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The Co-Editors and editorial team of the *Western Journal of Orthopaedics (WJO)* express sincere thanks to our peer reviewers, whose volunteered time and effort enhance the Journal's scientific quality and relevance of content. As a team, we continue to move forward in our path toward official indexing in PubMed.

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Thank you for considering *WJO* as an avenue to feature your research.

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**Fellowship: Trauma, Sonoran Orthopaedic Trauma Group**

I grew up south of Buffalo, New York, close to the shores of Lake Erie, with long winters and short summers. I spent most of my time

either running cross country or aspiring to be a heavy metal rock star. I then obtained my biochemistry degree at Geneseo State in rural upstate New York, all the while hoping I would be able to drop out to pursue stardom with my band "The Love Handles." At some point I decided to apply for medical school and continued at SUNY Medical University in Syracuse, New York—which crushed the rock and roll dream. I was discouraged during the first 3 years of medical school as I searched for a specialty that was a good fit. In the beginning of my last year, as I was contemplating a career change, I did a one-week rotation on an orthopaedic trauma service and the rest is history. After rotating at The University of New Mexico (UNM) as a medical student, I was lucky enough to match in Albuquerque for orthopaedic residency. The last 5 years have been some of the most arduous and trying—but also the most fun. I will be completing orthopaedic trauma fellowship this upcoming year in Phoenix, Arizona with the Sonoran Orthopaedic Trauma Group.

I am thankful for the training opportunities and mentors I have had here at UNM during the last 5 years. I cannot imagine learning how to be a doctor anywhere other than Albuquerque. I owe everything to my beautiful and patient wife, Rachel, who has been more than encouraging and thoughtful during the last 5 years. Thanks to my parents who taught me hard work and humility and have been supportive of my life pursuits—even though it landed me almost 1800 miles from home. Thank you to my creative, intelligent, and witty sister, Jillian, who always seems to be one step ahead of me. Special thanks to my grandparents, James and Patricia, who taught me to always smile, to always make sure the job is well done, and to always leave something better than how you found it. Lastly, thank you to all my fellow residents. The amount of respect and appreciation I have for everything I have learned from you all is indescribable.

# Chiefs



**Travis Hughes, MD**

**Medical School: Arizona State University**

**Fellowship: Trauma, UT Health**

I was born and raised in Bullhead City, Arizona where the sun is high and the heat is hot. I went to Arizona State University where I really found myself. I then went to the University of Arizona College

of Medicine, where I met my wife, Jen, who straightened me out enough to get me into residency here at The University of New Mexico (UNM).

It has been a privilege to train here at UNM for the last 5 years. I have grown and changed a lot as a person and as a physician. I have learned many different perspectives on surgery and on taking care of people.

The next step for my family and I is to move to Houston, Texas, in July to start my trauma fellowship. It will be warm and humid, but an unbelievable opportunity to advance my training and to explore a different part of the country.

I am so lucky to have my wife Jen and our beautiful, happy baby girl, Annabelle, to keep me going during these interesting times. I would like to thank my family for being the crazy people that keep me sane. I would also like to thank my co-residents for keeping things fun and the attendings for keeping us honest.



**Aditi Majumdar, MD**

**Medical School: The University of New Mexico School of Medicine**

**Fellowship: Sports Medicine, Boston Children's Hospital/ Harvard Medical Schools**

My younger years were a perfect blend of growing up in Dayton, Ohio, and small town Socorro, New Mexico. I grew up playing

sports, being a kid outdoors, and playing piano. Our move to New Mexico brought sunshine, and plenty of it. I discovered pole vaulting as a sport, an instant hit and passion, going on to compete collegiately at The University of New Mexico (UNM). I look back at that time in my life fondly, as if meant to be. Naturally drawn to the technical elements of my sport, I discovered an inherent interest in injury and biomechanics, leading me towards undergraduate and graduate degrees in Exercise Science. This was enhanced by a quintessential ACL injury and reconstruction, both character defining and career inspiring. Ultimately, this journey led me to countless influential people in my life, transitioning to my pursuit in orthopaedics.

Following medical school, I was truly fortunate to land residency at UNM. Quite simply, this program has given me more than I can express. From my shadowing days as an undergraduate student to today, it has been a tremendous and personal experience to evolve as an orthopaedic surgeon under the guidance of my mentors and teachers. Furthermore, it has been a privilege to train alongside some of the most genuine, talented, and inspiring people. Although 5 years of residency have flown by, it is on those days that test your resilience, that you realize you are part of something special. Next year, I look forward to pursuing a Sports Medicine Fellowship at Boston Children's Hospital.

I would like to thank my parents for their unyielding love and support throughout the years and for always epitomizing compassion, modesty, work ethic, and discipline. I would also like to thank my naturally talented, and more athletic, younger brother, Jay, for always cheering me on and motivating me to be the best version of myself. Finally, a sincere thank you to my teammates, co-residents, co-chiefs, and mentors for being an integral part of my journey. Proud to be a Lobo!

# Chiefs



**Andrew Parsons, MD**  
**Medical School: University of Oklahoma**  
**Fellowship: Baylor College of Medicine**

I am from Springfield, Missouri. I went to The University of New Mexico for undergrad and played soccer (when they still had a team). I attended the University of Oklahoma for medical school. I would of course like to acknowledge my family for helping me through my years and years of schooling as well as my wife, Rachel, for her support and unending encouragement during residency. The Lord has allowed me to accomplish what I have in my life, and anything good I have done or been a part of has been through Him. Outside of work, I enjoy playing soccer and spending time with family. I will be doing a pediatric orthopaedic fellowship at the Baylor College of Medicine in Houston, Texas.



**Christopher Shultz, MD**  
**Medical School: University of Arizona**  
**Fellowship: Sports Medicine, Duke University**

I am from Tucson, Arizona. I went to the University of Arizona and majored in chemistry. I went to medical school at the University of Arizona, also located in Tucson. I was born into a family of blue collar workers; my father was a mechanic and my mom changed the money out of pay phones. Growing up in the heat of Southern Arizona as a first generation college student, the thought of graduating from medical school, let alone becoming an orthopaedic surgeon remains surreal. I want to thank my smokeshow wife for all of her amazing support and for never resenting me for all of the late nights and long hours put into taking care of patients. She has stood by my side through every step of this journey. Through this journey I've been gifted with three amazing children who have helped me to grow as a father, surgeon, and human.

I've truly enjoyed my time training at The University of New Mexico (UNM); I've made unforgettable memories and unwavering friendships that will stick with me for a lifetime. I've been able to pursue hobbies like woodworking, smoking meat, and baking sourdough throughout this training process to maintain balance and unwind, and plan to continue these hobbies. I don't know what the future holds for me and my family, but I know it will be exciting. The next chapter in our journey takes my family to Duke University for sports fellowship, where we plan to soak up the southern hospitality, Carolina BBQ, and opportunities for learning. My family and I feel truly happy and blessed to be a forever part of the UNM family, no matter where our road takes us.



## Residents: PGY Four



**Scott Plaster MD**  
University of Oklahoma



**Jordan Polander MD**  
Louisiana State University-Shreveport



**Amber Price MD**  
Creighton University



**Jory Wasserburger MD**  
University of Washington



**Matthew Wharton MD**  
University of Arizona

## Residents: PGY Three



**Benjamin Albertson MD**  
University of Vermont



**Kathryn Helmig MD**  
University of Oklahoma



**Nathan Huff MD**  
The University of New Mexico



**Christopher Kurnik MD**  
University of Nevada-Reno



**Benjamin Packard MD**  
Creighton University

## Residents: PGY Two



**Aamir Ahmad MD**  
University of Arizona



**Bryce Clinger MD**  
Virginia Commonwealth University



**Jordan Kump MD**  
University of Utah



**Alicia Imada MD**  
University of Vermont



**Kate Yeager MD**  
Oregon Health & Science University

## Residents: PGY One



**Tim Choi MD**  
The University of Texas Health Science  
Center at Houston



**Ryan Dahlberg MD**  
University of Illinois-Chicago



**Filip Holy MD**  
University of Oklahoma

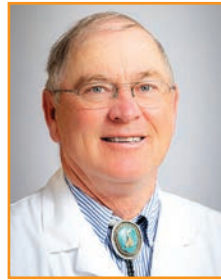


**Casey Slattery MD**  
University of Washington



**Marisa Su MD**  
Drexel University

# Division of Research



**Thomas DeCoster MD**  
Professor



**Deana Mercer MD**  
Vice Chair of Research  
Associate Professor



**Dustin Richter MD**  
Assistant Professor



**Christina Salas PhD**  
Assistant Professor



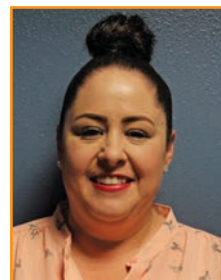
**Leorrie Atencio**  
MS, Genetics & Genomics -  
Iowa State University,  
BS, Biology - Northern  
New Mexico College



**Anjelica Baros**  
BA, Health Education and  
Communications - The  
University of New Mexico



**Damian Fountain**  
BS, Biochemistry - The  
University of New Mexico



**Celia Hernandez**



**Angelique Tapia**  
MA in progress, English  
BA, English - The University  
of New Mexico



**Laurie Wells**  
PhD, Theoretical Quantum  
Optics - The Air Force Institute  
of Technology  
MS, Engineering Physics - The  
Air Force Institute of Technology

# Orthopaedic Biomechanics & Biomaterials Laboratory



**Christopher Buksa**  
MS in progress, Mechanical Engineering  
BS, Mechanical Engineering -  
The University of New Mexico



**Daniella Martinez**  
MS in progress, Biomedical Engineering -  
The University of New Mexico  
BS, Chemical Engineering - The University  
of New Mexico



**Nafisa Elghazali**  
Post-Baccalaureate Research and  
Education Program - The University of  
New Mexico  
BS, Public Health Sciences -  
University of California-Irvine  
PhD program - The UC - San Francisco/  
UC - Berkeley Joint Program



**Natalia McIver**  
PhD in progress, Biomedical Engineering  
- The University of New Mexico  
MS, Biomedical Engineering - The  
University of New Mexico  
BS, Biology and Psychology - The  
University of New Mexico



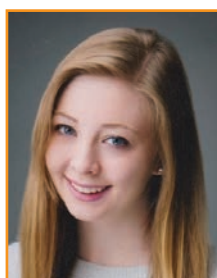
**Mystique Lamb**  
BS in progress, Mechanical Engineering -  
The University of New Mexico



**Lorraine Mottishaw**  
MS, Biomedical  
Engineering - The University  
of New Mexico  
BS, Chemical Engineering and  
Chemistry - University of Idaho



**Ana Love**  
BS in Progress, Mechanical Engineering -  
The University of New Mexico



**Ryan Ormesher**  
MD in Progress (year 2)  
BS, Biomedical Engineering - University  
of North Carolina and North Carolina  
State University Joint Program



# Orthopaedic Biomechanics & Biomaterials Laboratory



**Durante Pioche-Lee**  
BS in progress, Chemical Engineering  
(Concentration, Bioengineering) - The  
University of New Mexico



**Tony Sapradit**  
BS in progress, Mechanical Engineering  
- The University of New Mexico



**Fermin Prieto**  
MD in progress (year 3)  
BS, Biomedical Engineering -  
University of Arizona



**Ankit Shah**  
BS in progress, Electrical Engineering  
and Computer Science - The University of  
New Mexico



**Matthew Rush**  
PhD, Nanoscience and Microsystems  
Engineering (NSMS) - The University  
of New Mexico  
MS, NSMS - The University  
of New Mexico  
BS, Mechanical Engineering -  
New Mexico Institute of Mining and  
Technology



**Benjamin Spangler**  
MD in Progress (year 1)  
BS, Biomedical Engineering - University  
of Miami



**Orion Sanchez**  
BS in progress, Biochemistry - The  
University of New Mexico

# Letter from the Chair

Robert C. Schenck Jr, MD



As chair of The University of New Mexico (UNM) Department of Orthopaedics & Rehabilitation since 2005, I am pleased to present the ninth volume of *The University of New Mexico Orthopaedics Research Journal (UNMORJ)*, recently renamed the *Western Journal of Orthopaedics (WJO)*. This volume marks a

period of transition to our goals of becoming a peer-reviewed orthopaedic journal with citations in PubMed and creating an avenue for publishing papers in western United States. We are proud to publish papers from physicians all around the United States, including the many graduates of our program over the past several years. This is our fourth year of initiating the peer-review process as well as improving overall publication process. We are grateful to the many peer reviewers who made this happen for our previous volumes, including the following individuals:

- *UNMORJ* 2017—Adam Adler, Eric Benson, Jenni Buckley, Shane Cass, Tahseen Cheema, James Clark, Thomas DeCoster, Rebecca Dutton, Fabio Figueiredo, David Grow, Daniel Hoopes, Andrea Lese, James Love, Christopher McGrew, Moheb Moneim, Patrick Mulkey, Jorge Orbay, John Phillips, Ashkan Pourkand, Jeffrey Racca, Dustin Richter, John Ruth, Andrew Schannen, Jordan Smith, Daniel Stewart, Mahmoud Reda Taha, Ahmed Thabet-Hagag, Lauren Vernon, and Jason Wild.
- *UNMORJ* 2018—Stephen Becher, David Burk, Michael Decker, Rebecca Dutton, Fabio Figueiredo, Katherine Gavin, Jenna Godfrey, J. Speight Grimes, David Grow, Bryon Hobby, Andrea Lese, Heather Menzer, Nathan Morrell, Drew Newhoff, Blake Obrock, Jorge Orbay, Dustin Richter, Selina Silva, Ahmed Thabet-Hagag, Lauren Vernon, and John Wiemann.
- *UNMORJ* 2019—Tamás Bárdos, Justin Bartley, David Bloome, Henry Chambers, Michael Charles, Lauren Decker, Paul Durfee, Gregory DeSilva, Fabio Figueiredo, Sumeet Garg, Jenna Godfrey, David Grow, Speight Grimes, Zbigniew Gugala, Sebastian Heaven, Bryon Hobby, Stephen Incavo, Stephen Jacobsen, Ray Jensen, Galen Kam, Matthew Karam, Andrea Lese, Sukanta Maitra, Seth McCord, Kevin McGee, Heather Menzer, Charles Metzger, Richard Miller, Drew Newhoff, Blake Obrock, Jorge Orbay, Briana Patti, Ian

Power, Daniel Romanelli, Amir Sandiford, Frederick Sherman, Ahmed Thabet, Lauren Vernon, Laura Wells, John Wiemann, Jon Wyatt, and Colby Young

- *WJO* 2020—Christopher Bankhead, Tamás Bárdos, Justin Bartley, David Bloome, Patrick Bosch, David Chafey, Henry Chambers, Thomas DeCoster, Gregory DeSilva, Fabio Figueiredo, Erika Garbrecht, Rick Gehlert, Jenna Godfrey, J. Speight Grimes, Zibi Gugala, Sebastian Heaven, Bryon Hobby, Nathan Hoekzema, Mischa Hopson, Thomas Howdieshell, Stephen Jacobsen, Paul Johnson, Galen Kam, Charles Metzger, Drew Newhoff, Jim Ninomiya, Blake Obrock, Jorge Orbay, Brianna Patti, Brielle Plost, Ian Power, Leroy Rise, Daniel Romanelli, Frederick Sherman, Ahmed Thabet-Hagag, Lauren Vernon, Jay Wells, John Wiemann, Jon Wyatt, Colby Young

Thank you for the outstanding work from *WJO* editorial board, with leadership from Co-Editors Christina Salas, PhD, and Deana Mercer, MD, who have made the publication an established entity within the department and university. We hope you enjoy this ninth volume, and first as the newly renamed *Western Journal of Orthopaedics*. My personal thanks to the many others responsible for the continued expansion of research at UNM Orthopaedics.

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.

Sincerely,

Robert C. Schenck Jr, MD  
Professor and Chair  
Department of Orthopaedics & Rehabilitation

# Letter from the Co-Editors

Deana Mercer, MD; Christina Salas, PhD



Welcome to the ninth volume of the *Western Journal of Orthopaedics (WJO)*, featuring efforts of faculty, alumni, fellows, residents, and students. We are excited to announce the name change to the *Western Journal of Orthopaedics (WJO)* from *The University of New Mexico Orthopaedics Research Journal*. We feel that the name change will help us accommodate a larger audience and the diverse group of authors that our journal produces. We would also like to announce that we will be accepting art submissions for the cover of our tenth volume. The theme should be western,

including landscape photographs, original paintings, or drawings. For more information, please contact the journal team at [UNMORJ@salud.unm.edu](mailto:UNMORJ@salud.unm.edu).

This is the fourth 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, with eventual indexing in MEDLINE and PubMed—the primary database listings for scholarly biomedical articles.

We would like to express the utmost gratitude to our reviewers who lent their expertise, efforts, and time to make our ninth volume a successful, peer-reviewed publication. We sincerely thank all the contributors to this production—as well as Gail Case, Department Administrator; Angelique Tapia, Managing Editor and Copy Editor; Joni Roberts, Managing Editor; Jonathan Sisneros, Copy Editor—whose work and dedication were instrumental in bringing the journal to fruition. We are grateful for the help of our editorial intern Lauren Nuanes, as well as our layout editor Jana Fothergill.

Lastly, we would like to extend an invitation to submit to our 2021 volume, with a deadline of October 5, 2020. Please keep in mind that there is no submission fee and the authors maintain copyright. *WJO* highlights

high-quality articles relevant to orthopaedic surgery and engineering, including clinical and basic-science original research, case reports, reviews, technical notes, new technology, pilot studies, education articles, and reflections. Thank you for your continued interest in *WJO*.

Sincerely,

Deana Mercer, MD  
Associate Professor  
Department of  
Orthopaedics &  
Rehabilitation

Christina Salas, PhD  
Assistant Professor  
Department of  
Orthopaedics &  
Rehabilitation

# Letter from the Chief of the Division of Physical Therapy

Beth Moody Jones, PT, DPT, EdD, MS



The University of New Mexico (UNM) Division of Physical Therapy (PT) encompasses a stellar group of 96 students within the UNM School of Medicine and the Health Sciences Center. We stand as the only PT program in New Mexico, proudly graduating 30 new doctors of PT in May 2020. I am honored

to lead this remarkable group of faculty, staff, and students.

The UNM PT program is about to launch their 50th year celebration in 2024. In gearing up for this momentous occasion, we have launched a campaign aimed at creating an enduring legacy of scholarship support for our PT students. In honor of the 50th anniversary of our PT program, the “50 by 50” campaign is raising \$50,000 for the “Physical Therapy Faculty Emeriti Endowed Scholarship.” This scholarship benefits UNM’s most outstanding PT students in their final semester of the program and recognizes the outstanding faculty that have helped change the PT landscape of New Mexico. Interested in donating? Please go to [www.unmfund.org/ptfs](http://www.unmfund.org/ptfs).

We are excited to announce that the American Board of Physical Therapy Residency and Fellowship Education has granted candidacy for the PT program to launch an orthopaedic PT residency program. A PT residency is a post-professional program that gives students the knowledge and skills required to be an advanced physical therapist within a defined area of practice. A graduate of a residency program is eligible to sit to become a board certified specialist in a subset of PT. Therefore, our graduates will be eligible to become board certified orthopaedic physical therapists upon finishing the residency program. This is the first PT residency program in the state of New Mexico, as previously our graduates have had to go out of state to pursue residency programs. On average, residents pass the board certification examination 20% to 40% more than those who did not graduate from a residency program. Having this program at UNM will greatly increase the number of board certified specialists we have in the state, thus continuing to raise the level of care provided to our community.

The mission of UNM orthopaedic PT residency program is to provide exceptional, evidence-based, post-professional training that will advance the resident’s knowledge, skills, and critical thinking in orthopaedic PT to that of a clinical expert, thereby optimizing the human experience of New Mexico communities. The residency is a 12-month long program consisting of a didactic curriculum, clinical hours, skills labs, journal clubs, case rounds, written and practical examinations, and becoming a lab assistant for the UNM PT program. Residents will work at various orthopaedic clinical sites throughout Albuquerque as a fully licensed physical therapist, gaining mentoring from clinicians who specialize in orthopaedic PT. All didactic and skills work will be through the UNM PT program.

Respectfully,

*Beth Moody Jones, PT, DPT, EdD, MS*

Board-Certified Orthopaedic Clinical Specialist  
Certified in Dry Needling  
Associate Professor  
Division Chief

# Letter from the Residency Director

Gehron P. Treme, MD



Another year is in the books, which means I'm a little more sore after running and that it's time to honor another class of orthopaedic residency graduates.

It is my great pleasure to congratulate Paul Goodwyn, Travis Hughes, Aditi Majumdar, Andrew Parsons, and Chris Shultz on completing their training here at The University of

New Mexico (UNM), and to wish them well as they embark on their next adventures.

I can clearly recall having dinner with our new interns on June 17, 2015, and then leaving that night with a smile on my face anticipating entertaining dynamics for the next 5 years. They have not disappointed. I can say that I have tremendously enjoyed getting to know this group of residents and appreciate the effort, dedication, and passion that they bring to their work every day, and especially the many contributions that each has made to the advancement of our training program. We are much better off for having had them here, and they are leaving UNM Orthopaedics better than they found it.

We speak frequently of our culture in this program and feel real pride in what we have been charged with stewarding over the years. I always enjoy the annual comments from our residency applicants pointing to this particular strength of our program, which is so evident year round. We often speak of our group as an orthopaedic family and perhaps that may seem hyperbolic to some. Yet every year I reflect on our short falls and victories—some small, many large—and I am grateful that we have such a caring and engaged group in our department. We have been able to celebrate great success together, provide support during times of real loss, counsel, commiserate, and challenge one another in a way not possible without the partnerships that are present throughout our team.

I am proud to be part of the UNM Orthopaedic family and to have been given the chance to know and work with our five graduates. I am glad to have contributed to their growth here in some small part and know that they will all make us proud as graduates of the program. Congratulations Paul, Travis, Aditi, Andrew, and Chris. It has been a true pleasure and enjoyable ride. You will be greatly missed.

