound vacuum placement for methicillin-sensitive *Staphylococcus aureus* infection with wound dehiscence. His wound eventually granulated in after he completed his intravenous and oral antibiotic regimen. Another patient informed us that he was treated at an outside hospital for methicillin-resistant *Staphylococcus aureus* infection with intravenous antibiotics. The third patient had some early signs of superficial cellulitis at their 2-week follow-up, in which oral cephalexin was prescribed. The patient did not return to clinic. Most of our patients were treated with at least one dose of intravenous antibiotics with gram-positive coverage. They were discharged on 5 to 14 days of oral gram-positive antibiotic coverage. A few patients were also discharged with ciprofloxacin to cover gram-negative organisms. Standardized procedures to recommend only gram-positive coverage under most circumstances may be indicated in the treatment of gunshot injuries to the foot and ankle.

Limitations of this retrospective review include its retrospective nature, possible errors in charting, and lack of significant follow-up. If the orthopaedic service

### Table 4. Summary of foot and ankle gunshot injuries treated operatively

<table>
<thead>
<tr>
<th>Operative Procedures</th>
<th>Inpatient/Outpatient</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>I&amp;D</td>
<td>Inpatient</td>
<td>2</td>
</tr>
<tr>
<td>I&amp;D, external fixation</td>
<td>Inpatient</td>
<td>1</td>
</tr>
<tr>
<td>I&amp;D, removal of foreign bodies, ORIF</td>
<td>Inpatient</td>
<td>1</td>
</tr>
<tr>
<td>I&amp;D, removal of foreign bodies</td>
<td>Outpatient</td>
<td>3</td>
</tr>
<tr>
<td>I&amp;D, removal of foreign bodies</td>
<td>Inpatient</td>
<td>1</td>
</tr>
<tr>
<td>EHL repair</td>
<td>Outpatient</td>
<td>1</td>
</tr>
<tr>
<td>I&amp;D, removal of bony prominences</td>
<td>Outpatient</td>
<td>1</td>
</tr>
</tbody>
</table>
was not consulted, which can happen when there is no fracture or concern for neurovascular or tendon injury, they were not included in the study. We believe that our list captures most patients with this injury, but we may have missed some soft-tissue-only injuries. Many patients did not follow-up in the outpatient clinic, and there was a large range of follow-up length for patients that did come back. We were limited by data available in patient records.

Presented here is the largest case series to our knowledge of foot and ankle gunshot injuries, associated treatment, and outcomes. Most patients were treated with bedside irrigation and debridement, a dose of intravenous antibiotics, immobilized in a splint or hard-soled shoe, and discharged on oral antibiotics with gram-positive coverage. Of the patients that followed up, most of them did well with excellent clinical outcomes.

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10. You DZ, Schneider PS. Surgical timing for open fractures: middle of the night or the light of day, which fractures, what time? OTA International. 2020;3(1):e067. doi:10.1097/OI9.0000000000000067
A Novel Method in the Classification of Proximal Fifth Metatarsal Fractures

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Funding The authors received no financial support for the research, authorship, and publication of this article.

Conflict of Interest The authors report no conflict of interest.

ABSTRACT

Background: Proximal fifth metatarsal fractures are common. The authors previously performed a study examining the inter- and intraobserver reliability of the Lawrence and Botte Classification, which showed poor interobserver reliability of 16.67%. A novel approach was proposed for the classification of fifth metatarsal fractures using a mortise ankle radiographic view.

Methods: The observers from the authors’ prior study reviewed non-weight bearing mortise views of 20 patients with isolated fifth metatarsal base fractures. These radiographs were identified from the 60 radiographs from the authors’ prior study. Five physicians evaluated the radiographs and classified the fractures as type 1, 2, or 3. Results were then analyzed for interobserver reliability.

Results: Five observers reviewed 20 radiographs. Total interobserver reliability was 55.0% (11/20) with a Fleiss’ kappa of 0.565 (moderate agreement). The ankle mortise radiograph agreed with previous anteroposterior, oblique, and lateral radiographs at 56.0%, 57.0%, and 57.0%, respectively.

Conclusion: There is poor inter- and intraobserver reliability in the current proximal fifth metatarsal classification system. The use of a mortise radiographic view for classification provides equivocal results in the reliability of classifying proximal fifth metatarsal fractures when compared to the typical 3- view of the foot. A future study should be aimed at a classification system with higher reliability.

Keywords: Metatarsal, Bone, Classification

INTRODUCTION

Sir Robert Jones first described proximal fifth metatarsal fractures in 1902. His initial report described a fracture in the metadiaphyseal region of the proximal fifth metatarsal.1 Today, the term “Jones fracture” is used inconsistently to describe fifth metatarsal fractures from the metaphysis to the proximal diaphyseal region. Because of this inconsistency, standard classifications should be used rather than the term “Jones fracture.”2 Metatarsal fractures are a common injury. In a study examining 411 metatarsal fractures, Petrisor et al3 found proximal fifth metatarsal fractures were the most common fracture type.

Accurate classification of these fractures is imperative to choosing the correct treatment. Certain fractures have higher incidences of nonunion and require strict non-weight bearing or surgical intervention, while other fractures may be made weight bearing as tolerated. The Lawrence and Botte Classification is the most widely used classification system for proximal fifth metatarsal fractures.4 Fractures are classified as type 1, 2, or 3 based on their location. Avulsions of the tuberosity that may or may not extend into the tarsometatarsal articulation are classified as type 1. Type 2 fractures involve the metaphysis-diaphysis junction, including the fourth-fifth intermetatarsal facet. Proximal diaphyseal fractures that are distal to the fourth-fifth intermetatarsal articulation are classified as type 3 (Figure 1).4

It is imperative to determine the location of the fracture to guide appropriate treatment. Zone 1 injuries typically heal with good functional outcomes. Standard

![Figure 1. Figure representing the Lawrence and Botte Classification as a way to classify proximal fifth metatarsal fractures.](image-url)
treatment is nonoperative with a walking boot, and patients generally are allowed to weight bear. Owing to these fractures being located in a vascular watershed area, healing is more variable for zone 2 and 3 injuries. These fractures have a higher propensity for nonunion and are typically managed with strict non-weight bearing in a cast or operative fixation.

The authors previously found that the Lawrence and Botte Classification has poor inter- and intraobserver reliability when classifying proximal fifth metatarsal fractures. Therefore, we sought to use an alternative radiographic view to classify fifth metatarsal base fractures to find better inter- and intraobserver reliability. We hypothesized that a non-weight bearing mortise view would improve interobserver reliability of the Lawrence and Botte Classification when compared to standard anteroposterior (AP), lateral, and oblique foot radiographic views.

**METHODS**

Institutional Review Board approval (HSC #19-506) was obtained. From the cohort of our previous study of 60 patients with fifth metatarsal base fractures, we identified 20 of these patients who also had non-weight bearing mortise radiographs of the ankle at the time of their injury (Figure 2). These 20 mortise view radiographs were distributed to five observers, each of whom classified the fracture as a type 1, 2, or 3, according to the Lawrence and Botte Classification (Figure 1). The five observers included one radiology resident, two orthopaedic surgery residents, one fellowship-trained musculoskeletal radiologist, and one fellowship-trained foot and ankle orthopaedic surgeon. The same five observers who participated in the previous study were used.

The classifications were performed in a blinded manner. The observers did not know how the other observers classified the fractures or how they classified the foot radiographs previously. The results of the mortise view classifications were compared between observers and with the results from the AP, lateral, and oblique foot radiographs of the same patients from our previous study.

Results were then analyzed to determine the agreement between observers. Interobserver reliability was the primary outcome measure. In this study, interobserver reliability represents the rate at which the five observers identified the same fracture type for a given radiograph or patient. Fleiss’ kappa was calculated for interobserver reliability to find the statistical measure of reliability. Fleiss’ kappa values can be interpreted using the description in Table 1.

**RESULTS**

There were 20 patients in total. Each patient had one non-weight bearing radiographic view of the ankle mortise. The radiographs were reviewed by the five observers, producing a total of 100 observations. All five observers chose the same fracture type in 11 out of the 20 radiographs, which was an interobserver reliability of 55.0% (11/20). Fleiss’ kappa was calculated to be 0.565, indicating moderate agreement (Table 2).

When compared with the prior study, the ankle mortise radiograph classifications agreed with the AP, lateral, and oblique radiograph classifications at a rate of 56.0%, 57.0%, and 57.0%, respectively (Table 3). In this study, all five observers chose the same classification for 11 out of the 20 patients using the ankle mortise view.

---

**Table 1. Landis and Koch’s Interpretation of Kappa Values**

<table>
<thead>
<tr>
<th>Kappa</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0</td>
<td>Poor agreement</td>
</tr>
<tr>
<td>0.01 – 0.20</td>
<td>Slight agreement</td>
</tr>
<tr>
<td>0.21 – 0.40</td>
<td>Fair agreement</td>
</tr>
<tr>
<td>0.41 – 0.60</td>
<td>Moderate agreement</td>
</tr>
<tr>
<td>0.61 – 0.80</td>
<td>Substantial agreement</td>
</tr>
<tr>
<td>0.81 – 1.00</td>
<td>Almost perfect agreement</td>
</tr>
</tbody>
</table>


---

*Figure 2. An example of a non-weight bearing mortise view used in a novel classification. Note the proximal fifth metatarsal fracture.*
The proximal metaphysis has a more robust system of arterioles that allows for more predictable healing. There is also variability in the stability of the region. The metaphyseal region is more stable than the metadiaphyseal region, which promotes reliable healing. The meta-diaphyseal region is more mobile, creating a less favorable environment for healing.6,14

This study shows similar interobserver reliability in the classification of proximal fifth metatarsal fractures using the ankle mortise view compared to the prior study, which used AP, lateral, and oblique radiographs for classification. The previous study showed interobserver reliability of 56.7% for AP view with Fleiss’ kappa of 0.643, 35.0% for lateral view with Fleiss’ kappa of 0.441, and 45.0% for oblique view with Fleiss’ kappa of 0.508. In comparison, the present study showed interobserver reliability of 55.0% with a Fleiss’ kappa of 0.565. Thus, the ankle mortise view provided a similar interobserver reliability for classification when compared with the AP view when both are used in isolation.

This study is not without limitations. First, having residents participate as observers may have skewed the data owing to their limited training and experience. Furthermore, the study design does not consider other information that would likely be available to the physician, such as a full set of foot and ankle radiographs instead of an isolated radiographic view. Additionally, clinical history and mechanism of injury can provide further information about the character of the fracture. Further study might examine the inter- and intraobserver reliability of the Lawrence and Botte Classification when using a combination of all radiographic views.

In conclusion, the authors’ previous study showed poor inter- and intraobserver reliability in the Lawrence and Botte Classification as a way to classify proximal fifth metatarsal fractures.9 The current study’s aim to identify a more reliable radiographic view for classification showed similar results with moderate reliability. Between the two studies, the AP and ankle mortise views showed the highest interobserver reliabilities. Further study is needed to evaluate the optimal radiographic study for reliable classification of fifth metatarsal fractures. However, the present information from these two studies indicates that AP and mortise views should be used for the classification and treatment planning for these injuries.

Table 2. Inter-rater agreement, comparing the 5 observers’ scores for 20 participants for non-weight bearing mortise view of the ankle

<table>
<thead>
<tr>
<th>Radiographic View</th>
<th>Rate of Agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ankle Mortise</td>
<td>11/20</td>
</tr>
<tr>
<td>Foot Anteroposterior</td>
<td>11/20</td>
</tr>
<tr>
<td>Foot Oblique</td>
<td>10/20</td>
</tr>
<tr>
<td>Foot Lateral</td>
<td>5/20</td>
</tr>
</tbody>
</table>

DISCUSSION
Our proposed method for classifying proximal fifth metatarsal fractures using an ankle mortise view radiograph shows moderate interobserver reliability. This trend was seen across various medical providers, including orthopaedic surgery residents, radiology residents, attending radiologist with musculoskeletal fellowship training, and an orthopaedic attending with fellowship training in foot and ankle surgery. The rate of agreement among observers was not significantly different when compared to that observed using the classic radiographic views for classification (AP, lateral, and oblique foot series).9

Proper classification of proximal fifth metatarsal fractures is essential to guide the appropriate treatment of these fractures. Fracture location correlates with differences in outcome secondary to the distinct blood supply of the proximal fifth metatarsal. The metaphyseal-diaphyseal junction is a watershed area creating an increased risk for delayed union and nonunion.13 The proximal metaphysis has a more robust system of arterioles that allows for more predictable healing. There is also variability in the stability of the region. The metaphyseal region is more stable than the metadiaphyseal region, which promotes reliable healing. The meta-diaphyseal region is more mobile, creating a less favorable environment for healing.6,14

Table 3. Inter-rater agreement, comparing the 5 raters

<table>
<thead>
<tr>
<th>Radiographic View</th>
<th>Inter-Rater Agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>AP View</td>
<td>57%</td>
</tr>
<tr>
<td>OBL View</td>
<td>45%</td>
</tr>
<tr>
<td>LAT View</td>
<td>35%</td>
</tr>
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Fleiss’ kappa

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<thead>
<tr>
<th>AP View Inter-Rater Agreement</th>
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<th>LAT View Inter-Rater Agreement</th>
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<tr>
<td>0.643 (Substantial agreement)</td>
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<td>0.441 (Moderate agreement)</td>
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Z-score

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P-value

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Table 4. Rate at which all 5 observers classified fracture the same

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<th>Radiographic View</th>
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<tr>
<td>Ankle Mortise</td>
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<tr>
<td>Foot Anteroposterior</td>
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<tr>
<td>Foot Oblique</td>
<td>10/20</td>
</tr>
<tr>
<td>Foot Lateral</td>
<td>5/20</td>
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7. Landorf KB. Fifth metatarsal fractures are not all the same: proximal diaphyseal fractures are prone to delayed healing. The Foot. 1998;8(1):38-45. doi:10.1016/S0958-2592(98)90018-9


Early Open Reduction and Internal Fixation of Acute Low-Energy Tibial Plateau Fractures Does Not Increase the Rate of Perioperative Complications

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Funding The authors received no financial support for the research, authorship, and publication of this article.

Conflict of Interest The authors report no conflicts of interest.

ABSTRACT

Introduction: The treatment algorithm for tibial plateau fractures continues to evolve as surgeon experience increases. Initial surgical procedures have been fine-tuned over time.

Methods: This is a retrospective chart review of 132 patients with low-energy tibial plateau fractures (Schatzker I–IV) treated at a level-1 academic trauma center between January 2008 and February 2018. This study analyzes patient outcomes managed with primary operative intervention within 48 hours of admission. The average age was 45 years (range, 19 to 84 years). There were 92 men and 40 women. Statistical analysis focused on comparisons between historical complication rates and the findings of this study. The study was powered for short-term outcomes (1- to 3-month follow-up), with a few select patients followed-up with for 12 to 15 months. Study variables consisted of length of hospital stay, age, and time to follow-up.

Results: The average length of stay was 4.68 days with an overall complication rate of 10.6%. Complications included infections (6.06%), compartment syndrome (1.52%), persistent pain and stiffness (1.52%), and other causes (1.52%). There were no statistically significant differences when compared to complication rates cited in the literature ($P > 0.05$).

Conclusion: Although the optimal timing of treatment for tibial plateau fractures remains debatable, it is clear that early surgical intervention provides the advantage of immediate repair. Our data shows that Schatzker fractures (I–IV) may be safely operated on within 48 hours without a significant increase in complications. Early surgical intervention provides several advantages, including easier anatomical reduction, speedier recovery, reduced hospital length of stay, and reduced cost.

Keywords: Tibial Fractures, Postoperative Complications, Open Fracture Reduction, Fracture Fixation, Perioperative Care

INTRODUCTION

The tibial plateau is a critical load-bearing area in the human body. Fractures of the tibial plateau affect knee joint alignment, stability, and motion,\textsuperscript{1} with an incidence of 10.3 per 100,000 annually.\textsuperscript{2} Multiple classifications of tibial plateau fractures have been developed to assess injury severity, create appropriate treatment plans, and predict clinical prognosis. The Schatzker,\textsuperscript{3} Hohl,\textsuperscript{4} Moore,\textsuperscript{5} and AO classifications are the most used systems for this type of fracture.

Sir Astley Cooper first described proximal tibial fractures in 1825.\textsuperscript{6} Astley treated most minimally displaced fractures with realignment splintage and early mobilization.\textsuperscript{6} Sarmiento popularized functional cast bracing of most tibial condylar fractures,\textsuperscript{7} and Rasmussen introduced open reduction and internal fixation (ORIF) of this fracture class.\textsuperscript{8}

Methods and implants of internal fixation of this fracture have improved, and ORIF has become more common. Initial comparisons of closed and open treatment showed similar results.\textsuperscript{9-11} However, ORIF has become well accepted for displaced fractures, and indications have expanded.\textsuperscript{3,7,12-14} Although early external fixation followed by delayed internal fixation has been widely adopted for high-energy bicondylar fracture types,\textsuperscript{15-17} there is a scarcity of literature guiding management and optimal timing of surgical fixation for low-energy tibial plateau fractures. Recent data trends
have favored acute operative intervention because it allows for an overall facilitated anatomical reduction and offers earlier patient mobilization, increased range of motion, and likely improved recovery. Early studies comparing immediate-to-delayed intervention showed reduced infection rates and perioperative damage with delayed surgery, which is attributed to the quelling of soft-tissue inflammation when sufficient time before intervention is allotted. When surgery is delayed, there are risks, including infection, wound breakdown, loss of fracture reduction, and higher rates of failure of internal fixation.

There is great benefit in reducing hospitalization time because it effectively correlates with faster recovery, early return to work, and reduced cost. Increased hospital stay can hinder the opportunity for mobility and early rehabilitation while increasing the rate of nosocomial infection and other iatrogenic complications.

This study aimed to analyze postoperative trends over the past 10 years that support the notion that the benefits of immediate surgery were attainable, while overall perioperative complication rates remain unchanged.

**METHODS**

After receiving Institutional Review Board approval (TTUHSC #E18091), we retrospectively identified 1200 trauma patients with tibial plateau fractures. Inclusion criteria consisted of 18 years or older patients with low-energy fractures (Schatzker I-IV) treated within 48 hours of presentation. Exclusion criteria included patients with high-energy tibial plateau fractures (Schatzker V-VI), open tibial plateau fractures, any category tibial plateau fracture treated by external fixation with delayed internal fixation, or those with interventions after 48 hours. A total of 132 of 1200 patient charts met the criteria. Study variables consisted of the duration of hospital stay, age, and time to short-term follow-up (1 to 3 months), with identification and classification of complications.

**Statistical Method**

Demographic data were summarized using descriptive statistics. To test for statistical significance, 2-tailed Chi-Square analyses were performed using IBM SPSS Statistics Software (IBM Corporation; Armonk, NY). The focus was placed on comparing complication rates to historical data, which were calculated separately and as a composite for each follow-up period. Complications were further classified into sub-groups, including infections, persistent joint pain and stiffness, compartment syndrome, and other perioperative complications.

**RESULTS**

Patient demographics included 92 men and 40 women with an average age of 45 years (range, 19 to 84 years). In most cases, patients presented with isolated fractures (82 patients, 62.1%) versus polytrauma (50 patients, 37.9%). Cases classified by fracture type are summarized in Table 1.

The average length of hospital stay following definitive, operative treatment was 4.68 days (range, 0.51 to 13.5) from time of presentation. There were 14 complications (10.6%), with the majority occurring in the younger age group (18 to 49 years) (Figure 1).

The overall infection rate was 6.06%. A total of six patients developed a superficial infection that resolved within 1-week postoperatively with oral antibiotics. Two patients developed deep-tissue infections. In the first patient, early signs of infection became apparent at 3-week follow up. Clinical symptoms consisted of impaired wound healing with purulent discharge, erythema, and hyperthermia. Staphylococcus aureus was identified. The patient was readmitted and taken back to the operating room for debridement with implant retention, followed by 6 weeks of intravenous antibiotics. He had an uneventful 12-month follow-up. The second patient demonstrated signs of deep infection 4 weeks postoperatively. There were no clinical signs of inflammation, but the patient reported vague chronic pain. Plain radiographs revealed signs of periosteal reaction. The patient was diagnosed with chronic osteomyelitis attributed to Staphylococcus epidermidis that was ultimately addressed with hardware removal and external fixation.

One patient developed bilateral pulmonary emboli 5 days postoperatively, which was treated with therapeutic anticoagulation. At 6 months follow-up, the patient reported multiple bouts of lower-extremity deep venous thrombosis.

One patient experienced acute patellar tendon rupture postoperatively. The integrity of the tendon was compromised as a result of the presenting trauma, making the initial surgery difficult to perform. The complication was addressed through primary repair of the tendon. However, at 5 weeks follow-up, the patient demonstrated tenderness and swelling at the inferior pole of the patella, which is suggestive of patellar tendon re-rupture. Further inquiry revealed poor compliance with bracing and physical therapy.

### Table 1. Demographic Data by Age, Sex, and Fracture Type

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Number of Complications (18-49 years)</th>
<th>Number of Complications (50+ years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early treatment (n=132)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean Age (Range)</td>
<td>45 (19 - 84)</td>
<td>5</td>
</tr>
<tr>
<td>Sex (Male/Female)</td>
<td>92/40</td>
<td>13</td>
</tr>
<tr>
<td>Schatzker 1</td>
<td>31</td>
<td>1</td>
</tr>
<tr>
<td>Schatzker 2</td>
<td>58</td>
<td>13</td>
</tr>
<tr>
<td>Schatzker 3</td>
<td>30</td>
<td>5</td>
</tr>
<tr>
<td>Schatzker 4</td>
<td>13</td>
<td>9</td>
</tr>
</tbody>
</table>
After the second surgical repair, the patient was immobilized in a long-leg cast in extension for 6 weeks with partial weight bearing using crutches. Intensive physical therapy was prescribed. The patient returned to baseline activity at 6 months follow-up.

Two patients developed compartment syndrome. One of the patients developed compartment syndrome preoperatively while awaiting surgery, and the other patient developed it approximately 18 hours postoperatively. There were no lasting complications in this group at 3- and 6-month follow-up.

Finally, two patients had concerns of persistent postoperative pain and stiffness with only mild improvement at a mean time of 6 months (range, 5 months to 7 months). Joint stiffness was defined as subjective pain and discomfort reported by the patient and evidence of decreased range of motion or radiographic evidence of arthritis. One of these patients developed persistent knee stiffness that was thought to be related to hardware misalignment, for which revision surgery was offered at 5-month follow-up. The other patient developed arthrofibrosis detected at their 7-month follow-up with arthroscopic lysis offered. Both patients ultimately declined revision procedures.