My very best regards,

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



# Systematic Review of Cost-Effective Analyses in Sports Medicine from 2014 to 2020

Casey Slattery, MD<sup>1,2</sup>; Mia S. Hagen, MD<sup>1</sup>; Amy Cizik, PhD, MPH<sup>1</sup>; Albert O. Gee, MD<sup>1</sup>; Christopher Kweon, MD<sup>1</sup>

<sup>1</sup>Department of Orthopaedic Surgery and Sports Medicine, University of Washington, Seattle, Washington

## Changed Affiliation

<sup>2</sup>Department of Orthopaedics & Rehabilitation, The University of New Mexico Health Sciences Center, Albuquerque, New Mexico

**Corresponding Author** Christopher Kweon, MD. Department of Orthopaedic Surgery and Sports Medicine, 3800 Montlake Blvd NE, Seattle, WA 98195 (email: ckweon@uw.edu).

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

**Conflict of Interest** The authors report no conflicts of interest.

## ABSTRACT

The quality of recent cost-effectiveness studies and whether there is sufficient evidence to achieve value-based health care in sports medicine are unknown. The purpose of this study was to perform a systematic review of recent cost-effective analyses (CEA) in sports medicine to determine the quality of publications from the last 6 years. A literature search was conducted for CEA studies on diagnostic tests, treatment options, and surgical procedures for sports medicine-related conditions between 2014 and 2020 in the United States. Two reviewers scored each study using the Quality of Health Economic Studies (QHES) instrument to assess methodological quality. Eighteen CEA studies met the inclusion criteria. The quality of the studies ranged from moderate to excellent using the QHES instrument (mean: 83.3, range: 52-100). The quantity and mean quality of CEA studies in sports medicine have increased since 2014. More high-quality randomized control trials are needed to reduce bias and to further improve value-based health care in sports medicine.

**Keywords:** Cost-Effective Analysis, Sports Medicine, Cost

## INTRODUCTION

Allocation of funds and cost control have become critical components in healthcare as spending continues to increase.<sup>1</sup> Surgeons are in a unique position to control the cost of surgical care because most of the decision-making is surgeon-led. As such, surgeons must become familiar with the economics impacting healthcare policy.<sup>2</sup> In recent years, cost-containment strategies have focused on delivering value-based healthcare and have led to an increased number of published studies using cost-effective analytic (CEA) techniques.<sup>3</sup> Surgical literature, especially studies concerning orthopaedics, lag behind other fields of medicine in terms of studying, reporting, and prioritizing value-based care.<sup>4</sup>

CEA compares the relative costs and outcomes (ie, effects) of different treatment options, which is an

important tool to identify procedures that allow the greatest outcome improvements at the lowest cost. CEA models collect data from various sources, and these models project outcomes and costs over a longer timeframe than randomized control trials (RCT).<sup>5</sup> In 1996, the First Panel of Cost Effectiveness in Health and Medicine summarized and provided guidance for CEA.<sup>6</sup> Subsequently, there has been an increase in the number of CEA studies across all disciplines of medicine.<sup>7</sup> In 2016, the Second Panel of Cost Effectiveness emphasized improvements in CEA model development and data reporting, which has resulted in better methodology in subsequent CEA studies in orthopaedics.<sup>5,8</sup>

Despite the growth of CEA literature in other fields,<sup>9-15</sup> there is still a lack of studies examining CEA within sports medicine. For instance, a 2014 systematic review found only 12 United States-based studies over a 16 year time period, with an average Quality of Health Economic Studies (QHES) rating of 81.8. The purpose of our study was to assess the quality and evaluate the number of recent sports-medicine CEA studies since the 2014 systematic review.<sup>3</sup> CEA studies in sports medicine are important given the elective outpatient nature of the field. We hypothesized an increase in both the quantity and quality of cost-effective analyses of sports-medicine conditions.

## METHODS

A literature review was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines to identify all studies that: 1) involved an orthopaedic sports-medicine procedure or intervention, 2) performed a cost-effective analysis, 3) were clinically-based, 4) pertained to the United States healthcare system, and 5) were published after January 1, 2014.<sup>16</sup> The studies that were published after January 1, 2014 were not included in the systematic review published in 2014.

The online databases PubMed, Embase, Web of Science, and Scopus were used to search for appropriate

**Table 1. Identified Studies and Conclusions**

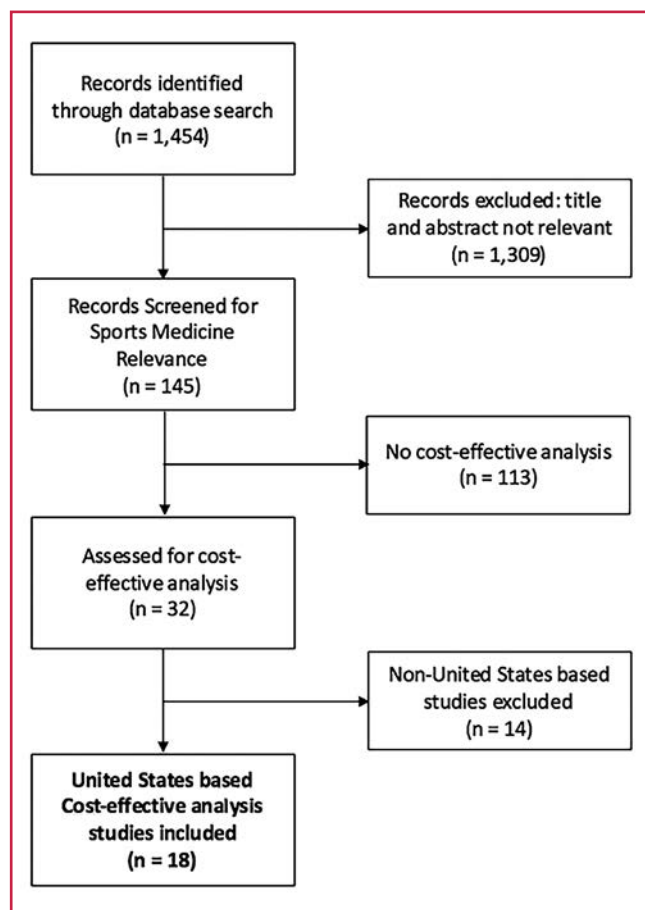
Study	Year	Area of Analysis	Duration	Conclusions
Rogers et al <sup>28</sup>	2019	Meniscal repair vs partial meniscectomy for red-red zone	40 years	\$3,935 ICER/QALY favoring meniscal repair as the dominant procedure.
Bendich et al <sup>32</sup>	2018	Meniscus allograft transplant	30 years	Not currently cost effective.
Lester et al <sup>30</sup>	2018	Meniscal repair vs partial meniscectomy in ACLR	40 years	Increase of 0.84 QALYS with a repair compared to a meniscectomy.
Min et al <sup>27</sup>	2018	Open Latarjet vs arthroscopic Bankart	Lifetime	Bankart is more cost effective, although with a higher failure rate.
Cunningham et al <sup>36</sup>	2017	FAI diagnosis	Lifetime	H&P with injection has ICER of \$59,228/QALY compared to H&P alone. WTP threshold favoring injection for GP is \$70,000 and \$990,000 for hip specialists.
Dornan et al <sup>23</sup>	2017	RCR vs RTSA for massive rotator cuff tear	Lifetime	RTSA after RCR had incremental effectiveness of +0.11 QALYs with ICER of \$3,959.55/QALY compared to revision RCR after RCR.
Gyftopoulos et al <sup>25</sup>	2017	MRI vs US for rotator cuff tear	2 years	US least costly (\$1,385) and most cost effective, but not dominant over MRI. MRI was most effective (1.332 QALYS).
Kang et al <sup>24</sup>	2017	Massive irreparable rotator cuff tear: RTSA vs AD-BT vs HA vs PT	Lifetime	RTSA had an incremental gain of 1.0 QALYs (\$25,522/QALY) over AD-BT.
Stewart et al <sup>35</sup>	2017	ACLR in athletes	6 years	ACLR vs physical therapy is 0.372 or \$22,702/QALY gained.
Feeley et al <sup>29</sup>	2016	Meniscal repair vs partial meniscectomy	Lifetime	Meniscal repair had a 0.19 QALY gain over partial meniscectomy and \$2,701 cost discount.
Lodhia et al <sup>37</sup>	2016	Hip arthroscopy for labral tear	Lifetime	Surgery had 3.94 QALYs more than rehabilitation with an ICER of \$754/QALY.
Makhni et al <sup>22</sup>	2016	RCR vs reverse TSA for large tears	Lifetime	RCR had a \$15,500/QALY gain over nonoperative therapy and reverse TSA had a \$37,400/QALY gain over nonoperation.
Makhni et al <sup>26</sup>	2016	Latarjet vs revision Bankart for recurrent shoulder instability	Lifetime	Latarjet had a 7.02 QALY gain (\$1,941/QALY) gain over revision arthroscopic Bankart repair.
Ramme et al <sup>31</sup>	2016	Meniscal allograft vs partial meniscectomy for torn discoid meniscus	25 years	Meniscal allograft had incremental effectiveness gain of 4.80 QALYs with an ICER of \$842/QALY compared to partial meniscectomy.
Samuelson et al <sup>21</sup>	2016	PRP in RCR	10 years	RCR with PRP is \$6,775/QALY and without PRP is \$6,612/QALY. No difference.
Mather et al <sup>33</sup>	2015	Meniscus tear diagnosis	5-10 years	H&P was most cost effective for degenerative tears For traumatic tears, MRI w/ H&P was preferred with ICER \$40,565/QALY for GP and \$10,631/QALY for orthopaedist,
Vavken et al <sup>19</sup>	2015	PRP in RCR	2 years	RCR with PRP had a difference of 0.0059 QALYS (\$127,893/QALY) compared to without PRP.
Mather et al <sup>34</sup>	2014	Early vs late ACLR	Lifetime	Early group had an incremental gain of 0.28 QALYS over the delayed group, with a cost difference of \$1,572.

FAI, Femoroacetabular impingement; RCR, rotator cuff repair; RTSA, reverse total shoulder arthroplasty; MRI, magnetic resonance imaging; US, ultrasound; AD-BT, arthroscopic debridement and biceps tenotomy; HA, hemiarthroplasty; PT, physical therapy; ACLR, anterior cruciate ligament reconstruction; TSA, total shoulder arthroplasty; PRP, platelet-rich plasma; H&P, history and physical; WTP, willingness to pay; GP, general practitioner; QALYS, quality-adjusted life years; ICER, incremental cost effectiveness ratio.

studies. An Apriori search algorithm combined the economic term “cost” with the following MeSH (PubMed Medical Subject Headings) terms related to sports medicine: “anterior cruciate ligament,” “ACL,” “posterior cruciate ligament,” “PCL,” “cartilage,” “meniscus,” “meniscal,” “arthroscopy,” “microfracture,” “rotator cuff,” “instability,” “labrum,” “tendon,” “femoroacetabular impingement,” and “FAI.” The titles and abstracts were then reviewed to find the studies that met the inclusion and exclusion criteria. A review of the entire article was performed if there was still uncertainty.

The QHES instrument was used to evaluate the methodological quality of the CEA articles listed in this study.<sup>17</sup> QHES has been validated and used to evaluate economic studies in other fields of medicine, but it has rarely been used in orthopaedics. It consists of 16 criteria with “yes” or “no” weighted-questions. Each criterion has a point system ranging from 0 to 9, with “no” answers equating to 0 points. Overall scores range from 0 to 100, with 80 to 100 being considered a high-quality study and 50 or less being a low-quality study.<sup>18</sup>

Each study that met inclusion criteria was reviewed by two sports-medicine trained orthopaedic surgeons (CK and MH), and their quality was scored using QHES.<sup>18</sup> Any scoring disagreement was discussed, and the score was averaged if no resolution could be met between the two reviewers.



**Figure 1.** Study flow diagram of studies meeting inclusion and exclusion criteria.

## RESULTS

The search algorithm identified 1,454 studies (Figure 1).<sup>16</sup> A total of 1,309 studies (90%) were not relevant to sports medicine. Of the remaining 145 studies, there were only 32 cost-effective analyses. When excluding the studies not performed in the United States, we found a total of 18 CEA studies to include in this review (Table 1). We reviewed the references of each of the 18 studies and did not find any further studies that met the inclusion criteria. There were various topics within the 18 studies, including rotator cuff tears (6 studies), meniscal tears (6 studies), anterior cruciate ligament reconstruction (2 studies), femoroacetabular impingement syndrome and hip arthroscopy (2 studies), and shoulder instability (2 studies).

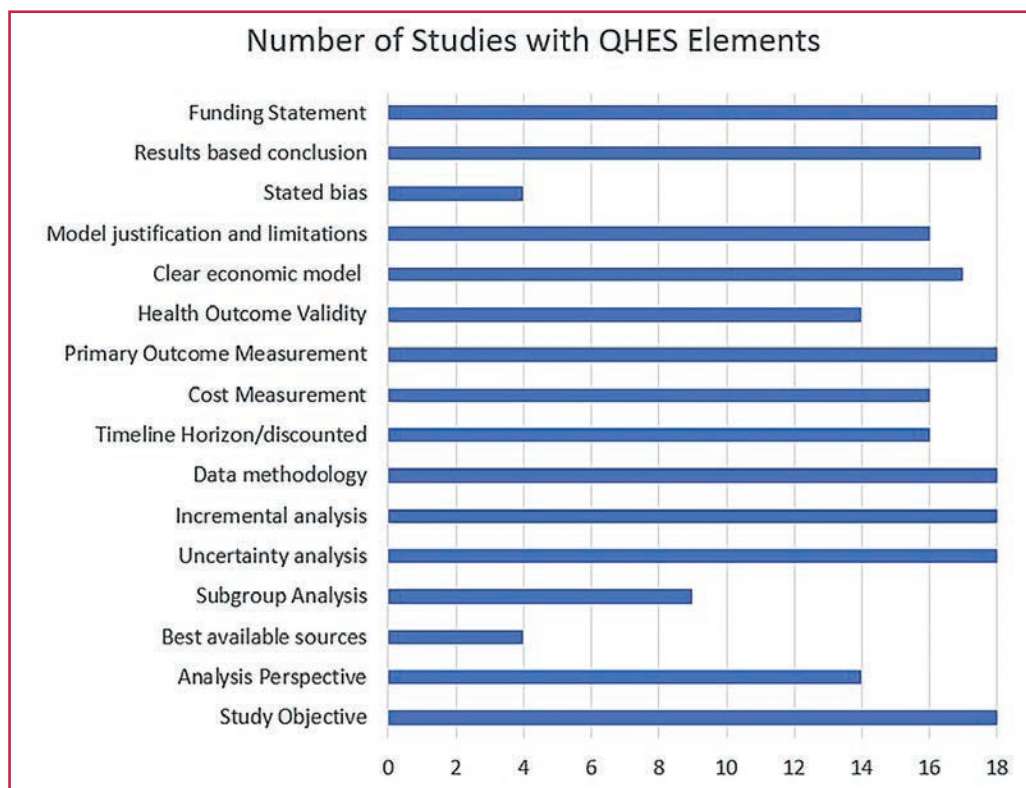
The 18 studies had an average QHES score of 83.3 (range: 52-100), which showed excellent quality. Of the 16 QHES criteria, most were met in this review (Figure 2). All scores were agreed upon between the two reviewers except one, which was then averaged. The majority of the QHES criteria were met among the articles reviewed; however, some criteria were met by as few as four studies (Figure 2). Only 3 studies used randomized controlled-trials as their source of clinical outcome data. The majority of studies in this review also failed to explicitly state the magnitude and direction of potential biases.

### Findings of the Included Studies

The majority of the CEA studies in this review focused on rotator cuff repairs (RCR) (n = 6). There were 2 studies that looked at the cost effectiveness of platelet rich plasma (PRP) in RCR. Vavken et al<sup>19</sup> found PRP with large rotator cuff tears insufficient to compensate for the tissue damage. In small and medium sized tears, the authors found PRP to possibly promote healing and decrease re-tear rates, but concluded that PRP was currently not cost effective for these tears. They found an incremental gain of only 0.0059 quality adjusted life years (QALYs) compared to RCR without PRP, resulting in an incremental cost-effectiveness ratio (ICER) of \$127,893 per QALY.<sup>19</sup> This was in contrast to typical United States’ intervention thresholds of \$50,000 to \$100,000 per QALY.<sup>20</sup> Similarly, a study by Samuelson et al<sup>21</sup> showed no difference in cost effectiveness between RCR with PRP and RCR without PRP.

Two studies compared the economic impact between RCR and total shoulder arthroplasty (RTSA). Makhni et al<sup>22</sup> compared arthroscopic RCR with primary RTSA and nonoperative management in patients with symptomatic large and massive tears. Both RCR and RTSA had a QALY gain over nonoperative treatment (0.71 and 0.7, respectively). Despite the high re-tear rate, initial RCR was found to be more cost effective than RTSA. Dornan et al<sup>23</sup> evaluated treatment options for massive rotator cuff tears in patients with pseudoparalysis and non-arthritic shoulders. Arthroscopic RCR with conversion to RTSA on potential





**Figure 2.** The number of studies that satisfy each of the Quality of Health Economic Studies instrument components.

failure was found to be the most cost-effective strategy. Revision arthroscopic RCR after a failed initial RCR was less cost effective. Kang et al<sup>24</sup> evaluated massive and irreparable rotator cuff tears and found RTSA to be the preferred and most cost-effective method compared to a repair, specifically for the elderly population. Arthroscopic debridement with biceps tenotomy was a cheaper option for pain relief but lacked any functional improvement.

A study by Gyftopoulos et al<sup>25</sup> compared magnetic resonance imaging (MRI) and ultra-sound imaging for full-thickness supraspinatus tears. Both MRI and ultra-sound imaging were found to be cost effective in full-thickness supraspinatus tears that were symptomatic. Based on the cost-effective criteria, the results indicated MRI to be the preferred strategy. Regarding shoulder instability, Makhni et al<sup>26</sup> performed a study on recurrent instability that compared Latarjet to revision arthroscopic repair. The Latarjet procedure showed lower cost and improved clinical outcomes over revision arthroscopy and nonoperative treatment. Min et al<sup>27</sup> found both open Latarjet and arthroscopic Bankart to be cost effective.

There were 6 studies that focused on meniscal tears. The economic effect between meniscal repair and partial meniscectomy was evaluated by both Rogers et al<sup>28</sup> and Feeley et al.<sup>29</sup> Meniscal repair was found to be a cost-effective strategy despite having substantially higher failure rates. For ACL reconstruction, Lester et al<sup>30</sup> found a meniscus repair to be more cost effective than a meniscectomy.

Using a study population of young-adult women, Ramme et al<sup>31</sup> looked at meniscal allografts for discoid lateral meniscus tears. The model showed that although initially more costly, meniscal allografts were more effective in delaying a total knee replacement than partial meniscectomy. Bendich et al<sup>32</sup> determined that meniscus allograft transfers are not currently cost effective, but younger and non-obese patients are closer to the threshold. When looking at the cost effectiveness for the diagnosis of meniscal tears, Mather et al<sup>33</sup> found a patient history and physical examination to be the most cost effective for degenerative tears. Additionally, an MRI to confirm patient history and physical examination was their preferred method for diagnosing traumatic tears, with orthopaedic surgeons having a lower incremental cost-effective ratio than general practitioners.

Two studies looked at the economic effect of ACL reconstruction. Mather et al<sup>34</sup> evaluated the difference between QALYs of early versus late ACL reconstruction. From a societal health-system perspective, early ACL reconstruction (ie, < 10 weeks) was found to be more cost effective than rehabilitation with optional delayed ACL reconstruction. When evaluating ACL reconstruction in competitive athletes, Stewart et al<sup>35</sup> found surgery to be the most cost effective with the highest return-to-play rate.

Two studies by Cunningham et al<sup>36</sup> and Lodhia et al<sup>37</sup> focused on the hip. When examining the cost effectiveness of femoroacetabular impingement (FAI), Cunningham et al<sup>36</sup> found that advanced imaging

was not as cost effective as the willingness to pay (ie, threshold > \$50,000/QALY). For the general practitioner, patient history and physical examination with radiographs and diagnostic injections were preferred compared to advanced imaging. While studying the economic impact of acetabular labral tears, Lodhia et al<sup>37</sup> found hip arthroscopic surgery to have a considerably lower incidence of symptomatic osteoarthritis. Additionally, hip arthroscopic surgery was found to be more cost effective than rehabilitation alone for symptomatic labral tears.

## DISCUSSION

The number of CEA studies in sports medicine has increased over the past several years. Since the 2014 systematic review with 16 studies, there have been 18 new publications. Similar to the 2014 review, investigation procedures discussed in this study focused mainly on rotator cuff and ACL. However, this review additionally focuses on diagnostic tests and other treatment options to fully grasp the breadth of cost effectiveness in sports medicine, which in part explains the increase in recent CEA studies. Physicians and policy makers can apply this increased economic knowledge toward the complex problem of rising healthcare expenditure.<sup>2</sup>

This study and the 2014 systematic review showed that cost-effective surgeries included ACL reconstruction, RCR, hip arthroscopic surgery, shoulder instability surgery, and autologous chondrocyte implantation.<sup>24</sup> In this study, quality assessment showed the overall studies were of reasonable quality. However, it concluded that careful attention needed to be paid to the methodology of CEA research for future sports-medicine publications.<sup>3</sup>

Other orthopaedic subspecialties are also actively researching cost effectiveness within their respective fields.<sup>7,38-40</sup> Within orthopaedics, a systematic review over spine literature is the largest review to date.<sup>39</sup> The authors identified 33 CEA studies between 1976 and 2010 and did not limit their research to only United States studies, which can potentially limit generalizability. Various studies have also commented on the lack of cost-analysis literature within orthopaedics.<sup>7,38,40</sup> As this review demonstrates, sports-medicine researchers are actively working to answer these concerns and determine cost effectiveness within the field.

The quality of CEA studies presented in this review ranges from moderate to excellent methodology and data reporting. The majority of studies in this review had excellent methodology in terms of models, cost measurements, and analyses. Overall, the study's methodology is acceptable. However, high quality sources (eg, RCTs) are lacking for clinical outcome data. Future CEA studies will aim to use RCT data to improve the validity of their results, but this will be reliant on more high-quality primary trials being performed,

especially in the United States. Explicitly stating the direction and magnitude of potential biases will also improve the reporting and quality of CEA studies. The QHES instrument is a simple and reliable tool to score CEA studies and should be used as a reference for researchers conducting cost-effectiveness studies.

There are a number of limitations within this review. The breadth of CEA studies within sports medicine remains limited. This review shows the focus has been on RCR, ACL reconstructions, meniscus surgery, and FAI. There is also a lack of CEA randomized control trials in sports medicine. Having more randomized control trials will lead to further decreased bias, which has proved deficient in this review. Although a thorough review of multiple databases and relevant references was performed, it is possible that our literature search did not find all relevant CEA studies within sports medicine. The QHES instrument was designed to assess the methodology of CEA studies, but it mainly focuses on the quality of reporting information. A study did not receive a qualifying score if it did not explicitly state one aspect of the scoring instrument or it could not be easily implied. This results in the lack of clarity with the study's methodology and not necessarily a lack in the methodology itself. QHES scores were also susceptible to subjective bias, although this was limited by having two authors independently score each study.

## CONCLUSION

Within sports medicine, there has been an increasing number of CEA studies published over the past several years. However, the breadth of studied conditions is still limited and there are many areas of sports medicine that lack cost-effectiveness evaluation. The overall quality of recent studies as a whole is excellent, although widely variable. To improve quality of future studies, authors should continue to be critical of data reporting and improving methodology. To fully understand cost effectiveness within sports medicine, further high-quality research spanning a greater breadth of conditions is still needed.

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# Identification and Management of Injuries Associated with Femoral Shaft Fracture

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## ABSTRACT

Femoral shaft fractures are common injuries typically due to high-energy trauma. Injuries associated with femoral shaft fractures include ipsilateral femoral neck fractures, ipsilateral distal femur fractures, ipsilateral patella fractures, ipsilateral tibial shaft fractures, ipsilateral knee ligament injuries, acetabular and pelvis fractures, and small bone fractures. These injuries can go unnoticed, and it is important to recognize and treat these injuries accordingly.

**Keywords:** Femur Shaft Fracture, Femur Fractures, Associated Injuries, Fractures, High-Energy Trauma

## INTRODUCTION

Femoral shaft fractures (FSF) can occur in isolation or in combination with other injuries. The associated injuries may not be initially recognized. Delayed diagnosis of associated injuries often results in suboptimal and occasionally disastrous outcomes. Even if recognized early, associated injuries can complicate treatment and outcomes in patients with FSF. This current concepts review article identifies injuries associated with FSF, recommends protocols to identify associated injuries in a timely fashion, and outlines treatment recommendations when associated injuries exist. The most common injuries associated with FSF are listed in Table 1. These injuries are often not diagnosed initially for a variety of reasons (Table 2). The associated injury may preclude standard treatment of isolated FSF. The failure to initially diagnose associated injuries may increase the risk of complications.

## ASSOCIATED FEMORAL NECK FRACTURE

FSF, combined with femoral neck fractures (FNF), occur most commonly in high-energy trauma such as motor-vehicle accidents (MVA) or motorcycle accidents. FSF combined with FNF typically occur in the younger population.<sup>1</sup> The latest literature has shown that 2.5 to 9% of FSF have an associated ipsilateral FNF.<sup>2</sup> The presentation is usually a comminuted middle third of the diaphysis FSF with 15 to 33% of the cases being an open fracture.<sup>2</sup> The associated FNF in 60% of the cases

**Table 1.** Common injuries associated with femoral shaft fractures

Femoral Neck Fracture
Distal Femur Fracture
Ipsilateral Knee Ligament Injury
Ipsilateral Tibia Shaft Fractures
Ipsilateral Patella Fractures
Acetabular/Pelvis Fractures
Small Bone Fractures

**Table 2.** Reasons associated injuries are initially missed

Reason	Why Associated Injury is Missed
Distracting obvious injury (ie, femur shaft fracture)	No radiographs taken of associated injury
Satisfaction of search	Radiograph taken and associated injury exists
Radiologically occult	Radiograph taken but associated injury exists but not visible
Symptomatically occult	Patient doesn't complain

is a vertical, basilar, and minimally displaced fracture.<sup>2</sup> This is most likely due to the axial compression mechanism on the femur at the time of injury. Recent literature has shown between 6 to 22% missed diagnosis of the FNF on the initial assessment.<sup>2</sup>

FNF can result in avascular necrosis (AVN) of the femoral head. The risk of AVN after FNF is increased with delay in diagnosis and treatment. The risk of AVN, nonunion, and malunion is increased by suboptimal reduction and fixation.<sup>1</sup> These complications are much more common in the displaced FNF, and they are difficult to treat in the younger population. FNF are usually caused by trauma but can be iatrogenic during antegrade femoral nailing, especially with an anterior starting point.<sup>3</sup> It is critical to diagnose the FNF before placing the intramedullary nail (IMN), so one can choose the correct operative fixation and be mindful not to displace the FNF. Tornetta et al<sup>4</sup> recommends obtaining anteroposterior (AP) radiographs of the internal rotation of the hip, a thin cut (2 mm) high-resolution computed tomography scan, and normal preoperative



radiographs of the femur.<sup>4</sup> Additionally, they recommend intraoperative fluoroscopic lateral evaluation of the hip prior to operative fixation, and intraoperative AP and lateral radiographs of the hip prior to awakening the patient.<sup>4</sup> Rogers et al<sup>5</sup> added a preoperative rapid limited sequence (ie, T1 and STIR sequences on the coronal view only) magnetic resonance imaging (MRI) protocol if the thin cut (2 mm), high-resolution CT scan was negative. They found an additional 12% of their patients with high-energy FSF had FNF that was not recognized on the radiographs or thin cut, high-resolution CT imaging.<sup>5</sup> The MRI took less than 10 minutes to perform and, in the majority of cases, was conducive to a multi-trauma patient (Table 3).<sup>5</sup>

#### **Treatment of Associated FNF**

The FNF takes priority. Most of the time, FNF is fixed prior to fixing the FSF, and it should be at least provisionally fixed before addressing the FSF. In their study from three trauma centers, Ostrum et al<sup>6</sup> showed good outcomes from treating the FNF with either a compression hip screw (CHS), short side plate and anti-rotational screw, or cannulated screws and retrograde IMN. There were 40 patients treated with CHS, short side plate, and anti-rotational screw, and 52 patients treated with cannulated screws. They saw no difference in femoral neck union or alignment when comparing cannulated screws to sliding hip screw. Their union rate was 98% (90 of 92 fractures) for the FNF, and 91.3% (84 of 92 fractures) for the FSF.<sup>6</sup> If the FNF is recognized after antegrade nailing and is non-displaced, then the “Miss-a-nail technique” can be considered. This technique uses lag screws across FNF, around the nail. Another option is using a “reconstruction” nail with proximal locking screws into the femoral head and across the FNF. If this method is chosen, then extra screws outside the nail can be considered to give more stability and fixation to the FNF.

#### **DISTAL FEMUR**

It is important to evaluate the distal femur for articular disruption either from extension of the FSF or a complete separate fracture. Literature shows a few cases of a coronal plane fracture of the femoral condyles (Hoffa Fracture) with FSF.<sup>7</sup> It is imperative to get radiographs of the joints above and below the FSF to rule out associated fractures. If radiographs look suspicious then order a CT scan.

#### **Treatment of Distal Femur Fractures**

Distal femur fractures with FSF can be treated various ways depending on the distal femur fracture type. When there is a distal intra-articular femur fracture associated with a FSF, then a retrograde nail with lag screws in the large articular fragments is an effective strategy. When the shaft fracture is in the distal one-third of the shaft, it is possible to treat this combination with a long lateral side plate and screws. If there is a Hoffa fracture of medial or lateral femoral condyle associated with FSF,

**Table 3. Protocol for Diagnosing femoral neck fractures (FNF)<sup>4,5</sup>**

1	For acute, high-energy femoral shaft fractures (FSF): obtain femur radiographs and an anteroposterior (AP) internal rotation hip radiograph preoperatively.
2	Obtain thin cut (2 mm), high-resolution computed tomography (CT) scan of the ipsilateral femoral neck of the FSF or reformat the initial trauma chest, abdomen, and pelvis CT scan to a thin cut.
3	If radiographs and thin cut (2 mm), high-resolution CT scan is negative, one may consider ordering a rapid limited sequence (T1 and STIR on coronal view only) magnetic resonance imaging of the ipsilateral hip.
4	Intraoperative fluoroscopic lateral evaluation of the hip prior to operative fixation of the FSF.
5	If FNF is not seen on fluoroscopy while performing operative fixation of FSF, then obtain AP and lateral radiographs of the hip in the operating room prior to awakening the patient.
6	At follow-up visit, obtain femur radiographs and ask about hip pain. If hip pain present, then obtain AP and lateral radiographs of the ipsilateral hip.

then appropriate treatment is comprised of antegrade or retrograde nailing with anterior to posterior, or posterior to anterior, lag screws across coronal plane fracture.

#### **PATELLA FRACTURE**

Patella fractures account for about 1% of all fractures,<sup>8</sup> and can occur in combination with FSF. To fully evaluate for a patella fracture, radiographs of the knee need to include an AP, lateral, sunrise, and Merchant views.

#### **Treatment of Patella Fracture**

Assessment of the patella fracture characteristics is needed to delineate whether operative fixation is indicated. Nonoperative treatment may be appropriate if the extensor mechanism is intact, articular step-off is less than 2 mm, or fracture displacement is less than 3 mm. However, the patient will not be able to flex the knee greater than 30° for 6 weeks.<sup>8</sup> Operative fixation is warranted if the extensor mechanism is disrupted, articular step-off is greater than 2 mm, fracture step-off is greater than 3 mm, or if one wants to expedite rehabilitation.<sup>8</sup> If the FSF is amenable to retrograde nailing, then one incision can be used to fix both patella and FSF. Fractures of the patella can be treated with a tension band construct with Kirschner wires and an 18-gauge wire or 4.0 mm cannulated screws with an 18-gauge wire for tension band. Biomechanically, the 4.0 mm cannulated screws with an 18-gauge wire is a stronger construct.<sup>9</sup> Other options are patella plating, cerclage wiring, lag screws, tension band construct with large braided suture, or partial patellectomy (if unable to capture the inferior pole or superior pole with fixation).

## IPSILATERAL TIBIAL SHAFT (“FLOATING KNEE”)

The combination of FSF and tibial shaft fractures (TSF) are usually due to high-energy trauma from MVA, motorcycle accidents, or pedestrian-versus-vehicle accidents.<sup>10</sup> The “floating knee” fracture can be various combinations ranging from intra-articular fractures of one bone with a shaft fracture of the other bone, intra-articular fractures of both bones, or shaft fractures of both bones. Additionally, vascular injuries, knee injuries, and open fractures are common with floating knee injuries and should be fully investigated.<sup>10</sup> Radiographs of the complete tibia with the ankle and knee joints included are needed. If intra-articular extension is suspected, then dedicated radiographs and CT scan of the involved joint are needed.

### *Treatment of Ipsilateral TSF*

Operative planning can begin once diagnosis is confirmed with imaging. Only FSF with TSF is addressed in this article. This combination is an indication for retrograde nailing of the FSF and antegrade nailing of the TSF. Careful investigation is needed to make sure that the TSF or the FSF does not propagate into their respective articular surfaces. The appropriate approach to use depends on where the FSF and TSF are located. The most convenient approach is using a single incision distal to the patella, which one can retrograde the femur and antegrade the tibia. Gregory et al<sup>11</sup> reported good or excellent results in 13 of 20 patients. Of these patients, seven patients had single incisions for both fractures and had acceptable results. They also reported an average of 120° of knee range of motion (95 to 140°), with no one having more than occasional knee pain. If the TSF is a proximal fracture, then it is much more difficult to nail with the infrapatellar approach, thus consideration of doing a supra-patellar approach to the tibia and an antegrade approach to the FSF is appropriate. If the patient has a soft-tissue defect or a contaminated wound, then one can proceed with an external fixator for provisional or definitive treatment.

## KNEE LIGAMENT INJURY

Ligament injuries of the knee have been associated with FSF. Szalay et al<sup>12</sup> stated in their research that 27% of their patients had knee ligament laxity with an isolated FSF. Dickob et al<sup>13</sup> examined FSF and ligament injury, and they found that 18.6% of patients had damage to at least one of the cruciate ligaments. DeCoster et al<sup>14</sup> reported an 11.6% ipsilateral knee ligament injury out of 163 FSF, with medial collateral ligament being the most common ligament injured followed by anterior cruciate ligament, posterior cruciate ligament, and lateral collateral ligament, respectively. Giannoudis et al<sup>15</sup> reported five cases of FSF with knee dislocation, which were managed by reducing all knees, placement of IMN in the femur, angiography, followed by either

bracing or ex-fixation for 6 weeks. It is difficult to do a knee examination when the patient has FSF. If the diagnosis of a knee dislocation is being considered, it is imperative to do at least an ankle-brachial index on the ipsilateral leg. The literature shows to proceed with a CT angiography to rule out an injury to an artery. A complete knee examination needs to be performed under anesthesia to achieve more accurate results.

### *Treatment of Knee Ligament Injury*

Depending on the number and severity of knee ligaments disrupted, one can treat the knee with an external brace versus an external fixator. If an artery injury is ruled out then it is best to proceed with nailing of the FSF to stabilize the extremity followed by treating the knee injury with bracing or external fixation. One can proceed with the ligament reconstruction at a later date.

## ACETABULAR AND PELVIC RING FRACTURE

Acetabular and pelvis fractures with ipsilateral FSF have been termed “floating hip.” Rajasekaran et al<sup>16</sup> reported the incidence of floating hip to be around 1 in 10,000 fractures. In their study examining pedestrian and MVA, Brainard et al<sup>17</sup> showed that 35 of 115 patients had an ipsilateral pelvis fracture, femur fracture, and a higher mortality rate. Müller et al<sup>18</sup> also stated in their study that there is a high morbidity and mortality rate with ipsilateral femur and pelvis fractures. Burd et al<sup>19</sup> reported between 26 to 35% injury to the sciatic nerve with a floating hip injury. It is important to do a good physical examination and obtain adequate imaging to diagnose and plan for operative intervention.

### *Treatment of Floating Hip injuries*

According to injury patterns, the surgeon needs to determine whether to operate on the pelvis or femur first. One has to be mindful of the next surgery and where to place incisions. If one is doing a posterior approach to the acetabulum, then a Gibson approach can be considered, which will also allow access to the posterior acetabulum and access for antegrade nailing of the FSF. If antegrade-nailing incision will block the incision needed for the acetabulum or pelvis, then a retrograde approach can be used to address the FSF.

## SMALL BONE FRACTURES

Fractures of small bones can go unnoticed owing to the distracting injury of FSF. It is imperative to do a secondary survey to confirm that no fractures of the small bones are missed (eg, scaphoid, metacarpals, metatarsals). Long-term sequelae may occur if these injuries are missed, including nonunion, malunion, or chronic pain.

## CONCLUSION

It is important to recognize injuries associated with femoral shaft fractures in order to obtain optimal patient results. This requires a high level of suspicion,

due diligence in pursuit of radiographic images over time, and clinical investigation (ie, secondary survey, etc). When associated injuries are recognized, the treatment of the femoral shaft fracture may need to be adjusted. Along with the FSF, the associated injuries need to be treated in an optimal, timely fashion.

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# Predicting Running Ability After Lower Extremity Amputation: A Review

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## ABSTRACT

The ability to ambulate with a prosthesis after lower extremity limb loss is an important determinant of functional independence and quality of life. Some individuals may be capable of achieving higher levels of mobility (eg, running) that can further improve function, physical health, and mental health. Thus, a fundamental understanding of the variables that help predict ambulation ability after lower limb loss is important. Particular attention should be given to modifiable predictors, as interventions directed at these conditions can help facilitate optimal mobility and function. This article reviews various factors that influence the ability to both walk and run after lower extremity limb loss.

**Keywords:** Amputation, Lower Extremity, Walking, Running

## INTRODUCTION

The ability to ambulate with a prosthesis after lower extremity limb loss is an important determinant of functional independence and quality of life. It has been suggested that the ability to walk with a prosthesis has the greatest influence on predicting quality of life in patients undergoing lower limb amputation due to peripheral vascular disease.<sup>1</sup> Studies reveal improved coping mechanisms, mood, and self-esteem with higher levels of physical activity after amputation.<sup>2,3</sup>

Owing to advances in prosthetic science, running may be achievable for some individuals after lower extremity amputation. Higher levels of physical activity may further enhance function and return to preinjury lifestyle, with important implications for chronic disease risk reduction. This may be of particular significance in amputees, who generally demonstrate higher rates of cardiovascular disease and diabetes mellitus.<sup>4,5</sup> Even so, individuals with lower extremity limb loss tend to be less active than their able-bodied counterparts.<sup>6</sup>

It is critical that practitioners know what elements influence successful mobility after amputation. It is especially important to recognize and address the modifiable factors to maximize ambulatory potential. Therefore, the present article aims to review the

predictors of independent walking and running after major lower extremity amputation, defined as amputation above the level of the ankle. Although prosthetic design can be important to enhance performance and endurance, specialized prostheses (eg, running-specific prostheses) are not an independent determinant of the ability to run after amputation and are beyond the scope of this review.

### **Predictors of Walking After Lower Extremity Amputation**

In the current context, the proverbial phrase “we must learn to walk before we can run” rings true. Before considering those predictive factors for running after lower extremity limb loss, it is important to understand the various circumstances that influence ambulation potential with a prosthesis. Broadly, these factors may be categorized into three groups: 1) personal or intrinsic characteristics, 2) residual limb qualities, and 3) systems of care (Figure 1).

### **Intrinsic Characteristics**

Fitness and pre-amputation ability to ambulate are two of the greatest predictors for walking with a prosthesis after amputation.<sup>7</sup> Patient fitness as assessed by VO<sub>2</sub> max (ie, maximal oxygen uptake during exercise) has been associated with the ability to walk with a prosthesis. Three studies from the same research group evaluated sets of elderly patients with transfemoral amputations.<sup>8-10</sup> These studies measured VO<sub>2</sub> max while participants performed a single-leg cycling exercise with the intact limb, and they found that higher pre-rehabilitation VO<sub>2</sub> max was correlated with successful prosthetic ambulation. This gives patients the ability to walk at least 100 meters with or without a cane. Ultimately, the authors concluded that a VO<sub>2</sub> max of at least 50% may be a valid threshold to predict successful ambulation with a prosthesis.<sup>8-10</sup>

In a similar vein, pre-amputation independent walking has been correlated with walking ability post-amputation. One study of dysvascular amputees found that the ability to walk alone outdoors before amputation was a primary predictor of walking with a prosthesis after amputation.<sup>11</sup> A second study

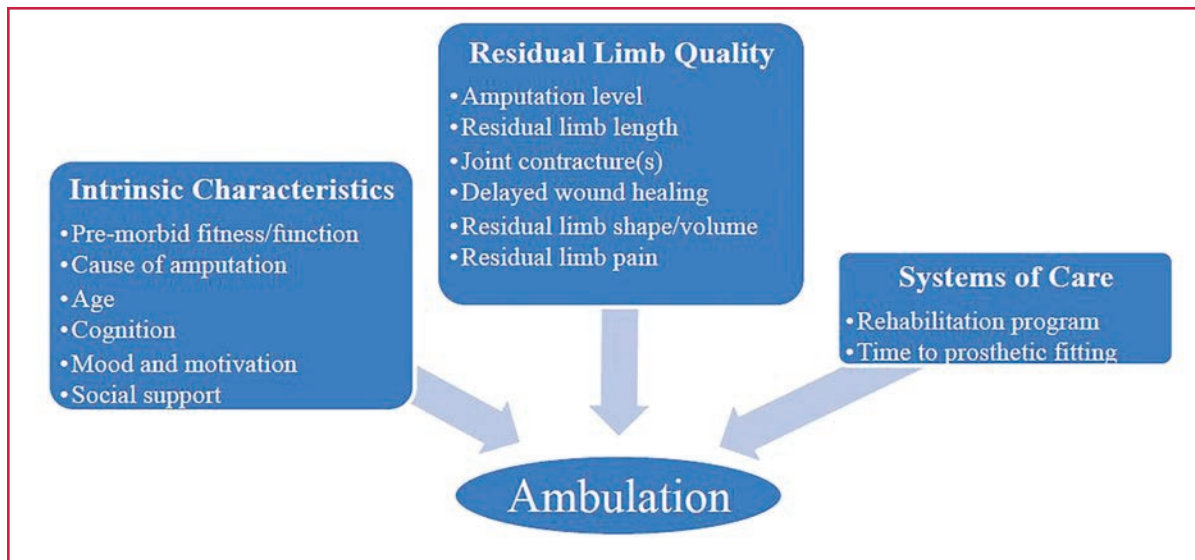
**Table 1.** A proposed residual limb quality grading scale

Residual Limb Characteristic		Points
<b>Wound</b>	Healed	+10
	Unhealed	-5
	Infected	-10
<b>Edema</b>	None	+10
	Minimal	+5
	Significant	-5
<b>Scar</b>	Fully Mobile	+10
	< 1/4 Adherent	-5
	1/4 - 1/2 Adherent	-6
	> 1/2 Adherent	-10
<b>Skin</b>	Sensate	+6
	Insensate	-6
	Insufficient	-6
<b>Length</b>	Suitable	+10
	Acceptable	+5
	Unsuitable	-10
<b>Shape</b>	Conical/Cylindrical	+6
	Bulbous	-6
<b>Tenderness</b>	None	+10
	Moderate	+5
	Severe	-10
<b>Proximal Joint Contracture</b>	None	+10
	< 20°	+5
	> 20°	-20
<b>Bone End Sculpted</b>	Satisfactory	+10
	Acceptable	+5
	Unsatisfactory	-10
	Bone End Exposed	-20
<b>Dog-ears</b>	None	+6
	Minimal	0
	Significant	-6
<b>Redundant Tissue</b>	None	+6
	Minimal	+3
	Significant	-6
<b>Additional Scars</b>	No	+6
	Yes	-6
<b>Total</b>		

of individuals undergoing major lower extremity amputations reported individuals who were able to walk before amputation had 14.4 times the odds of walking with a prosthesis post-amputation.<sup>12</sup> Such findings have likely influenced patient selection for prosthetic fitting. Indeed, it has been demonstrated that the ability to walk independently before amputation is a common determinant for receiving a prosthesis after amputation,<sup>11,13</sup> further lessening the potential for prosthetic ambulation in premorbid non-ambulators.