**DISCUSSION**

Time is a consideration that directly influences the surgical outcomes of low-energy tibial plateau fractures. A study that exclusively examined Schatzker fractures (type IV-VI) found that when early internal fixation is feasible, it could effectively shorten the length of hospital stay, decrease the cost of hospitalization, and promote early functional rehabilitation.

One study compared outcomes between immediate and delayed ORIF of tibial plateau fractures in skiing and snowboarding trauma patients. The study showed that patients treated immediately (defined as less than or equal to 24 hours postinjury) had significantly fewer occurrences of compartment syndrome (3.0% vs 27.0%), needed fewer fasciotomies (6.0% vs 31.0%), and had a shorter average length of stay (3 days vs 6.5 days). These results were all statistically significant ($P < 0.05$).

The Dedicated Orthopaedic Trauma Room (DOTR) model is worth mentioning because it provides the framework to maximize the operating room, staff, and resource availability, allowing for the timely completion of the cases outlined in this study. This model delineates an operating room scheduling system that prioritizes urgent trauma and strategically allocates support staff, resources, and experienced trauma personnel. Research documenting the spread of this model to multiple institutions over the past 10 years has demonstrated consistent improvement in patient outcomes, including decreased length of stay, improved rehabilitation, and patient satisfaction.

**Infections**

Infection-related sequelae have been attributed to extensive soft-tissue tearing from diffuse inflammation during early operative intervention. The treatment of tibial plateau fractures has evolved dramatically over the last 20 years, with greater attention to protecting the soft-tissue envelope. Our study featured an overall infection rate of 6.06% observed at short-term (1 to 3 months) follow-up with the more complicated cases followed for longer periods. Papagelopoulos et al estimated that the infection rate among treated tibial plateau fractures lies between 2.0% to 13.0%. This number is derived from a range of studies featuring both urgent and delayed surgical interventions.
Literature that focused exclusively on ORIF without external fixation estimated a similar incidence of infectious wound complications, reportedly in the range of 5.0% to 15.0%.\textsuperscript{28} The findings of historical data trends compared to the data obtained in this present study revealed no statistically significant difference in infection rates ($P > 0.05$).

Zhao et al\textsuperscript{29} constructed a meta-analysis with an extensive look at common complications associated with tibial plateau fractures. They separated the analysis into two groups: ORIF versus external fixation with or without surgical intervention. Although it featured a collection of data that encompassed a complete gradient of Schatzker-classified fractures, it had a higher propensity of Schatzker types (V–VI). However, it did not exclusively organize data by time, as this pool of data consisted of immediate and delayed ORIF versus external fixation with delayed intervention (Table 2). The infection rates between the outlined studies that were managed exclusively by ORIF (both delayed and immediate) described in this meta-analysis and our study were determined not significantly different via 2-tailed Chi-Square analyses ($P = 0.56$). However, when we compared overall infection rates and subtyped superficial infection rates in the “external fixation” group, we determined the existence of statistically significant findings. External fixation with delayed or no surgical intervention had a higher propensity of infection ($P = 0.01$) and superficial infections ($P = 0.02$) (Table 3). Perhaps this can be attributed to this meta-analysis focusing primarily on Schatzker types V through VI instead of our data collection featuring Schatzker types I through IV.

### Compartment Syndrome

Compartment syndrome is an important, often underappreciated complication. As stated in the literature, the risk of compartment syndrome appears to be highest among high-impact (Schatzker V–VI) tibial plateau fractures and fracture dislocations, but it can also occur in any class of tibial plateau fracture. Complications associated with compartment syndrome can be devastating because they can result in the loss of function and limbs, with prolonged recovery with limited regain of function.\textsuperscript{30-32} Generally, the literature lacks concrete treatment strategies for severe tibial plateau fractures. However, most studies favor early external fixation with delayed internal fixation.\textsuperscript{33-35} Recent studies suggest that this practice may contribute to intramuscular pressure by lengthening the limb and reducing myofascial compartment volumes. If compartment syndrome occurs in this patient population, the fasciotomies must be planned carefully. Incorrectly placed fasciotomy wounds may compromise future attempts of ORIF, especially in delayed management.\textsuperscript{36}

| Table 2. Summarized infection rates as per Zhao et al\textsuperscript{1} |
|-----------------|--------|--------|
| **Total Infections** | | |
| Study | ORIF | External Fixation |
| Boston (1994)\textsuperscript{2,3} | 42.9% | 50.0% |
| Krupp (2009)\textsuperscript{4} | 7.1% | 13.3% |
| Guryel (2010)\textsuperscript{5} | 2.5% | 0.0% |
| Chan (2012)\textsuperscript{6} | 12.5% | 25.7% |
| Jansen (2013)\textsuperscript{7} | 9.5% | 100.0% |
| Ahearn (2014)\textsuperscript{8} | 4.7% | 28.6% |
| Pun TB (2014)\textsuperscript{9} | 0.0% | 16.7% |
| Conserva (2015)\textsuperscript{10} | 15.8% | 12.2% |
| Total | 8.3% | 16.8% |

| Table 3. Comparison of infection rates between this current study and Zhao et al\textsuperscript{1} |
|-----------------|--------|--------|
| **Statistical Significance Summarized (ORIF vs ORIF)** | | |
| Complication | Current Study | Zhao et al | P-value |
| Infection | 6.06% | 8.00% | 0.56 |
| Superficial | 4.54% | 5.00% | 0.99 |
| Deep | 1.52% | 4.00% | 0.16 |

| **Statistical Significance Summarized (ORIF vs External Fixation)** | | |
| Complication | Current Study | Zhao et al | P-value |
| Infection | 6.06% | 17.00% | 0.01 |
| Superficial | 4.54% | 13.00% | 0.02 |
| Deep | 1.52% | 5.00% | 0.16 |
Joint Stiffness and Limited Range of Motion

Joint stiffness with reduced knee motion is common and can compromise the outcome of tibial plateau fractures treated with operative fixation. Loss of knee range of motion is thought to result from damage to the extensor retinaculum attributed to presenting trauma or surgical exposure. Papagelopoulos et al. attribute the main mechanism of reduced mobility and stiffness to extensor scarring, with (or without) arthrofibrosis of the knee or patellofemoral joint. Other studies have suggested damage results from prolonged immobilization after fracture or internal fixation. Immobilization of the knee for periods of more than 3 or 4 weeks has often been linked to frequent patient outcomes reporting some degree of permanent stiffness. Timely surgical intervention with a shorter hospital course, rapid transition to weight bearing status, and increased mobility are reasons to support early surgical intervention. In reference to Zhao et al., the incidence of joint stiffness in the “ORIF” subgroup compared to the findings of the current study demonstrated no significant difference ($P>0.05$). There was a significant difference in rates compared to groups managed by external fixation and delayed surgical intervention. These findings are summarized below in Table 5.

**Approach to High-Energy Tibial Plateau Fractures**

While the two-step approach has become the standard of care for high-energy tibial plateau fractures, no specific guidelines exist. Most providers recommend a thorough evaluation of the soft tissues in all patients presenting with tibial plateau fractures before deciding if urgent surgical intervention can be tolerated. Such judgments are difficult to quantify because they largely depend on operator experience and the visual integrity of the affected limb. In cases of uncertainty, a staged protocol employing provisional stabilization with an external fixator is traditionally recommended to maintain length and alignment and facilitate soft-tissue healing. Despite the benefit in reduced infection rate and improved soft-tissue healing, there is growing evidence of adverse events, such as prolonged treatment course, muscular atrophy, and joint stiffness at the fracture site that ultimately impacts functional rehabilitation. Simpler fractures (Schatzker I–IV) often have a less severe soft-tissue injury and may benefit from immediate surgical intervention. In our study, we found no statistically significant difference in the overall perioperative complication rate in low-energy trauma patients surgically treated within 48 hours versus those managed with delayed intervention.
Case Report
A 46-year-old man presented to the emergency department with a right leg tibial plateau fracture (Schatzker VI) following a motor-vehicle collision. Imaging revealed a comminuted fracture of the proximal third of the tibial diaphysis with superior extension into the metaphysis (Figures 2 and 3). The lateral depression was 1.5 cm, and the patient underwent ORIF within 14 hours. A 13-hole plate was placed on the anterolateral aspect of the tibia. Distally, a combination of regular and locking screws was placed. Proximally, one regular screw and three locking screws were used (Figure 4). Synthetic bone graft and calcium triphosphate were applied at the tibial plateau region. A prophylactic fasciotomy of the anterolateral compartment was performed to reduce the risk of compartment syndrome, followed by skin closure. Plain radiographs were taken postoperatively (Figures 5 and 6).
were no immediate complications after surgery, and the patient was discharged home with a knee immobilizer and non-weight bearing status. At 1-week follow up the patient’s motor and sensory function was intact. There was appropriate postoperative swelling with no signs of infection. He initiated range of motion exercises and physical therapy. At his 6-week follow-up, he started at 25.0% partial weight bearing with progression to full weight bearing status. At his 3-month follow-up, he was using a cane to assist with ambulation. He could fully extend the right knee with approximately 110° of flexion. Radiographs showed intact plate and screws, good alignment, and fracture line with proper healing (Figure 7). At 2 years postoperatively, the patient regained full function. X-rays demonstrated a well-healed fracture with proper joint alignment and no evidence of hardware loosening or breakage (Figure 8).

Limitations and Considerations
Patients were generally followed 1 to 3 months postoperatively, with a select few followed up to 24 months. We would have liked to track patient data for up to 12 months postoperatively across the board. However, given the hospital’s unique location, most outpatient follow-up was completed at sites outside the hospital’s network. Longer-term follow-up data could reveal a higher-than-usual complication rate. Data were obtained from a level-1 trauma center located along the United States-Mexico border, with a preference for Hispanic and Mexican-American patients. Data may not be generalizable to other ethnic groups.

Other considerations include an in-depth analysis of the use of peripheral nerve blocks in our patient population. Given its relative modern outlook, it was not included in this study. However, it is worth noting that its implementation in patients with tibial plateau fractures has positively impacted outpatient management by decreasing perioperative opioid use, hospital length-of-stay, and other iatrogenic complications. It would be worth analyzing and implementing such trends moving forward because they could potentially magnify the impact of the findings of this study.

CONCLUSION
We have observed that many low-energy fractures may be safely operated within the first 48 hours without a significant increase in complication rates. The orthopaedic surgeon should base their approach on both fracture pattern and soft-tissue integrity. Further investigative efforts are warranted to solidify current advancements of optimal treatment of tibial plateau fractures.
REFERENCES


Risk Factors for the Development of a Symptomatic Contralateral Discoid Lateral Meniscus

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Funding The authors received no financial support for the research, authorship, and publication of this article.

Conflict of Interest The authors report no conflicts of interest.

Acknowledgements We would like to thank Gayle Allenback, our Research Coordinator, for assisting with organization and submission.

ABSTRACT

Background: Discoid menisci (DM) are oval or disc-shaped menisci, differing from the normal crescent shaped menisci. This difference in shape may be one factor as to why DM are more prone to injury when compared to normal menisci. The purpose of this study was to evaluate potential risk factors that may lead to the development of symptoms, requiring arthroscopic sauerization in adolescents with a history of symptomatic DM in the contralateral extremity.

Methods: We retrospectively reviewed 126 patients with an arthroscopic diagnosis of DM to evaluate for the presence of a symptomatic contralateral DM variant. Mildly symptomatic DM status was identified by patient need for operative intervention, including a pain or popping sensation of the knee. We performed statistical analysis to identify potential risk factors predisposing patients to the development of symptomatic DM in the contralateral extremity, ultimately requiring operative intervention.

Results: Of the 126 patients identified with lateral DM, 21 patients had a subsequent symptomatic contralateral DM that required operative intervention, while the remaining 105 patients may have had an asymptomatic DM variant of the contralateral knee. Patients who actively participated in sports, particularly basketball, and patients less than 10.8 years old were at higher risk for developing symptomatic contralateral DM requiring operative intervention.

Conclusions: Younger patients participating in athletics presenting with symptomatic lateral DM are at increased risk of developing symptoms requiring operative intervention in the contralateral knee.

Keywords: Discoid Lateral Meniscus, Contralateral, Symptomatic, Knee, Adolescent, Arthroscopy

INTRODUCTION

Discoid meniscus (DM) is a common congenital anatomical variation found in children and was first described by Young et al in 1889. In the literature, the reported incidence of DM varies from 0.4% to 17.0%, but it ultimately depends on the specific population being studied and discoid laterality involvement. Smillie et al performed the largest study of DM incidence of nearly 10,000 meniscectomy patients and reported an incidence of 4.7%. Several smaller studies have supported the findings of Smillie et al, reporting values between 3.5% to 5.0%. However, incidences are likely underreported owing to most discoid variants having no symptoms. Resultantly, the reported value for the incidence of DM can be more reliably interpreted using the incidence of symptomatic discoid variants.

Similar dilemmas arise when determining bilateral DM incidence, with a reported incidence rate of approximately 20.0%. Previous studies mainly include surgical patients and do not reflect the true incidence of bilateral DM. Recent publications have suggested that bilateral discoid variants are more common than previously reported. Connolly et al reported bilateral DM in 9 of 10 patients who underwent bilateral imaging, substantiated by 11 out of 33 (33.0%) cases of lateral DM with tears. In a Japanese cadaveric study, menisci of the same shape were found in the bilateral knees of 253 of 279 (91.0%) cadavers. Therefore, identifying unilateral, symptomatic DM increases the incidence of asymptomatic DM in the contralateral knee. Ahn et al and Bae et al reported that magnetic resonance imaging and arthroscopic evaluation reveals bilateral DM rates as high as 79.0% to 97.0% in patients presenting with unilateral, symptomatic lateral DM.

In this study, we aimed to identify any risk factors that may predispose patients who underwent operative intervention for a symptomatic DM to symptomatic progression of DM of the contralateral knee.
METHODS

Data Gathered
After obtaining exemption status from our Institutional Review Board, we reviewed medical records, radiographic studies, operative reports, and arthroscopic images of 126 patients. All patients were treated arthroscopically for symptomatic DM of the initial knee at presentation by a single surgeon between 2006 and 2017. Data collected included sex, age at the time of surgery, participation in sports, sport type, the need for operative intervention for the contralateral knee, and follow-up length. DM morphology was recorded, including if a meniscal tear was present and whether the lesion was complete, incomplete, or Wrisberg type.

Procedures
DM morphology and stability of the ipsilateral knee were determined during operative intervention under direct visualization and probing. Arthroscopic sauceration of the ipsilateral knee was performed with standard arthroscopic shavers and bitors to restore the normal shape of the meniscus. In the presence of meniscal tears, a meniscectomy was performed until the meniscus was deemed to be stable based on arthroscopic probing. Repairs were performed when standard meniscal repair indications were met.

Statistical Methods
We calculated descriptive statistics, including frequencies, means, and standard deviations for the total population and subgroups using Excel (Microsoft; Redmond, WA). Comparison groups were unilateral DM injury and bilateral DM injury. Univariate comparison between groups was performed using student t-tests and Fisher’s exact tests when appropriate. Multivariate logistic regression was performed for independent variables, which predicted the binary outcome of unilateral or bilateral DM injury using SAS 9.4 (SAS: Cary, NC). An efficient multivariate model was selected based on forward selection methods while controlling for demographic variables. Significance level was set at \( P < 0.05 \) with no adjustment for multiple testing.

RESULTS
We reviewed a total of 126 cases of patients with symptomatic DM undergoing arthroscopic debridement or sauceration. Demographic data for the entire population is presented in Table 1. Mean age was 12.6 years (standard deviation = 3.39). Approximately 125 (99.2%) of the study population underwent sauceration at the time of debridement or received both debridement and repair.

Risk Factor Rates
Among the population, 21 patients (16.7%) subsequently presented for contralateral knee pain and were eventually diagnosed with a contralateral, symptomatic DM (bilateral grouping). Comparison of population differences between patients with unilateral or bilateral injury can be seen in Table 2. Upon initial presentation, patients with bilateral discoid injury were on average younger than those presenting with only single-sided symptoms (10.8 years vs 12.9 years, respectively, \( P = 0.008 \)). Additionally, there was a higher frequency of overall sports participation for those with bilateral involvement (Table 3, \( P = 0.001 \)). All patients with bilateral involvement participated in sports; however, when compared by specific sport, bilateral cases were only found to be significantly associated with basketball participation (Table 3, \( P = 0.038 \)). No differences were found between populations regarding sex, type of discoid, presence of a discoid tear or lateral femoral condyle osteochondritis dissecans lesion, or operative procedures performed.

Univariate logistic regression was performed on all independent variables predicting the binary outcomes of unilateral versus bilateral involvement (Table 4). Sport (as a binary variable) and sauceration were excluded from the analysis because they had a 100.0% frequency and correlation among bilateral cases, which prevented the logistic regression from convergence.

<table>
<thead>
<tr>
<th>Variable</th>
<th>n (%), n = 126</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, mean (SD)b</td>
<td>12.6 (3.39)</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>50 (39.7%)</td>
</tr>
<tr>
<td>Female</td>
<td>76 (60.3%)</td>
</tr>
<tr>
<td>Discoid Type</td>
<td></td>
</tr>
<tr>
<td>Unknown</td>
<td>3 (2.4%)</td>
</tr>
<tr>
<td>I</td>
<td>55 (43.7%)</td>
</tr>
<tr>
<td>II</td>
<td>56 (44.4%)</td>
</tr>
<tr>
<td>III</td>
<td>12 (9.5%)</td>
</tr>
<tr>
<td>Torn Discoid</td>
<td>69 (54.8%)</td>
</tr>
<tr>
<td>Saucerization</td>
<td>125 (99.2%)</td>
</tr>
<tr>
<td>Repair needed</td>
<td>57 (45.2%)</td>
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<tr>
<td>Re-operation</td>
<td>80 (63.5%)</td>
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<td>Associated LFC OCD</td>
<td>4 (3.2%)</td>
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<tr>
<td>Sport Participation</td>
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<tr>
<td>Basketball</td>
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<tr>
<td>Soccer</td>
<td>28 (22.2%)</td>
</tr>
<tr>
<td>Football</td>
<td>16 (12.7%)</td>
</tr>
<tr>
<td>Gymnastics/Cheer/Dance</td>
<td>16 (12.7%)</td>
</tr>
<tr>
<td>Other</td>
<td>14 (11.1%)</td>
</tr>
<tr>
<td>No Sport</td>
<td>35 (27.8%)</td>
</tr>
<tr>
<td>Bilateral Discoid</td>
<td>21 (16.7%)</td>
</tr>
</tbody>
</table>

SD, Standard Deviation; LFC OCD, lateral femoral condyle osteochondritis dissecans

\*Values for age reported as mean and standard deviation. All other values are reported as frequencies with percentages in parentheses.
Among the population, 21 patients (16.7%) subsequently presented for contralateral knee pain and were treated arthroscopically for symptomatic DM of the ipsilateral knee, a meniscectomy was performed until the meniscus was deemed to be stable based on arthroscopic images of 126 patients. All patients were treated with debridement and repair procedures, and saucerization. Demographic data for the entire total population and subgroups using Excel (Microsoft; Cary, NC). An efficient multivariate model was selected after obtaining exemption status from our institutional review board. 

Univariate logistic regression was performed on all independent variables predicting the binary outcomes of DM morphology and stability of the ipsilateral knee. The majority of patients had unilateral meniscal involvement, with type Watanabe Type I variants comprising the majority of repairs and produced unrealistic odds ratios (ORs). As such, we have included each sport as a separate binary variable. Only two independent variables significantly predicted cases with bilateral involvement, age, and basketball participation. Age was treated as a continuous variable. For each 1-year increase in age at initial presentation of the ipsilateral knee, there was approximately a 17.0% decrease in the odds of having a contralateral or bilateral discoid injury (OR = 0.83, 95.0% confidence interval (CI) 0.72-0.96, P = 0.011). Patients that participated in basketball were 3.4 times more likely to have a bilateral discoid injury (OR = 3.42, 95.0% CI 1.10-10.63, P = 0.034).

A multivariate logistic model was created by forward selection means. For control purposes, predictive variables included in the final model were age (P = 0.012), basketball participation (P = 0.048), and gender (P = 0.53)(Table 5). ORs among the variables were similar to their univariate counterparts. The final model presented in Table 5 yielded an adjusted r² = 0.15.

### Table 2. Comparison of Unilateral and Bilateral Discoid Meniscus

<table>
<thead>
<tr>
<th>Variable</th>
<th>Unilateral n (%)</th>
<th>Bilateral n (%)</th>
<th>P-Value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, mean (SD)</td>
<td>12.9 (3.4)</td>
<td>10.8 (2.8)</td>
<td>0.008</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>44 (41.9)</td>
<td>6 (28.6)</td>
<td>0.331</td>
</tr>
<tr>
<td>Female</td>
<td>61 (58.1)</td>
<td>15 (71.4)</td>
<td></td>
</tr>
<tr>
<td>Discoid Type</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unknown</td>
<td>3 (2.9)</td>
<td>0 (0)</td>
<td>0.345</td>
</tr>
<tr>
<td>I</td>
<td>49 (46.7)</td>
<td>6 (28.6)</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>43 (41.0)</td>
<td>13 (61.9)</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>10 (9.5)</td>
<td>2 (9.5)</td>
<td></td>
</tr>
<tr>
<td>Torn Discoid</td>
<td>55 (52.4)</td>
<td>14 (66.7)</td>
<td>0.337</td>
</tr>
<tr>
<td>Saucerization</td>
<td>104 (99.0)</td>
<td>21 (100)</td>
<td>1.000</td>
</tr>
<tr>
<td>Repair needed</td>
<td>48 (45.7)</td>
<td>9 (42.9)</td>
<td>1.000</td>
</tr>
<tr>
<td>Re-operation</td>
<td>68 (64.8)</td>
<td>12 (57.1)</td>
<td>0.621</td>
</tr>
<tr>
<td>Associated LFC OCD</td>
<td>2 (1.9)</td>
<td>2 (9.5)</td>
<td>0.129</td>
</tr>
</tbody>
</table>

SD, standard deviation; LFC OCD, lateral femoral condyle osteochondritis dissecans.

*Significant values (<0.05) bolded. Fisher’s exact test was used for comparison of categorical variables.