The presence of medical comorbidities in general have unclear influence on ambulation potential after lower extremity limb loss.<sup>14</sup> However, peripheral vascular disease specifically is likely a negative predictor for walking after amputation. Many studies have described poor outcomes, including reduced mobility, after amputation due to peripheral vascular disease.<sup>15</sup> A recent retrospective analysis of 42 patients with a history of dysvascular amputation concluded that an outpatient prosthetic training program was associated with improvements in performance-based functional measures including ambulation.<sup>16</sup> Despite these improvements, gait speed and performance remained notably inferior to clinically important thresholds, indicating that this population may have a reduced capacity for community-level ambulation and a higher risk for falls.<sup>16</sup>

The connection between age and outcome after amputation is complex. An association between advancing age and reduced ability to ambulate has been inferred.<sup>15,17,18</sup> Schoppen et al<sup>18</sup> evaluated 46 patients over the age of 60 undergoing unilateral amputation and demonstrated a consistent association between older age and reduced function. However, this finding is confounded by the interdependence of age, chronic disease, and pre-amputation fitness. As the incidence of medical comorbidities rises with age while fitness declines with age and chronic disease, it may be challenging to standardize for the influence of age alone.<sup>19</sup>



**Figure 1.** Predictors of ambulation after lower extremity limb loss.

A final intrinsic condition worth mentioning is the individual's mental state, including cognitive ability, mood, and motivation. Premorbid dementia has been associated with a lower probability of independent living and walking after amputation.<sup>7,12,13,20</sup> Larner et al<sup>21</sup> found that individual performance on a learning ability test was predictive of the capacity to learn to use a prosthesis after amputation. Meanwhile, reduced overall mental health status as well as lower attention and working memory scores have been linked to lower levels of prosthetic use and mobility 1 year after amputation.<sup>22</sup> It has also been suggested that mood disorders, particularly depression and anxiety,<sup>23</sup> as well as low patient motivation<sup>24</sup> are likely to negatively influence outcomes after lower extremity limb loss.

### **Residual Limb Qualities**

Regarding the residual limb itself, the level of amputation is believed to play an important role in patient outcome. Energy expenditure during ambulation is expected to be greater with more proximal amputations. It has been estimated that individuals with transtibial amputations expend 9 to 33% more energy, and those with transfemoral amputations expend 37 to 100% more energy when walking compared to those without amputations.<sup>25</sup> This energy cost may limit ambulatory potential, particularly in individuals with lower pre-morbid fitness. In support of this, several studies have corroborated longer walking distances<sup>15,26</sup> and faster walking speeds<sup>27</sup> in transtibial compared to transfemoral amputees. Through-knee amputations generally demonstrate outcomes (eg, prosthetic use, walking distance, and walking speeds) that are inferior to transtibial amputees but superior to transfemoral amputees.<sup>28-30</sup>

It has also been suggested that bilateral amputees expend greater effort than unilateral amputees,<sup>31</sup> which is again expected to affect walking ability. Indeed, in a study comparing 15 bilateral and 15 unilateral (primarily transtibial) traumatic lower extremity amputee patients, bilateral amputees demonstrated decreased prosthetic use as well as reduced walking speeds.<sup>32</sup> A systematic review of 27 studies of military and civilian patients with traumatic lower limb amputations revealed that a higher proportion of below-knee and through-knee amputees were able to walk more than 500 meters when compared to above-knee and bilateral amputees.<sup>33</sup> Notably, there was no significant difference in mobility between the unilateral above-knee and bilateral amputation groups.<sup>33</sup> Similarly, Eskridge et al<sup>34</sup> surveyed 82 patients with lower extremity amputations and found that a higher proportion of individuals with unilateral below-knee amputations were able to easily perform various mobility and walking tasks, with fewer differences noted in the unilateral above-knee and bilateral amputation groups. Taking this a step further, the authors found that more unilateral below-knee amputees reported the ability to run one block when compared to unilateral above-knee and bilateral

amputees.<sup>34</sup> Thus, it might be inferred that patients with more proximal unilateral amputations (eg, transfemoral and hip disarticulation) and bilateral lower extremity amputations generally have worse mobility outcomes.

Residual limb quality is another important determinant of walking ability after amputation. One marker of residual limb quality, residual limb length, is likely to influence energy expenditure and in turn walking tolerance, with longer residual limb lengths linked to lower energy requirements.<sup>35</sup> Pohjalainen et al<sup>26</sup> evaluated 155 consecutive patients with lower limb amputation and found that among those with transtibial amputations, a longer residual limb was associated with greater walking distance. A similar pattern was observed in the transfemoral amputation group, although not statistically significant.<sup>26</sup>

The shape, volume, flexibility, and position of the residual limb are also important determinants of prosthetic fit and, in turn, ambulation.<sup>35-37</sup> In particular, joint flexion contractures involving the hip (for transfemoral amputees) and/or knee (for transtibial amputees) can result in suboptimal limb position, altered biomechanics, and impaired gait. One study linked the presence of a hip flexion contracture to lower mobility scores in individuals undergoing bilateral transfemoral amputations,<sup>36</sup> whereas another study found that the absence of hip and knee contractures was a significant predictor of successful prosthetic ambulation in a mixed population of transfemoral and transtibial amputees.<sup>38</sup> Wound complications and delayed healing may also be problematic, resulting in postponed postoperative rehabilitation and prosthetic fitting.<sup>19,35,38</sup> Other negative prognosticators related to residual limb structure potentially include bulbous shape, poorly controlled edema, adherent scars, and redundant tissue.<sup>35</sup> A grading system to quantify residual limb quality has been proposed, which may help more accurately predict outcomes and mobility scores (Table 1).<sup>39</sup>

Lastly, the presence of pain involving the amputated limb has been consistently associated with impaired mobility.<sup>15,26,36</sup> Residual limb pain (formerly "stump pain") refers to pain involving the remaining limb after amputation. This can have many causes including, but not necessarily limited to, scar tissue, neuroma, insufficient tissue coverage, bone spurs, vascular insufficiency, and infection. In contrast, phantom limb pain describes the perceived sensation of pain involving the portion of the limb that has been amputated. It remains unclear whether a specific type of pain, residual limb versus phantom, may have a greater negative effect on walking ability, as most studies to date combine the two for analytic purposes.

### **Systems of Care**

The rehabilitation process reflects an important component of recovery after lower extremity limb loss. A specialized rehabilitation program plays a vital role in upholding ambulatory capacity and

community reintegration. Several large retrospective studies have demonstrated increased medical stability, improved 1-year survival, and a higher likelihood of prosthetic prescription among individuals exposed to inpatient rehabilitation.<sup>40,41</sup> Rau et al<sup>42</sup> compared a group of amputees undergoing an intensive training program comprised of strengthening, weightbearing, coordination, obstacle management, and functional exercise to a group undergoing a supervised walking program alone, and the authors found improved weight-bearing capacity and 2-minute walk test performance for those receiving rigorous physical therapy. Further investigation is necessary to establish the ideal setting and process for post-amputation rehabilitation.<sup>23</sup>

As an extension of specialist rehabilitation treatment, the provision of a prosthesis is necessary to optimize mobility. In general, earlier prosthetic fitting is favored. It has been suggested that overall satisfaction and utilization of a prosthesis is maximized when pretraining wait times are less than 60 days.<sup>43</sup> Conservatively, initial prosthetic fitting within 6 months may be appropriate to ensure wound healing and limb shaping, particularly in the context of dysvascular amputations.

Nonetheless, several interventions may help reduce time to prosthetic fitting. The use of a rigid dressing in the immediate postoperative period was recently shown to result in lesser times to fitting of a prosthesis.<sup>44</sup> It has also been suggested that the application of an immediate postoperative prosthesis or pneumatic post-amputation mobility device may result in shorter intervals to prosthetic fitting<sup>45,46</sup>; however, one contemporary study failed to associate an immediate postoperative prosthesis with earlier physical activity.<sup>47</sup>

#### ***Predictors of Running after Lower Extremity Amputation***

Of patients who are able to achieve basic ambulatory skills, only a subset will attain the ability to run. In fact, one study found that that only 5% of previously active individuals reported running regularly after lower extremity amputation.<sup>48</sup> Respondents in this study indicated that jogging was among the activities that caused the most discomfort. In addition, running and jumping were the most physically difficult to perform.<sup>48</sup>

The transition of walking to running is marked by the elimination of a double stance phase of gait and is associated with higher vertical ground reaction forces. Muscle activity increases to respond to the higher demands of weight acceptance and to promote acceleration of the limb against the forces of gravity and the running surface. The amputee runner, however, must compensate for the loss of muscle absorption and propulsion ordinarily provided by way of the foot and ankle. To this end, the hip extensors become a major source of energy absorption and generation.<sup>49</sup> Amputee runners also demonstrate reduced mechanical work of the prosthetic limb during stance phase with a concurrent increase in mechanical work of the intact

limb, resulting in energy transfer across the pelvis that is critical to uphold propulsion.<sup>49,50</sup>

It is not surprising then that hip strength, and particularly hip extensor strength, appears to be an important determinant of running capability after lower extremity limb loss. Hip and thigh weakness have been frequently reported in sedentary individuals after amputation.<sup>51-53</sup> More recently, Nolan et al<sup>54</sup> compared hip strength between sedentary amputees and sports-active amputees and found significantly greater peak hip flexor and hip extensor torques among active amputees. There was relatively little asymmetry in hip flexor and hip extensor strength between the residual and intact limbs of active amputees, whereas the inactive group demonstrated considerable relative weakness in the residual limb.<sup>54</sup> In particular, hip extensor peak torque of the residual limb in the active group was double that of the inactive group, and was up to 26% greater than that of an active, able-bodied comparison group.<sup>54</sup> Correspondingly, the application of a directed training program emphasizing hip strength and balance has been shown to promote running following limb loss.<sup>55</sup> Among eight individuals with a history of lower extremity amputation, six (three transtibial and three transfemoral) were able to run within 10 weeks of such a prescribed rehabilitation program.<sup>55</sup>

Dynamic balance is also likely to influence running ability after lower extremity amputation. Balance is impaired after amputation due to loss of proprioception as well as motor function from the foot and ankle mechanism and also the knee (for transfemoral amputees).<sup>18,56</sup> Single-leg balance on the intact limb has been implicated as a predictor of functional outcome in amputees.<sup>18</sup> One study found hip extensor strength followed by the ability to balance on the sound limb (without the use of the upper extremities) to be the two most significant contributors to walking speed during a 6-minute walk test.<sup>57</sup> Regarding higher-level mobility more specifically, Gurnard et al<sup>58</sup> concluded that rehabilitation factors, and explicitly lower-limb strength and dynamic balance, were associated with greater high-level mobility.

With these predictive factors of strength and balance in mind, the Comprehensive High-Level Activity Mobility Predictor (CHAMP) was developed to quantify function and gauge readiness for higher levels of activity in individuals with lower extremity limb loss.<sup>59</sup> Specifically, CHAMP comprises four tests that measure coordination, power, speed, and agility (Table 2). Each test item is scored on a scale of 1 to 10 for a total of 40 possible points, with higher scores reflecting better performance.<sup>60</sup> For reference, one study reported an average CHAMP score of 35.4 (range, 33-39) for active, non-disabled individuals.<sup>60</sup> Higher CHAMP scores have been associated with higher amputee mobility predictor scores as well as enhanced performance on a 6-minute walk test, supporting CHAMP as a tool to help predict



**Table 2.** The Comprehensive High-Level Activity Mobility Predictor

CHAMP <sup>1</sup> Test Item	Skill(s) Measured	Testing Procedure
Single Limb Stance	Balance, Postural stability	Subject raises foot $\geq 15.2$ cm from the floor, maintaining single limb stance. Number of seconds (up to 30) without error is recorded.
Edgren Side-Step Test	Coordination, Power, Speed and Agility	Subject performs side-step for 10 seconds. Number of one-meter intervals completed is recorded.
T-Test	Coordination, Power, Speed and Agility	Subject moves through a T-shaped course: forward, lateral (both left and right), and backward. Time to complete course, in seconds, is recorded.
Illinois Agility Test	Coordination, Power, Speed and Agility	Subject moves through a pre-set course that involves forward running and weaving. Time to complete course, in seconds, is recorded.

<sup>1</sup>CHAMP = The Comprehensive High-Level Activity Mobility Predictor

higher-level mobility in amputees.<sup>60</sup> It is worth noting that CHAMP has been validated specifically among male servicemembers with a history of traumatic lower extremity amputation. Further studies are needed to substantiate its use in more diverse populations of individuals with lower limb loss.

## CONCLUSION

Many variables influence the ability to ambulate after lower extremity limb loss. Predictive factors for walking at a minimum include pre-amputation fitness, history of peripheral vascular disease, mental status, post-amputation pain, and residual limb quality, as well as referrals for specialized rehabilitation and early prosthetic fitting. Superior hip strength and dynamic balance further differentiate the capacity for advanced mobility, including running. It is especially important to direct interventions toward those modifiable factors in order to maximize ambulatory potential and foster physical activity after amputation. This may include psychological support, optimization of residual limb shape, pain control, earlier prosthetic fitting, and rehabilitation programs emphasizing lower limb range of motion, hip strength, and dynamic balance.

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# Malreductions Following Intramedullary Nail Fixation of Femur Shaft Fractures

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## ABSTRACT

Femur shaft fractures are common injuries frequently treated with intramedullary fixation. Although satisfactory alignment is usually achieved, malreductions can happen in sagittal and coronal planes, as well as along the longitude axis. The causes of malposition with femoral nailing include fracture location, comminution, and suboptimal technique. We identify the most common patterns of malreduction of nailed femur shaft fractures as well as how to avoid and treat them.

**Keywords:** Femur Shaft Fracture, Intramedullary Nail, Malunion, Surgical Complications

## INTRODUCTION

Femoral shaft fractures are common injuries encountered by orthopaedic surgeons, and intramedullary nailing has become the standard of care for management.<sup>1</sup> Despite many excellent outcomes, intramedullary nailing can lead to malreduction of the femur if the surgeon is not vigilant. The goal with intramedullary nailing of femoral shaft fractures is to restore length, rotation, and alignment and provide relative stability to achieve healing by callus.<sup>2</sup> These factors allow the patient to mobilize quickly, often within 1 day of fracture fixation.

It is not necessary to obtain a perfect anatomic reduction of all fracture fragments for an acceptable outcome, in contrast to articular fractures. The nail acts as a strut to align the medullary canals of the proximal and distal fragments so translation deformities can be spontaneously corrected by placement of the nail, especially if the nail fits tightly within the medullary canal.<sup>3</sup> When the fracture is transverse in the mid-shaft, there is also spontaneous correction of coronal and sagittal plane translation and angulation. However, there are several instances in which passage of the intramedullary nail does not cause a serendipitous global reduction. This paper describes common scenarios in which additional steps must be taken to ensure adequate alignment for femur shaft fractures treated with intramedullary nail fixation.

The incidence of malunion is estimated to be 30%, although the true incidence is unknown because there is not universal agreement on the amount of deformity necessary to constitute a clinically significant amount of deformity and hence "malunion."<sup>4</sup> The frequency of malreduction is high enough to be a clinical problem but low enough to preclude high-quality randomized controlled studies. Therefore, our recommendations are generally based on best available evidence, which is often senior author experience consistent with existing literature. The topic is particularly important to young surgeons as it is one of the American Board of Orthopaedic Surgery assessment milestones for treatment of long bones and a common topic of Part II Board Examination.

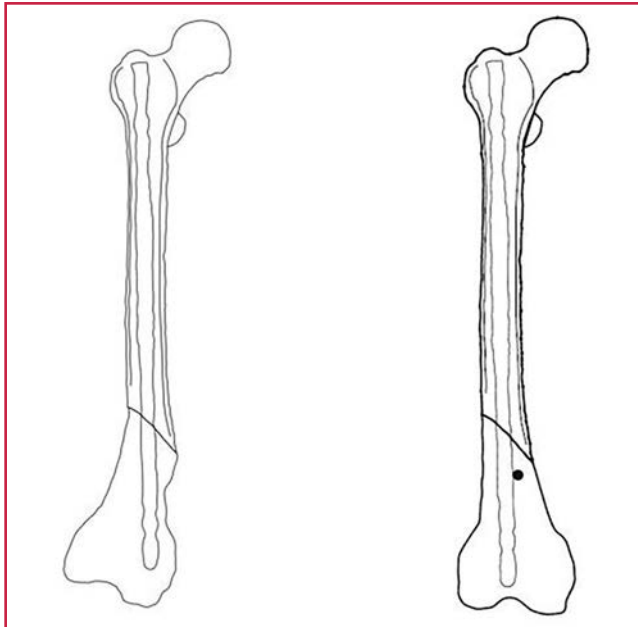
### **Fracture Comminution**

When comminution is present, there may be sufficient distance between the nail and the endosteal cortical bone that sagittal and coronal plane angulation or displacement are not spontaneously corrected. Blocking screws are an effective technique to prevent these types of malunions. Blocking screws placed across the medullary canal effectively reduce the internal diameter of the canal to more closely match the external diameter of the straight nail and effect reduction of the fracture. If a fracture malreduces with nail placement (angulation or displacement), the nail will not be in the center of at least one of the bone fragments (proximal or distal). One or more blocking screws across the medullary canal positioned to force the nail into the center of the fragment will correct the deformity (Figure 1).

### **Metaphyseal Location**

Similar to fracture comminution, when the fracture occurs in meta-diaphyseal bone or severely osteoporotic bone with a very wide medullary canal, there is no contact of the nail with the endosteal cortex of the bone. When the nail is not in contact with the cortical bone in both the proximal and distal fragments, significant angulation is possible. Several techniques can address this problem. The nail diameter can be increased if the isthmus of the canal will permit.

Another option is to use a blocking screw as mentioned above (Figure 1). A third option is to make a “mini-open” approach, directly reduce the fracture, and place fixation to hold reduction during nailing and inter-lock screw placement.<sup>5</sup> This can be done with temporary clamps, permanent or temporary cerclage wire, or a unicortical locking plate (Figure 2).



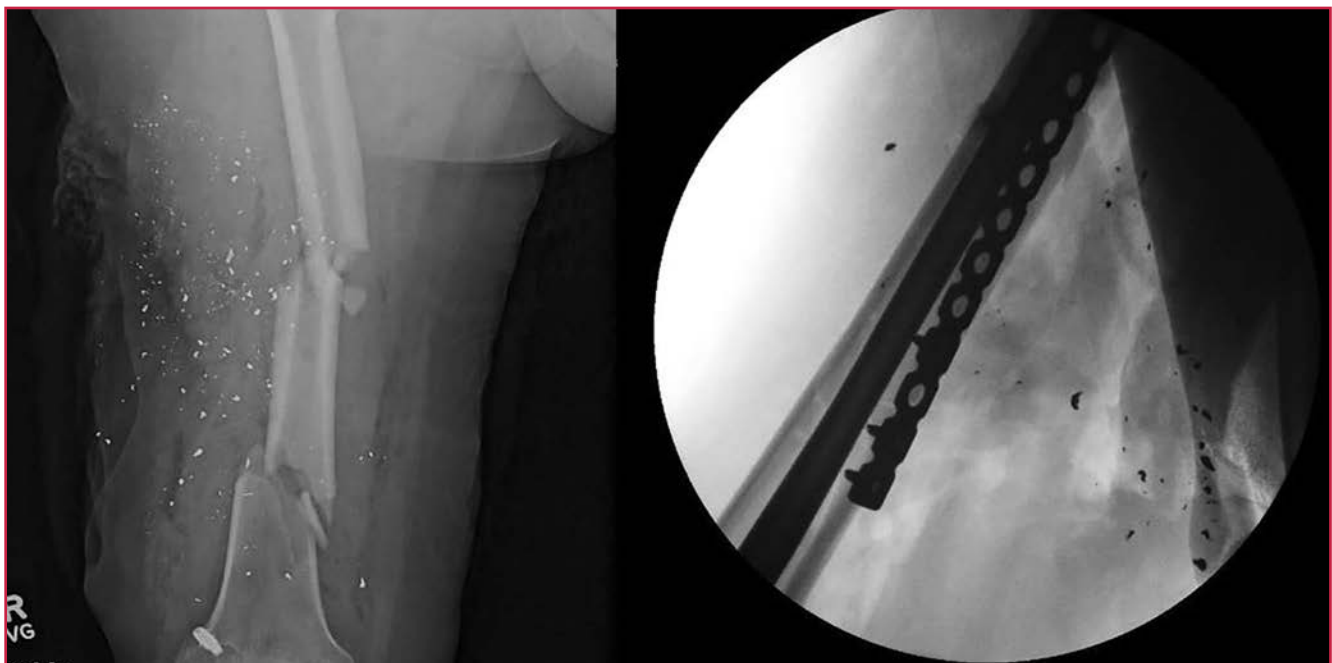
**Figure 1.** Blocking screw is placed anterior to posterior medially in the proximal aspect of the distal fragment to create an artificial “endosteum.” The lateral aspect of the nail contacts the blocking screw, forcing the nail into the center of the distal fragment correcting the tendency toward lateral displacement malreduction.

When the fracture is metaphyseal (subtrochanteric or supracondylar), the fracture should be reduced prior to obtaining the starting point and this reduction should be maintained while reaming to avoid malunion.

#### **Starting Point**

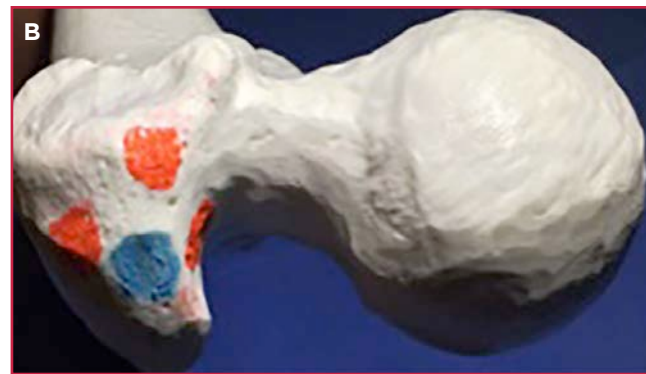
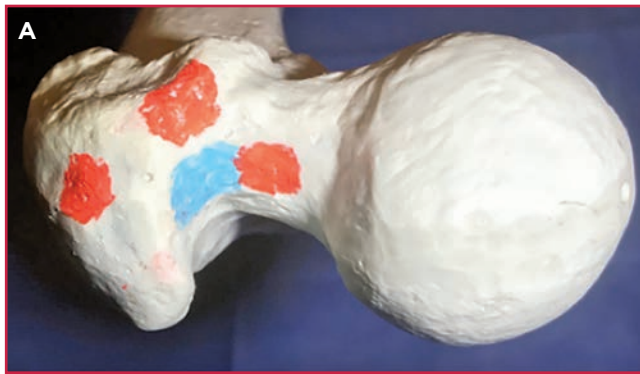
Femoral nail entry points can be either proximal or distal depending on antegrade or retrograde technique. There are three different proximal entry points for antegrade femoral nails (piriformis, trochanteric, or “trochaformis”), depending on nail design (Figures 3A and 3B). The piriformis fossa was traditionally used for straight nails. For easier insertion, nails were designed for insertion through the tip of the greater trochanter. Some authors suggested an intermediate entry point (so called “trochaformis”).<sup>6</sup> For antegrade nails, an excessively anterior entry point will cause an apex anterior angulation at the fracture site in the sagittal plane (Figures 4A and 4B). Similarly, a lateral entry point will cause an apex lateral angulation at the fracture site in the coronal plane. Using a trochanteric entry point for a nail designed for piriformis entry will produce apex medial angulation.

Retrograde nails are placed through a distal femur entry point that is centered in the coronal and sagittal plane (Figure 5).<sup>7</sup> The entry point is in line with the femoral shaft in all planes. Entry points are typically made percutaneously under fluoroscopic guidance, and when an entry point is incorrect, passage of the nail will force a malreduction at the fracture site even if good alignment was achieved before nail placement. For retrograde nails, an entry point made with residual apex posterior angulation at the fracture site will result in an apex posterior angulation at the fracture site when the nail is inserted, even if good alignment is achieved



**Figure 2.** A segmental femur shaft fracture treated with augmented fixation. A unicortical plate was placed before reaming to help with fracture reduction. Additionally, the plate protects the bone from devitalization during reaming.

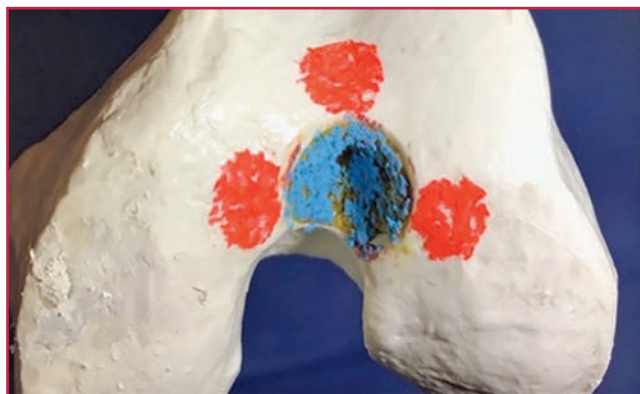




**Figure 3.** Correct starting point (blue) and common entry point errors (red) for A) piriformis entry and B) trochanteric entry. In the piriformis entry, the most medial red entry increases the risk of damage to the medial femoral circumflex artery and likely avascular necrosis. The anterior and lateral red areas will result in apex anterior and lateral deformities, respectively.



**Figure 4.** Radiographs of a femur after antegrade nailing. A) Lateral view shows starting point that is too anterior, resulting in an apex anterior deformity. B) Anteroposterior view shows starting point that is too lateral, resulting in an apex lateral deformity.



**Figure 5.** Distal femur with the correct retrograde entry site in blue and common mistakes in red. Starting lateral, anterior, or medial will cause apex lateral, anterior, and medial deformities, respectively.

**Figures 3, 4, and 5** reprinted with permission from Thomas A. DeCoster (DeCoster TA, Bozorgnia S, Kakish S. Antegrade nailing of femur shaft fractures: a review. *Univ N M Orthop Res J.* 2017;6:37-45).

before nail passage. In contrast to most antegrade nails, retrograde nailing requires reduction of the fracture before establishing the entry point to avoid subsequent sagittal plan malangulation. Fracture reduction before entry site is important with antegrade nailing when the fracture is subtrochanteric and muscle tone pulls the proximal fragment away from the anatomic position.

#### **Sub-Optimal Reaming**

After the entry point is chosen and the femur accessed with the entry reamer, the guide wire is placed. It is imperative to ensure adequate reduction of the fracture site before reaming.<sup>8</sup> Reaming of a malreduced fracture site will result in eccentric reaming, meaning the opposing ends of the fracture site are reamed along the opposite cortices.<sup>9</sup> This will prevent the correct



endosteal contact with the intramedullary nail at the fracture site; in other words, the improperly reamed position will be maintained after the nail has been placed. Eccentric medullary reaming can be prevented by manually holding reduction while reaming. Reaming can cause fragment displacement. A technique used to prevent displacement of comminution is a “push-past” technique, in which the reamer is stopped before the fracture site, advanced without spinning, then re-started after the cutting flutes are beyond the fracture site.<sup>10</sup> When dealing with intercalary segments, reaming of a segment of bone that is not rotationally stabilized can also cause catastrophic consequences and segment devitalization. This fragment of bone must be controlled by either direct clamping or temporary fixation while reaming (Figure 2).

#### **Matching Nail Design to Femoral Anatomy**

The femur has an anterior bow that is inversely measured as “radius of curvature” (ROC). The smaller the ROC, the greater the bow; the larger the ROC, the straighter the femur. Nails are manufactured with various ROCs by different companies. Most nails in current use have an ROC between 1 and 2 meters. Femoral ROC averages 2 meters in patients aged 20 years and 1 meter in those aged 65 years (increased femoral bow with age). With metabolic bone disease, the femoral bow can be even greater. Small amounts of mis-match between ROC of the broken femur and nail are not clinically significant. However, large mis-match between ROC of broken femur and nail will create clinical problems, including iatrogenic comminution, nail protrusion through the bone or malreduction at the fracture site.<sup>11</sup> Placing a nail that is straighter (larger ROC) than the ROC of the bone (smaller ROC) will result in apex posterior angulation at the fracture site when the nail is placed. Patients over 50 years old with femur shaft fractures often have increased bow which is important for the surgeon to identify preoperatively. The surgeon should know the ROC of available nails and either select a nail with smaller ROC or adjust the bow of the chosen nail in the operating room by gently bending it with a large plate bender.

#### **Length Deformity**

Another challenge with femoral nailing is Z-axis deformity, comprising length and rotational alignment. Unlike coronal and sagittal plane translation and angulation, which often spontaneously reduce with nail placement, Z-axis deformities do not usually spontaneously correct. Distraction can occur with any fracture pattern and can be the result of excessive traction, inadequate distal reaming, or inattention to detail. Shortening is more common in the presence of oblique fracture lines or extensive comminution.<sup>12,13</sup>

To avoid length problems (distraction or shortening), the surgeon must assess both direct and indirect radiographic signs. The intraoperative technique includes releasing traction before interlock screw

placement and longitudinal manual tamping to avoid lengthening or correct distraction at the fracture site. Length should be assessed in the operating room using external references, although these can be unreliable owing to draping and patient positioning. Described techniques involve preoperative imaging of the contralateral limb with objective reference, like a Bovie cord or metallic ruler, that can then be referenced during the procedure.<sup>14</sup> If shortening is present, then additional traction can be provided to dis-impact the fracture and restore proper length before placement of a second set of locking screws.

Length should also be assessed immediately after completion of the procedure, in the operating room while the patient is still intubated. This can be performed by holding both lower extremities in a symmetric position and manually assessing limb length by either palpating the medial malleolus with knees and hips in full extension or palpating the medial femoral condyle. The earlier a limb length difference can be recognized, the easier it is to correct. Small length differences less than 20 mm in the femur are not typically clinically significant and are well tolerated.<sup>15</sup> As with other non-anatomic reductions, the exact amount of shortening or lengthening that may cause some clinical problem is not well defined nor universally accepted. Length restoration back to pre-fracture status should be the goal.

#### **Rotational Deformity**

Malrotation is probably the most common deformity after nailing of femur shaft fractures, but it is under recognized. This is due to the difficulty in accurately assessing rotation as well as the variation that exists in normal anatomy. One study identified a 22% incidence of malrotation more than 15°.<sup>16</sup> The clinical consequences of femoral malrotation are not completely understood. Biomechanical studies suggest that it causes a substantial change in load bearing in the affected extremity.<sup>17</sup> Malrotation will cause gait abnormality with in-toeing or out-toeing. Techniques including clinical examination and fluoroscopy are useful in measuring femoral rotational alignment intraoperatively. Postoperatively, computed tomography (CT) is useful in identifying the magnitude of malrotation and is very helpful in planning corrective de-rotation surgery.

Various techniques exist to recognize and avoid rotational malreductions. In general, the surgeon needs to identify the rotation of the proximal fragment relative to anatomic position, adjust the rotation of the distal fragment to match, and maintain that reduction until placement of the statically locked nail. The proximal radiographic landmarks include the greater and lesser trochanters. The distal radiographic landmarks include the position of the patella relative to the femur on anteroposterior (AP) view and the overlap of the medial and lateral femoral condyles on the lateral. One preferred technique involves fluoroscopy of the

uninjured limb, then comparison of the fractured limb to the image before performing rotational reduction. The initial fluoroscopic step is to obtain a perfect AP of the knee with the patella exactly in the center of the distal femoral condyles, then hold that rotation on the fluoroscope and take an AP at the hip. The profile of the lesser trochanter is used to assess the degree of rotation of the proximal femur. The images are reversed (to make the right look like the left) and saved until the rotation of the fractured limb is reduced. The final rotationally reduced fracture images are compared and matched to the preoperative images of the contralateral femur (a variation of described technique by Deshmukh et al<sup>18</sup>).

At completion of the case, while the patient is still asleep, rotation should always be assessed by physical examination. Limbs should be compared for symmetry, particularly hip range of motion in internal and external rotation. A gunsight CT scan is the most objective measure of femoral rotation.<sup>19</sup> This can be obtained if there is postoperative concern for rotational malreduction. When identified early, rotational malunions can be corrected by removal of locking screws, de-rotation at the fracture site by manual manipulation in the operating room, and replacement of locking screws along a new path. If rotational malunion is found late, the fracture should be allowed to heal completely and then a de-rotation osteotomy and nail revision should be performed. Small rotational differences of less than 20° are often well tolerated by hip range of motion and do not require treatment.<sup>20</sup>

It is also important that the nail be placed in correct rotational relationship relative to both the proximal and distal femoral fragments so that the inherent geometry of the nail corresponds to the femoral anatomy and allows for proper interlocking screw placement.

## CONCLUSION

Despite reduction difficulties often encountered during femoral nailing, knowledge of common pitfalls will allow for excellent outcomes including avoidance of malreductions.<sup>1,21,22</sup> It is important to identify and correct malreductions if they occur. Special operative techniques include appropriately selected and precisely placed entry sites and blocking screws. Understanding bow, ROC, and execution of rotation and length protocols can help avoid the problem of mal-reduction of nailed femur shaft fractures. When clinically significant malalignments occur in patients, they should generally undergo correction of the deformity with revision fixation.

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# Cost Analyses of Nonoperative Treatment of Sports-Medicine Conditions Are Lacking

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## **ABSTRACT**

The purpose of this study was to qualitatively review existing studies that examined cost data within sports medicine. A literature search was conducted for all economic studies related to sports-medicine conditions from 2000 to 2017 within the United States. Area of analysis, data source utilized, and the type of collected cost data was identified. There were 29 studies that met criteria, with the majority of studies (60%) focused on rotator cuff repair and anterior cruciate ligament reconstruction. Substantial variability in data source, practice setting, data metrics, and reported measures makes interpretation of existing reports challenging. Greater diversity in topics and more standardized methodology are necessary to better understand value and quality in sports medicine.

**Keywords:** Cost, Cost Analysis, Sports Medicine

## **INTRODUCTION**

Providing high-value healthcare is a growing priority in the face of an increasing economic burden associated with healthcare.<sup>1-3</sup> Value is commonly understood to be the ratio of outcome to cost.<sup>4</sup> Although there are many outcome studies in sports medicine, there are few cost studies. Such economic studies are challenging to perform, and there is significant inter-study variation in region, methodology, and data source. Existing studies commonly report reimbursement or charges.<sup>5</sup> However, such figures are known to be disparate from actual cost. Conversion of these data sources to cost is unreliable as global cost-charge ratios lack adequate granularity.

Cost data that are more reliable and accurate is necessary. When combined with clinical outcome data, value and cost effectiveness can be determined.<sup>5</sup> Understanding the costs associated with various interventions is important for patient counseling, institutional resource allocation, reimbursement, and practice management. The purpose of this study was to determine the amount and variety of cost-identification studies within sports-medicine literature.

## **METHODS**

A literature search was conducted using PubMed, Embase, Web of Science, and Scopus. Published economic articles that involved sports-medicine procedures, diagnostic tests, or treatment options between January 1, 2000 and December 31, 2017 were included in the initial search. The search included both economic and specific terms. The economic terms were “economic,” “cost,” and “cost analysis.” The specific terms were “anterior cruciate ligament,” “ACL,” “posterior cruciate ligament,” “PCL,” “cartilage,” “meniscus,” “meniscal,” “arthroscopy,” “microfracture,” “femoroacetabular impingement,” “FAI,” “labrum,” “rotator cuff,” “instability,” and “tendon.” Articles that were not cost-identification studies were excluded from this study, along with any study not based in the United States. The currency and author affiliation were both used to determine if a study was a United States-based study. Foreign studies were excluded to decrease study heterogeneity while increasing generalizability to the United States population. Two of the authors independently determined study size, time, clinical area, comparisons, economic data, data source, practice setting, cost and charge subcategories, findings, and level of evidence.

## **RESULTS**

### **Search Results**

The search algorithm identified 1,895 studies. There were 157 studies (8.28%) related to sports medicine (Figure 1). Thoroughly assessing abstracts and articles resulted in a total of 42 cost and economic studies. When excluding studies that were not based in the United States, a total of 29 articles (1.53% of the original search) were to be included in this review (Table 1).

Article references were searched, and the “related citations” function on PubMed was used. No further articles were found. Twenty studies (70%) addressed costs associated with surgical care. Eight studies (30%) evaluated costs related to diagnostic modalities.

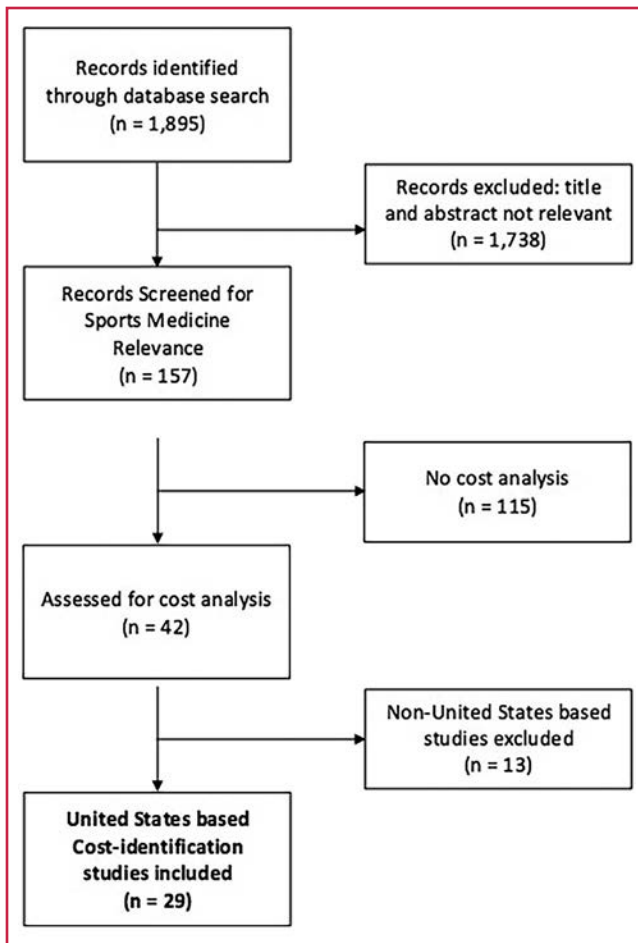


Figure 1. Study Cohort Flowchart

Only one study focused on the cost associated with nonoperative treatment for a specific condition. Eighteen studies (60%) focused on rotator cuff repairs (RCR) and anterior cruciate ligament reconstruction (ACLR). Other studies evaluated Achilles tendon ruptures, various treatments for cartilage lesions, and diagnostic and follow-up tests.

There was large variation in the cost metrics analyzed in the studies as well as the sources of collected data (Table 1). The cost data collected showed a wide variety between studies ranging from direct and indirect costs, charges, and reimbursement (Table 1).

#### Anterior Cruciate Ligament Reconstruction

ACLR was the most common clinical area studied. Of the 11 ACLR studies, there were 7 studies that presented cost subcategories (ie, facility, operating room, implant, graft, and supply fees) in addition to total costs.<sup>6-12</sup> One sole study presented therapy fees, and only three studies presented surgeon and professional fees.<sup>6,10,11</sup> Larson et al<sup>6</sup> was the only anterior cruciate ligament study to look at clinical outcome scores along with cost data.

Two studies examined costs beyond the immediate encounter for ACLR.<sup>13,14</sup> In 4 of 5 studies, allograft was significantly more expensive than autograft, even when factoring decreases in operating room time

and supplies.<sup>7,9-12</sup> Archibald-Seiffer et al<sup>8</sup> reported inter-surgeon variation in suture, instrumentation, and allograft costs despite all surgeons being in the same hospital system (Table 1). These studies reported excellent direct cost data largely centered on time of surgery, with the exception of one study that evaluated 90-day direct costs for ACLR.<sup>14</sup>

#### Rotator Cuff Repair

RCR was also a common clinical area of study. Of the 8 RCR studies, there were 7 studies that presented cost subcategories in addition to total costs.<sup>15-21</sup> Operating room, implant, graft, and supply fees were the most common cost subcategories presented. Only one study included therapy-related costs after RCR (Table 1),<sup>15</sup> with the remainder looking a direct costs centered on time of surgery.

Similar to ACLR, RCR had high inter-surgeon variability in supply costs despite being in the same hospital system.<sup>18</sup> Reimbursement for both RCR and physical therapy afterwards was lower with Medicare payers than with non-Medicare payers despite similar costs for RCR.<sup>15,17</sup> A study by Bisson et al<sup>19</sup> compared single versus double-row RCR and found the latter cost to be as high as \$5,407 more than the former, emphasizing the need for a proper cost-effectiveness analysis (CEA) to evaluate the two techniques. Two studies looked at the costs for transosseous RCR versus double-row transosseous equivalent (TOE) surgeries, and they found the mean implant cost for TOE repairs to be significantly more expensive than anchorless repairs, with no difference in operative time or short-term outcomes (Table 1).<sup>16,21</sup> Seidl et al<sup>21</sup> was the only group to associate clinical outcome measures with cost data among RCR studies. Both studies have good methodology but were also limited in their cost analysis. Black et al<sup>16</sup> also did not provide any clinical outcome analysis. These studies would benefit from having a clear economic model and outcome measure to be able to perform proper CEA in the future.

#### Chondral Defects

Only two studies examined treatment of articular chondral defects. Miller et al<sup>22</sup> did a cost analysis and found similar results between microfracture and osteochondral allograft transplantation (OAT), with microfracture being cheaper. However, the cost of OAT decreased postoperatively at the 10-year follow-up. Schrock et al<sup>23</sup> found microfracture to be more cost-effective than osteochondral allograft transplantation or first-generation autologous chondrocyte implantation, as measured by cost-per-point change in functional outcome scores (Table 1). Both of these studies incorporated clinical outcome measures with direct costs from surgery thorough an extended follow-up period.