### Table 3. Comparison of Sport Type by Discoid Laterality

<table>
<thead>
<tr>
<th>Sport</th>
<th>Unilateral n (%)</th>
<th>Bilateral n (%)</th>
<th>P-Value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basketball</td>
<td>11 (10.5)</td>
<td>6 (28.6)</td>
<td>0.038</td>
</tr>
<tr>
<td>Soccer</td>
<td>24 (22.9)</td>
<td>4 (19.0)</td>
<td></td>
</tr>
<tr>
<td>Football</td>
<td>13 (12.4)</td>
<td>3 (14.3)</td>
<td>0.730</td>
</tr>
<tr>
<td>Gymnastics/Cheer/Dance</td>
<td>11 (10.5)</td>
<td>5 (23.8)</td>
<td>0.143</td>
</tr>
<tr>
<td>Other</td>
<td>11 (10.5)</td>
<td>3 (14.3)</td>
<td>0.703</td>
</tr>
<tr>
<td>Any Sport</td>
<td>70 (66.7)</td>
<td>21 (100)</td>
<td>0.001</td>
</tr>
</tbody>
</table>

*Significant values (<0.05) bolded. Fisher’s exact test was used for comparison of categorical variables.
The current recommendation for treatment of symptomatic DM is conservative management, including rest, physical therapy, nonsteroidal anti-inflammatory drugs, activity modification, and observation for possible transition of asymptomatic into symptomatic DM in the contralateral knee. Operative intervention with arthroscopic saucerization is only considered in cases of persistently symptomatic menisci or the presence of a meniscal tear. Classic symptoms of DM include pain, popping, snapping, and decreased knee extension. 

Historically, treatment for DM was a total meniscectomy. More recently, there have been vast improvements in arthroscopic surgical techniques, and the importance of meniscus preservation has become evident, resulting in meniscus-sparing procedures becoming the gold standard. Complete meniscectomies are avoided because of the high rate of osteoarthritic changes seen at long-term follow-up. These changes are due to the impaired ability of the meniscus to transmit loads and stabilize the knee joint.

Of the multiple classification systems of lateral DM proposed, the Watanabe system (Figure 1) is the most common and widely used. Watanabe described three major DM variants: 1) complete, disc-shaped meniscus covering the tibial plateau; 2) incomplete, semilunar-shaped meniscus with partial tibial plateau coverage; and 3) Wrisberg-type, hypermobile meniscus resulting from deficient posterior meniscotibial attachments. Both the incomplete and Wrisberg types have been associated with higher risks of meniscal tears, typically resulting in complex tear patterns that lead to large meniscal resections, commonly requiring subtotal or total meniscectomies to achieve stability. Several studies have theorized why DM are more prone to tearing. One theory is that DM is thicker with poorer vascularity than normal menisci. In Wrisberg types, the decreased peripheral attachments lead to increased mobility and a higher incidence of tearing. Evidence also suggests that the compositional arrangement of DM itself can be predisposed to meniscus tearing, owing to the number and orientation of collagen fibers that differ from normal menisci. Normally, menisci contain inner circular fibers that allow for the dissipation of hoop stresses during weight bearing and peripheral radial fibers, typically completed in two functions. The first function is to protect circular fibers from tearing, and the second function is to serve as an anchor to the joint capsule. The fibers of DM are disorganized and smaller in number, resembling the characteristics in a degenerating meniscus, resulting in the decreased meniscal ability to dissipate hoop stresses during weight bearing. Decreases in collagen concentration and an inability to effectively dissipate hoop stresses predispose the DM to tears. Rohren et al found that the incidence of tears in DM is significantly higher when compared to those with normal semilunar meniscus (71.0% vs 54.0%, respectively). Other studies have shown an increase in the incidence of either lateral or medial DM tears, ranging between 38.0% and 88.0%. Bilateral DM have a reported incidence ranging from 5.0% to 20.0%. However, these studies reported incidence based on patients that developed symptoms requiring operative intervention in opposite knees after the affected knees had already been treated. Of these, between 54.0% to 84.0% were operated on, secondary to the torn menisci in the contralateral knee. In our series, the incidence of symptomatic bilateral DM was 16.0% (21 of 126 patients) among patients treated by arthroscopic saucerization with or without a meniscal repair. Of these, all 21 patients participated in sports. Approximately 14 (66.7%) developed symptoms secondary to a meniscal tear in the contralateral knee. We identified several characteristics that lead to an increased risk of developing a symptomatic contralateral DM. Patients younger than 11 years old and patients active in athletics, especially those participating in basketball, resulted in a higher risk for developing a symptomatic contralateral DM that required operative intervention. Although statistically significant, basketball participation does not appear to demonstrate clinical relevance. Two-thirds (66.0%) of the time, symptoms began as a result of a contralateral DM tear. In the presence of a tear, the saucerization and resection plane is determined by the tear pattern and the stability of the remaining tissue, typically resulting in larger meniscectomies. In contrast, during saucerization for DM in which there is no tear present, the operating surgeon could resect only what was necessary to resemble a normal semilunar meniscus. This technique will result in a much smaller meniscectomy mimicking the shape and stability seen in a normal semilunar meniscus. We hypothesize that earlier and more aggressive strategies in the diagnosis and treatment of young, active patients may afford the treating surgeons more control over the
meniscal resection. Comparative studies of different treatment strategies for DM that access clinical differences may be a possible area of future research.

In conclusion, the presence of symptomatic DM in the ipsilateral knee increases the risk of the development of future symptomatic DM in the contralateral knee. Several factors increase the risk of development of DM in the contralateral knee, including younger age, participation in sports (particularly basketball), and bilateral discoid injury. Identification of these risk factors will allow clinicians to better identify asymptomatic DM of the contralateral knee before symptomatic progression. Further studies, such as comparing treatment strategies for DM, are required to address treatment options once an asymptomatic DM of the contralateral knee is identified.

REFERENCES

Hamstring Strength Recovery in Relation to Landing Patterns Following Anterior Cruciate Ligament Reconstruction: A Case Comparison Report

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Funding This project was supported in part by the National Center for Research Resources and the National Center for Advancing Translational Science of the National Institutes of Health through grant number UL1TR001449, at The University of New Mexico Clinical and Translational Science Center.

Conflict of Interest The authors declare no conflicts of interests.

Acknowledgments We would like to thank Dr. Minner, Mrs. Baca, and our research coordinators and staff at The University of New Mexico Clinical and Translational Science Center for assistance in data collection. Also, special thanks to Mr. Killinger and Mrs. Atencio for their assistance in coordinating this project.

ABSTRACT

Introduction: Deficits in quadriceps strength following anterior cruciate ligament reconstruction (ACLR) are common and can be associated with biomechanical asymmetries during landing tasks. The relationship between quadriceps strength and knee function during ACLR recovery is well established. However, less is known regarding the role of hamstring strength in functional recovery after ACLR. We examined movement patterns during a drop-landing task in three patients following ACLR with different levels of quadriceps and hamstring strength.

Methods: Three participants were assessed for quadriceps and hamstrings strength, functional performance, and lower-extremity biomechanics captured by a 3D motion analysis 6 months after ACLR. We examined movement patterns during a drop-landing task in three patients following ACLR with different levels of quadriceps and hamstring strength.

Results: Participant one, who presented with relatively recovered quadriceps and hamstring strength of the operated limb, demonstrated the highest limb symmetry indices across multiple tests compared to the other two participants. Participant two, who had insufficient recovery in quadriceps strength yet preserved hamstring strength, demonstrated similar recovery in drop-landing mechanics than participant one and a lower overall hop performance than participant one. Participant three, who had residual deficits in both quadriceps and hamstring strength, exhibited the largest asymmetries in overall hop performance, vertical ground reaction force, and knee flexion angle upon bilateral landing.

Conclusion: This study suggests that quadriceps strength alone does not account for variability in functional recovery and altered biomechanics following ACLR. It is important to evaluate both quadriceps and hamstring strength as indicators for functional recovery and readiness for return to sport after ACLR.

Keywords: Anterior Cruciate Ligament Reconstruction, Functional Performance, Muscle Strength Dynamometer, Hamstring Muscles, Quadriceps Muscles

INTRODUCTION

Injury to the anterior cruciate ligament (ACL) is common among competitive athletes.\(^1\) ACL reconstruction (ACLR) reflects the mainstay of treatment for ACL injuries in athletes, with the goals of promoting a safe return to sport and restoring knee stability and kinematics.\(^2,3\) However, many athletes undergoing ACLR fail to achieve pre-injury activity levels. A recent meta-analysis suggested that nearly half of individuals do not reach pre-injury activity levels following ACLR,\(^4\) and the likelihood of return to sport may be as low as 19.0% in certain athletic populations.\(^5\) A variety of factors may limit functional recovery, including age,\(^4,6\) impaired quadriceps strength of the injured limb, altered biomechanics,\(^4,7,8\) and psychological responses.\(^9,11\)

Following ACLR, recovery of quadriceps strength of the injured limb is often used as one of several clinical factors to gauge readiness for return to sport.\(^8,12\) Yet, only about 20.0% of patients can achieve near symmetric quadriceps strength by 6 months after ACLR,\(^7,13\) and some patients demonstrating persistent ipsilateral quadriceps weakness as long as 5 years after ACLR.\(^14,15\) Recovery and symmetry of functional
movement have also been used to assess readiness for return to sport. The Landing Error Scoring System (LESS) test has been established to evaluate the risk of ACL injury and clarify the appropriateness of return to sport after ACLR. Kuenze et al suggested that residual quadriceps weakness may be associated with impaired functional movement and lower LESS scores. Other studies have indicated that quadriceps weakness after ACLR is associated with reduced knee joint moments and ground reaction forces, which is known as the “stiff” knee landing pattern. This pattern can contribute to excessive knee valgus and increased torsional forces, subsequently placing undesirable stress on the reconstructed ACL. Consequently, quadriceps strength and lower-extremity biomechanics have become pivotal in promoting and predicting return to pre-injury activity levels, including sport.

While significant research has focused on quadriceps strength, hamstring strength is also likely to influence lower-extremity biomechanics and successful return to sport after ACLR. Insufficient hamstring recovery in the injured limb has been reported in up to 50.0% of patients undergoing ACLR. Blackburn et al reported that higher hamstring viscoelasticity may be associated with reduced anterior tibial shear forces and lower peak knee valgus moment during landing, which may, in turn, lower the risk of ACL injury. There remains a relative lack of evidence to explain the biomechanical role of hamstring strength in predicting clinical outcomes, including return to competition following ACLR. This case comparison report is designed to examine different movement patterns during landing tasks according to the varying recovery of both quadriceps and hamstring strength after ACLR. We hypothesized that the greater strength of both muscles would be associated with improved landing patterns.

METHODS

Participants

We evaluated three competitive athletes between the ages of 21 and 23 years who sustained an ACL tear and underwent ACLR (Table 1). Participant one was primarily reconstructed with a quadriceps tendon autograft using a bone plug. Participant two initially underwent bone-patellar tendon-bone autograft and subsequently required revision with a soft-tissue quadriceps tendon autograft. Participant three was managed primarily with a soft-tissue quadriceps tendon autograft. Participant three also suffered a simultaneous medial collateral ligament (MCL) tear that was reconstructed with a hamstring tendon autograft.

The three participants were differentiated by lower-extremity strength 6 months after ACLR. Quadriceps and hamstring strength were assessed by maximal voluntary isometric contraction using a dynamometer (Biodex Medical Systems, Inc; Shirley, NY). Strength testing was performed bilaterally, with the participant seated, the hip flexed to 110°, and the knee flexed to 90°. The hip flexion and knee flexion angles were standardized and set on the Biodex dynamometer for all participants. Participants were provided with up to three submaximal practice trials. Peak torque over a 5-second contraction was then recorded for three trials with a 1-minute rest between trials to minimize fatigue. As per standard protocol, the highest value among the three trials was used for the analysis. Quadriceps and hamstring strength of the injured and non-injured limbs were recorded.

Testing Procedures

In addition to muscle-strength testing as outlined previously, all participants underwent functional movement assessment and biomechanical motion analysis 6 months postoperatively. Participants performed all physical testing wearing their own athletic footwear.

Functional Movement Assessment

Functional movement assessment included timed lateral step-down, lateral leap and catch, square hop test and hop sequences (ie, timed hop, single-leg hop, triple hop, and crossover hop). All included tests have established test-retest reliability and are often used in clinical settings. All participants were supervised during testing, and they were provided with adequate rest to prevent fatigue or missteps during testing.

Biomechanical Assessment

A ten-camera Vicon Motion Capture System with Vicon Nexus software (Vicon Motion Capture Systems Ltd; Oxford, UK) synchronized with three force plates (AMTI; Watertown, MA) captured each participant’s torso and lower extremity during a drop-landing maneuver. Kinematic and kinetic data were integrated for simultaneous collection at 100 Hz and 1000 Hz, respectively. Additionally, two digital cameras (Vicon Motion Capture Systems Ltd; Oxford, UK) were used in the frontal and sagittal planes to determine functional quality during the drop-landing task. A total of 48 reflective markers (14 mm diameter) were placed on bony prominences to determine the center of each joint and the end of individual body segments, based on 6° of freedom as previously reported. We performed a standing calibration to define joint centers and distinguish a coordinate system for each body segment before motion analysis.

Each participant was recorded while performing a double leg drop jump from a 30-cm step. A total of three usable attempts were recorded for each participant. Participants were instructed to drop off of the box with both feet simultaneously, land with each foot on separate force plates, and then immediately perform a maximal effort vertical jump in place.

Data Analysis

A post-capture analysis was conducted (Visual 3D; Germantown, MD) to calculate joint kinematics and kinetics. A post-capture analysis was conducted (Visual 3D; Germantown, MD) to calculate joint kinematics.
and kinetics. Microsoft Excel (Microsoft Corporation; Redmond, WA) was used for statistical analysis. Descriptive statistics were used to compare functional movement scores and biomechanical measures across participants. A limb symmetry index (LSI) was calculated for strength and hop sequence performance as the injured limb result divided by the non-injured limb result multiplied by 100 (\(\text{LSI} = \frac{\text{injured limb result}}{\text{non-injured limb result}} \times 100\)). The hamstrings quadriceps index was calculated for the injured limb as hamstring strength divided by quadriceps strength multiplied by 100 (\(\text{hamstrings} \quad \text{quadriceps index} = \frac{\text{hamstrings MVIC}}{\text{quadriceps MVIC}} \times 100\)).

**RESULTS**

**Quadriceps and Hamstring Strength**

Participant one demonstrated relatively symmetric quadriceps and hamstring strength between injured and non-injured limbs. Participant two demonstrated significantly reduced quadriceps strength of the injured limb but relatively symmetric hamstring strength. Participant three demonstrated significantly reduced quadriceps and hamstring strength of the injured limb. The classification for each case based on the quadriceps and hamstring strength is presented in Table 1.

**Functional Movement Assessment**

For the affected limb, limb symmetry indices for the timed hop, triple hop distance, crossover hop distance tests, and mean hop performance across the three tests are reported in Table 2. Participant one showed relative symmetry during functional movement assessment, with hop performance LSIs between 84.0% to 108.0% and an overall mean hop performance LSI of 91.0%. Participant two demonstrated hop performance LSIs between 71.0% to 88.0%. Participant three demonstrated the greatest limb asymmetry during timed hop, triple hop, and crossover hop tests, with LSIs between 54.0% to 56.0%.

**Biomechanical Analysis**

For the drop-landing task, all three participants showed significantly lower vertical ground reaction forces through their injured limb following ACLR (Figure 1). Data collected for knee kinematics during

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**Table 1. Isometric Muscle Strength and Limb Symmetry Indexes**

<table>
<thead>
<tr>
<th></th>
<th>Participant 1</th>
<th>Participant 2</th>
<th>Participant 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>21 years</td>
<td>23 years</td>
<td>21 years</td>
</tr>
<tr>
<td>Gender</td>
<td>Female</td>
<td>Female</td>
<td>Female</td>
</tr>
<tr>
<td>Body Mass Index (kg/m²)</td>
<td>18.6</td>
<td>27.2</td>
<td>21.5</td>
</tr>
<tr>
<td>Graft Type</td>
<td>Quadriceps autograph with bone plug</td>
<td>Primary: Patella BTB autograph</td>
<td>Soft tissue quadriceps autograph</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Revision: Soft tissue quadriceps autograph</td>
<td>MCL with hamstring autograph</td>
</tr>
<tr>
<td>Participated Sports</td>
<td>soccer</td>
<td>rugby</td>
<td>rugby</td>
</tr>
<tr>
<td>Quadriceps MVIC Operated (N•m)</td>
<td>98.3</td>
<td>43.9</td>
<td>53.3</td>
</tr>
<tr>
<td>MVIC Non-operated (N•m)</td>
<td>135.4</td>
<td>239.3</td>
<td>125.6</td>
</tr>
<tr>
<td>LSI</td>
<td>72.6%</td>
<td>18.3%</td>
<td>42.4%</td>
</tr>
<tr>
<td>Hamstrings MVIC Operated (N•m)</td>
<td>67.3</td>
<td>53.7</td>
<td>19.4</td>
</tr>
<tr>
<td>MVIC Non-operated (N•m)</td>
<td>73.2</td>
<td>55.2</td>
<td>72.5</td>
</tr>
<tr>
<td>LSI</td>
<td>91.9%</td>
<td>97.3%</td>
<td>26.8%</td>
</tr>
<tr>
<td>Injured Hamstrings Quadriceps Index</td>
<td>68.46%</td>
<td>122.32%</td>
<td>36.40%</td>
</tr>
</tbody>
</table>

**Table 2. Hop Performance Limb Symmetry Indices**

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Participant 1</th>
<th>Participant 2</th>
<th>Participant 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timed Hop</td>
<td>87.19%</td>
<td>71.43%</td>
<td>54.04%</td>
</tr>
<tr>
<td>Triple Hop Distance</td>
<td>84.51%</td>
<td>73.39%</td>
<td>53.97%</td>
</tr>
<tr>
<td>Crossover Hop Distance</td>
<td>83.99%</td>
<td>84.69%</td>
<td>56.21%</td>
</tr>
<tr>
<td>Overall Hop LSI</td>
<td>91.00%</td>
<td>79.56%</td>
<td>88.81%</td>
</tr>
</tbody>
</table>

LSI, limb symmetry index

*The hamstrings quadriceps index is a value of strength comparing the quadriceps strength to the hamstrings strength in the operated limb for each participant.

*The limb symmetry index (LSI) between injured and non-injured limbs of each subject for each of the 4 hop performance measures as well as overall hop performance.
the drop-landing task are shown in Figure 2. All three participants demonstrated reduced peak knee flexion of the injured limb when compared to the non-injured limb. Participants one and two exhibited substantially greater limb symmetry in knee flexion, with LSI greater than 90.0% compared to participant three (LSI, 80.0%). In addition, participants one and three demonstrated higher peak knee adduction angles of the injured limb when compared to the non-injured limb. Participant two exhibited greater peak knee adduction angles of both the injured and non-injured limbs when compared to the other two participants; however, knee adduction angles were relatively greater on the non-injured limb when compared to the injured limb.

DISCUSSION

In this study, we analyzed the functional and biomechanical characteristics of three competitive athletes 6 months after they underwent ACLR with different grafts. Despite established clinical expectations, all participants demonstrated inter-limb asymmetry during hop performance tests (LSI, 79.6%-91.0%). Patterns of inter-limb asymmetry were apparent across all hop tests, except the single-leg hop for distance test. Cristiani et al. found no correlation between quadriceps or hamstrings LSI greater than or equal to 90.0%. The single-leg hop test performance could explain why the participants demonstrated high variability when performing this
test despite three distinct strength presentations. Excluding single-leg hop test for distance, mean limb asymmetry indices for hop performance were 82.5% for participant one, 76.5% for participant two, and 54.7% for participant three.

An interesting finding in this case series is the apparent influence of persistent hamstring weakness on functional and biomechanical outcomes after ACLR. Overall hop performance symmetry declined from participants one to three as the quadriceps and hamstring strength symmetry also declined. Similarly, vertical ground reaction force and peak knee flexion symmetry decreased with decreasing quadriceps and hamstring strength symmetry. It is important to note that participant three had a concurrent MCL reconstruction utilizing a hamstring autograft, which may have contributed to more severely reduced hamstring strength and LSI. The more extensive surgical intervention in participant three may have also resulted in a slower recovery trajectory than participants one and two, accounting in part for lower overall strength at 6 months postoperatively. Regardless, the fact remains that relative hamstring strength appears to influence functional performance following ACLR. Konrath et al. showed deficits in hamstring muscle size and knee flexion strength 2 years after ACLR with a hamstring autograft. Another recent study compared short-term Biodex strength results among three groups (ie, quadriceps graft, bone-patella tendon-bone graft, and hamstring graft) following ACLR. The authors demonstrated that persistent quadriceps or hamstring tendon weakness following quadriceps tendon or hamstring ACLR, respectively, may last up to 15 months. These results indicate that current rehabilitation, including graft-specific protocols incorporating neuromuscular training, is inadequate despite established evidence-based protocols.

Our findings are consistent with previous studies demonstrating an association between quadriceps strength, functional performance, and biomechanical performance across dynamic tasks. Our findings add to the current literature by suggesting that quadriceps strength alone does not account for variability in functional and biomechanical measures following ACLR. Recovery of hamstring strength also plays an important role in determining functional restoration. We reviewed “accelerated” ACLR rehabilitation protocols prescribed by orthopaedic surgeons and found many surgeons begin quadriceps sets immediately after surgery. They also focus on gaining quadriceps strength within the first 4 to 6 weeks following surgery to allow for full weight bearing without any bracing. There is no mention of strengthening hamstrings in some of these protocols until 4 to 6 weeks following surgery. While some protocols mention no active range of motion or strengthening of hamstrings for a period of time following a hamstring autograft, other protocols using alternate graft options still do not incorporate hamstrings strengthening until at least 1 month after surgery. Although better functional outcomes and symmetrical landing maneuvers are significantly correlated with the quadriceps strength of the operated limb, obtaining greater than 90.0% quadriceps strength symmetry is only one piece to the puzzle related to a safe return to sport. Because varied physical therapy protocols exist, the standardized evaluation and plan of care remain controversial.

For example, many clinics are not able to measure accurate quadriceps strength due to the required expensive equipment (ie, isokinetic dynamometer). Yet, recent studies describe excellent reliability in quadriceps strength assessments through a handheld dynamometer and introduce valid functional performance-based tests to assess quadriceps strength, which could become reasonable options for clinicians. Additionally, some evidence-proven interventions are not routinely applied, such as neuromuscular electrical stimulation and open-chain exercises. As shown in the current study, hamstring strength also needs to be a critical focus and regularly assessed, particularly for hamstring autograft patients.

Limitations
Due to the recruitment process, these three participants underwent varied surgical techniques, including graft selection. Postoperative rehabilitation was not standardized. Thus, we cannot rule out differences in the surgical approach or the rehabilitation process as factors influencing observed strength, functional performance, and biomechanics across participants. The site of autograft harvesting in each participant and concurrent MCL reconstruction in participant three are important to note. All three participants had an autograft harvested from their quadriceps. However, participant two initially had a bone-patellar-tendon-bone graft performed, and participant three had a hamstring autograft harvested for MCL reconstruction. We would suspect all three participants have affected quadriceps function, but the additional procedures performed on participants two and three may have contributed to the functional outcome measures observed at the time of testing. Furthermore, a hamstring-only graft reconstruction was not used in this small case series. Due to the small sample size, it is unknown if these results are generalizable to all ACLR patients.