#### Nonoperative Management

Only one study included nonoperative management of Achilles tendon rupture versus surgical management.<sup>24</sup>



**Table 1. Breakdown of Sports Medicine Cost Analysis Studies from 2000-2017 in the United States**

Study	Clinical Area	Comparison	Study Size	Economic Data	Summary of Economic Data Presented	Findings
Herzog et al 2017 <sup>13</sup>	ACLR	ACL with or without other knee injuries	229,446	Charges	Immediate Procedure Total, 9-month window total	Concomitant collateral ligament repair associated with higher costs. Subsequent procedures were more expensive than the index procedure.
Rosas et al 2017 <sup>14</sup>	ACLR	N/A	10899	Reimburse-ments	Same-day, 90-day reimbursements	There is no significant difference in same-day or 90-day costs between age-matched males and females.
Schrock et al 2017 <sup>23</sup>	Cartilage Defects	Microfracture vs OAT vs ACI	730	Charges	Procedural, diagnostic imaging, rehabilitation	Microfracture was found to be the most cost-effective option.
Truntzer et al 2017 <sup>24</sup>	Achilles Rupture	Operative vs. Nonoperative Management	5,044	Charges	Surgeon, facility, office visits, physical therapy, supply, complication	Surgical management of Achilles rupture was significantly more costly than nonsurgical management.
Wester-mann et al 2017 <sup>28</sup>	Shoulder MRI	Urban vs. Critical Access Hospital vs. Rural and Rural Referral Centers	94	Charges	MRI technical costs	Independent imaging centers have significantly lower charges to consumers for MRI compared to hospital-owned centers.
Black et al 2016 <sup>16</sup>	RCR	Transosseous Rotator Cuff Repair vs Transosseous Equivalent Rotator Cuff Repair	344	Direct Costs	Implant Costs, OR Time	Costs associated with arthroscopic transosseous rotator cuff repair were lower than costs associated with transosseous equivalent repairs.
Narvy et al 2016 <sup>17</sup>	RCR	Medicare vs. Non-Medicare Patients	184	Charges	Implant and Variable Charges	Reimbursement is lower in the Medicare group, but charges are similar.
Seidl et al 2016 <sup>21</sup>	RCR	Transosseous Rotator Cuff Repair vs Transosseous Equivalent Rotator Cuff Repair	43	Implant Costs	Implant Costs, OR Time	Mean implant cost lower in the transosseous rotator cuff repair group than in the transosseous-equivalent rotator cuff repair group.
Terhune et al 2016 <sup>18</sup>	RCR	Between Surgeon Differences	62	Cost	Suture anchors, suture-passing devices, suture, and disposable instruments and tools	There is significant variation across surgeon and case. Suture anchors were the most expensive and variable surgeon-directed cost.
Archibald-Seiffer et al 2015 <sup>8</sup>	ACLR	Surgeon Variation in Costs for ACL Reconstruction	49	Limited Direct Costs	Fixation, Device, Implant, Supply Cost	Significant variation in cost of tibial or femoral fixation as well as in cost for sutures, instruments, and allografts.
Arshi et al 2015 <sup>15</sup>	RCR	Medicare vs. United Healthcare Groups	365,891	Charges	Per-patient average charge, Utilization-weighted per-patient average charge	Utilization of physical therapy after rotator cuff repair is higher in privately insured than Medicare patients. Per-patient charges are similar between groups.
Bisson et al 2015 <sup>19</sup>	RCR	Single Row vs. Double Row vs. Suture Bridge	N/A - Cost Modelling	Calculated Costs	Implant, Professional Fee, Anesthesia Fee, Opportunity Cost, Therapy Fee	Double row and suture bridge techniques are more expensive than the single row technique. Double row and suture bridge would need to have significantly lower revision rates than single row to justify their increased costs.
Miller et al 2015 <sup>22</sup>	Cartilage Defects	Microfracture vs OAT for Distal Femoral Articular Cartilage Defects	N/A - Cost Modelling	Direct Costs	Anesthesia, OR fees, Surgeon Fees, Return Visits, MRI, Initial procedure cost, secondary procedure cost	Net direct costs and cost-effectiveness of microfracture and OAT are comparable for distal femur articular lesions.
Stucken et al 2015 <sup>39</sup>	ACL Evaluation	N/A	340	Charges	Radiograph costs	Postoperative radiograph after ACL rarely resulted in changes in management and had significant costs.
Greene et al 2014 <sup>31</sup>	Knee Arthroscopy	N/A	3797	Charges	Discordant diagnosis, discrepant diagnosis costs	Routine pathologic examination of knee arthroscopy specimens rarely altered management of patients

Iyengar et al 2014 <sup>20</sup>	RCR	N/A	NR	Estimated Costs from Hospital Charges	Total Hospital Charges	Charges associated with inpatient rotator cuff repair increased in Nationwide Inpatient Sample over time. Increase in healthy patients undergoing rotator cuff repair in outpatient surgery centers
Kahlenberg et al 2014 <sup>27</sup>	Hip Evaluation	N/A	78	Charges	Healthcare provider visits, diagnostic imaging, conservative management	There are significant costs associated with delay to diagnosis of femoroacetabular impingement and labral tears
Voigt et al 2014 <sup>25</sup>	Shoulder and Knee Evaluation	Diagnostic Office Arthroscopy vs MRI	705000	Calculated Costs	Treatment, Complication Costs	Suggests that Diagnostic Office Arthroscopy is significantly more cost-effective than MRI
Keeney et al 2013 <sup>29</sup>	Hip Evaluation	Impact vs nonimpact Hip MRI	218	Procedural Cost Utility	Cost Utility of MRI	MRI of the hip rarely impacts clinical decision making independent of hip x-ray.
Yeranosian et al 2013 <sup>30</sup>	Rotator Cuff Evaluation	N/A	92688	Charges during 90-day period prior to Rotator Cuff Repair	Diagnostic Imaging, Injections, Outpatient Visits, Physical Therapy, Laboratory/Preoperative Studies, Miscellaneous, Unknown	Majority of preoperative costs comes from MRI related costs.
Greis et al 2012 <sup>7</sup>	ACLR	Allograft vs Autograft for ACL Reconstruction	96	Charges, Direct Costs, Reimbursement	OR costs, intraoperative supplies, anesthesia, pharmacy, recovery, total	Allograft cost was not offset by decrease in OR time. However, could be cost-effective in an outpatient setting
Barrera et al 2011 <sup>10</sup>	ACLR	Allograft vs Autograft for ACL Reconstruction	164	Cost and Calculated Costs from Case Details	Supply, Labor, and Facility Costs	Allograft ACL reconstruction cost significantly higher than autograft ACL reconstruction cost
Churchill and Ghorai 2010 <sup>41</sup>	RCR	Mini-open vs. All-arthroscopic	5,224	Charges	Total Charges	Mini-open is cheaper than all-arthroscopic. Low and intermediate volume centers were cheaper than high volume centers.
Cooper and Kaeding 2010 <sup>9</sup>	ACLR	Allograft vs Autograft for ACL Reconstruction	98	Direct Costs	Anesthesia, Pharmacy, Medical Supply, Operating Room, and Recovery Room Costs	Allograft cost was not offset by decrease in OR and recovery room time.
Brophy et al 2009 <sup>32</sup>	ACLR	Double Bundle vs Single Bundle ACL Reconstruction	N/A - Cost Modelling	Direct Costs	Total estimated hospital costs	Model predicted that double bundle technique significantly increased cost of ACL reconstruction.
Nagda et al 2009 <sup>12</sup>	ACLR	Allograft vs Autograft for ACL Reconstruction	155	Cost and Calculated Costs from Case Details	Graft, implant, operating room, recovery room, anesthesia, supplies costs	Allograft ACL reconstruction is costlier than autograft ACL reconstruction in the outpatient setting
Cole et al 2005 <sup>11</sup>	ACLR	Allograft vs Autograft for ACL Reconstruction	123	Charges	Hospital, Surgical Center, Pharmacy, Anesthesia, Anesthesia Supplies, Radiology, OR supplies, PACU, Laboratory, Central supplies, Respiratory Care, Cast Room, Other Charges	Allograft ACL reconstruction cost significantly lower than autograft ACL reconstruction. Autograft has likely increased hospital stay
Larson et al 2004 <sup>6</sup>	ACLR	Single vs Two Encounters for Bilateral ACL Reconstruction	57	Charges	Total charges, OR costs, ancillary fees, anesthesiologist, surgeon, allograft, equipment, rehabilitation	Bilateral ACL reconstruction over one encounter was associated with significant cost savings versus a two episodes of unilateral ACL reconstruction
Jari et al 2002 <sup>40</sup>	ACLR	Bilateral Simultaneous vs. Unilateral Reconstruction	56	Charges	Hospital	Unilateral ACL reconstruction was cheaper than bilateral simultaneous ACL reconstruction, however they not did report statistical significance.

ACL, anterior cruciate ligament; ACLR, anterior cruciate ligament reconstruction; RCR, rotator cuff repair; MRI, magnetic resonance imaging

These authors used a database to compare billing codes with the assumption that outcomes were similar between operative and nonoperative groups based on prior literature.<sup>24</sup>

### **Diagnosis**

Several studies looked at the diagnostic costs of different sports-medicine conditions. Two studies evaluated in-office diagnostic arthroscopy for knee and shoulder intra-articular injuries. These studies suggested that diagnostic arthroscopy resulted in cost savings; however, these studies had no clinical outcome data using prior studies and used Medicare billing information for cost data.<sup>25,26</sup> Magnetic resonance imaging (MRI) evaluation and other workup for joint pain was assessed in four studies.<sup>27-30</sup> These studies reported in their cohorts that the use of MRI as a screening tool for hip pain is not cost effective, that MRI accounts for a significant portion of preoperative costs before RCR, and that independent facility shoulder MRIs are cheaper than large institutional facility MRIs.<sup>28-30</sup> These studies provided no clinical outcome data and used cost information ranging from Medicare billing information to direct charges from hospitals and imaging centers. Greene et al<sup>31</sup> reported that routine pathology specimens following knee arthroscopy was not cost effective (Table 1).

There has been an increasing amount of cost analysis studies through the timeline of this study. The data used for cost analysis is still widely variable over the years, and quality of data analysis also varies from study to study. The majority of studies in this review lacked direct future costs and indirect costs to patients, which needs to be taken into the total cost equation.

## **DISCUSSION**

In the past 18 years, there have only been 29 sports-medicine economic studies within the United States. Over the course of this review, there has been a trend of increased studies published per year. Economic studies in sports medicine have mostly focused on RCR and ACLR. This was also the case for CEA in sports medicine in a review from 2014.<sup>2</sup> There is a large need for economic studies that evaluate other areas within sports medicine. Although the studies presented here provide valuable information, variation in source data and type of cost data limits the generalizability of their conclusions.

In many of the included studies, reimbursement or charges were used in lieu of cost data. However, charges can be as much as twice or triple the amount of the actual cost.<sup>14</sup> The use of reimbursement is also limited as the contribution margin (revenue-direct cost) is highly variable. Furthermore, there are significant indirect and societal costs that should be accounted for, including lost wages and productivity, family burden costs, and other non-medical costs that are deficient in these studies.<sup>5</sup> Direct costs certainly underestimate the total cost of an illness or treatment. Cost remains the

most complex component in value calculation, and the most complete model should include direct and indirect costs.<sup>5</sup>

The variety of settings in these studies also limits their generalizability to larger populations. Most studies focused on patients within a single institute or small region. There were six studies that used large and privately insured financial databases, which are more useful when comparing to an entire healthcare system. However, these databases do have their limitations such as only accounting for the insured population. Other studies in this review gathered financial data from multiple sources such as implant companies and surgical centers without using any patient information, whereas one study prospectively questioned patients about their diagnostic workups and reviewed their medical records to fully capture all financial information.<sup>19,25,27</sup> Other studies were economic models rather than observational studies.<sup>19,22,32</sup> Regardless of the design, it should be noted that findings from all economic studies are difficult to generalize across different populations. For this reason, the amount and diversity of economic literature within sports medicine needs to continue to increase.

Despite the variability and limitations discussed above, there are some preliminary conclusions that providers and policy makers can draw to help reduce their expenditure. Two studies, although from the same institution, reported significant inter-surgeon differences in supply costs.<sup>8,18</sup> It is unclear whether this is a widespread practice; however, our institutional experience suggests that this variability may be common. Furthermore, similar trends have been reported in other fields.<sup>33-37</sup> Some of this variability can be mitigated by surgeons choosing less expensive surgical equipment if they feel it will not negatively impact patient outcomes. However, most of the cost information presented here should be used to further evaluate the cost-effectiveness of their various interventions. Even though Bisson et al<sup>19</sup> found single-row RCR to be less costly than double-row RCRs, a CEA will help determine if the decreased revision rates associated with double-row repairs justifies the increased cost, as other reports have done with mixed results.<sup>38</sup>

## **CONCLUSION**

More economic studies that focus on all possible cost information are needed to further understand the economic impact of sports medicine. Future studies should explore different treatments and diagnostic options and should try to reproduce previous findings with different populations. Calculation of indirect and societal costs of nonoperative treatment for sports-medicine conditions would also be a useful direction for future research.

In a healthcare economy with limited resources, it is important to provide the greatest health benefit at

the lowest possible cost. With a trend toward more economic studies over the last several years, sports medicine is moving toward that goal. The biggest limitation to CEA remains obtaining accurate cost data, which allows for greater generalizability across different populations. These existing studies provide a foundation for future researchers to utilize their results alongside patient outcome measures to conduct CEA.

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# Can the Contralateral Knee Effectively Estimate Pre-Injury Patellar Height? A Control Study

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## ABSTRACT

**Introduction:** Patellar height abnormalities have been associated with patellar instability, which is common among adolescents and young adults. Pre-injury patellar height is often unknown in patients with a patellar instability episode. The purpose of this study was to determine whether patellar height of one knee could effectively estimate patellar height of the contralateral knee in control patients between the ages of 13 and 25 years.

**Methods:** A retrospective chart review was conducted to identify 40 patients who obtained bilateral knee radiographs with no prior surgical intervention or diagnosis of injury to the extensor mechanism. Caton-Deschamps Index (CDI) was measured by three different examiners on two separate occasions. Inter- and intra-observer intraclass correlation coefficients (ICCs) were calculated, and mean side-to-side difference was calculated between left and right CDI measurements. Additionally, left and right means were compared, and 95% confidence intervals were calculated.

**Results:** Intra-observer reliability of ICCs were good to excellent among all examiners (0.92, 0.91, and 0.86), and inter-observer reliability was good at 0.85. Mean CDI side-to-side difference was 0.02 (95% confidence interval 0.05, -0.01). Average CDI ratios were left knee CDI of 1.10 and right knee CDI of 1.12.

**Conclusions:** Good to excellent inter- and intra-observer reliability was demonstrated. There was no difference found between left and right knee CDI measurements. These results confirm that patellar height measurements in one knee can reliably estimate the patellar height in the other knee in patients between the ages of 13 and 25

**Keywords:** Patellofemoral Joint, Patellar Ligament, Patellar Dislocation, Joint Instability, Adolescent

## INTRODUCTION

Patellar height is a measurement of the location of the patella in relation to the knee joint line, and increased patellar height (ie, patella alta) has been associated with

patellar instability.<sup>1</sup> Patellar instability is a topic that has received considerable attention in sports-medicine studies in the last few years, as the popularity of medial patellofemoral ligament reconstruction (MPFL) has increased. Patellar instability is most common in the 10- to 17-year-old population, and the incidence of patellar instability within this group is estimated to fall between 29 to 31 cases per 100,000 people, with 30 to 60% of these patients sustaining recurrent dislocations.<sup>2-5</sup> Recent studies have shown a decrease in patellar height after isolated MPFL reconstruction without any associated tibial tubercle distalization procedures.<sup>2</sup>

There are various methods for measuring patellar height. The most commonly used methods are the Insall-Salvati ratio, the modified Insall-Salvati ratio, the Caton-Deschamps index (CDI), and the Blackburne-Peel ratio.<sup>6</sup> The CDI method is highly reproducible, validated in the pediatric population, reliable in patients 9 years and older, and reflective of postsurgical changes of tibial tubercle distalization procedures.<sup>7</sup> Thus the authors prefer the CDI method for assessing patellar height.

Patellar ossification begins between 6 to 8 years of age and completed by 16 to 17 years of age, making assessment of patellar height particularly difficult in young children. Previous studies have shown that the normative CDI range for patients who are 12 years and older is unchanged from adult range, with normal values between 1.3 and 0.6.<sup>8</sup>

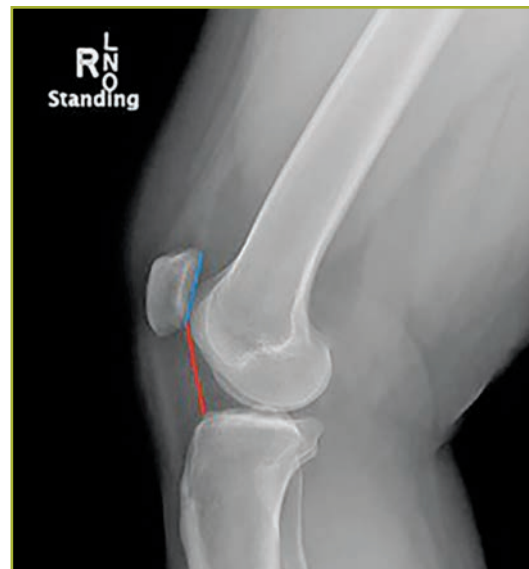
The pre-injury patellar height in children who sustain episodes of patellar instability remains unknown, because it is unlikely for these children to have pre-injury radiographs of the injured knee. The contralateral knee may serve as a surrogate marker for pre-injury patellar height. Previous work by Berg et al<sup>6</sup> showed inconsistency among side-to-side patellar height comparisons in adult patients; however, the majority of these patients had osteoarthritic changes that may have affected the accuracy of measurements. The purpose of our study was to 1) examine the reliability of patellar height measurements in adolescent patients without

significant osteoarthritic changes, and 2) assess for differences in side-to-side patellar height among these patients. We hypothesized that the contralateral knee can be used to accurately estimate the patellar height for the knee of interest in adolescent patients, providing a surrogate marker of pre-injury patellar height in patients with patellar instability. Additionally, we hypothesized that patellar height measurements using CDI can accurately and reproducibly be obtained by medical trainees of varying experience.

## METHODS

We received approval from our Human Research Review Committee (HRRRC #18-159). Forty patients' radiology records were obtained at our institution's pediatric and adult orthopaedic clinic over the course of 2 years. We reviewed patients presenting with bilateral knee pain and no history of trauma. A priori power analysis was conducted to determine a sample size of 40 patients based on a 95% confidence interval for the difference in patellar height of two side-to-side uninjured knees. Radiographs and patient charts were reviewed. Patients were included in the study if they were between the ages of 13 to 25 at the time of radiographic assessment, with bilateral knee sports series radiographs (weight bearing anteroposterior, lateral, sunrise, and notch view) available. The age of 13 years was chosen as the lower limit of our study population based on previous research that found reliable measurements of CDI with similar mean values to adults at the age of 12 years or greater.<sup>1</sup> The age of 25 years was chosen as the upper age limit to mirror the population most at risk for patellar dislocation and to minimize exposure to radiographic evidence of osteoarthritis.<sup>4</sup> Our standard sports series radiographs include a weight-bearing lateral x-ray with the knee in 30° of flexion, and these lateral radiographs were used for measurement of CDI. The CDI was chosen over other patellar height measurements because its validation in pediatric patients, good to excellent inter- and intra-observer reliability, and ability to reflect post-surgical changes of distalization procedures, which are all commonly performed in patients with patellar instability.<sup>1,6,9</sup> Exclusion criteria for our study included patients with radiographic evidence of osteoarthritic changes (Kellgren-Lawrence grade > 0)<sup>10</sup>; history of patellar dislocation; previous surgical intervention to either knee; acute or chronic injury to the extensor mechanism, including quadriceps or patellar tendon rupture, patella fracture, Osgood-Schlatter Disease, or Sinding-Larsen-Johansson Syndrome; acute injury with resulting knee joint effusion; or any evidence of ligamentous instability on clinical examination by an independent pediatric surgeon or sports-medicine, fellowship-trained orthopaedic surgeon.

All radiographs were measured by three examiners who were not involved in the care of the patients. The three examiners were a medical student, orthopaedic surgery resident, and an orthopaedic surgery, sports-medicine fellow. Measurements of the CDI were



**Figure 1.** Lateral knee weight bearing radiograph at approximately 30° flexion showing Caton Deschamps Index (CDI) measurements with red line A representing distance from inferior articular surface of patella to the anterior aspect of the tibial plateau, and blue line B representing distance from superior to inferior articular surface of patella. CDI ratio = A/B.

conducted, as described by Caton et al,<sup>11</sup> as the distance from the inferior aspect of the articular surface of the patella to the most proximal anterior portion of the tibia, divided by the distance from the superior to the inferior aspect of the articular surface of the patella (Figure 1). All measurements were obtained using Philips Intellispace PACS (Philips Healthcare, Cambridge, Massachusetts). Right and left knees were measured independently by all 3 examiners, and each knee was measured on two separate occasions by each examiner. To avoid biasing measurements, there was at least one week between measurements.

All measurements of the de-identified data for each examiner were assessed for intra-observer reliability using an intraclass correlation coefficient (ICC). Additionally, the average of the two measurements for each knee was used to calculate inter-observer reliability using ICCs. The measurements were rated in accordance with previously defined standards as poor (ICC < 0.5), moderate (ICC 0.5-0.75), good (ICC 0.75-0.90), and excellent (ICC > 0.90).<sup>12</sup> All measurements for each knee were averaged, and the side-to-side CDI difference was obtained for each patient. For the entire cohort, mean difference in side-to-side knee CDIs was calculated with a 95% confidence interval. All statistical analysis was conducted with Microsoft Excel (Microsoft Corporation, Redmond, Washington).

## RESULTS

Of the 40 patients enrolled in the study, there were 27 young women and 13 young men, some of whom were adolescent. The mean age of the enrolled patients was 17.7 years old, with ages ranging from 13 to 25 years.

Patellar height measurements varied between 0.83 and 1.37, with a mean CDI of 1.11 (95% CI 1.08 - 1.14).

Reliability of the CDI measurement within our patient population was tested with intra-observer and inter-observer ICCs. Intra-observer reliability, as calculated with ICCs, was good to excellent for all examiners. The sports-medicine fellow had an ICC of 0.92, the resident had an ICC of 0.91, and the medical student had an ICC of 0.86. Inter-observer reliability was also good with ICC of 0.85.

Side-to-side patellar height comparison was evaluated using mean difference of CDI between left and right knees for each patient. The mean side-to-side CDI difference for all patients was 0.02, with a 95% confidence interval (0.05, -0.01). The mean CDI of the left knee and right knees were 1.10 and 1.12, respectively. Each patient's mean side-to-side CDI difference was examined, and 22 of the 40 patients showed an absolute mean side-to-side CDI difference of less than 0.05. A total of 90% of the patients showed an absolute mean side-to-side CDI difference of less than 0.15. A histogram showing the distribution of mean side-to-side CDI difference was created, which shows a normal distribution centered at 0 (Figure 2).

## DISCUSSION

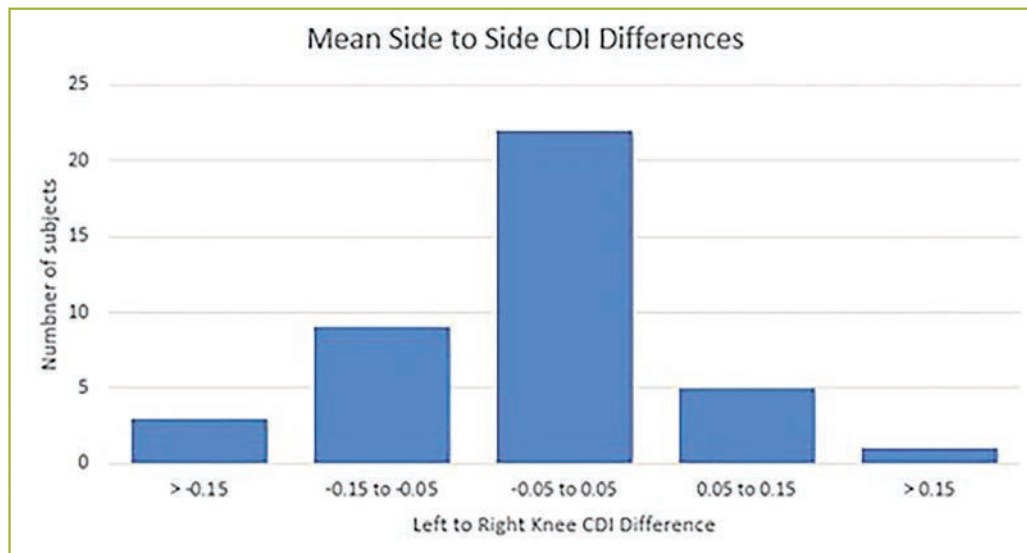
Our results show that patellar height can accurately be measured in children and adolescents without radiographic signs of osteoarthritis, and there is very little variation in patellar height measurements between sides. This proves that one knee can reliably estimate the patellar height of the other knee.

Patellar height, or patella alta, has been associated with recurrent patellar instability. Appropriate treatment of patients with recurrent patellar instability requires a detailed assessment of the patient's anatomic and predisposing risk factors, including patellar height, tibial tubercle to trochlear groove distance, limb alignment, patellar tilt, and trochlear dysplasia.<sup>9,13,14</sup> Previous studies

have shown that an isolated MPFL reconstruction will decrease patellar height. However, it is not known whether MPFL reconstruction restores the patellar height to normal, or if it risks overconstraining the patellofemoral joint. Additionally, whether the patellar height is affected by an acute MPFL tear remains unknown at this point. We plan to conduct future research to see if patients with a first-time dislocation have an increased patellar height in comparison to their uninjured knees.

Our overall mean CDI value of 1.11 is similar to those seen in the adolescent population, with one previous study showing an average CDI of 1.07 for patients between the ages of 12 to 15 years.<sup>1</sup> Our average was slightly higher than the 0.97 presented by Berg et al<sup>6</sup>. This may be due to differences in patient population, given that our patient population was younger and lacked arthritic changes, specifically proximal patellar pole osteophytes. Additionally, the majority of our patients were diagnosed with bilateral patellofemoral pain syndrome, and thus may have a slightly higher CDI than the general population. Although this is a potential limitation of our study, it is likely a closer representation of the at-risk patient population for recurrent patellar instability.

In their study, Berg et al<sup>6</sup> found a side-to-side mean CDI difference of 0.16, which is far greater than our side-to-side difference of 0.02. Berg et al<sup>6</sup> included adult patients, and it is possible that patellar and tibial osteophytes affected the accuracy of the measurements. This suggests that the contralateral knee may not serve as an appropriate control in adult patients with arthritic changes, but in adolescent and young adult patients without arthritic changes, the contralateral knee provides an effective and accurate estimate of the patellar height of the other knee.



**Figure 2.** Histogram of mean side-to-side differences in patellar height with normal distribution centered at 0.

These findings are important for future work that examines the effect of knee injuries on patellar height. Additionally, this work proves that the contralateral knee can be used for estimation of pre-injury patellar height in the injured knee. This research will allow future investigations to determine whether patellar dislocation increases patellar height. Previous research has shown MPFL reconstruction decreases patellar height, but it is unknown if this is reestablishing the anatomic patellar height, or overconstraining the patellofemoral joint. Future work building on this study will aim to quantify the presence or absence of change in patellar height associated with first time lateral patellar dislocation.

This study has several limitations, including the inability to extrapolate these results to patients outside of our 13- to 25-year-old age group and those with radiographic signs of arthritis. Our patient population primarily had diagnoses of patellofemoral pain syndrome and may not truly represent the anatomic structure of the uninjured general population. However, given that our study population was primarily pediatric patients and young adults, we felt that this group closely resembled patellar instability patients and also avoided patients with additional radiation exposure. Additionally, a large proportion of our patients were skeletally immature, and considering their remaining growth potential, it is possible that this may result in future changes to their patellar height with continued growth. This was taken into account in study design, and only patients 13 years of age or greater were enrolled, as previous studies have shown no change in CDI ratios between skeletally mature patients and skeletally immature patients 12 years of age or greater.<sup>1</sup> This age group is also at the greatest risk of patellar instability. For this reason, skeletally immature patients aged 13 and greater were included for generalizability of future work. Finally, there was inherent variability in the quality of the lateral weight-bearing 30° flexion radiographs obtained, and this may have affected the accuracy of our measurements.

This study shows no side-to-side differences in patellar height between knees in adolescent and young adult patients. The study supports the use of the contralateral knee as a control for estimating patellar height in this patient population. Additionally, our results show that the CDI can accurately and precisely be calculated by trainees of all levels.

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# The Vulcan Sign: A Radiographic and Clinical Indicator of Plantar Plate and Collateral Ligament Injury

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## ABSTRACT

**Introduction:** There is no consensus on terminology used to describe the radiographic and clinical findings commonly encountered in second metatarsophalangeal (MTP) instability. We propose the use of a consensus term, the Vulcan sign, to describe the deformity commonly seen in second MTP instability and verify its utility as an adjunct in the diagnosis and treatment of plantar plate and collateral ligament pathology.

**Methods:** We retrospectively evaluated preoperative anteroposterior weight-bearing x-rays of 156 feet of patients who underwent operative intervention for second MTP instability and the presence of a Vulcan sign at the second webspace, defined as more than 50% medial deviation of the second proximal phalanx base past the congruent joint midline with the third proximal phalanx base neutral or laterally deviated at the MTP joint. Patients were further evaluated for concurrent procedures, physical examination findings, advanced imaging, and radiographic recurrence.

**Results:** Thirty feet had a positive Vulcan sign (19.2%). Ten feet with a Vulcan sign had collateral ligament repair, plantar plate repair, or both, while only two out of 124 feet without a Vulcan sign had a plantar plate repair or collateral ligament repair (1.6%),  $P < 0.0001$ . The presence of a Vulcan sign increased the probability of a plantar plate or collateral ligament repair in the operating room by about 35% (+LR 6). The negative predictive value of the Vulcan sign is 98.4%. Radiographic recurrence was lower in the Vulcan sign group that had plantar plate and/or collateral ligament repair.

**Conclusion:** The Vulcan sign is a simple and intuitive radiographic and clinical finding that identifies those patients most likely to have plantar plate pathology.

**Keywords:** Crossover Toe, Hammertoe, Metatarsophalangeal Joint, Plantar Plate, Collateral Ligament, Instability

## INTRODUCTION

The term “crossover toe” was developed in 1987 by Coughlin<sup>1</sup> to describe the deformity that results from instability at the second metatarsophalangeal (MTP) joint. The plantar plate is the primary stabilizer of the lesser MTP joints, secondarily aided by the collateral ligaments; whereby their incompetence leads to the sagittal and coronal plane deformity seen in a crossover toe.<sup>2-5</sup> The etiology, diagnosis, and treatment of lesser MTP instability has been a common topic of discussion in foot and ankle literature. Several classification systems have been developed to aid in the diagnosis and treatment of second MTP instability.<sup>4,6-9</sup> Discussions regarding treatment have shifted from indirect stabilization of the joint<sup>1,3,4,7,10-13</sup> to direct repair of the plantar plate and collateral ligaments.<sup>6,12,13-18</sup> Advanced imaging, such as magnetic resonance imaging (MRI), ultrasound, arthroscopy, and arthrography, are higher-level diagnostic tools available in addition to traditional radiographs.<sup>8,19-25</sup>

There is no consensus on the terminology used to describe the radiographic and clinical deformity seen in the progression toward a true crossover toe. Commonly applied terms are toe “splay,” “drift,” “spread,” “medial,” “lateral deviation,” “subluxation,” and “pre-dislocation.” It can be difficult to apply detailed clinical and radiographic classifications designed to direct appropriate treatment in a timely fashion. High healthcare costs and poor reimbursements discourage providers from pursuing advanced imaging. We propose the use of a consensus term, the “Vulcan sign,” to describe the radiographic and clinical findings commonly seen with second MTP instability. We aim to verify its utility as an adjunct in the diagnosis and treatment of plantar plate and collateral ligament pathology. We chose to use the term Vulcan sign because the forefoot deformity discussed in this paper closely resembles the Vulcan salute popularized by Spock on the 1960s television series *Star Trek*.





**Figure 1A.** Clinical weight bearing photo of a typical Vulcan sign appearance



**Figure 1B.** Weight bearing anteroposterior radiograph of the foot demonstrating a Vulcan sign, with more than 50% of the base of the proximal phalanx medially deviated past the vertical line depicting the congruent joint midline

## MATERIALS AND METHODS

We received Institutional Review Board approval (#17093002). Our institution's foot and ankle registry was searched using relevant Current Procedural Terminology (CPT) codes for all patients who underwent operative intervention for second MTP instability between January 2015 and January 2018. The following CPT codes were included: 28308 (osteotomy with or without lengthening, shortening or angular correction, metatarsal), 28313 (reconstruction, angular deformity of toe, soft-tissue procedures only), 28270 (capsulotomy, metatarsophalangeal joint with or without tenorrhaphy, each joint), and 28285 (correction hammertoe). All surgeries were performed by any one of four foot and ankle fellowship-trained orthopaedic surgeons at our institution. We retrospectively evaluated preoperative weight bearing anteroposterior (AP) radiographs for the presence of a Vulcan sign.

A typical Vulcan sign is defined as greater than 50% medial deviation of the second proximal phalanx base past the congruent MTP joint midline, with the third proximal phalanx base at neutral or laterally deviated from the congruent MTP joint midline (Figures 1A and B). An atypical Vulcan sign is located at either the first or third web space with the same parameters as described above.

A power analysis to estimate sample size was performed, based on data from the published study by Klein et al,<sup>23</sup> "The underlying osseous deformity in plantar plate tears: a radiographic analysis" (N = 97). With an alpha of .05 and power of 0.80, the projected sample size needed is approximately 99.

Inclusion criteria included a primary surgical procedure for at least one of the CPT codes listed above and adequate weight-bearing preoperative AP radiographs. The primary outcome measure was the presence or absence of a Vulcan sign on radiographs, and its relationship to plantar plate and collateral ligament repair done intraoperatively.

Secondary outcome measures were examined for patients with a positive Vulcan sign, including any preoperative advanced imaging and physical examination findings such as tenderness, drawer sign, descriptive toe position terminology, postoperative recurrence of a Vulcan sign at latest follow-up radiograph, and associated forefoot surgeries.

We evaluated the operative report for mention of "crossover toe realignment," or whether a direct primary plantar plate and/or collateral ligament repair were performed. Statistical methodology included traditional methods and a significance value of  $P = 0.05$  using the 2-tailed Fisher's Exact Test.

## RESULTS

Our study included 155 patients (156 feet) who underwent surgical procedure for second MTP instability. A total of 30 patients (19.2%) had feet that met the definition of a Vulcan sign, including one

**Table 1.** Relationship between Vulcan Sign occurrence and operation performed

	Plantar Plate/Collateral Ligament Repair	Indirect Repair
<b>Vulcan Sign Present</b>	10	20
<b>Vulcan Sign Absent</b>	2	124

$P < 0.0001$

Of the 126 operative patients in our study who did not have a positive Vulcan sign but still had their second metatarsophalangeal instability surgically addressed, only two patients had a plantar plate repair, equating to 1.6%.

**Table 2.** Statistics related to Vulcan Sign incidence

VULCAN SIGN	
Sensitivity	83.3% (95% CI 51.6-97.9)
Specificity	86% (95% CI 79.3-91.3)
Positive Likelihood Ratio	6 (95% CI 3.72-9.69); 35% increase
Positive Predictive Value	33%
Negative Predictive Value	98.4%

CI, confidence interval

A Vulcan sign has a relatively high sensitivity and specificity with a very high negative predictive value. Also, a positive Vulcan sign increases the probability of having a plantar plate and/or collateral ligament repair in the operating by about 35%.

patient with an atypical Vulcan sign at the first web space. Of the 30 patients with a Vulcan sign, there were 10 patients who had either a collateral ligament repair or plantar plate repair, or both (33%). The 20 patients who had a Vulcan sign but did not undergo plantar plate or collateral ligament repair had any combination of the following procedures: traditional hammer toe correction with proximal interphalangeal joint resection arthroplasty, metatarsal shortening osteotomy, extensor tenotomy or lengthening, dorsal capsulotomy, and pinning across the MTP joint. None of these 20 patients had a traditionally described secondary repair of the plantar plate with flexor to extensor transfer such as the Girdlestone-Taylor procedure or extensor brevis rerouting.<sup>7</sup> There were 126 operative patients in our study who did not have a positive Vulcan sign but still had their second MTP instability surgically addressed. Of these, only 2 patients had a plantar plate repair, equating to 1.6% ( $P < 0.0001$ ) (Table 1).

The probability that a Vulcan sign will be present if a plantar plate and/or collateral ligament repair was done in the operating room (sensitivity) was 83.3% (95% confidence interval (CI) 51.6-97.9). The probability of no Vulcan sign if no plantar plate or collateral ligament repair was done in the operating room (specificity) was 86% (95% CI 79.3-91.3). The positive likelihood ratio was 6% (95% CI 3.72-9.69). A positive Vulcan sign increases the probability of having a plantar plate

**Table 3.** Associated surgical procedures in patients with positive Vulcan sign

Concurrent Forefoot Procedures	86.7%
1st MTP Fusion	9
Lesser Toe Procedures	7
None	4
Bunion/Akin (add'l lesser toes)	3
Bunion/Akin (no add'l lesser toes)	2
Lapidus	2
Keller resection arthroplasty	1
Bunionette	1
Neuroma	1

MTP, metatarsophalangeal

Of the 30 operatively treated patients with Vulcan signs, twenty-four had associated procedures (86.7%), including lapidus, first MTP fusion, bunionectomy, and lesser toe deformity correction.

and/or collateral ligament repair in the operating room by about 35%.<sup>23</sup>

The probability that a plantar plate repair and/or collateral ligament repair was performed in the operating room when a Vulcan sign was present (positive predictive value) was 33%. The probability that a plantar plate repair and/or collateral ligament repair was not performed when a Vulcan sign was not present (negative predictive value) was 98.4% (Table 2).

#### Physical Examination

Words used to describe the clinical appearance of the forefoot in preoperative physical examination included (in order of frequency) crossover toe, varus, splay, hammer toe, dislocated toe, and external progression. The examining provider documented presence of tenderness to palpation under the second MTP joint eighteen of thirty times. Negative drawer sign was never mentioned. Positive drawer was mentioned in 3 of 30 patients. Of these 3 patients, there were 2 patients who had collateral ligament repair and 1 patient had a plantar plate repair.

#### Advanced Imaging

Of the 4 patients with a positive Vulcan sign that had an MRI, there were 3 patients who had a plantar plate repair and 1 patient who had a radiologist interpret a plantar plate tear. One MRI was of extremely poor quality. All MRIs were done prior to evaluation at our tertiary referral center. No patients had ultrasound, arthrogram, or other advanced imaging.

#### Associated Forefoot Procedures

Of the 30 operatively treated patients with Vulcan signs, there were 24 patients who had associated procedures (86.7%), including lapidus, first MTP fusion, bunionectomy, and lesser toe deformity correction (Table 3). The remaining 4 patients who did not have an associated forefoot procedure performed underwent collateral ligament and/or plantar plate repair.

**Table 4.** Recurrence in relation to surgery performed

	Plantar Plate/ Collateral Ligament Repair	Indirect Repair
Vulcan Sign Recurred	1	8
Vulcan Sign Did Not Recur	8	7
		$P < 0.08$

One of the nine patients available for follow-up that had a collateral ligament and/or plantar plate repair recurred ( $P=0.08$ ), which means eight feet did not recur in either the sagittal or transverse plane (88.9%).

### Recurrence

Radiographic, clinical, and patient reported outcomes were not the primary objective for this study. We did evaluate the radiographic recurrence of a Vulcan sign. Six of the 30 patients with a positive Vulcan sign were excluded for evaluation of recurrence due to lack of appropriate follow-up radiographs, leaving 24 patients left for evaluation. Mean time for follow-up radiographs was not recorded.

Nine patients who underwent surgical procedure for positive Vulcan signs had radiographic recurrence (37.5%). Eight of these patients did not have the collateral ligament nor the plantar plate repaired; however, they did have an indirect deformity correction as previously stated. Two patients had recurrence in the sagittal plane only, and it was noted that they had severe crossover toe deformity before undergoing operation. Seven patients had recurrence in a traverse plane with or without a contribution in the sagittal plane. Eight indirect repairs recurred (53.3%). One of the nine patients available for follow-up had a collateral ligament and/or plantar plate repair recur ( $P = 0.08$ ). Eight did not recur in either the sagittal or transverse plane (88.9%) (Table 4). This patient had recurrence after a traumatic fall with fracture of the base of the proximal phalanx.

## DISCUSSION

The Vulcan sign is a quick and reliable radiographic tool to guide providers toward the correct diagnosis and subsequent treatment of second MTP joint instability resulting from plantar plate or collateral ligament injury. The presence of a Vulcan sign increases the likelihood of a plantar plate and/or collateral ligament repair intraoperatively by 35%. The negative predictive value of the Vulcan sign is 98.4%. Patients without a Vulcan sign were unlikely to have a collateral ligament and/or plantar plate repair.

In their retrospective review of 97 feet with plantar plate tears confirmed intraoperatively, Klein et al<sup>23</sup> found that the angle of digital splay was significantly greater on radiographs of those patients with plantar plate tears (mean, 8.8°) than those patients without (mean, 1.8°). With an angle of digital splay threshold of 5° or greater, they had a 77.8% specificity for a plantar

plate tear and a positive predictive value of 94.2%. With an odds ratio of five, they found that patients with second and third toe digital splay had a 5 to 6 times greater chance of have a plantar plate tear confirmed in the operating room. Kaz and Coughlin<sup>8</sup> noted that the most reliable radiographic indicator of second MTP joint instability is the angle of second MTP joint in relation to both the hallux and the adjacent third MTP joint angle. Klein et al<sup>22</sup> noted that second and third digital splay on AP radiograph was a potentially important radiographic predictor of a high-grade tear.

Angular measurements are difficult to apply in an everyday clinical setting. With its simple radiographic definition, the Vulcan sign can be efficiently applied in a busy clinical setting and includes the previously defined angular parameters. A positive Vulcan sign is designed to include deformity that is subtle or severe, and single or double planed.

Several classifications exist in relation to second MTP joint instability, crossover toe deformity, and plantar plate repair. An early classification by Yu<sup>9</sup> defined second MTP instability as pre-dislocation syndrome. Haddad et al<sup>7</sup> described stages 1 to 4 of deformity for a crossover second toe based on clinical findings. Coughlin's cadaver study from 2012<sup>4</sup> described intraoperative findings, graded 0 to 4. Coughlin et al<sup>6</sup> in 2011 described a clinical staging system considering alignment and physical examination. In 2014, Nery et al<sup>17</sup> noted a high correlation between clinical findings and anatomic types of tears and created a combination classification system, graded 0 to 4, which includes clinical alignment of the toe, physical examination, and surgical anatomy.

Our physical examination documentation is quite variable. Words such as splay, spread, and deviation can be replaced by our proposed descriptor, the Vulcan sign. In the 3 patients with a positive drawer, all had plantar plate and/or collateral ligament repair. This further emphasizes the importance of documenting this sensitive examination finding. Unfortunately, the documentation of a drawer sign (positive or negative) in the patients of this study was not consistent; however, it really needs to be. The Vulcan sign can lead surgeons toward thinking about plantar plate pathology. Additionally, surgeons can use the above classification systems to further narrow down their diagnosis and treatment plan.

A recently published review by Hsu et al<sup>26</sup> discusses that MRI sensitivity for diagnosis of plantar plate injuries is low, and further states that MRI is not indicated in most cases. They emphasized that radiographs and clinical examination are sufficient. This was confirmed in our study as 4 patients had an MRI and only one radiologist interpreted a plantar plate tear. Three of the 4 patients had obvious plantar plate tears on their MRI.

The most common radiographic finding is a pattern of "varus/medial/tibial angular deviation of the proximal phalanx of the second toe" and that "widening of the

space between the second and third toes that may be described as splaying.” The term Vulcan sign may be utilized to clean up common word jargon encountered in the literature.

Patients with a positive Vulcan sign had a clear trend toward radiographic recurrence in those who did not have a direct plantar plate and/or collateral ligament repair ( $P = 0.08$ ). This highlights the importance of a positive Vulcan sign in triggering a surgeon to closely consider the potential need for plantar plate and/or collateral ligament repair.

Gregg et al<sup>16</sup> noted clinical recurrence in 3 of 17 feet. Flint et al<sup>14</sup> noted 6 of 138 plantar plate repairs had recurrence of a positive drawer sign at follow-up (all 138 had positive drawer tests preoperatively). Our study compares to both of these studies with the lowest recurrence rate in those patients that had a direct plantar plate repair. To date, no study compares radiographic recurrence between plantar plate and/or collateral ligament repair and an indirect repair for second MTP instability. Indirect techniques may not provide as good of results in patients with a positive Vulcan sign, considering our high recurrence rate in this population (53.3%).

Limitations to this study include its retrospective nature and limited scope. We had a low number of patients that had a Vulcan sign, even though we had 156 feet included in the study. This ultimately limited the power. We did not include nonoperatively treated patients that had a diagnosis of second MTP instability.

We found the Vulcan sign to be a reliable, efficient, and useful tool for identifying patients at highest risk for collateral ligament and plantar plate pathology as it relates to second MTP joint instability.

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# The Importance of the Screening Anteroposterior Pelvis Radiograph in Trauma Patients: A Level-1 Trauma Center's Experience with Traumatic Hip Dislocations

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## ABSTRACT

**Background:** Advanced Trauma Life Support guidelines strongly recommend obtaining anteroposterior (AP) pelvis radiographs when evaluating patients with traumatic injuries. Recently, there has been a trend at our institution to forego AP pelvis radiographs, and to obtain computed tomography (CT) scans as the initial imaging modality of the pelvis instead. Lifesaving interventions, such as the application of a pelvic binder, can be delayed due to the time it takes to complete a primary survey and a CT scan. This study aims to evaluate the effects of bypassing an AP pelvis radiograph on the management of acute traumatic dislocations of the hip.

**Methods:** We performed a retrospective review at a single level-1 trauma center over a 2-year period. Current procedural terminology codes were used to identify patients with traumatic hip dislocations and fracture dislocations that required reduction. We then identified whether an AP pelvis radiograph or pelvis CT was performed. Timing of reduction, need for repeat pelvis CT, radiation exposure, and cost of CT imaging were recorded.

**Results:** There were 52 patients identified with traumatic dislocation or fracture dislocation of the hip. Of those, there were 18 patients who had a CT performed with a dislocated hip (34%), and 9 patients who had a CT identifying the hip dislocation without a prior AP pelvis performed for evaluation. Time to reduction for the 18 patients who had a CT performed was greater than for the 34 patients who had reduction following AP pelvis (200 minutes vs 116 minutes,  $P = 0.01$ ). The 14 patients that required a repeat CT after reduction had greater amounts of radiation exposure compared to the 29 patients that did not require a repeat CT (2,233mGy-cm vs 1,142mGy-cm,  $P = 0.004$ ).