Despite these limitations, our findings suggest that the restoration of both quadriceps and hamstring strength is critical to achieving optimal functional and biomechanical outcomes following ACLR. Further research with a larger sample size will provide further insight regarding the role of quadriceps and hamstring recovery and graft-specific rehabilitation protocols to optimize outcomes and return to sport following ACLR.
This case study suggests that quadriceps strength alone does not account for variability in functional recovery and altered biomechanics following ACLR. It is important to evaluate both quadriceps and hamstring strength as indicators for functional recovery and readiness for return to sport after ACLR.

REFERENCES


A Novel High Tibial Biplanar Osteotomy Technique for Simultaneous Coronal and Sagittal Correction: A Case Example

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Funding The authors received no financial support for the research, authorship, and publication of this article.

Conflict of Interest The authors report no conflicts of interest.

Informed Consent The patient was informed that the data concerning their case would be submitted for publication, and they provided verbal consent.

ABSTRACT

Medial opening wedge high tibial osteotomy (HTO) can provide symptom relief, improved ligamentous stability, and lower failure rates in patients with symptomatic medial knee osteoarthritis, ligament instability, and varus alignment after ligament reconstruction. It has been reported that correcting coronal plane abnormalities with a medial opening wedge HTO has resulted in altered posterior tibial slope angle (PTSA). We describe a 38-year-old woman with a history of severe polytrauma who presented with an anterior cruciate ligament tear in the setting of increased PTSA and a posterolateral corner injury with varus deformity of the knee. A medial biplanar HTO was performed using plate position to correct varus malalignment and decrease PTSA simultaneously. This case describes a method for simultaneously correcting varus malalignment while deliberately changing PTSA.

Keywords: High Tibial Osteotomy, Biplanar Osteotomy, Posterior Tibial Slope Angle, Genu Varum, Anterior Cruciate Ligament

INTRODUCTION

High tibial osteotomy (HTO) is a well-established treatment method for correcting knee mechanical malalignment. The knee’s biomechanical axis is commonly altered in isolated medial compartment osteoarthritis and when correcting coronal (varus and valgus) deformities in patients with ligamentous injuries of the knee. The literature has shown that correction of coronal plane abnormalities with a medial opening wedge HTO also produces alterations in the sagittal plane, potentially increasing posterior tibial slope angle (PTSA). Research has shown an increase in the incidence of failure and stress on the anterior cruciate ligament (ACL) to be associated with increased PTSA. This increased incidence and added stress emphasize the importance of thorough preoperative and intraoperative assessment to recognize and address possible PTSA changes when evaluating patients for ACL reconstruction. Savarese et al. describe a technique for evaluating PTSA changes with HTO by measuring the size of the anterior and posterior aspects of the osteotomy site. This method can be used to purposefully make changes to the PTSA or minimize inadvertent PTSA changes with HTO. We describe a simple and reproducible surgical technique for correcting varus malalignment of the knee and an associated reduction of PTSA.

CASE REPORT

A 38-year-old woman presented to our clinic for chronic left knee instability after sustaining multiple traumatic injuries. Findings of the physical examination revealed varus thrust during gait and a positive Lachman with an increased opening to varus stress at 0° and knee flexion of 30°. Initial radiographs showed 7° of varus malalignment of the tibia (Figures 1A and 1B) and a 15° PTSA (Figure 1C) with retained intramedullary nail in the left femur. The posterior tibial slope was measured using the angle between a line perpendicular to the posterior cortex of the tibia and a line tangential to the tibial plateau. A staged procedure was planned to include femoral nail removal and a biplanar medial opening wedge HTO to correct varus malalignment to neutral and decrease PTSA to 7° simultaneously. This procedure would be followed by staged ACL and posterolateral corner (PLC) reconstruction after healing of the osteotomy.

During the index procedure, a diagnostic arthroscopy of the left knee confirmed ACL and PLC tears. The intramedullary nail was extracted without incident. A reamer irrigator aspirator was used to harvest an...
intramedullary bone autograft from the left femur to graft the osteotomy. A medial approach to the proximal tibia was then performed, maintaining the pes anserine insertion. Two parallel guide pins were placed from anterior to posterior in the tibia using a parallel drill guide. To allow a visual guide during PTSA correction, we positioned one pin proximally and one pin distally to the planned osteotomy. The biplanar osteotomy was performed using an inverted-L technique previously published by Monllau et al.8 (Figure 2A).

Correction of varus malalignment was accomplished by manipulating the horizontal plane of the HTO, which was performed using a 7-mm iliac crest allograft bone wedge soaked in the intramedullary bone autograft. Allograft chips and demineralized bone matrix were also placed in the osteotomy opening. An AO TomoFix plate (Depuy Synthes; Warsaw, IN) was secured to the proximal tibia with locking screws. The plate was secured so that its distal aspect was angled slightly anterior to the anterior cortex of the tibia, allowing for posterior translation of the plate and a resultant decrease of the PTSA (Figure 2B and 2C). A Verbrugge clamp was used to rotate and compress the plate down to the tibia shaft, bringing the distal aspect of the plate posteriorly and thus reducing the PTSA (Figure 2D). Convergence of the previously placed parallel guide pins indicated successful PTSA reduction (Figure 2D). Fluoroscopy and a sterile goniometer were then used intraoperatively to measure the planned 8° of PTSA reduction precisely, resulting in a final PTSA of 7° (Figure 2E). The sterile goniometer was used to measure the change in angle of the parallel pins, plate translation off the anterior cortex of the tibia, and angle of the PTSA on fluoroscopic images. The plate was then fixed distally with bicortical locking screws (Figure 2F).

The osteotomy site was radiographically healed 3 months postoperatively, and the patient underwent ACL and PLC reconstruction 23 months later. The staged procedure was delayed for social reasons. The HTO plate was removed. ACL reconstruction with
the quadriceps autograft tendon and LaPrade-type reconstruction of the PLC were performed. At 2-year follow-up, the patient had excellent subjective function of the left knee with resolution of her instability both clinically and subjectively. Radiographs at 2 years showed maintained improved alignment (Figure 3A through 3C).

**DISCUSSION**

Several studies have shown increased rates of ACL graft failure in patients with uncorrected varus malalignment, even as little as 5°. Multiple studies have also reported increased rates of ACL graft rupture in patients with increased PTSA. In general, PTSA greater than 12° is accepted as an indication for a...
proximal tibia osteotomy to decrease the slope and reduce rates of graft failure.\(^1\) In a biomechanical study, Bernhardson et al.\(^1\) showed a linear relationship between PTSA and the amount of force placed on an ACL graft, which supports prior clinical studies\(^2,3\) showing increased graft failure rates in patients with increased PTSA.

Studies have shown that medial opening wedge HTO inadvertently increases PTSA from 2.5° to 4°, which can be unfavorable in the setting of ACL deficiency.\(^2,3,12\) Lateral knee radiographs should be carefully evaluated in patients where a medial opening wedge osteotomy is planned. The technique described in this paper can be used in patients with increased PTSA to simultaneously address coronal and sagittal plane deformities and maximize knee function. This technique reduces the likelihood for lateral cortical fractures in the intact portion of the medial opening osteotomy.

Novel techniques are needed to correct or ensure the preservation of PTSA in patients undergoing medial opening wedge HTO. As described in our case, parallel pins placed before the osteotomy can provide visual feedback on PTSA, in which convergence of the pins indicates a decrease in PTSA. Additionally, the alignment of the plate on the distal aspect of the tibia can provide another source of visual feedback intraoperatively. If the plate is fixed proximally and lying anteriorly with regard to the tibia shaft, the posterior pull of the plate will decrease PTSA.

Lateral closing wedge osteotomy may also be considered as an alternative to medial opening wedge osteotomy. Ranawat et al.\(^14\) reported that lateral closing wedge HTO allows greater PTSA neutralization when compared to medial opening wedge HTO. However, lateral closing wedge HTO allows less fine-tuning of the coronal malalignment correction and has a higher

Figure 3. Radiographs at 2 years postoperatively, including: A) bilateral anteroposterior (AP) hip to ankle alignment radiographs showing improvement in varus malalignment of the left knee. B) Bilateral knee AP radiograph. C) Lateral radiograph of the left knee showing healed osteotomy site and maintained improvement in coronal and sagittal alignment with a posterior tibial slope angle of 7°.
Bernhardson et al. showed a linear relationship between graft, which supports prior clinical studies showing PTSA and the amount of force placed on an ACL can be unfavorable in the setting of ACL deficiency. Inadvertently increases PTSA from 2.5° to 4°, which proximal tibia osteotomy to decrease the slope and address coronal and sagittal plane deformities and used in patients with increased PTSA to simultaneously in patients where a medial opening wedge osteotomy is lateral knee radiographs should be carefully evaluated pull of the plate will decrease PTSA.

Although HTO has shown utility in correcting coronal and sagittal plane malalignment, the literature showing simultaneous correction of coronal and sagittal plane deformity with a single osteotomy is limited. We describe a unique technique for treating patients with ligament insufficiency and complex deformity that can potentially decrease both graft failure rates and the progression of osteoarthritis. Further studies are needed to better understand and ultimately compare different techniques for altering coronal and sagittal alignment in simultaneous or staged procedures.

REFERENCES


Distal Radial Shaft Malunion and Distal Radioulnar Joint Instability 8 Years After Postoperative Plate Failure: A Case Report

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Acknowledgements We would like to acknowledge Kara Weber and Amber West for assisting with data collection.

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Funding The authors received no financial support for the research, authorship, and publication of this article.

Conflict of Interest The authors report no conflict of interest.

Informed Consent The patient was informed that the data concerning the case would be submitted for publication, and they provided verbal consent.

ABSTRACT

Radius shaft fractures often require operative treatment after skeletal maturity to restore functional range of motion. If the radial bow is not anatomically restored, pain and instability can occur from bony impingement and disruption of the distal radioulnar joint (DRUJ). We describe a 25-year-old woman with a radius shaft malunion and DRUJ instability. Eight years prior, at the age of 17, she underwent open reduction and internal fixation for a radial shaft fracture with subsequent reinjury at 10 weeks postoperatively. The reinjury was treated nonoperatively, and the patient went on to have painful range of motion and DRUJ instability. Radiographs at the time of presentation to our clinic revealed a bent compression plate. We performed surgical hardware removal, radial osteotomy with fixation, and DRUJ reduction. The patient healed and went on to have functional, painless range of motion with activities of daily living. While we do not have her prior records, we presume she re-fractured after her initial surgery, and the hardware subsequently failed. It is important to restore the normal radio-ulnar anatomic relationship in the forearm to give patients functional outcomes.

Keywords: Radius, Forearm, Osteotomy

INTRODUCTION

The radius and ulna are the most common fracture sites in patients younger than 20 years old.1 Nonoperative treatment with closed reduction and casting is the gold standard when treating skeletally immature patients. However, some fractures require operative fixation, especially after skeletal maturity.2 The amount of acceptable angulation and deformity is based on the patient’s skeletal maturity. For skeletally immature patients younger than 10 years old, surgeons should operatively treat radius fractures when there is greater than 20° of angulation in the distal shaft, 15° in the mid-shaft, and 10° in the proximal shaft.2,3 In adolescents and adults, anatomically restoring the radial bow is the goal to preserve functional range of motion (ROM).4,5 Adolescent patients over 10 years old have a higher risk of failing nonoperative treatment of forearm fractures than younger children, owing to decreased remodeling potential.6 Operative management is often required in the treatment of diaphyseal forearm fractures. During pronation and supination, the radius rotates around a stationary ulna with stability through the interosseous membrane.8 Disruption of the normal radio-ulnar relationship is associated with distal radioulnar joint (DRUJ) instability.9 If radial length and anatomic reduction are not achieved after reduction, patients can suffer from decreased and painful pronation and supination and DRUJ pathology.

Revision surgeries for failed implants are not benign, and the risk of complications is higher than for initial surgeries.8,9 There is no clear standard regarding the treatment of failed hardware, and implant retention with loss of reduction can lead to malunion.

We describe a patient who presented with radial shaft malunion at the site of a bent compression plate placed 8 years earlier that was not removed after reinjury.

CASE REPORT

A 25-year-old, right-hand dominant woman presented to our clinic with right forearm and DRUJ pain with ROM. A review of her medical history revealed that she fractured her right distal radial shaft at age 17 from a fall while playing tennis. She was initially treated for this injury at an outside hospital with closed reduction and casting. After 8 weeks of casting, she underwent open reduction and internal fixation (ORIF) using a volar...
and they provided verbal consent. The patient was informed that the data concerning the case would be submitted for publication, and consent was obtained. Informed Consent Conflict of Interest

The authors received no financial support for the research, authorship, and publication of this article. Funding

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Postoperative Plate Failure: A Case Report

Radioulnar Joint Instability 8 Years After Distal Radial Shaft Malunion and Distal

is important to restore the normal radio-ulnar anatomic relationship is associated with distal radioulnar joint pain and instability can occur from bony impingement on the volar interosseous membrane.5 Disruption of the normal radio-ulnar relationship results in rotational and translational instability of the distal radio-ulna joint.6

Radius, Forearm, Osteotomy

Keywords: radius, forearm, osteotomy

8 years earlier that was not removed after reinjury. We describe a patient who presented with radial shaft pain and instability 8 years after a surgical procedure. She was referred to our orthopaedic hand clinic for treatment options. On initial examination, it was observed that her right arm bowed dorsally. She had full, painful ROM in supination and pronation of her right arm, with a prominent distal ulna, mild (DRUJ) laxity, and palpable hardware. Passive pronation and supination resulted in a palpable, painful clicking over the dorsal protuberance. Radiographs of both forearms revealed that a diaphyseal distal third fracture of the radial shaft healed in varus malalignment, ulnar positive variance, with a bent six-hole plate at 27° of angulation and six screws (Figures 1A through C). Contralateral forearm films showed ulnar negative variance (Figures 1D and 1E). A small amount of lucency was noted along one of the distal screws with no other evidence of hardware loosening. Surgical treatment of the malunion and DRUJ instability were recommended.

In the operating room, a volar Henry approach to the forearm was used through the interval between the brachioradialis and flexor carpi radialis. Osteotomes were used to remove the initial hardware encased in bone and to create the osteotomy after closed DRUJ reduction under fluoroscopy. Fixation was achieved with a 3.5-mm low contact dynamic compression plate and screws (Figures 2A and 2B). After correcting her malunion and normal radial height, radiographs showed ulnar negative variance similar to her left wrist. She was discharged the same day in a splint.

Figure 1. A) Anteroposterior and B) lateral radiographs of the right forearm at the time of preoperative clinic visit. C) Photograph of patient’s forearms. D) Anteroposterior and E) lateral radiographs of the left forearm showing ulnar negative variance.

Figure 2. Immediate postoperative A) anteroposterior and B) lateral radiographs of the right wrist in a splint.

Figure 3. A) Anteroposterior and B) lateral radiographs of the right forearm at 3 months postoperatively. Note the callus formation in the osteotomy site.
At her 2-week postoperative visit, she felt well and had returned to work. At 5 weeks postoperatively, she began pronation and supination with occupational therapy. At 7 weeks postoperatively, measurements revealed a ROM of 70° for wrist flexion, 65° for extension, 75° for pronation, and 65° for supination.

At the patient’s 3-month postoperative visit, she was pleased with her decreased pain and rated it two out of ten. Radiographs showed evidence of bony healing of her osteotomy (Figures 3A and 3B). She had losses of 20° wrist extension and 30° wrist flexion, with a 20° decreased supination compared to her left side. She also noted some subjective decreased grip strength relative to her left arm that was improving. She was able to perform activities of daily living.

At 15 months postoperatively, the patient felt coming into the clinic for final evaluation was unnecessary as she was pleased with the surgery and could perform her activities without pain or difficulty. The patient shared images of her forearms during ROM. She had similar pronation and supination at extremes when compared side-to-side and symmetry when viewed from the radial side (Figures 4A through 4C).

**DISCUSSION**

Operative treatment of radius shaft fractures requires an anatomic restoration of the radial bow to restore pronation and supination and prevent DRUJ instability. Even when this goal is immediately achieved, the patient’s follow-up should occur until radiographic healing. Postoperative events should be addressed appropriately. We report a case of hardware failure after repeat injury in a presumably skeletally mature patient, resulting in malunion with DRUJ instability and painful ROM. We do not have any records of the patient’s initial injury. However, the patient presented with pain from activities of daily living and an obvious deformity with 27° of angulation that was unacceptable for her.

While the goal acutely is for anatomic reduction of the radius, sequelae of malunion can be challenging to treat. Acute reduction and fixation of these injuries, often with compression plating, is ideal for preventing soft-tissue contracture or injury of structures, such as the intraosseous membrane, DRUJ, and proximal radio-ulnar joint. When malunions do occur, osteotomies have been described to correct these forearm deformities successfully. One study showed better results when corrective osteotomy was performed within 1 year of injury. While most forearm malunions occur after attempted nonoperative management, our patient’s malunion presumably occurred after operative management and implant failure. She was treated successfully with an osteotomy.

Our patient did have DRUJ pain and instability with her malunion, which previous studies have described as radius diaphyseal malunion. The radioulnar articulation is distally stabilized by the triangular fibrocartilage complex. This can be disrupted when the normal anatomic relationship between the radius and ulna no longer exists, such as diaphyseal radius shaft fracture and malunion, which causes pain and instability. DRUJ instability after radius shaft malunion has been successfully treated with corrective osteotomy. Our patient’s ulnar positive malunion was restored to ulnar negative variance similar to her left wrist after osteotomy.

Currently, minimal data support retained implants in patients after hardware failure. Known complications of revision surgery exist, such as neurovascular injury, radio-ulnar synostosis, infection, and compartment syndrome. However, our patient was dissatisfied with the nonoperative treatment of her malunion. Patients should be educated about these risks and known risks of diaphyseal forearm malunion.

Although nonoperative management of radius shaft fractures is possible in skeletally immature patients, especially in patients under 10 years of age, adolescents and adults often require ORIF with compression plating to anatomically restore the radial bow. Our patient had undergone ORIF for an injury 8 years before...
presentation at our clinic. She was treated successfully with corrective osteotomy after malunion of her radius shaft fracture.

REFERENCES
The Chevron Capitate-Trapezoid Joint: A Case Report

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Funding The author received no financial support for the research, authorship, or publication of this article.

Conflict of Interest The author reports no conflict of interest.

Informed Consent The patient was informed that the data concerning their case would be submitted for publication, and they provided verbal consent.

ABSTRACT
Anatomical variations to the human skeletal system are common and frequently reported in the literature. The structures around the hand and wrist are no exception, and these variations can affect ligaments, tendons, muscles, nerves, arteries, joints, and bone morphology. Musculoskeletal health care providers must be familiar with normal, individual variations when encountered during patient care and diagnostic imaging. In some instances, morphological variations have resulted in differences in kinematics, while others have been found in association with certain medical conditions. We discuss an unusual variation of the capitate-trapezoid joint. To the best of our knowledge, no prior studies have previously reported on this topic.

Keywords: Anatomy, Wrist Joint, Carpal Bones

INTRODUCTION
Knowledge of radiographic and topographical anatomy of the hand and wrist is essential to upper-extremity specialists. Nakamura et al1 and Patterson et al2 described hundreds of normal anatomical variants in the human carpus regarding bone morphology, ligaments, and joint relationships. The capitate is the largest and most centrally located carpal bone. Studies have reported anatomical variations of the long finger metacarpal, hamate, trapezoid, and lunate relationships.3-7

We describe a patient with a chevron-shaped, capitate-trapezoid joint and an enlarged capitate body identified on plain radiographs and magnetic resonance imaging (MRI). Two distinct joints are noted in association with the capitate along the proximal and ulnar surfaces of the trapezoid. The significance of this study is not yet known, but it may add a normal variation of this joint to the literature or be a residual presentation of a rare os centrale carpi coalition with the capitate.

CASE REPORT
A 32-year-old man with no history of wrist trauma or wrist problems presented for evaluation of a non-tender progressive mass on the dorsal aspect of his dominant right wrist. Range of motion of the right wrist was within normal limits and equal to the left wrist. The dorsal wrist mass was mobile, compressible, and had clinical and MRI findings consistent with a dorsal wrist ganglion.

Posteroanterior radiographs (Figures 1A and 1B) and a T2 coronal MRI (Figure 2) showed a chevron-shaped, capitate-trapezoid joint and capitate diameter of 22 mm and 20 mm, respectively. Widening at the scapholunate interval and a dorsal ganglion was noted on the MRI, along with intact intercarpal ligaments.

DISCUSSION
Understanding wrist anatomy and its associated carpal attachments and carpal joints, as well as any potential normal variations are important when assessing traumatic, degenerative, and other pathological conditions in the wrist. Previous anatomical studies of the wrist and capitate have defined various normal osseous and articular features with the capitate and trapezoid.3-7

We searched the literature on human capitate morphology and did not find additional radiographic descriptions of chevron-shaped, capitate-trapezoid joints. We did find unpublished communications identifying a teenage patient with a widened scapholunate interval and a congenital chevron-shaped, capitate-trapezoid joint on both wrists.6

Possible explanations, in this case of the capitate-trapezoid findings, include previously undescribed variant of a normal capitate-trapezoid joint or an os centrale carpi (accessory ossicle) coalition to the radial side of the capitate. In a cadaveric anatomical study involving 80 wrists, Nakamura et al7 reported three types of capitate-trapezoid joints, including volar only single facet, 75.0% of specimens; double dorsal and volar facet, 11.0% of specimens; and a large-single facet, 14.0% of specimens. The facet on the capitate side was concave...
Knowledge of radiographic and topographical anatomy of wrist and capitate have defined various normal anatomical variants. Patterson et al2 found that the volume, maximum length, and surface areas of the capitate were greater in males. In a radiographic tomography study of live and cadaveric wrists, Hawkins-Rivers et al11 reported on capitate and lunate length, diameter, and circularity. They found an average MRI diameter of the capitate in the coronal plane of 12.9 mm (+/-1.89 mm) and an average radiographic capitate diameter in the same plane of 11.9 mm (+/- 1.8 mm).

The capitate-trapezoid joint reported in this case is most similar to the large-single facet described by Nakamura, but it is distinctly different because it involves an angulated joint in the axial and sagittal plane, forming a chevron-shaped joint with the trapezoid. The capitate coronal diameter was 9 mm larger on MRI than the average capitate diameters previously reported.

Over twenty-five accessory ossicles have been described in the human carpus. The os styloideum is the most common carpal accessory ossicle and is considered one of the underlying contributors to the formation of the metacarpal boss.10 The os centrale carpi is the third most common accessory ossicle in the wrist and has been traced phylogenetically to some members of the primate family and other hominins.11 When present, the os centrale carpi is considered an asymptomatic normal variant in most cases.12,13 During the early stages of normal human embry development, the cartilaginous os centrale carpi appears and eventually fuses with the distal ulnar scaphoid.14,15 In some instances after gestation, a residual os centrale carpi forms an accessory ossicle between the scaphoid, trapezoid, and capitate7 and has been reported in conjunction with congenital malformation syndromes.
such as Holt-Oram syndrome. However, there is some debate over the cause of carpal accessory ossicles as either the residual expression of phylogenetic evolution or just normal genetic human variation. Although uncommon, os centrale fusion with the capitate or trapezoid has also been described.12,16

In summary, the abnormal capitate-trapezoid joint described in this case was asymptomatic. The radiographic findings in the carpus were incidental and not involved with the dorsal wrist ganglion. Further anatomical study of a larger cohort of wrists would better determine if the chevron-shaped, capitate-trapezoid joint results from an unusual and uncommon os centrale coalition with the capitare or the fourth type of a normal but less common capitate-trapezoid joint.

REFERENCES

Cartilage Restoration of the Patella Using ProChondrix® Osteochondral Allograft: A Case Report

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Funding The authors received no financial support for the research, authorship, and publication of this article.

Conflict of Interest James R. Slautebeck, MD, is a research consultant for the ProChondrix® Osteochondral Allograft through Allosource®. All other authors declare no conflict of interest.

Acknowledgements We would like to acknowledge Matthew G. Geeslin, MD, for his assistance in interpretation of radiographic studies.

Informed Consent The patient was informed that the data concerning their case would be submitted for publication, and they provided verbal consent.

ABSTRACT
Articular cartilage injuries are challenging to treat because of the limited healing potential of articular cartilage. Various cartilage restoration procedures have been developed to restore the protective role of articular cartilage and to delay or prevent additional damage to the articular surface. ProChondrix® Cartilage Restoration Matrix is a cryopreserved hyaline cartilage allograft with viable chondrocytes and growth factors necessary to promote its incorporation and viability. We describe a 19-year-old man with a well-contained, full-thickness cartilage defect on his patella. He subsequently underwent cartilage restoration with a ProChondrix® osteochondral allograft. At 1-year postoperatively, the patient had both clinical and radiographic evidence of an excellent outcome and had returned to sport.

Keywords: Fractures, Cartilage, Articular

INTRODUCTION
For patients sustaining articular cartilage injuries within the knee joint, various cartilage repair techniques are available to prevent or prolong the need for a total joint replacement. Traditional treatment strategies include microfracture, osteochondral autograft (OATS), osteochondral allograft (OCA), and autologous chondrocyte implantation (ACI). Selecting the appropriate treatment strategy for each patient relies on the patient’s age, activity level, willingness or hesitancy to undergo multiple procedures; size and location of the defect; and whether this is the initial procedure or a procedure following a failed operation.

Microfracture is considered first-line treatment for small cartilage lesions less than 2 cm because of its technical ease, low cost, minimally invasive nature, and low morbidity. However, microfracture biopsies have shown that the new filling cartilage is predominately fibrocartilage and only 10.0% hyaline cartilage. OATS type procedures fill cartilage defects with mature, hyaline articular cartilage immediately. This procedure is not recommended in defects greater than 4 cm, and donor site morbidity can be problematic. OCA has emerged as a successful treatment option, with graft survivorship approaching 80.0% at 10 years. OCA remains limited by cadaver availability, shelf life, and disease transmission. ACI has shown promising results, with survivorship up to 71.0% at 10 years and 75.0% of patients showing improvement in function. The major limitations of ACI include the high cost and the need for a two-stage operation.

Despite the favorable results observed with these traditional treatment options, cartilage restoration techniques continue to evolve. One of the recently developed technologies includes the ProChondrix® Cartilage Restoration Matrix (AlloSource; Centennial, CO). This matrix is a cryopreserved hyaline cartilage allograft prepared on a thin, semi-flexible platform of bone, with viable chondrocytes and growth factors necessary to promote its incorporation and viability. ProChondrix® has been shown to have 87.5% chondrocyte viability at 35 days when utilizing conventional cryopreservation techniques. When using a proprietary cryopreservation method designed by AlloSource® (Centennial, CO), ProChondrix® was found to have a viability of 95.0% at 2 years. This is longer than the current shelf life for conventional osteochondral allografts, which is 28 days postmortem when stored at 4°C. To our knowledge, no studies have been published on the use and outcomes of this implant in human patients.
CASE REPORT

A 19-year-old man presented after sustaining a traumatic patella dislocation of his right knee when playing soccer. He had a history of contralateral patella dislocation. Findings during patellofemoral examination showed mild tenderness over the medial patellofemoral ligament, a medial and lateral patellar glide of 30.0%, 5° of negative patellar tilt, and a seated Q angle of 25°. He was very apprehensive during examination maneuvers. Significant radiographic findings consisted of a small effusion and an Insall-Salvati ratio of 1.4. Magnetic resonance imaging (MRI) revealed bone contusions on the medial patella and lateral femoral condyle, with a large intra-articular loose body and a significant patellar defect measuring 1 cm in diameter with adjacent delamination (Figures 1A and 1B).

At this time, the patient elected to proceed with arthroscopic debridement of the patellar defect and loose body removal because of his desire for a short rehabilitation period and quick return to sport. During arthroscopy, a well-shouldered, 1-cm diameter, full-thickness cartilage defect was identified on the medial facet of the patella. The defect was minimally debrided, and a sizable and delaminated area extending beyond the injured patellar cartilage surface was recorded.

Over the next year, the patient sustained various right patellar dislocations with subsequent development and progression of patellofemoral pain. An MRI and computed tomography (CT) Fulkerson series were obtained. Findings showed a large loose body measuring at least 20 mm in diameter, a large well-circumscribed patella defect (Figures 2A and 2B), a dysplastic patellofemoral joint with significant lateral patella tilt, slight patella subluxation, and the tibia tubercle-trochlear groove distance (TTTG) of 25 mm (Figure 3).

At this point, conservative management had been maximized and was unlikely to prevent further dislocations. Therefore, 15 months after the initial injury, the patient underwent operative intervention to address his multiple patella dislocations, excessive TTTG, lateral tilt, lateral subluxation, and large patellar cartilage defect. The operation included a Fulkerson procedure with an anteromedial tibia tubercle osteotomy to address the excessive lateral position of the tibia tubercle and the patella alta. It also included a lateral retinaculum release to decrease the negative patellar tilt and a medial retinacular reefing to decrease the patella subluxation proximally. To address the cartilage defect, a well-shouldered, 1-cm diameter, full-thickness cartilage graft was placed into the defect with a Fulkerson procedure using microfracture to stimulate the ingrowth of cartilage. The graft was fixed with a bioabsorbable screw and a continuous passive motion (CPM) machine was used with a range of 0° to 130°. A brace was used for 48 hours postoperatively and non-weight bearing. Immediate weight bearing of 50.0% in full flexion was allowed because of the robust fixation of the tibial tunnel.

Immediate postoperative imaging revealed placement of the graft in place. At 6 weeks, the patient’s range of motion was 0° to 130°. X-rays confirmed good healing at the osteotomy site, and he was progressed to full weight bearing and full range of motion. At 5 months postoperatively, the patient had no pain with activities of daily living, work, or any casual life activity.

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At his 1-year postoperative visit, he had no pain with recreational activities, including light squats without limits. His range of motion was full and equal to the uninjured side. X-rays confirmed good healing at the osteotomy site, and he was progressed to full weight bearing and full range of motion. At 5 months postoperatively, the patient had no pain with activities of daily living, work, or any casual life activity.

The postoperative rehab protocol consisted of immediate weight bearing of 50.0% in full extension. A CPM machine was used with a range of 0° to 130°. Once the brace was removed, a continuous passive motion (CPM) machine was used with a range of 0° to 130°. A CPM machine was used with a range of 0° to 130°. At his 1-year postoperative visit, he had no pain with recreational activities, including light squats without limits. His range of motion was full and equal to the uninjured side.

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CASE REPORT

A 19-year-old man presented after sustaining a traumatic patella dislocation of his right knee when playing soccer. He had a history of contralateral patella dislocation. Findings during patellofemoral examination showed mild tenderness over the medial patellofemoral ligament, a medial and lateral patellar glide of 30.0%, 5° of negative patellar tilt, and a seated Q angle of 25°. He was very apprehensive during examination maneuvers. Significant radiographic findings consisted of a small effusion and an Insall-Salvati ratio of 1.4. Magnetic resonance imaging (MRI) revealed bone contusions on the medial patella and lateral femoral condyle, with a large intra-articular loose body and a significant patellar defect measuring 1 cm in diameter with adjacent delamination (Figures 1A and 1B).

At this time, the patient elected to proceed with arthroscopic debridement of the patellar defect and loose body removal because of his desire for a short rehabilitation period and quick return to sport. During arthroscopy, a well-shouldered, 1-cm diameter, full-thickness cartilage defect was identified on the medial facet of the patella. The defect was minimally debrided, and a sizable and delaminated area extending beyond the injured patellar cartilage surface was recorded.

Over the next year, the patient sustained various right patellar dislocations with subsequent development and progression of patellofemoral pain. An MRI and computed tomography (CT) Fulkerson series were obtained. Findings showed a large loose body measuring at least 20 mm in diameter, a large well-circumscribed patella defect (Figures 2A and 2B), a dysplastic patellofemoral joint with significant lateral patella tilt, slight patella subluxation, and the tibia tubercle-trochlear groove distance (TTTG) of 25 mm (Figure 3).

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At his 1-year postoperative visit, he had no pain with recreational activities, including light squats without limits. His range of motion was full and equal to the uninjured side. X-rays confirmed good healing at the osteotomy site, and he was progressed to full weight bearing and full range of motion. At 5 months postoperatively, the patient had no pain with activities of daily living, work, or any casual life activity.

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defect on the patella, which measured approximately 20 mm with a healthy bone base, microfracture was performed and the defect was repaired using a 20-mm ProChondrix® graft placed within a fibrin clot to hold the graft in place.

The postoperative rehab protocol consisted of bracing with the knee locked in extension for 48 hours. Once the brace was removed, a continuous passive motion (CPM) machine was used with a range of motion of 0° to 90° for 10 hours per day for 4 weeks. Immediate weight bearing of 50.0% in full extension was allowed because of the robust fixation of the tibial tubercle osteotomy.

At 6 weeks, the patient’s range of motion was 0° to 130°. X-rays confirmed good healing at the osteotomy site, and he was progressed to full weight bearing and full range of motion. At 5 months postoperatively, the patient had returned to running, jogging, and weight training, including light squats without limits. His range of motion was full and equal to the uninjured side. At his 1-year postoperative visit, he had no pain with activities of daily living, work, or any casual life activity. The patient was able to walk, jog, and play Frisbee without any difficulties. After several consecutive days of skiing, he would get a small effusion that would go away within 24 hours with ice, rest, and activity modification. An MRI was obtained to investigate the source of effusion. The Magnetic Resonance Observation of Cartilage Repair Tissue (MOCART), MOCART 2, and the Osteochondral Allograft MRI Scoring System (OCAMRISS) scoring systems were used to analyze and evaluate the MRI findings (Tables 1 through 3 and Figures 4A and 4B). This patient had a

![Figure 3. Computed tomography scan of the right knee following the Fulkerson procedure showing a tibial tubercle to trochlear groove distance of 25 mm.](image)

![Figure 4. Sagittal A) and axial B) magnetic resonance images of the right knee at 1-year postoperatively showing filling of the articular defect with the ProChondrix® allograft and the incorporation of the graft into the surrounding native tissue. Filling is at a similar level compared to the adjacent articular cartilage.](image)

### Table 1. MOCART Scoring

<table>
<thead>
<tr>
<th>Variable</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degree of defect repair and filling of the defect</td>
<td>Incomplete with greater than 50.0% of the adjacent cartilage</td>
</tr>
<tr>
<td>Integration to border zone</td>
<td>Defect visible with less than 50.0% of the length of the repair tissue</td>
</tr>
<tr>
<td>Surface of the repair tissue</td>
<td>Surface damaged (fibrillation, fissures, and ulcerations) with less than 50.0% of the repair tissue depth</td>
</tr>
<tr>
<td>Structure of the repair</td>
<td>Inhomogenous or cleft formation</td>
</tr>
<tr>
<td>Signal intensity of the repair tissue</td>
<td>Moderately hyperintense</td>
</tr>
<tr>
<td>Subchondral lamina</td>
<td>Intact</td>
</tr>
<tr>
<td>Subchondral bone</td>
<td>Intact</td>
</tr>
<tr>
<td>Adhesions</td>
<td>No</td>
</tr>
<tr>
<td>Effusion</td>
<td>No</td>
</tr>
</tbody>
</table>

MOCART: Magnetic Resonance Observation of Cartilage Repair Tissue
ProChondrix® serves as an option for both a primary articular surface geometry, restore adequate cartilage as it is readily available, can reconstitute complex presents a unique option for contained cartilage defects and form healthy hyaline cartilage. ProChondrix® of BMDCs will lead to the incorporation of the allograft cartilage and chondrogenesis and promote bone marrow-derived cell (BMDC) migration into the surgical site after being liberated via microfracture. The goal is that the combination of a live cell-signaling matrix and migration of BMDCs will lead to the incorporation of the allograft and form healthy hyaline cartilage. ProChondrix® presents a unique option for contained cartilage defects as it is readily available, can reconstitute complex articular surface geometry, restore adequate cartilage depth, and perform in a single-stage procedure. ProChondrix® serves as an option for both a primary repair and as a salvage procedure for chondral defects.

Indications for the use of ProChondrix® include chondral defects without bone involvement and within the dimensions of the available implants (11-20 mm). Contraindications are chondral injuries with bone involvement.

To our knowledge, there are no current studies evaluating outcomes following chondral repair with ProChondrix® allograft in humans. At 1-year postoperatively, the patient displayed excellent clinical results. He had returned to running and skiing and had no pain with activities of daily living, work, or causal life. An MRI was obtained due to intermittent joint effusions. It showed the graft had become incorporated with the surrounding native tissue, and there was filling of the defect to a similar level compared to the adjacent cartilage. However, given this patient had multiple, simultaneous operations with his chondral repair using ProChondrix®, it is impossible to quantify how much of his outcome is attributable to the chondral repair alone.

We used the MOCART, MOCART 2.0, and OCAMRISS grading systems to analyze the MRI and grade graft incorporation. Previous studies have compared MRI findings of the individual components of both the MOCART to clinical outcomes and OCAMRISS to histologic findings to validate these scoring systems. There is currently a lack of strong evidence to suggest MRI scoring systems reliably correlate with clinical outcomes. Therefore, we felt it was pertinent

---

**Table 2. MOCART 2.0 Scoring**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume of cartilage defect filling compared to native cartilage</td>
<td>Underfilling 50.0% to 74.0%</td>
</tr>
<tr>
<td>Integration into adjacent cartilage</td>
<td>Defect greater than 2 mm, but less than 50.0%</td>
</tr>
<tr>
<td>Surface of the repair tissue</td>
<td>Irregularities less than 50%</td>
</tr>
<tr>
<td>Structure of the repair tissue</td>
<td>Inhomogenous</td>
</tr>
<tr>
<td>Signal intensity of the repair tissue</td>
<td>Minor hyperintense</td>
</tr>
<tr>
<td>Bony defect or bony overgrowth</td>
<td>No defect or overgrowth</td>
</tr>
<tr>
<td>Subchondral changes</td>
<td>Edema-like</td>
</tr>
</tbody>
</table>

MOCART, Magnetic Resonance Observation of Cartilage Repair Tissue

**Table 3. OCAMRISS Scoring**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cartilage signal of graft</td>
<td>Altered intensity (either hypointense or hyperintense, but not fluid)</td>
</tr>
<tr>
<td>Cartilage “fill” of graft</td>
<td>51.0%-75.0%</td>
</tr>
<tr>
<td>Cartilage edge integration at host-graft junction</td>
<td>Discernable boundary</td>
</tr>
<tr>
<td>Cartilage surface congruity of graft and host-graft junction</td>
<td>Flush</td>
</tr>
<tr>
<td>Calcified cartilage integrity of the graft</td>
<td>Intact, thin, and smooth</td>
</tr>
<tr>
<td>Subchondral bone plate congruity of graft and host-graft junction</td>
<td>Intact and flush</td>
</tr>
<tr>
<td>Subchondral bone marrow signal intensity of graft relative to epiphyseal bone</td>
<td>Normal</td>
</tr>
<tr>
<td>Osseous integration at host-graft junction</td>
<td>Crossing trabeculae</td>
</tr>
<tr>
<td>Presence of cystic changes of the graft and host-graft junction</td>
<td>Absent</td>
</tr>
<tr>
<td>Opposing cartilage</td>
<td>Abnormal</td>
</tr>
</tbody>
</table>

OCAMRISS, Osteochondral Allograft MRI Scoring System
to explore this correlation in the case reported here. This patient had a MOCART 2.0 score of 50 out of 90 (90 being the best possible score) and an OCAMRISS score of 4 out of 14 (0 being the best possible score) in the setting of an excellent clinical outcome. Again, we cannot attribute this outcome entirely to the ProChondrix® chondral repair because of the other operations performed.

REFERENCES
Bisphosphonate Associated Atypical Femur Fracture and Contralateral Impending Atypical Femur Fracture in a Pediatric Patient with Osteogenesis Imperfecta: A Case Report

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Funding The authors received no financial support for the research, authorship, and publication of this article.

Conflict of Interest The authors report no conflict of interest.

Informed Consent The patient and their guardian were informed that the data concerning their case would be submitted for publication, and they both provided verbal consent.

ABSTRACT

Atypical femur fractures are rare, low-energy fractures that involve a specific constellation of radiographic findings. These fractures have been well described in adult osteoporotic patients on long-term bisphosphonates; however, little to no literature exists on atypical femur fractures in pediatric patients on long-term bisphosphonates. The use of bisphosphonates as treatment of osteogenesis imperfecta is common to reduce fracture rate and improve bone mineral density. We describe a 15-year-old adolescent boy with type I osteogenesis imperfecta on long-term bisphosphonate therapy. He presented with an atypical right femur fracture and an impending left femur fracture. To the authors’ knowledge, these findings represent the first case of an atypical femur fracture with a contralateral impending atypical femur fracture in a pediatric patient on long-term bisphosphonate treatment. This case highlights the importance of evaluating pediatric patients for bisphosphonate-associated complications, as is typical in adult patients. Physicians should carefully weigh the risks and benefits of bisphosphonate therapy in pediatric patients to better understand the potential adverse effects.

Keywords: Osteogenesis Imperfecta, Bisphosphonates, Subtrochanteric Fractures, Pediatrics

INTRODUCTION

Osteogenesis imperfecta (OI) is a genetic disorder affecting type I collagen production, resulting in bone fragility. OI has been associated with several genes, most commonly COL1A1 and COL1A2. There are four common types of OI. Type I includes minimal long-bone deformities or issues with mobility, type II is lethal, type III is the most severe and survivable form of the disease with skeletal deformities and limited ambulation, and type IV is of moderate severity.

Bone fragility caused by OI typically results in fractures throughout the patient’s life. The most common medical treatment for children with recurrent fractures is bisphosphonate therapy, which is typically continued throughout skeletal maturity. Bisphosphonate therapy has been used to treat children with OI for 30 years, with increasing acceptance. The goal of bisphosphonate therapy is to improve bone mineral density and bone pain, decrease the incidence of fractures and skeletal deformity, and increase functional independence in patients.

Long-term bisphosphonate therapy in adults has been linked to atypical femur fractures, and risks of these fractures appear to increase drastically with prolonged usage. It is currently recommended that osteoporotic adults limit bisphosphonate use to 5 years to avoid the increased risk of atypical femur fractures. Atypical femur fractures are defined by meeting at least four out of the five criteria: minimal trauma, transverse fracture line through the lateral cortex, complete fracture often associated with medial spike, non-committed or minimally comminuted fracture, and periosteal or endosteal thickening of the lateral cortex.

There are a small number of case reports of suspected bisphosphonate-associated atypical femur fractures in children with OI. We describe an adolescent boy with OI on long-term bisphosphonate therapy. He sustained an atypical subtrochanteric femur fracture with a contralateral impending atypical femur fracture. To our knowledge, this is the first case report describing atypical femur fractures in a patient with type I OI.

CASE REPORT

A 15-year-old adolescent boy with a history of type I OI presented to our institution after tripping over a step while hiking. He fell on the right side of his body,
sustaining a right subtrochanteric femur fracture and a right proximal humerus fracture. The patient had a history of multiple fractures, including right and left femur fractures in 2014 and 2007, respectively. The prior right femur fracture was treated with open reduction and plating, with subsequent removal of hardware. The left femur fracture was treated with a closed reduction and hip spica casting. Before his most recent fall, he denied any prior pain in his right and left hip and legs. He had been on bisphosphonate therapy for 12 years, and at the time of injury, was being treated with IV Palmidronate infusions every 4 months.

Upon presentation to our institution, radiographs of the right femur were obtained. The patient was found to have an atypical transverse femur fracture of the right subchondral femur with lateral cortical thickening (Figure 1). The patient's right proximal humerus fracture was assessed radiographically and treated nonoperatively with a cuff and collar sling. Radiographs of the left femur were obtained, owing to the atypical appearance of the right subtrochanteric femur fracture and the history of long-term bisphosphonate use. Radiographs showed considerable lateral cortical beaking with transverse lucency through the lateral cortex in the subtrochanteric region (Figures 2A and 2B). Considerable deformity to the left femur was evident, which was secondary to prior fracture.

The patient was placed into Buck's traction for comfort. He was brought to the operating room for trochanteric entry intramedullary nail fixation of the right subtrochanteric femur fracture using an 8.5-mm trochanteric entry intramedullary nail for adolescents (Smith and Nephew; Watford, UK) (Figure 3).

Postoperatively, the patient was made weight bearing as tolerated. A discussion about prophylactic fixation of the left femur was had with the patient and his father. It was emphasized that due to the deformity of the left femur from the prior fracture, the left leg would require an osteotomy to facilitate the intramedullary nail passage. Given that the patient was from out of town, he and his father elected to return home for definitive treatment of the impending left femur fracture. The patient was able to ambulate postoperatively and demonstrated good pain control. He was discharged 2 days postoperatively to return home for further recovery and rehabilitation. We were in contact with his home orthopaedic surgeon before and after the

Figure 1. A transverse atypical subtrochanteric fracture of the right femur with lateral cortical thickening, small medial spike, lack of comminution, and intramedullary canal narrowing, which is consistent with a cortical stress response to increased stress from long-term bisphosphonate use. Sequelae of prior right femoral shaft open reduction internal fixation with residual screw holes are visible distal to the fracture.

Figure 2. A) Left femur with transverse subtrochanteric lucency within the lateral cortex and surrounding lateral cortical thickening, and a medial cortical stress reaction. B) Zebra lines visible within the distal femur and sequelae of prior left femoral shaft fracture with resultant deformity preventing passage of intramedullary nail.

Figure 3. Intraoperative radiographs of right femur following closed reduction and intramedullary nailing.
surgery to ensure the appropriate transition of care was coordinated. The patient’s right femur fracture went on to form bridging callus and healing without pain with asymptomatic heterotopic ossification (Figure 4). His left impending femur fracture was treated nonoperatively with continued weight bearing and observation by his home orthopaedic surgeon, and it went on to heal without complication (Figure 5).

**DISCUSSION**

In the past few years, multiple case reports have been published on atypical femur fractures in children with OI treated with long-term bisphosphonate therapy (Table 1). There has been increasing recognition of atypical femur fractures in osteoporotic adults receiving long-term bisphosphonate therapy. It is important to consider this same possibility occurring in children with OI.

Bisphosphonates work by inhibiting osteoclast activity and inducing apoptosis. There are two classes of bisphosphonates. The first is nitrogenous, which inhibits farnesyl diphosphonate synthase, causing cytoskeleton disruption, loss of ruffled border, and eventual apoptosis. The second is non-nitrogenous, which induces osteoclast apoptosis. Atypical femur fractures associated with bisphosphonate use is thought to occur because of 1) its relationship to impaired bone turnover secondary to osteoclast inhibition, and 2) resultant poor remodeling potential of the bone in high-stress areas like the lateral cortex of the proximal femur, with resultant microfractures weakening the bone leading to eventual fatigue with complete fracture.

A retrospective study compared femoral shaft fractures within patients with OI and no bisphosphonates to patients with OI treated with bisphosphonates. It showed a trend of increasing fractures in the subtrochanteric region among patients treated with bisphosphonates. This study suggests that the change in femur fracture pattern sustained by these patients may be related to bisphosphonate usage.

Another study retrospectively examined children with OI who sustained femur fractures. The authors evaluated x-rays for signs of atypical femur fracture and stratified patients by those who did and did not receive bisphosphonate therapy. They found that 22.0% of those who did not receive bisphosphonate therapy had radiographic evidence of atypical femur fractures, and 27.0% of those who did receive bisphosphonate therapy had radiographic evidence of atypical femur fractures. They concluded that no difference existed between the bisphosphonates group and the non-bisphosphonates group in terms of atypical femur fracture risk. They found the increasing severity of disease type to correlate with the increased risk of atypical femur fractures.

Patients with OI do not have the same bone quality as osteoporotic adults, and atypical femur fracture diagnosis was not designed for this patient population. Prior studies have shown that children with OI can sustain low-energy fractures that mimic atypical femur fractures without bisphosphonate therapy. However, the changing pattern of femur fractures seen in children treated with bisphosphonates and the increasing prevalence of case reports detailing atypical femur fractures in children on bisphosphonate therapy are cause for concern. Recent literature suggests that bisphosphonate therapy improves bone mineral density and may lower fracture rates in children with OI.

Bisphosphonate therapy does not appear to change functional outcomes and bone growth or affect bone pain as previously thought. Risks and benefits of bisphosphonate therapy in pediatric patients should be weighed carefully to understand the potential adverse effects better.

This case report details an atypical femur fracture and contralateral impending atypical femur fracture as a sequela of long-term bisphosphonate therapy in a pediatric patient with OI. To our knowledge, this is the
first described account of a simultaneous contralateral impending atypical femur fracture in this population. Further research is needed to determine the efficacy and safety of bisphosphonate therapy in children with OI. There is a large variation in the dose, the interval between infusions, and the duration of intravenous bisphosphonates between institutions. Consistent treatment protocols and cumulative dose and length of appropriate treatment guidelines need to be established in this population. Practitioners must maintain vigilance when detecting these impending fractures in patients on bisphosphonate therapy and order appropriate imaging for patients with prodromal pain.

REFERENCES

New Diagnosis of X-Linked Agammaglobulinemia Presenting as Multi-Focal Acute Pseudomonal Osteomyelitis and Septic Arthritis in a 16-Month Old Boy: A Case Report

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Funding The authors received no financial support for the research, authorship, and publication of this article.

Conflict of Interest The authors report no conflict of interest.

Informed Consent The patient’s guardian was informed that the data concerning their case would be submitted for publication, and they provided verbal consent.

ABSTRACT
A previously healthy 16-month-old boy presented with 5 days of fever, a limp favoring his right side, and swelling and erythema of the dorsal left foot and left great toe. Contrast magnetic resonance imaging revealed septic arthritis of the left knee, the interphalangeal joint of the left great toe, and the left subtalar and ankle joints. He had osteomyelitis of the left talus and intraosseous abscess formation in the left calcaneus. Cultures of the blood, left knee synovial fluid, and abscess fluid all showed growth of Pseudomonas aeruginosa. He was subsequently diagnosed with X-linked agammaglobulinemia with a novel mutation in the Bruton’s tyrosine kinase gene. He had a promising recovery after intravenous immune globulin and antimicrobial therapy. Unusually severe infections in children, particularly with atypical organisms, should prompt suspicion of an underlying immunodeficiency.

Keywords: Osteomyelitis, Pseudomonas Aeruginosa, X-linked Agammaglobulinemia

INTRODUCTION
Osteoarticular infections in otherwise healthy children are typically caused by a limited number of pathogens, most notably Staphylococcus aureus. Pseudomonal osteoarticular infections are rare and primarily limited to individuals with pre-existing risk factors (eg, postoperative nosocomial infections). Primary immunodeficiency disorders, such as X-linked agammaglobulinemia, may present with atypical pathogens. However, to our knowledge, pseudomonal osteoarticular infections have not been previously described with this condition.

CASE REPORT
A previously healthy, fully-immunized, 16-month-old, Native American boy presented to a hospital in Northern New Mexico with a 5-day fever of up to 103°, anorexia, and irritability. Two days into his fever, his family noted swelling and redness over his left foot’s dorsum and left great toe, with a worsening limp and unwillingness to bend his left knee. He had undergone drainage of a paronychia of his left great toe 2 months before admission, which never fully healed. He also received five courses of antimicrobial therapy with three different antibiotics for recurrent acute otitis media in the 3 months before admission. Thrush was noted at the time of presentation to the emergency department. Blood cultures from admission grew Pseudomonas aeruginosa, which prompted a transfer to our facility.

His initial laboratory investigations revealed a white blood cell count of 25.5 x 10^3 cells/µL. A C-reactive protein level was 16.3 mg/dL, with an erythrocyte sedimentation rate of 55 mm per hour. Plain films of the lower extremities showed diffuse soft-tissue swelling. Over the first 4 days of his hospitalization, his blood cultures grew Pseudomonas aeruginosa. A contrasted magnetic resonance image (MRI) of the lower extremities revealed synovial tissue inflammation in the left knee and the interphalangeal joint of the left great toe, bilateral quadriceps myositis, and a 2.0 x 1.0 x 1.5 cm soft-tissue abscess adjacent to the left tibia. The patient underwent arthotomy of the left knee and the interphalangeal joint of the left great toe, with drainage of the peri-tibial abscess. Intraoperative cultures of the synovial fluid from the left knee and the abscess grew Pseudomonas aeruginosa. He began therapy with cefepime.
An immunological evaluation demonstrated undetectable antibody responses to tetanus, pneumococcal, and diphtheria immunization, along with an undetectable response to toll-like receptor-three stimulation. His CD3-19+ level was 0.0% (normal range, 11.0% - 45.0%), in addition to low levels of IgG (155 mg/dL; normal range, 413 - 1200 mg/dL). DNA sequencing of the Bruton’s Tyrosine Kinase (BTK) gene revealed a novel mutation with a six-base pair deletion in exon 11, consistent with X-linked agammaglobulinemia.

Due to persistent fevers 2 weeks into his hospitalization, a repeat contrasted MRI of the lower extremities was performed. It revealed osteomyelitis of the left talus and left calcaneus, a 1.0 cm abscess of the proximal right calf, and new septic arthritis in the left ankle and subtalar joints (Figures 1 and 2). He underwent operative drainage of these sites 2 days later.

The patient was admitted to the hospital for 73 days. He completed 134 days of total anti-pseudomonal therapy, with 69 days of parenteral therapy and 2 months of oral ciprofloxacin. He received intravenous immune globulin infusions every 3 weeks during his hospital stay, which continued after discharge. His IgG levels increased to 521 mg/dL (normal range, 413 - 1200 mg/dL) 3 weeks after instituting this therapy.

No leg-length discrepancy was present on follow-up imaging 10 months after his hospitalization. The patient made a good recovery with no orthopaedic concerns 7 years after his initial diagnosis.

**DISCUSSION**

X-linked agammaglobulinemia is caused by a mutation in the BTK gene on the long arm of the X-chromosome, which results in a near absence of mature B lymphocytes in circulation and produces a lack of circulating antibodies. Approximately 15.0% to 20.0% of mutations in the BTK gene arise de novo. Given the mode of inheritance, the onset is almost entirely in young boys, who may present with recurrent bacterial infections. The onset typically occurs before the patient’s first birthday when transplacentally transferred antibody levels decline. Children with family histories of this disorder have a mean age of diagnosis of 2.6 years. However, large registries of patients with this disorder have shown that patients without a family history of X-linked agammaglobulinemia typically have a delayed diagnosis, with a mean age of diagnosis of 5.4 years. The absence of complete ethnicity...

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**Figure 1.** Magnetic resonance image 2 weeks into the patient’s hospital stay showing diffusion-weighted abnormalities in the left calcaneus consistent with osteomyelitis (red arrow) and an abscess formation in the proximal right calf (blue arrow).

**Figure 2.** Contrast magnetic resonance image 2 weeks into the hospital stay showing enhancement of the tibio-talar joint concerning for septic arthritis (blue arrow).
data in many data registries may also lead to an underestimation of the prevalence of this disease in underrepresented minorities, such as our patient.

Osteoarticular infections are rarely reported in patients with X-linked agammaglobulinemia.\textsuperscript{4,6,7} \textit{Pseudomonas} has been described in patients with X-linked agammaglobulinemia presenting with sepsis, though to our knowledge, it has not been described as an agent of osteoarticular infections before.\textsuperscript{4,6}

Treating X-linked agammaglobulinemia consists of replacing antibodies with intravenous immune globulin every 3 to 4 weeks. Using intravenous immune globulin has had a profound effect on mortality, with mortality rates now less than or equal to 1.0%, compared with historical rates of approximately 25.0%.\textsuperscript{5} Daily prophylaxis with trimethoprim-sulfamethoxazole may also help prevent infections with bacterial organisms, though data on this is inconclusive.\textsuperscript{5,5}

Several features of our case increased suspicion of an immune deficiency. The patient had a history of recurrent acute otitis media, reports of a poorly healing paronychia despite adequate drainage, and history of thrush. He presented with bilateral leg involvement and developed septic arthritis in four joints and concurrent osteomyelitis. Though the involvement of multiple joints and bones may occur in the setting of certain pathogens (most notably disseminated disease with \textit{Staphylococcus aureus}), such a presentation is atypical for an osteoarticular infection in an immunocompetent child.\textsuperscript{18} Lastly, the organism involved (\textit{Pseudomonas aeruginosa}) was highly unusual for a community-associated osteoarticular infection in a presumably otherwise healthy child. Osteoarticular infection with this organism is essentially confined to rare case reports.\textsuperscript{25} Thus, these findings should raise suspicion of a primary immune deficiency. It is possible that the frequent use of antimicrobial therapy may have selected for colonization with \textit{Pseudomonas}, with the poorly healing paronychia serving as the nidus of infection.

Surgeons and medical providers caring for children with osteoarticular infections should be aware of clinical presentations that may herald an undiagnosed, underlying immunodeficiency. They should recognize that such patients may require more aggressive medical and surgical treatment.

\textbf{REFERENCES}

Reconstruction of a Chronic Quadriceps Tendon Rupture After Multiple Failed Repair Attempts: Technique and Case Report

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Funding The authors received no financial support for the research, authorship, and publication of this article.

Conflict of Interest The authors report no conflicts of interest.

Informed Consent The patient was informed that the data concerning the case would be submitted for publication, and they provided verbal consent.

ABSTRACT
Rupture of the quadriceps tendon is a relatively uncommon injury that requires prompt surgical intervention to restore the function of the extension apparatus of the knee. Early, definitive surgical intervention generally produces excellent results. In the case of delayed surgery or re-rupture, the tendon is often retracted and scarred, thus complicating subsequent repairs and resulting in poor outcomes. We describe a middle-aged man who presented 4 years after his initial quadriceps rupture, following two repair attempts that failed. Upon presentation, he was unable to perform any active extension at the knee, and he ambulated with the use of a hinged brace locked in extension. Owing to central tendon deficiency, previously described V-Y advancement was contraindicated, so we developed a novel surgical technique. His quadriceps tendon was successfully reconstructed using a combination of soft-tissue releases, tendon transposition, and allograft reinforcement. His postoperative course was uneventful, and at 5 months, he was ambulating comfortably without a brace, showing full active motion and good quadriceps strength.

Keywords: Tendon Injuries/Surgery, Lower Extremity, Orthopaedic Procedures

INTRODUCTION
Complete ruptures of the quadriceps tendon are relatively rare but debilitating injuries resulting in the loss of the extensor mechanism of the knee. These injuries occur most commonly in middle-aged men and people with certain predisposing conditions, including diabetes, gout, renal failure, rheumatoid arthritis, fluoroquinolone use, and corticosteroid use. Traditional surgical treatment consists of a transosseous repair, in which sutures attached to the quadriceps tendon are passed through vertical tunnels in the patella and secured at the inferior pole. More recently, the use of suture anchors has grown in popularity owing to the advantage of limiting surgical exposure and improving the biomechanical strength of the repair. When treated with prompt surgical intervention, regardless of repair technique, outcomes are generally excellent, with multiple studies reporting good to excellent subjective results, frequent return to pre-injury activity, and good range of motion and strength. Failure of acute quadriceps repair is a relatively rare complication. In a systematic review including 319 patients with quadriceps tendon rupture who underwent primary repair, Ciriello et al. reported failures in only 2.0% of cases. In the case of a failure, subsequent repairs are often complicated by tendon scarring and retraction. There is limited literature on surgical technique and management in this circumstance.

We describe a patient who underwent quadriceps tendon reconstruction utilizing a novel technique following two unsuccessful surgical repairs. A successful result was obtained by transposing the vastus lateralis and medialis to midline, and then using an Achilles tendon allograft to reinforce the reconstructed quadriceps tendon (Figure 1). This case report represents a novel approach to surgical management in a patient with failed previous repairs and persistent loss of active knee extension.

CASE REPORT
A 53-year-old African-American man presented to our clinic with no active extension of the right knee 4 years after two unsuccessful quadriceps repairs. In the initial, acute, post-injury period, the
defect 8 cm proximal to the superior pole of the patella, brace locked in extension. The patient had a palpable reciprocal heel-toe gait, using a cane and hinged-knee malnutrition, infection, or underlying diabetes. Complete preoperative workup showed no evidence of history of smoking, although now he is smoke-free. A traditional bone-tunnel technique. Upon presentation was performed shortly thereafter using the same traditional transosseous suture technique. His original postoperative course was complicated by a fall 3 weeks after surgery, resulting in dehiscence of the surgical incision and failure of the repair. Revision surgery was performed shortly thereafter using the same traditional bone-tunnel technique. Upon presentation to our clinic, his pain and swelling were managed with anti-inflammatory medication, and he had received several intra-articular steroid injections from other providers. His medical history was significant for a prior history of smoking, although now he is smoke-free. A complete preoperative workup showed no evidence of malnutrition, infection, or underlying diabetes.

His physical examination was remarkable for a reciprocal heel-toe gait, using a cane and hinged-knee brace locked in extension. The patient had a palpable defect 8 cm proximal to the superior pole of the patella, which was indicative of quadriceps tendon retraction and atrophy (Figure 2). He showed full, passive range of motion of the knee but no active extension whatsoever. The remainder of his examination was noncontributory. Magnetic resonance imaging confirmed the diagnosis of quadriceps tendon rupture with severe atrophy, severe retraction, and no discernible tendon fibers intact (Figure 3).

**OPERATIVE TECHNIQUE**

The repair was completed through the previous midline incision. The tear had extended through the medial and lateral retinaculum, resulting in a 15-cm retraction of the entire quadriceps tendon complex. No evidence of infection was observed, but a deep culture was completed that was ultimately negative. Quadriceps mobilization was completed with release of considerable scar tissue superficial and deep to the quadriceps, followed by medial and lateral release to try to obtain length. The quadriceps had atrophied so extensively that there was very little reasonable central tendon tissue to work with; therefore, the decision was made to transpose the vastus lateralis and medialis to the midline to reconstruct the quadriceps tendon. These tendons were transposed and combined using two 5-0 high-strength, nonabsorbable sutures in Krackow fashion, resulting in four tails exiting the quadriceps tendon distally (Figure 4). The superior pole of the patella was freshened with subsequent placement of two 5.5-mm triple loaded PEEK corkscrew anchors (Zimmer Biomet; Warsaw, IN) in between three vertical 3.5-mm bone tunnels (Figure 1 and Figure 5). Suture tails from the quadriceps tendon were then passed distally through the bone tunnels, while four sutures from each anchor were passed proximally through the previously placed Krackow sutures to create a “gift box” construct (Figure 1 and Figure 6). The additional two

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**Figure 1.** Schematic showing repair followed by graft augmentation. Figure printed with signed permission from Mary Ellis.

**Figure 2.** Right knee with evident defect above the patella and healed previous midline incision.

**Figure 3.** Magnetic resonance image showing complete rupture of the quadriceps tendon with retraction.
sutures from each anchor were passed proximally at the outer margins of the reconstruction before passing distally to create a “pants over vest” construct (Figure 1 and Figure 6). Lastly, all sutures from the anchors were tied. The bone tunnel sutures tied over the inferior pole of the patella with the knee in maximum extension, thus creating excellent apposition of the reconstructed quadriceps to the superior pole of the patella without gap (Figure 7).

The decision was made to further support the reconstructed quadriceps tendon using a nonirradiated Achilles allograft soaked in a vancomycin-saline mixture. The graft was positioned over the distal quadriceps, patella, and patellar tendon. Simple intermittent sutures were placed with a high-strength, nonabsorbable suture around the entire periphery of the graft (Figure 1 and Figure 8), which was reinforced with absorbable intermittent sutures throughout the substance of the graft. The retinaculum was repaired to the newly constructed quadriceps tendon using 2-0 high-strength, nonabsorbable sutures in a figure-of-eight fashion. The surgical wound was closed in a layered fashion, and the patient was placed in a hinged-knee brace locked in extension.

The patient had an uneventful postoperative recovery. He was kept non-weight bearing for 6 weeks and subsequently transitioned to weight bearing as tolerated with the brace locked in extension as he gradually increased his range-of-motion (0°-30° initially and 30° progression every 2 weeks). The knee brace was unlocked during ambulation at 3 months.

The surgical technique included repair of the quadriceps tendon followed by reconstruction with an Achilles tendon allograft. This approach allowed for stable fixation and early functional recovery. The patient's active extension worsened and he began using a cane to ambulate. The patient was then placed in a hinged-knee brace and locked in extension. He gradually increased his range-of-motion, and the knee brace was unlocked during ambulation at 3 months.

The patient underwent quadriceps tendon repair with the traditional bone-tunnel technique. Upon presentation to our clinic, his pain and swelling were managed with anti-inflammatory medication. Further workup was performed following his discharge with a goal to elucidate the cause of his quadriceps retraction.

The patient was initially placed in a hinged-knee brace locked in extension. He gradually increased his range-of-motion (0°-30° initially and 30° progression every 2 weeks). The knee brace was unlocked during ambulation at 3 months.

The patient's physical examination was remarkable for a palpable gap (Figure 7). The bone tunnel sutures tied over the inferior pole of the patella with the knee in maximum extension, thus creating excellent apposition of the reconstructed quadriceps tendon to the superior pole of the patella without gap (Figure 7).

The patient was discharged with a home program that included isometric quadriceps exercises and light functional activity. He was gradually allowed to progress to more weight-bearing activities, with full weight-bearing allowed at 6 weeks postoperatively.

The patient's postoperative course was complicated by a fall 3 weeks postoperatively. He was admitted to the hospital for evaluation of his knee pain.

The patient was placed in a hinged-knee brace locked in extension. The knee brace was unlocked during ambulation at 3 months.
postoperatively, and he began strengthening the knee. At 5 months postoperatively, the patient was ambulating without pain or brace, and he showed 0° to 120° of active motion with good strength in extension of the knee. He was cleared to continue strengthening and pursue progressive activity as tolerated.

**DISCUSSION**

The rarity of unsuccessful quadriceps tendon repair limits the literature regarding intervention in the chronic setting. The poor tissue quality and loss of tendon length resulting from surgical delay leave patients with worse outcomes than repairs performed acutely.2,8-10 Patients are often burdened with severe limitations, including complete loss of active extension, requiring rigid knee braces and assistive devices. To address the unique challenges of a chronic repair failure, we performed the surgical technique of quadriceps reconstruction with soft-tissue releases,10 tendon transposition, reinforced fixation, and graft reinforcement.2,9,11

Regarding lengthening measures, the well-known Codivilla method consists of an inverted V-to-Y advancement of the quadriceps tendon to gain length and is useful to address considerable shortening in chronic injuries.10 A second method, and our chosen technique, is medial and lateral release along the distal borders of the vastus medialis and lateralis, providing adequate mobility for apposition to the superior pole of the patella.9

After quadriceps length is developed, attention is turned to the quality of the residual tendon and the potential need for additional reinforcement. Even after the transposition of the vastus lateralis and medialis to reconstruct the quadriceps tendon, the residual tissue is often of poor quality. Techniques in modern literature describe a hamstring tendon (allograft or autograft) through transverse bone tunnels in the patella,11 or Achilles tendon allograft with bone block fixation in the patella.9 In revision cases, with pre-existing longitudinal bone tunnels, there is a considerable concern for patellar fracture, which guided our decision to use an Achilles allograft overlay to reinforce the reconstruction. The technique depicted in this report provides an additional novel and robust approach to reconstructing a chronically torn quadriceps tendon in the setting of multiple previous failures, poor tissue quality, and considerable tendon retraction with atrophy.

**REFERENCES**

Bilateral Peroneal Tendon Subluxation Associated with Complex Hindfoot Fractures: A Case Report

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Funding The authors received no financial support for the research, authorship, and publication of this case report

Conflict of Interest The authors report no conflicts of interest.

Informed Consent The patient was informed that the data concerning their case would be submitted for publication, and they provided verbal consent.

ABSTRACT

A 41-year-old man presented to the emergency department after crashing his dirt bike and sustaining bilateral subtalar fracture dislocations. The left talus underwent open reduction internal fixation. At his first postoperative visit, the patient was found to have bilateral peroneal tendon subluxation (PTS). This case report discusses the cause of PTS and the challenges associated with accurate identification and diagnosis of this injury. We review the diagnostic and therapeutic challenges associated with injury, the negative impact on clinical outcomes, and the association between PTS and hindfoot trauma.

Keywords: Peroneal Dislocation, Bilateral, Traumatic, Reconstruction

INTRODUCTION

The primary function of the peroneal tendons is to evert and plantarflex the ankle.1 The peroneal tendons and superior retinaculum can be damaged when strong forces, such as a dirt-bike landing, cause the ankle to dorsiflex and invert suddenly. This motion causes the peroneus longus and brevis muscles of the lateral compartment of the leg to contract rapidly, resulting in injury to the superior retinaculum. The superior retinaculum helps stabilize the peroneal tendons and prevents them from subluxation. If chronic peroneal tendon subluxation (PTS) is left untreated, a patient can develop pain and snapping of the tendon over the lateral malleolus.2 Wong-Chung et al3 reported that PTS was missed on 53.0% of initial computerized tomography (CT) readings when patients presented with a calcaneus fracture. Swelling around the lateral malleolus can obscure the view of PTS, leading to inaccurate interpretations of the CT. Additionally, Wong-Chung et al identified the fleck sign as a useful indication for diagnosing PTS. Chauhan et al4 found that undiagnosed PTS led to potential chronic ankle instability requiring surgical treatment. They also describe the diagnostic utility of the fleck sign, nonsteroidal anti-inflammatory drugs, and swelling reduction methods being beneficial for the clinical detection of PTS while examining the ankle.

CASE REPORT

A 41-year-old man presented to the emergency department 4 hours after sustaining a bilateral ankle injury after crashing his dirt bike. He had concerns of right ankle numbness and noted that the right ankle hurt more than his left ankle. Initial radiographs and CT of the right foot and ankle showed a calcaneus fracture, lateral process talus fracture, and lateral malleolus avulsion fracture (Figures 1 and 2). Radiographs and CT findings of his left foot and ankle showed a calcaneus fracture, displaced talar neck fracture, fifth toe first proximal phalanx fracture, and lateral malleolus avulsion fracture (Figures 3 and 4).

The patient underwent closed treatment of his bilateral calcaneal fractures, right lateral malleolus fracture, and lateral talus process fractures. His left talar neck was treated with open reduction internal fixation after his soft tissue was amendable to surgical intervention and swelling had decreased.

At his first postoperative visit, the splint was removed, and the patient reported the right ankle “catching” with ankle motion. He had considerable swelling in both feet. The patient could flex and extend the great toe bilaterally, and he reported diffused full sensation with palpable pulses. The surgical incisions on the left ankle were healing well, and the sutures remained intact without evidence of complication. The patient had concerns about spasms of the right calf and clicking on the lateral aspect of the right ankle.
Re-examination of a previous bilateral lower extremity and ankle CT scan indicated entrapment with bilateral PTS of both the peroneal brevis and longus (Figures 2 and 4). Clinically, the right PTS was evident and painful, while the left remained asymptomatic. The treating surgeons made the decision to repair the bilateral PTS. The bilateral PTS fractures were likely an anatomic classification of type 4 superior retinacular tear. However, regardless of the classification, it was deemed necessary for the well being of the patient.

Approximately 2 weeks after the initial surgery, the patient returned to the operating room to treat bilateral PTS. On the right, the peroneal tendons were found necessary for the well being of the patient.
The doctors placed two 2.7-mm corkscrew anchors into the fibula and repaired the superior peroneal retinaculum. The peroneal tendons remained reduced. The same procedure was performed on the left ankle, which required a third radiolucent anchor to achieve sufficient tendon stability. Bilateral, short leg splints were applied with the feet in mild plantar flexion.

The patient returned for his 2-week postoperative visit without complications and was transitioned to walking boots at his 6-week visit. At his most recent visit, 6 months postoperatively, he was doing well overall. He had resolving paresthesia in his right medial plantar nerve distribution. He was weight bearing without considerable difficulty and had returned to work. We were not able to contact him for a final follow-up. The latest radiographs showed maintenance of the patient’s reduction (Figures 5 and 6). He was overall satisfied with his function and pain.

**DISCUSSION**

Wong-Chung et al. evaluated patients presenting with calcaneus fractures and the subsequent relationship with PTS. The aim was to determine how peroneal tendon dislocation (PTD) could go unrecognized on initial CT imaging by both radiologists and orthopaedic surgeons. They found that 18 of 40 patients with PTD had swelling at the malleolar level. When 4 mm of swelling was measured on CT, the sensitivity was 100.0% and specificity was 21.8%. At 6 mm of swelling, sensitivity was 90.5% and specificity was 49.1%. At 11.5 mm, the sensitivity was 71.4% and specificity was 79.2%. The absence of lateral malleolus swelling decreased the likelihood of the patient having a PTD. Wong-Chung et al. acknowledged that swelling makes it clinically difficult to diagnose subluxation, but a high index of suspicion should be maintained. They also reported that 14.0% of the calcaneus fractures (13 of 79) had a positive fleck sign.

Chauhan et al. recommend that while working up patients with suspected PTS, particularly with sports-related injuries, it’s advisable to obtain anteroposterior, lateral, and mortise radiographs. Although these scans can yield ambiguous results, a small fleck seen on imaging, such as a fibula fragment, can be helpful in making a diagnosis. With a diagnostic test sensitivity of 0.31, specificity of 0.98, and a positive predictive value of 0.84, the fleck sign can indicate a PTS or PTD. Furthermore, they suggest different imaging to assist in assessing for potential PTS. For example, when using ultrasound on a foot in a dorsiflexed and everted position, the peroneal tendon can be properly visualized. For our case, a CT scan with soft-tissue windows was diagnostic for PTS. VanPelt et al. reported another method using magnetic resonance imaging with kinetic assessment; however, it should not be the only imaging used to determine the need for corrective surgery in patients with PTS.

In conclusion, surgeons should maintain a high index of suspicion for PTS during traumatic injuries to the lower extremities. Although more obvious injuries may be present, such as a calcaneus fracture, there should be a high incidence of concurrent PTS, particularly in association with subtalar dislocation. For early diagnosis with associated fractures, reducing pain and swelling would be difficult, and other diagnostic methods would be preferable. The fleck sign has shown to be indicative of tears in the superior peroneal retinaculum. In this case, bilateral fleck signs and bilateral superior peroneal retinaculum tears that caused PTS were present. To provide the best long-term outcomes for the patient, surgeons should assume that PTS is indicated when a fleck sign is present until proven negative or treated accordingly.

**REFERENCES**

Chronic Complex Volar Dislocation of the Middle and Ring Finger Metacarpophalangeal Joint: A Case Report

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Funding: The authors received no financial support for the research, authorship, and publication of this article.

Conflict of Interest The authors report no conflicts of interest.

Informed Consent The patient was informed that the data concerning their case would be submitted for publication, and they provided verbal consent.

ABSTRACT

Metacarpophalangeal (MCP) joint dislocations are uncommon injuries. Most dislocations occur dorsally, with volar dislocations being rarer owing to the architecture of the joint. Because of the rarity of the condition, there is no accepted standard treatment for these injuries. The most commonly affected digit is the ring finger, followed by the middle finger and then the small finger. Management depends on the complexity of the injury, with complex dislocations requiring open reduction owing to interposed soft tissue and repair of damaged ligaments and tendons. We describe a 52-year-old man with chronic MCP dislocation who underwent unsuccessful open reduction and subsequently required joint arthroplasty.

Keywords: Dislocation, Metacarpophalangeal Joint, Arthroplasty, Chronic, Irreducible

INTRODUCTION

Finger dislocations can occur at three different locations, including the distal interphalangeal (DIP), proximal interphalangeal (PIP), or metacarpophalangeal (MCP) joints. PIP joint dislocations are the most common, while MCP joint dislocations are relatively rare injuries owing to the increased protection from the volar plate and collateral ligaments.1,2,3 Most finger dislocations occur dorsally.2 Volar dislocations are rare, with most of our knowledge obtained from case reports and small case series (Table 1). Given the limited number of reported cases, there is no consensus regarding the treatment of these injuries. Multiple surgical approaches have been described.2,4,5,6 In this case report, we describe a chronic irreducible, volar MCP joint dislocation of the middle and ring finger.

CASE REPORT

A 52-year-old man presented to an outside emergency department 2 hours after a 170-lb object fell from approximately 2 m onto his closed right hand. He had concerns of pain, swelling, and the inability to extend the fingers of his right hand. He was diagnosed with a hand contusion and placed in a volar resting splint for 3 weeks. The patient did not follow up, and he underwent 2 months of immobilization before initiating occupational therapy for range of motion (ROM) training.

After experiencing persistent limited motion, the patient was referred to our institution 6 months after the initial injury. He noted mild pain with terminal flexion. Physical examination showed 45° of extensor blockade of the right middle and ring fingers about the MCP joints. He had full flexion at the MCP joints and full active ROM of the interphalangeal joints. He denied any pain at the involved MCP joints. Plain films and computed tomography scans showed complete volar dislocation of the middle and ring proximal phalanges (Figure 1). The patient was diagnosed with a chronic volar dislocation of the MCP joints at the middle and ring fingers.

Closed reduction was not attempted in the clinic owing to the chronic nature of the dislocations. The patient was indicated and consented for open reduction. During the initial operation, the middle finger was explored first. A dorsal approach was used to expose the middle finger MCP joint. The dorsal capsule was interposed in the joint space and was subsequently removed. Erosive changes to the articular surfaces of the proximal phalangeal base and the metacarpal head were identified. Following reduction attempts, the joint remained dislocated volarly owing to pathologic contracture of the collateral ligaments. However, a collateral ligament release failed to allow adequate
The treatment of these injuries. Multiple surgical procedures have been performed, with most of our knowledge obtained from case reports. Dislocations occur dorsally. Volar dislocations are rare, with MCP joint dislocations being relatively uncommon, with incidence rates as low as 3.2%. Finger dislocations have a reported incidence of 166,000 cases per year in emergency departments in the United States. MCP joint dislocations are uncommon, with incidence rates as low as 3.2%. Owing to the rarity of the condition, there have been no epidemiological studies regarding the incidence of isolated volar MCP dislocations. Here, we describe a case of a chronic volar MCP dislocation of the middle and ring fingers that was ultimately treated with joint arthroplasty of both digits due to erosive joint cartilage destruction.

The rarity of volar dislocations is due to the architecture of the MCP joint. Dislocations commonly occur dorsally because the volar side is reinforced with the volar plate, flexor tendons, collateral ligaments, and the A1 pulley. The disruption of these structures during a traumatic volar dislocation, such as volar plate interposition into the joint, results in significant joint instability. A biomechanical analysis of volar MCP dislocations by Afifi et al. suggests the volar plate is the primary restraint to volar dislocation; however, surgical repair did not increase the stability of the joint. Chronic MCP dislocations can cause pathologic joint alignment through scarring, adhesion formation, and erosive articular surface changes, as observed in this case. These degenerative changes could further weaken the volar plate, thus making the joint even more unstable and necessitating more complex reconstructive procedures. Despite multiple attempts at open reduction, the proximal phalanx remained dislocated volarly. Prior reports of chronic injuries range from 5 weeks to 24 months, and all required multiple attempts at open reduction before achieving an acceptable joint alignment.

Our patient’s injury was classified as a chronic, complex volar MCP dislocation. To our knowledge, this is the only case report involving a chronic dislocation of both the middle and ring fingers and only the second describing chronic dislocation of multiple digits (Table 1). Delayed diagnosis is a problem in MCP dislocations because depression between the metacarpal head and the proximal phalanx base may be masked by significant dorsal swelling. In several previously reported cases, the diagnosis was initially missed. In our patient, dorsal swelling from the blunt trauma to his hand was likely why his injury was initially missed. When the patient presented to our clinic 6 months after the initial injury, we were able to palpate a depression on the dorsal surface of the proximal phalanx. Retained ability to actively flex the digits may also underestimate the severity of the injury. On the physical examination of our patient’s hand, he had retained full flexion of the MCP joint but had a significant extensor blockade of 45°.

Indications for open reduction include irreducible, unstable, or open joints. Approaches include the dorsal, volar, or combined approach. The dorsal approach is known to have a lower risk of neurovascular injury and easier access to the entrapped volar plate...
or dorsal capsule.\textsuperscript{5,6,11,14} However, the volar approach improves visibility of the volar plate and surrounding ligaments and tendons.\textsuperscript{5,14} We used a combination of the dorsal and volar approach to explore the joint, which revealed interposition of the dorsal capsule and volar plate into the joint space. In prior reports, the combined approach was the most commonly used while the isolated volar approach was the least.\textsuperscript{5,6,11,15}

If reduction of the joint cannot be achieved through open reduction, joint arthroplasty can provide structural stability and re-establish joint congruity.\textsuperscript{15} Joint replacement was used in our patient because of the significant cartilaginous and ligamentous damage incurred over the 6 months before presentation. Arthroplasty remains a viable option for unsalvageable joints due to chondrolysis and stiffness. Traditionally, silicone implants were used; however, due to high rates of complications, pyrolytic carbon is currently the material of choice.\textsuperscript{6,15,16} Wall et al.\textsuperscript{14} reported significant improvement in ROM, subjective improvement in pain, and high patient satisfaction (90.0\%) at an average of 4 years after surgery. This study found similar results.

This case represents a rare pathology with no described standard of care. Chronic MCP dislocations are challenging to treat owing to frequently missed diagnoses and the architecture of the MCP joint itself. Despite failed open reduction, this case had a satisfactory outcome with pyrolytic MCP reconstruction, suggesting this could be a viable treatment option for complicated cases.

REFERENCES
## APPENDIX 1. Summary of previous case reports of volar metacarpophalangeal dislocations

<table>
<thead>
<tr>
<th>Author (Year)</th>
<th>Age / Sex</th>
<th>Mechanism of Injury</th>
<th>Finger Involved</th>
<th>Acute / Chronic</th>
<th>Missed Initial Diagnosis</th>
<th>Treatment</th>
<th>Associated feature(s) (eg, interposed tissue, anatomic pathology)</th>
<th>Follow-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mclaughlin et al (1985)</td>
<td>--</td>
<td>Hyperextension injury</td>
<td>Middle</td>
<td>Acute</td>
<td>No</td>
<td>ORIF (dorsal approach)</td>
<td>Interposed dorsal capsule</td>
<td>--</td>
</tr>
<tr>
<td>Renshaw et al (1997)</td>
<td>48/M</td>
<td>Hyperextension injury</td>
<td>Small</td>
<td>Acute</td>
<td>No</td>
<td>ORIF (volar approach)</td>
<td>Interposed volar plate</td>
<td>15 months; ROM: 10 to 70°; no disability</td>
</tr>
<tr>
<td>Wood et al (1981)</td>
<td>17/F</td>
<td>MVA</td>
<td>Index</td>
<td>Chronic</td>
<td>(9 months)</td>
<td>No</td>
<td>Closed reduction attempt; Transarticular fixation with K-Wire failure; Arthrodesis (dorsal approach)</td>
<td>Volar displacement of collateral ligaments, ulnar lateral band, and interosseous tendon displacement; Articular damage of metacarpal head; Interposed dorsal capsule</td>
</tr>
<tr>
<td>--</td>
<td>20/M</td>
<td>MVA</td>
<td>Middle</td>
<td>Acute</td>
<td>No</td>
<td>Closed reduction attempt; ORIF (dorsal approach); Transarticular fixation with K-Wire</td>
<td>Interposed dorsal capsule; Articular surface erosion</td>
<td>Lost to follow-up</td>
</tr>
<tr>
<td>--</td>
<td>61/F</td>
<td>Hyperflexion injury</td>
<td>Middle</td>
<td>Chronic</td>
<td>(5 months)</td>
<td>Yes</td>
<td>Silastic implant arthroplasty</td>
<td>Interposed dorsal capsule; Articular surface erosion</td>
</tr>
<tr>
<td>Betz et al (1982)</td>
<td>70/F</td>
<td>Hyperextension injury</td>
<td>Ring</td>
<td>Acute</td>
<td>No</td>
<td>Closed reduction attempt; ORIF (volar and dorsal approach)</td>
<td>Interposed volar plate; Interposed ulnar collateral ligament</td>
<td>7 months; full ROM regained; no disability</td>
</tr>
<tr>
<td>Moniem et al (1983)</td>
<td>59/M</td>
<td>Hyperflexion with blunt trauma to dorsum of the hand</td>
<td>Small</td>
<td>Chronic</td>
<td>(5 weeks)</td>
<td>No</td>
<td>Closed reduction attempt; Closed reduction attempt with percutaneous pinning; ORIF (dorsal and volar approach); Transarticular fixation with K-wire</td>
<td>Scarring and attenuation of dorsal capsule; Scarring and attenuation of collateral ligaments; Articular surface erosion; Scarring and interposed volar plate</td>
</tr>
<tr>
<td>Khuri et al (1986)</td>
<td>31/M</td>
<td>Hyperflexion injury</td>
<td>Ring</td>
<td>Acute</td>
<td>No</td>
<td>Closed Reduction</td>
<td>Rotatory deformity; Ruptured unilateral collateral ligament</td>
<td>5 weeks; minor pain; full ROM regained</td>
</tr>
<tr>
<td>Qiu et al (1992)</td>
<td>20/M</td>
<td>Hyperflexion injury</td>
<td>Index</td>
<td>Chronic</td>
<td>(3 months)</td>
<td>Yes</td>
<td>ORIF (dorsal and volar approach)</td>
<td>Interposed volar plate</td>
</tr>
<tr>
<td>Hargarten et al (1992)</td>
<td>66/M</td>
<td>Hyperflexion injury; blunt trauma to dorsum of the hand</td>
<td>Small</td>
<td>Chronic</td>
<td>(4 months)</td>
<td>Yes</td>
<td>ORIF (unspecified approach)</td>
<td>Fixed flexion contracture of 45°</td>
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<tr>
<td>Hughes et al (1993)</td>
<td>63/M</td>
<td>MVA, Blunt trauma to dorsum of the hand</td>
<td>Small</td>
<td>Acute</td>
<td>No</td>
<td>Closed reduction attempt; ORIF (volar approach) failure; ORIF (volar approach) with trans-articular fixation with K-wire failure; ORIF (dorsal approach) with trans-articular fixation with K-wire</td>
<td>Avulsed volar plate</td>
<td>Follow-up time not specified; limited ROM (unspecified); degenerative changes on plain film</td>
</tr>
<tr>
<td>Paul et al (1995)</td>
<td>22/M</td>
<td>Blunt trauma (unspecified; fell while riding bike)</td>
<td>Ring</td>
<td>Acute</td>
<td>No</td>
<td>ORIF (unspecified approach)</td>
<td>Ruptured volar plate; Interposed volar plate</td>
<td>12 months; painless; full ROM regained</td>
</tr>
</tbody>
</table>

(Continued on next page)
<table>
<thead>
<tr>
<th>Author (Year)</th>
<th>Age / Sex</th>
<th>Mechanism of Injury</th>
<th>Finger Involved</th>
<th>Acute / Chronic</th>
<th>Missed initial diagnosis</th>
<th>Treatment</th>
<th>Associated feature(s) (eg, interposed tissue, anatomic pathology)</th>
<th>Follow-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vandeweyer et al (1998)¹¹</td>
<td>48/F</td>
<td>MVA; hyperflexion injury</td>
<td>Middle</td>
<td>Chronic (4 months)</td>
<td>Yes</td>
<td>Closed reduction attempt; ORIF (dorsal approach), trans-articular fixation with K-wire; ORIF (volar approach), trans-articular fixation with K-wire</td>
<td>Interposed dorsal capsule; Articular surface erosion; Interposed volar plate</td>
<td>12 months; ROM 0 to 80° (vs -30 to 90°)</td>
</tr>
<tr>
<td>Takami et al (1999)¹²</td>
<td>20/M</td>
<td>Blunt trauma (unspecified; fell while running)</td>
<td>Ring</td>
<td>Acute</td>
<td>No</td>
<td>Closed reduction</td>
<td>--</td>
<td>4 months; painless; full ROM regained</td>
</tr>
<tr>
<td>Lam et al (2000)¹³</td>
<td>44/M</td>
<td>Hyperflexion injury</td>
<td>Ring</td>
<td>Acute</td>
<td>No</td>
<td>Closed reduction attempt; ORIF (dorsal and volar approach) with intraarticular K-wire fixation</td>
<td>Scarred dorsal capsule; Scared collateral ligaments; Interposed volar plate</td>
<td>7 months; painless; ROM full extension, 75° flexion</td>
</tr>
<tr>
<td>Patel et al (2000)¹⁴</td>
<td>71/M</td>
<td>MVA; Hyperflexion injury</td>
<td>Small</td>
<td>Acute</td>
<td>No</td>
<td>Closed reduction attempt; ORIF (dorsal approach)</td>
<td>Ruptured collateral ligaments; Interposed Junturae tendinum; Avulsed dorsal capsule</td>
<td>3 months; painless; ROM 20° extension lag and 75° flexion; partial volar subluxation</td>
</tr>
<tr>
<td>Murase et al (2004)¹⁵</td>
<td>52/F</td>
<td>Hyperextension injury</td>
<td>Ring</td>
<td>Acute</td>
<td>No</td>
<td>Closed reduction attempt; ORIF (dorsal and volar approach)</td>
<td>Ruptured collateral ligaments; Avulsed dorsal capsule; Chondral defect at dorsoulnar aspect of metacarpal head; Ruptured flexor tendon sheath; Avulsed volar plate</td>
<td>8 months; painless; ROM 70° of flexion, extension only limited by 10°</td>
</tr>
<tr>
<td>Panchal et al (2010)¹⁶</td>
<td>45/M</td>
<td>Blunt trauma (unspecified; fell while riding bike)</td>
<td>Middle</td>
<td>Acute</td>
<td>No</td>
<td>Closed reduction</td>
<td>--</td>
<td>12 weeks; painless; ROM 0 to 85°; grip strength 48 kg</td>
</tr>
<tr>
<td>Basar et al (2014)¹⁷</td>
<td>22/M</td>
<td>MVA</td>
<td>Ring; Small</td>
<td>Chronic (24 months)</td>
<td>Yes</td>
<td>Closed reduction attempt; ORIF (dorsal approach) with intraarticular K-wire fixation; Volar closing wedge osteotomy</td>
<td>Ruptured dorsal capsule</td>
<td>12 months; painless; ROM 4th digit - full flexion, no extension limitation; ROM 5th digit - 10° flexion limitation, no extension limitation</td>
</tr>
<tr>
<td>34/M</td>
<td>Blunt trauma (punched wall)</td>
<td>Ring</td>
<td>Chronic (10 months)</td>
<td>Yes</td>
<td>ORIF (dorsal approach) with intraarticular K-wire fixation; Volar closing wedge osteotomy</td>
<td>Ruptured dorsal capsule</td>
<td>8 months; painless; ROM 30° limitation of flexion, no extension limitation</td>
<td></td>
</tr>
<tr>
<td>Keung et al (2016)¹⁸</td>
<td>49 / M</td>
<td>Blunt trauma (unspecified; fell on outstretched hand)</td>
<td>Ring</td>
<td>Acute</td>
<td>No</td>
<td>Closed reduction attempt; ORIF (volar approach) with trans-articular K-wire fixation</td>
<td>Interposed volar plate; Ruptured collateral ligaments; Cartilage defect on proximal phalangeal base</td>
<td>12 months; painless; ROM limited to 5 to 10°; Significant chondrolysis</td>
</tr>
<tr>
<td>Ramzi et al (2018)¹⁹</td>
<td>30 / M</td>
<td>MVA; Forced Hyperextension</td>
<td>Ring</td>
<td>Acute</td>
<td>No</td>
<td>Closed Reduction</td>
<td>--</td>
<td>No Pain, full ROM9</td>
</tr>
<tr>
<td>Current study (2020)</td>
<td>52 / M</td>
<td>Blunt trauma (unspecified; heavy object fell on hand)</td>
<td>Middle, Ring</td>
<td>Chronic (6 months)</td>
<td>Yes</td>
<td>Closed Reduction attempt; ORIF (dorsal and volar approach)</td>
<td>Interposed dorsal capsule; Scared collateral ligaments</td>
<td>Significant chondrolysis</td>
</tr>
</tbody>
</table>
Appendix 1. References

M, male; F, female; MVA, motor-vehicle accident; ORIF, open reduction internal fixation; ROM, range of motion; MCP, metacarpophalangeal
Excessive Tibial Overgrowth Associated Ankle Valgus Deformity After Pediatric Open Mid-Shaft Tibial Fracture: A Case Report

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Amr Abdelgawad, MD, MBA

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Funding The authors received no financial support for the research, authorship, and publication of this article.

Conflict of Interest The authors report no conflicts of interest.

Informed Consent Consent was obtained from the patient parent for the publication of the case.

ABSTRACT
Tibial overgrowth after pediatric tibial fractures has been reported in the literature. Multiple factors can affect the amount of overgrowth, including age and gender of patients, type of fracture (open vs closed), degree of comminution, reduction techniques, and fixation method. We describe a 10-year-old boy with a 2-cm overgrowth after sustaining an isolated open tibia fracture with an intact fibula, which is more than what has been previously described in the literature for tibia fractures. This overgrowth was associated with asymmetrical growth of the distal tibial physis, asymmetrical growth between tibia and fibula, and ankle valgus deformity.

Keywords: Tibial Overgrowth, Ankle Valgus, External Fixator, Tibial Fractures, Open Fracture, Pediatric Overgrowth, Pediatric Tibia Fracture

INTRODUCTION
The phenomenon of tibial overgrowth following tibial fractures in pediatric patients has been reported in the literature. It has been described following both operatively and nonoperatively treated tibial fractures, including tibial shaft fractures and proximal tibial fractures. The amount of overgrowth following pediatric tibial fractures can vary depending on whether the fracture is open or closed and the location of the fracture, degree of comminution, primary treatment (casting versus internal fixation versus external fixation), and gender and age of the patient. The average overgrowth following a pediatric tibial fracture is about 5 mm, and it rarely reaches 15 mm.

We describe the successful treatment of a 10-year-old boy with an open tibia shaft fracture and intact fibula. Treatment resulted in progressive longitudinal overgrowth (more medial than lateral) of the distal tibia with limb length discrepancy of 2 cm and apex medial deformity leading to ankle valgus deformity.

CASE REPORT
A 10-year-old boy was run over by a truck and developed an isolated open fracture of the right tibia classified as a Gustilo type IIIB (Figures 1 and 2). According to Orthopaedic Trauma Association’s open fracture classification, the injury had the following classifications: skin=2, muscle=1, arterial=1, contamination=2, and bone loss=1. The fibula was not broken, and there was no apparent direct injury to the distal tibial physis. First-generation IV cephalosporin (Cefazolin) was administered in the emergency department. The wound was covered with a sterile dressing, and the limb was splinted. He was taken emergently to the operating room and treated by irrigation and debridement. Open direct anatomical reduction was obtained using a uniplanar external fixator and loose wound approximation (Figures 3 and 4). At 18 weeks postoperatively, the radiographs showed progressive healing of the fracture with 3° of apex medial angulation at the fracture site (Figure 5). We used “micromotion” at the fracture site to enhance the healing process through dynamization of the frame. To do this, we removed one pin from the proximal cluster of pins and one pin from the distal cluster of pins (Figure 5). The external fixator was removed 22 weeks after its application.

At 17 months after injury (1 year after frame removal), the patient presented to our clinic due to a progressive gait abnormality and the development of a deformity on the affected right side. Anteroposterior and lateral radiographs of the affected side showed the fracture to be completely healed and remodeled with a minimal...
INTRODUCTION

The phenomenon of tibial overgrowth following tibial fracture in pediatric patients has been reported in the literature. Multiple factors can affect the amount of overgrowth, including age and gender of patients, type of fracture (open vs closed), fracture, degree of comminution, primary treatment (casting versus internal fixation versus external fixation), and location of the fracture is open or closed and the amount of overgrowth, including tibial shaft fractures and proximal tibial fractures in pediatric patients has been reported in the literature. It has been described following both fractures and gender. The amount of overgrowth following a pediatric tibial fracture is about 5 mm, and it rarely reaches 15 m.

ABSTRACT

We describe the successful treatment of a 10-year-old boy with valgus deformity. The patient presented to our clinic due to a progressive gait abnormality and the development of a deformity leading to ankle valgus deformity. Scanogram showed 2 cm of limb length discrepancy with the affected right side longer than the left side and valgus deformity of the ankle (Figure 6). There was 2 cm of overgrowth of the right tibia compared to the left tibia. Both right and left fibulae were at an equal length.

Deformity analysis showed that the center of rotation and angulation (CORA) of the distal deformity was at the right distal tibia physis with a 14° apex medial (Figure 7A) and added 3° of apex medial angulation at the level of the fracture. The CORA with the 14° apex medial angulation reflects both the asymmetrical distal apex medial deformity.

CASE REPORT

A 10-year-old boy was run over by a truck and developed an isolated open fracture of the right tibia at the midshaft tibial fracture (Gustilo type IIIB). Consent was obtained from the patient parent for the publication of the case.

Radiographic image after 4 months postoperatively showing that dynamization by removing pins from construct. Also, there is 3° of apex medial angulation at the level of the fracture.
tibial physeal growth (medial more than lateral) and the asymmetrical tibial/fibular growth (tibia growing more than fibula). The overall valgus deformity at the level of the ankle was 17° compared to the left side (Figure 7B).

The patient’s gait was greatly affected by the limb length discrepancy and severe ankle deformity. The family and the patient wanted to find a surgical option to correct the gait and ankle deformity. They were not interested in observing the deformity due to the affection of the gait and the relatively fast rate of deformity development. Treatment options for the limb length discrepancy were epiphysiodesis of the right side or lengthening the unaffected left side. For the valgus ankle deformity, the options for treatment were either osteotomy of the distal tibia or hemiepiphysiodesis of the medial side of the distal tibial physis. After discussion with the family and providing them with the options, the decision was to proceed with plate epiphysiodesis (medial and lateral plates) in the proximal right tibia as the treatment for overgrowth of the right tibia. For treatment for the valgus ankle, the decision was to proceed with hemiepiphysiodesis using a distal medial tibial screw. This treatment method was preferred because it was less invasive, did not involve non-weight bearing, excluded the possible complication compartment syndrome that may occur with tibial osteotomy, and was less effort and stress on the patient and family. Additionally, the distal tibial hemiepiphysiodesis had the advantage of being close to the CORA of the main deformity. Because of the patient’s age, the plate epiphysiodesis of the proximal
was preferred because it was less invasive, did not involve any physis injury, commonly result in abnormal longitudinal growth and, sometimes, in angular deformity.

In the largest study evaluating the overgrowth after tibial and femur fracture, Stilli et al. included 822 cases of pediatric tibial fractures. They found the average overgrowth after tibial fracture to be 5.7 mm, with more overgrowth in patients under 5 years old at the time of injury. The authors found that most of the overgrowth occurs in the first 2 years after fracture. The authors found that when the treatment involved less shortening initially, a greater final overgrowth can be expected. In our case, there was no initial shortening because we were able to obtain direct open reduction; thus, the amount of overgrowth did express itself as a final limb length discrepancy.

Age has been described as a factor of overgrowth following pediatric lower extremity fractures; however, this has been debated. Generally, overgrowth is a phenomenon of “middle-aged” children. Greiff and Bergmann found that overgrowth after a tibial fracture occurs mainly in boys 3 to 12 years of age and girls 3 to 10 years. Some authors did not find an effect for the skeletal age on the amount of overgrowth. Other studies found that the phenomenon of overgrowth is more pronounced in younger children, mainly boys, under the age of 5 years. In our case, the patient’s age at the time of injury was 10 years. Shapiro found that most of the overgrowth will occur in the first 18 months following a fracture. Our patient presented 1 year after healing (17 months after injury).

Spiral, comminuted fractures and fractures resulting from high-energy injuries were found to have more overgrowth than simple transverse fractures. This may be related to more disruption of the periosteum in spiral and comminuted fractures than simple transverse fractures. Our case was a type IIIA open transverse fracture with major disruption of the periosteum in which a significant amount of the bone was stripped entirely of the periosteum. Gasco noticed that fractures that required prolonged treatment until the fracture is consolidated had developed more overgrowth than those that healed faster. Our case was an open fracture that took 22 weeks to heal. This prolonged time to heal could have contributed to excessive overgrowth. Stilli et al. recommended creating intentional shortening of the fracture in anticipation of the overgrowth. With internal fixation and external fixation of tibial fractures becoming more popular for adolescent tibias and less dependent on closed reduction and casting, surgeons aim for as much anatomical reduction as possible. This may be the reason for tibial overgrowth after pediatric fracture becoming more pronounced with modern treatment options than previously reported treatment options.

DISCUSSION
In pediatric patients, bone overgrowth following fractures has been well described in the literature, which may be due to the stimulation of growth plates caused by the hyperemia of the affected bone during consolidation and remodeling. Overgrowth after pediatric fractures has been studied extensively following femur fractures and, to a lesser extent, after tibia fractures. Any time a skeletally immature bone fractures, there is the possibility it may not grow exactly to the same length. Diaphyseal fractures, not involving any physis injury, commonly result in abnormal longitudinal growth and, sometimes, in angular deformity.

Following the deformity correction surgery, the tibial overgrowth and valgus deformity at the ankle were corrected. Final scanogram showed an equal length of the right and left sides and full correction of the ankle valgus deformity (Figure 8). The normal relation between the tibia and fibula on the right side was restored. The patient was still not skeletally mature 2 years after the deformity correction surgery, and the implant was removed.

Figure 8. Final scanogram showing an equal length of the right and left side and full correction of the ankle valgus deformity.
The use of external fixators as treatment of tibial shaft fractures has been associated with more overgrowth than other internal fixation methods.\textsuperscript{19,20} This overgrowth is most likely not due to the usage of the external fixator itself, but due to the fact that external fixators are commonly used for comminuted open tibial fractures with a disrupted periosteum.

In the current case, several factors were associated with the excess overgrowth, including the fracture being open, spiral, and high energy; the sex of the patient; the use of an external fixator without initial shortening; and the prolonged time to healing. To our knowledge, this amount of overgrowth has not been reported with pediatric tibial fractures before.

The leg segment is a 2-bone segment that includes the tibia and fibula, and it is different from the thigh segment. If the tibia and fibula do not grow symmetrically, a deformity will develop over the time of differential growth. Some studies have explained this as the intact fibula acting as a cord or a partial tether for the tibial growth, leading to the progressive deviation.\textsuperscript{1} Other studies have attributed this phenomenon to the unequal growth of the tibial physis.\textsuperscript{2} The case in our current study had an overgrowth of 20 mm, which is more than what is typically described for tibial fractures. This amount of excess overgrowth may explain the large degree of valgus deformity at the ankle joint.

Although coronal deformities after distal tibial physeal fractures are commonly reported, we are not aware of a study describing a case of a more medial than lateral overgrowth at the distal tibial physis after a tibia shaft fracture. A coronal deformity can develop after a direct injury to the physis, resulting in abnormal physeal growth.\textsuperscript{22} However, we do not believe that the ankle valgus deformity in our case was due to direct injury of the physis because the primary fracture was at the level of the midshaft with no radiographic or clinical extension to the distal tibial physis. In addition, the open wound was medial, making an injury to the lateral physis extremely unlikely. The distal lateral physis also grew more than average when compared to the ipsilateral fibula and contralateral tibia, but not as much as the medial physis. It would be very unusual for a direct injury to cause that.

Treatment of the ankle valgus with guided growth has been well studied in the literature, with consistent results reporting it safe and effective.\textsuperscript{23-25} Using a similar technique as the current study, Chang et al\textsuperscript{25} found that the medial malleolar screw resulted in an average correction of about 0.37° per month. In our case, the 17° ankle valgus was corrected in only 24 months (0.71° per month), which was twice the average described by Chang et al.\textsuperscript{25} We do not think that the ankle valgus correction was entirely due to the medial malleolar screw during medial distal tibial hemiepiphysiodesis because a significant amount of correction was related to stopping the growth of the tibia by proximal medial and lateral plates epiphysiodesis, which allowed the fibula to reach proportionate length. Using the average correction rate described by Chang et al\textsuperscript{25} as a reference, it is reasonable to assume that 50.0% of the correction was by distal medial screw hemiepiphysiodesis and the other 50.0% by restoring the correct relation between the length of the tibia and fibula.

In our case, the CORA analysis (Figures 7A and 7B) showed the ankle valgus deformity was mainly related to disturbance of the growth of the distal tibial physis. The medial side of the physis grew at a faster rate than the lateral side of the physis, with the fibula acting as a partial tether for the tibial distal lateral physis. The ankle valgus deformity was also related to the relative lengthening of the tibia in relation to the fibula. Both of these factors contributed to the ankle valgus deformity. Ankle radiographs also showed an obvious tilt in the growth plate in relation to the distal tibial articular line (Figure 7B).

This study is the first description of the valgus ankle associated with tibial overgrowth after an isolated tibia fracture. Our analysis shows that this is related to the distal medial tibia growing faster than the lateral distal tibia, which is tethered by the distal fibula and unequal growth of the tibia and fibula. We hypothesized that the overgrowth of the tibia compared to the fibula could also occur in the distal part of the tibia, resulting in “valgus ankle.” Correction of the deformity should be at the level of the CORA either by osteotomy or guided growth modulation (if there is growth potential).

In conclusion, we present a case of the successful treatment of an isolated open tibia fracture that developed a 2-cm overgrowth. This amount of overgrowth is more than what has been previously described in literature before. Certain factors may have contributed to this excessive overgrowth (ie, open fracture, treatment by external fixator with no initial shortening, marked periosteal stripping, prolonged healing time, male patient). This excess overgrowth was associated with the asymmetrical growth of the distal tibial physis and unequal length of the tibia and fibula, resulting in valgus angulation of the ankle.
REFERENCES


Orthopaedic Residency and the COVID Kid

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Funding The authors received no financial support for the research, authorship, or publication of this article.

Conflict of Interest The authors declare no conflicts of interest.

I thought the hardest thing I had ever done was nearly completing orthopaedic residency. Then, I had my first baby in a global pandemic as a chief resident.

Orthopaedic surgery is a competitive field, and the residency positions are coveted. I worked hard and was fortunate enough to match to my top-choice program. It often felt like we were required to sacrifice everything to be a good resident, and there were no guidelines for balancing work and family. As a male-dominated profession, there were certainly no guidelines for female residents balancing residency and having children. There were also no female faculty members in my department whom I could ask for advice. I had always wanted children but in an ethereal, futuristic sense. However, as residency and years of my fertility passed by, I often worried if I would “find the time.” Having never tried, I had no idea if I would have difficulty or even success conceiving biological children. Maybe all that fluoroscopy had fried my ovaries?

Early in my chief year, I found myself excitedly, although somewhat unexpectedly, expecting. Even if I had planned the timing, I never would have admitted it to my program for fear of judgment. When a resident cannot perform a clinical duty or a call shift, that duty does not disappear; it just goes to someone else. I did not welcome the perception that I was intentionally dumping work onto my colleagues. When I did tell my program director I was pregnant, it was as if scripted in a sitcom. We were scrubbed in a 4-hour case. Thirty minutes into it, he went on an unprovoked rant about how inconvenient having children in residency is and how they have never had a pregnant female resident. He then asked me when I thought that might happen. Fighting back the tears, unable to really speak, I shrugged my shoulders and silently proceeded with the surgery. I sent him a text later that day: “in about 7 months.” To his credit, he was absolutely supportive during residency and remains so to this day, but that was not how I envisioned delivering my news.

For the first time, I found myself unable to ignore normal body cues like hunger. I learned quickly that I had very little control over the physical aspects of my pregnancy. I could not persuade myself out of nausea, which lasted nearly my entire pregnancy. I couldn’t dissuade the little feet intent on kicking me in the ribs for hours at a time. Sometimes I had to briefly scrub out of long cases or take 10 minutes between cases instead of just bouncing to the next scrub sink, as I was so accustomed. I already felt that I was disappointing my colleagues and superiors, and I hadn’t even needed time off yet.

As a chief, I had an influence on the call schedule, which allowed me to frontload all my call shifts for the year before I delivered, so I would not need to make any up after my “maternity leave.” I use the term loosely because there is no such thing as maternity leave in residency. I would get the same number of vacation days as every other resident, 15 days. If I needed additional time, it would be FMLA, which would delay my graduation and, therefore, the fellowship I had already matched. I was coping with the body aches and swollen feet secondary to standing all day in double thickness lead. I had persistent nausea, little time to eat, and subsequent trouble gaining weight. Eventually, the frequent late-night operations, preceded by long days, began to take a toll on my blood pressure. My doctor strongly urged me to stop operating for 12 plus hours at a time. She didn’t put me on bed rest at my request because she knew that would disrupt my graduation timeline. As much as I wanted to be a team player and good chief resident, I wanted a healthy baby more.

I was able to complete all but one of my allotted call shifts. I paid another resident to cover my final shift so I was able to complete all but one of my allotted call shifts. I paid another resident to cover my final shift so I could not come for the birth. None of them to help with the baby either, for fear of possible infection. Caring for a newborn for the first time is the hardest thing I have ever done. She is the hardest thing I have ever done. She is the hardest thing I have ever done.

Beyond that, our already tiny daughter had trouble with infection. Caring for a newborn for the first time is most surgeons would agree is distressing. I couldn’t even control my emotions rationally. I found myself out of control of the situation, which was dulled, and my efforts seemed futile. I then returned to spend as much time at the hospital. I was effectively home for 6 weeks rather than the 3 weeks I was able to work from home, and because my practice is absolutely worth it and has been a more successful...
our family was able to visit and help. Virtually all of our friends are health care workers, so we did not allow any of them to help with the baby either, for fear of possible infection. Caring for a newborn for the first time is challenging under any circumstances. However, it was more difficult without relief. The village we had counted on to help raise our child was quarantined a world away, unable to offer anything but video call sympathies. Beyond that, our already tiny daughter had trouble with breastfeeding, jaundice, and weight loss.

I found myself out of control of the situation, which most surgeons would agree is distressing. I couldn’t make my baby better at breastfeeding, clearing bilirubin, or sleeping. I couldn’t make my husband lactate. I couldn’t make my body or brain go back to baseline. I was unable to control my emotions rationally. I cried, seemingly to the point of dehydration. I will forever be grateful for how wonderful my husband was, but he was exhausted too. We simply did not have any extra hands, nor could we anticipate when we might. To say the least, it was hard.

The only upside to COVID-19 was that my husband was able to work from home, and because my practice was not performing elective cases, I was not required to spend as much time at the hospital. I was effectively home for 6 weeks rather than the 3 weeks I was anticipating. Between the episodic sobbing, pumping, feeding, doctor appointments, etc., I tried to study for my upcoming board examination. My mental capacity was dulled, and my efforts seemed futile. I then returned for a final month of orthopaedic trauma to complete my residency. I wrote this with my daughter asleep next to me. She is the hardest thing I have ever done. She is absolutely worth it and has been a more successful endeavor than getting my husband to lactate.
The University of New Mexico Department of Orthopaedics & Rehabilitation: Alumni in Each State

Number of alumni in each state. Map reprinted with permission from Vexels https://goo.gl/QtSLq5.

**Hand Surgery Fellows**

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Sports Medicine Fellows

Roy Abraham (a) 2006
Tamas Bardos (Hungary) 2015
Brandee Black (h) 2016
Todd Bradshaw (TX) 2014
Blake Clifton (CO) 2015
Lindsey Dietrich (TX) 2014
Matthew Ferguson (TX) 2013
David Hankins (SC) 2019
John Jasko (WV) 2010
Ray Jensen (SD) 2016
David Johannesmeyer (SC) 2018
Adam Johnson (OH) 2012
Brock Johnson (NY) 2020
A. John Kiburz (NE) 2009
Lucas Korcek (OR) 2018
John Mann (AL) 2010
Toribio Natividad (TX) 2011
Blake Obrock (TX) 2017
Andrew Ockuly (NM) 2002
Ben Olson (CO) 2009
Ralph Passerelli (PA) 2007
James Rose (CO) 2013
Heidi Smith (KS) 2020
Brad Sparks (AK) 2008
Brad Veazey (TX) 2007
Kavita Vakharia (PA) 2018
Jonathan Wyatt (AR) 2012

Trauma Fellows

Stephen Becher (GA) 2014
Shahram Bozorgnia (GA) 2008
Max de Carvalho (KS) 2011
Seth Criner (CA) 2016
Fabio Figueiredo (CA) 2007
Brian Hodges (TX) 2020
Shehda Homedan (VA) 2006
Matt Lilly (UT) 2017
Victoria Matt (NM) 2005
Gary Molk (AK) 2010
Urvij Modha (NM) 2013
Brianna Patti (AZ) 2018
Leroy Rose (NM) 2012
Scott Sandlains (FL) 2019
Ahmed Thabet (TX) 2015
Zhiqing Xing (AL) 2009

Residents

Alexander Aboka (VA) 2011
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Brook Adams (TX) 2011
Zachary Adler (WA) 2007
Amit Agarwala (CO) 2002
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*Deceased