**Conclusion:** The AP pelvis radiograph remains valuable for the early identification of hip dislocations, which allows for a faster time to reduction. Ignoring

or failing to obtain the AP pelvis radiograph leads to unnecessary delay in reduction and increased radiation exposure.

**Keywords:** Anteroposterior, Radiograph, Trauma Centers, Pelvis, Hip Dislocation

## INTRODUCTION

Patients are initially evaluated and managed in the trauma bay using Advanced Trauma Life Support (ATLS) protocol. When the mechanism of injury or physical examination is concerning for a pelvic injury, ATLS guidelines dictate that an anteroposterior (AP) pelvis radiograph be obtained as part of the secondary survey.<sup>1,2</sup> AP radiographs have been historically used to group pelvic fractures into four classifications (ie, anteroposterior compression, lateral compression, vertical shear, and a complex pattern), which can help guide trauma and orthopaedic surgeons toward considering associated injuries.<sup>3</sup>

At our institution, we noted a trend for the AP radiograph to be eschewed in favor of the computed tomography (CT) scan as the initial diagnostic study for pelvic injuries. Proponents of this line of thinking argue that the purpose of an early pelvic radiograph is to identify hemodynamically consequential fractures. A retrospective review of stable blunt trauma patients compared AP radiographs and CT angiographies of the abdomen and pelvis, and it found no changes in the therapeutic policy after the pelvic x-ray.<sup>4</sup> However, the review noted that 15% of patients with CT angiographies needed embolization. This is echoed by other authors who favor omitting the AP pelvis radiograph and obtaining the pelvic CT, given its higher sensitivity in detecting fractures.<sup>5,6</sup>

Physical examinations can help physicians identify injuries, with 90% sensitivity in identifying fractures in awake and alert patients,<sup>7</sup> and 98% sensitivity in detecting posterior pelvic ring injuries.<sup>8,9</sup> Soto et al<sup>10</sup> argue that AP pelvis radiographs add little value

to patient management if physical examination does not reveal pelvic instability or hip dislocation. Recommendations are being made for ATLS guidelines to be revised to reflect this perceived diminishing importance of the AP pelvis radiograph.<sup>10</sup> Dissidents argue that CT scans can be used to reconstruct the AP pelvis view,<sup>11,12</sup> with quality comparable to conventional x-rays versus virtual images, respectively.<sup>13</sup> Those who argue for the diminishing use of the AP pelvic radiograph do not make note of hip dislocations.<sup>9</sup> The gold standard of initial diagnostic examination is still AP pelvic radiograph, even in unstable patients.<sup>14</sup>

We initially had anecdotal experiences with the trauma team not using ATLS protocol, and patients being consulted upon with a CT scan of a dislocated hip. The orthopaedic department had concerns with delay of reduction and increased radiation, given that patients were receiving a post-reduction CT scan to evaluate for loose bodies in the joint and fractures.

The purpose of this study was to provide objective data to be used for interdepartmental education to decrease the amount of repeat CT scans, radiation exposure, and time to reduction for traumatic hip dislocations. We hypothesized that the use of CT scans as the initial diagnostic study leads to a delay in the diagnosis and treatment of hip dislocations, thus leading to an increased amount of radiation exposure.

## MATERIALS AND METHODS

After obtaining approval from our Human Subjects Protection Program (HSPP #1802319109), we performed a retrospective review of patients presenting to our level-1 trauma center over a 2-year period. Current Procedural Terminology (CPT) codes were used to identify traumatic hip dislocations or fracture dislocations that required reduction. The following CPT codes identify acetabular fractures and hip dislocations: 27220, 27226, 27227, 27228, 27250, 27252, 27253, 27254, 27256.

Using the CPT codes, we identified patients who suffered a traumatic hip dislocation that needed reduction. We then identified whether an AP pelvis radiograph or a pelvis CT was used to diagnose the traumatic dislocation. Time to reduction (minutes), need for repeat pelvis CT, radiation exposure (milligray), cost of CT imaging (dollars), and need for emergent operations for non-bony injuries (yes/no) were all recorded. At our institution, all traumatic hip reductions are followed by a post-reduction CT scan to evaluate for fracture versus loose bodies.

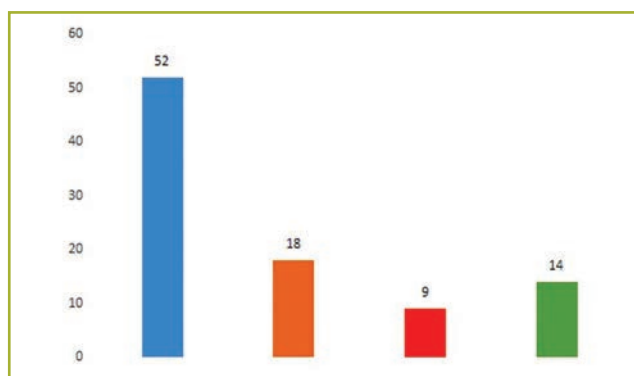
A 2-tailed *t* test was used to compare time to reduction averages, and to determine if there was an increased time to reduction (minutes) in the group that received a pelvis CT as the first radiographic test rather than an AP pelvis radiograph.

This is a single institution pilot study and quality improvement project without established data on times to reduction. This study will identify if there is a delay

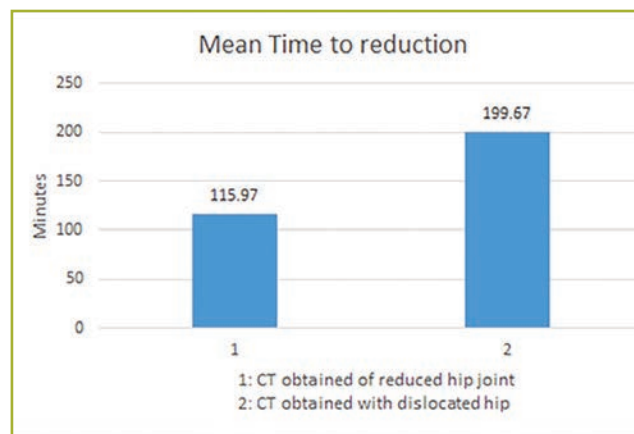
in identifying and reducing traumatic hip dislocations in this institution. If so, this study can provide a starting point towards an issue that will need to be further examined across other institutions.

## RESULTS

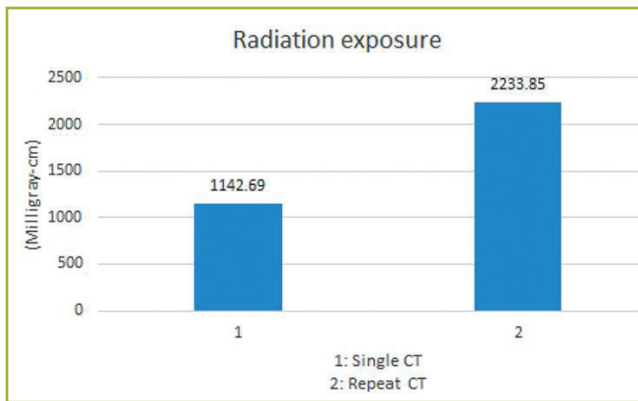
There were 52 patients identified with traumatic dislocations or fracture dislocations of the hip that required reduction. Of those, there were 18 patients who had a CT performed with a dislocated hip (34%), and 9 patients who had a CT identifying the hip dislocation without a prior AP pelvis radiograph performed for evaluation (Figure 1). Time to reduction for the 18 patients who had a CT performed was greater than for the 34 patients who had reduction after an AP pelvis radiograph (200 minutes vs 116 minutes,  $P = 0.01$ ). There were 14 patients who required a repeat CT after reduction to evaluate for retained fragments, and they had greater amounts of radiation exposure (milliGray-cm) versus the 29 patients that did not require a



**Figure 1.** *Imaging Obtained* - There were 52 patients identified with traumatic hip dislocations. Of those, eighteen patients had computed tomography (CT) of a dislocated hip, nine patients had a CT without prior anteroposterior (AP) pelvis, and fourteen patients obtained repeat AP pelvis.



**Figure 2.** *The mean time to reduction of the patients who had a computed tomography (CT) obtained of a dislocated hip was significantly greater than those who were initially reduced before a CT (200 vs 116 minutes,  $P = 0.01$ ).*



**Figure 3.** Patients who obtained a repeat computed tomography (CT) scan had a significantly greater exposure to radiation (milligray-cm) compared to those who did not require a repeat CT scan (2,233 mGy-cm vs 1,142 mGy-cm,  $P = 0.004$ ).

repeat CT (2,233 mGy-cm vs 1,142mGy-cm,  $P = 0.004$ ). Additionally, these 14 patients had a mean additional cost of \$1,126 for the repeated study (Figures 2 and 3).

There were no patients in our case series taken to the operating room emergently by the general surgical trauma service for non-bony injuries.

## DISCUSSION

Despite the enthusiasm for pelvis CT replacing the AP pelvis radiograph for patients with traumatic injuries, we argue in favor of the AP pelvis radiograph given the experience at our institution. Although the idea of a pan-CT scan has been used to evaluate severely injured patients, there are drawbacks to using it. The correlation is unclear between CT findings and the number of true and false positives and negatives. There is also the phenomenon in which the pan-CT may increase injury severity by detecting lesions that are not clinically significant, but will raise the injury severity score and lower the ratio of observed to expected deaths.<sup>15</sup>

Although cross-sectional imaging is more sensitive in detecting fractures, it is important to recognize that the CT scan gantry can underestimate the degree of pelvic ring displacement, with an average reduction of 6.6 mm,<sup>16</sup> This can potentially be the difference between operative and nonoperative management. It may also be a source of confusion in the emergency department, in which an anterior pelvic ring injury is unrecognizable as a contributing factor in a hemodynamically volatile patient. In a case like this, a pelvic binder could be helpful.

The AP pelvis radiograph quickly identifies hip dislocations, which can help trauma and orthopaedic surgeons take action earlier. The literature on emergency department management of pelvic injuries focuses predominantly on pelvic fractures and anterior pelvic ring injuries. The literature has had greater enthusiasm for discarding the AP pelvis radiograph, which has led to increased radiation and time to reduction.

Another fallacy is relying on the physical examination to recognize a clinically significant pelvic injury or dislocation to help decide whether an x-ray is warranted. Although physical examination sensitivity for fractures may be as high as 90% in one meta-analysis, they are unreliable in patients with neurologically impaired status, and poor for anterior pelvic ring injuries at 8%.<sup>17,18</sup> Again, the authors of these studies did not make note of sensitivity for identifying traumatic hip dislocations, which can be addressed expeditiously if identified appropriately. There is also scarcity of literature on physical examinations not identifying pelvic fractures, but instead on clinically significant unstable pelvic ring injuries requiring intervention.

Hip dislocations are important to identify early because they can result in long-term morbidity, post-traumatic arthritis, and can increase the risk of developing avascular necrosis of the femoral head.<sup>19</sup> In our case series of patients, physical examination has not been sufficiently sensitive enough to rule out all hip dislocations. Subsequently, repeat CT scans increased radiation to patients and accumulated costs to the healthcare system. Given that the AP pelvis radiograph can be obtained quickly during the initial stabilization of the patient and can help avoid unnecessary tests, we argue that it maintains its role as the primary pelvic imaging modality. Critically evaluating the AP pelvis radiograph is also important, as there were patients who went to the CT scanner with a known dislocated hip. Additionally, repeat CT scans can cause a delay for other patients waiting for imaging. This delay may slow the discovery of important findings pertinent to patient care and safety and how soon procedures are completed. It most certainly places a burden in the time to disposition of patients waiting to be discharged versus admitted to the hospital, and may very well have an effect on patient satisfaction with their care.

This study is limited because it only contains data from one institution, and thus cannot be universally generalizable. However, the institution is a level 1-trauma center that regularly deals with trauma patients. Our study shows how deviating from following standard ATLS protocol of an AP pelvis radiograph for blunt trauma patients can lead to missed findings. This study is only a cross sectional view at the time of initial emergency department evaluation, and does not follow these patients long term. Therefore, we do not have a comparison of the functional outcomes, rates of femoral head avascular necrosis, arthritis, or nerve deficits in patients who had the AP pelvis radiograph versus pelvic CT as first imaging. However, other studies show that the most important factors are the time between injury and reduction and the presence of other injuries.<sup>20,21</sup> Although we cannot control what injuries the patient suffered during the initial trauma, an AP pelvis radiograph can help reduce time to reduction.

In summation, we recommend utilizing the AP pelvis radiograph because it allows for the quick identification

of hip dislocations, and may identify injuries of the lumbar and sacral spine, pelvic ring, acetabular, and proximal femur. Identification of these injuries allows for early delivery of appropriate interventions, including the application of pelvic binder or timely reduction of dislocations. Failing to obtain the AP pelvis radiograph leads to unnecessary delay in reduction, increased radiation exposure, and increased cost owing to having to repeat CT scans.

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# Inter- and Intra-Observer Differences in Proximal Fifth Metatarsal Fractures

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## ABSTRACT

**Introduction:** Proximal fifth metatarsal fractures are common. When using the Lawrence and Botte Classification for these injuries, they are classified as type 1, 2, and 3. Identifying the zone of injury is crucial to guide treatment. The authors hypothesize that inter- and intra-observer reliability of these fractures is low.

**Methods:** Anteroposterior (AP), lateral, and oblique x-rays of 60 patients with isolated fifth metatarsal base fractures were reviewed. Five physicians evaluated the radiographs and classified the fractures as type 1,2, or 3. Each of the three radiographic views were examined separately. Results were then analyzed for inter- and intra-observer reliability.

**Results:** Sixty x-rays of each of the three views were reviewed by five observers, with a total of 900 observations. Observer 1 classified all three radiographs the same at a rate of 41.67% (25/60) with Fleiss' kappa (k) 0.31; for observers 2 through 5, their rate was 63.33% (38/60), 0.573 (k), 68.33% (41/60), 0.55 (k), 58.33% (35/60), 0.55 (k), and 36.67% (22/60), 0.31 (k), respectively. For the AP view, inter-observer reliability showed 56.67% (34/60) agreement with 0.64 (k). For the oblique and lateral views, rates were 45% (27/60), 0.51 (k), and 35% (21/60), 0.44 (k), respectively. Overall, inter-observer reliability was 16.67%.

**Conclusion:** There is poor inter-observer and intra-observer reliability in the current proximal 5<sup>th</sup> metatarsal classification. This study highlights the importance of using all radiographic views and clinical history for the correct treatment. Future study should be aimed at a classification with higher reliability.

**Keywords:** Metatarsal, Bone, Classification

## INTRODUCTION

The most common type of fifth metatarsal fracture is a proximal metatarsal fracture.<sup>1</sup> Petrison et al<sup>1</sup> examined 411 metatarsal fractures and most commonly found fractures of the fifth metatarsal base. Sir Robert Jones

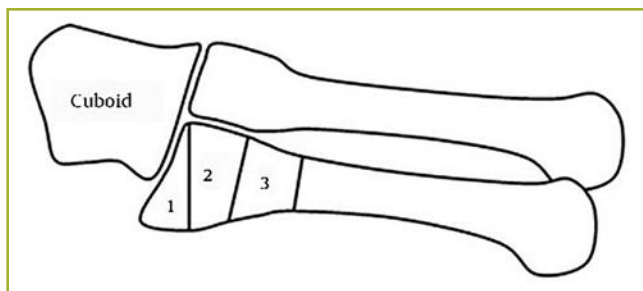
first defined fracture of the proximal fifth metatarsal in 1902. His description was a fracture, often caused by indirect force, in the metadiaphyseal region of the proximal fifth metatarsal.<sup>2</sup> The description is used variably, and the fracture is often identified as a "Jones fracture." Certain authors define it as a fracture at the metaphyseal-diaphyseal junction, while others describe it as a fracture at the proximal diaphysis.<sup>3</sup> It is suggested to use proper classification rather than the term "Jones fracture."<sup>3</sup>

Although many classification systems have been developed through the years, the most commonly used system was first described by Lawrence and Botte in 1993.<sup>4</sup> This system classifies fractures as type 1, 2, or 3 based on their location. Type 1 fractures describe an avulsion of the tuberosity, which may or may not involve the tarsometatarsal articulation. These fractures are typically caused during foot inversion by excess pulling of the peroneus brevis tendon or the lateral band of the plantar fascia. Type 2 fractures are described as fractures at the metaphysis-diaphysis junction that encompass the fourth-fifth intermetatarsal facet. These fractures are typically produced by forced forefoot adduction with hindfoot plantar flexion. Type 3 fractures describe proximal diaphyseal fractures that are distal to the fourth-fifth metatarsal base articulation. These are produced by excessive force to the region or chronic overloading (ie, stress fractures) (Figure 1).<sup>4</sup>

It is crucial to determine the location of the fracture because this helps guide treatment. Many physicians allow early weight bearing for type 1 injuries, but they recommend cast immobilization and non-weight bearing or possible early surgical intervention for type 2 and 3 fractures.

Avulsion tuberosity fractures (ie, zone 1 fractures) are typically managed conservatively with functional treatment and early weight bearing because the union rate and healing capacity are high and patients typically have good functional outcomes.<sup>3</sup> Weiner et al<sup>5</sup> showed





**Figure 1.** Lawrence and Botte Classification<sup>3</sup> of proximal fifth metatarsal fractures (zones 1, 2, and 3).

the effectiveness of nonoperative management of zone 1 fractures with either a soft dressing or a bulky Jones dressing. Sixty patients that had an avulsion of the proximal fifth metatarsal were examined for fracture healing and functional outcomes after being diagnosed and treated conservatively. With an average of 44 days, all patients achieved fracture union and good to excellent clinical outcome.

Zone 2 and zone 3 fractures are more prone to delayed union, non-union, and refracture. This is largely due to the anatomy of these areas, with a tenuous watershed area of blood flow in zones 2 and 3. Additionally, there are transitional forces along the fifth metatarsal, with strong ligaments anchoring the proximal bone, leaving the distal aspect mobile. For acute cases, conservative treatment with cast immobilization and non-weight bearing can be considered in less active individuals. In the athletic population, early surgical fixation with intramedullary screw is advised for faster time to union. Josefsson et al<sup>6</sup> showed that “Jones fractures” healed appropriately when treated conservatively. In their study, there were 40 patients who had fractures at the metadiaphyseal region or proximal diaphysis, and they were all treated with conservative management with immediate full weight bearing. At an average of 17-year follow-up, all fractures had healed. Seven fractures healed with delayed union or a refracture, and 39 fractures were symptom free. Fourteen of the injuries were reported to have occurred during sporting activity; however, the number of “athletes” in this study was not stated. Prolonged healing and increased nonunion rates have been document in zone 2 and 3 fractures.<sup>7</sup>

A patient’s lifestyle and activity level are also critical considerations. Zone 3 fractures, especially in athletes, are often stress fractures that are commonly problematic to heal and require more aggressive treatment. Dameron et al<sup>8</sup> showed that without surgical intervention, a zone 3 fracture may take up to 21 months to heal. Surgical fixation has shown to provide a more rapid recovery for zone 2 fractures.<sup>7</sup>

An accurate classification of the fracture is important to initiate appropriate treatment and to properly report outcomes regarding fifth metatarsal base fractures. The primary aim of this study was to determine the intra- and inter-observer reliability of the Lawrence and Botte

Classification, which is the classification system used most commonly for fifth metatarsal base fractures. The authors hypothesized that distinguishing the zone of injury on radiographs can be difficult, and that variation will exist between observers and different radiographic views in the same patient with a fifth metatarsal base fracture. Therefore, intra- and inter-observer reliability would be poor.

## METHODS

We obtained approval from our Human Research Review Committee (HRRC #19-119). Retrospective acquisition of anteroposterior (AP), lateral, and oblique radiographs of 60 patients with isolated fifth metatarsal base fractures were obtained through the radiology department of the authors’ institution. These were acquired through the radiology department system using keyword “proximal fifth metatarsal.” RM, who was not involved in classification to ensure no bias during identification, reviewed and identified the radiographs. A total of 60 patients were identified. Fractures that were not of the proximal fifth metatarsal, radiographs with any co-existing bony injuries, and pediatric radiographs with open physis were excluded. Five physicians evaluated the radiographs and classified the fractures as type 1, 2, or 3 per the classification by Lawrence and Botte. The physicians included two orthopaedic residents, one radiology resident, one orthopaedic attending, and one radiology attending. Prior to radiographic evaluation, each physician reviewed the classification of Lawrence and Botte (Figure 1<sup>3</sup>). Each radiographic view (ie, AP, lateral, and oblique) was examined separately. The physicians did not know which of the three radiographic views belonged to the same patient. Results were then compared to see the correlation between observers and between the three radiographic views of the same patient. For the purposes of this study, intra-observer reliability is the tendency for the evaluator to choose the same classification type on all three radiographic views of the same foot. Inter-observer reliability is the tendency for the five observers to choose the same classification type for a given radiograph or patient. Fleiss’ kappa was also calculated for both intra- and inter-observer reliability to further assess the statistical measure of reliability. Fleiss kappa value can be interpreted using the description in Table 5.

## RESULTS

There were 60 patients in total, each with three radiographic views of the foot. Five observers independently reviewed these radiographs for a total of 900 total observations.

There were 22 male and 28 female patients whose radiographs were reviewed, and a total of 29 left feet and 31 right feet. The average age was 42.3 years (range: 18 - 77 years). Intra- and inter-reliability were the primary outcome measures assessed. The demographics of the study are similar to those reported

in the literature. Petrisor et al<sup>1</sup> studied the epidemiology of fifth metatarsal fracture and observed over 400 fractures. The average patient age was 42 years with a majority of patients female, which was in line with this current study.

With regard to intra-observer reliability, each observer chose the same classification (type 1, 2, or 3) for all 3 radiographs. Observer one had a rate of 41.67% (25/60) with a Fleiss' kappa of 0.31, fair agreement; observer 2 had a rate of 63.33% (38/60) with a kappa

of 0.573, moderate agreement; observer 3 had a rate of 68.33% (35/60) with a kappa of 0.55, moderate agreement; observer 4 had a rate of 58.33% (22/60) with a kappa of 0.55, moderate agreement; and observer 5 had a 36.67% (22/60) with a kappa of 0.31, fair agreement (Tables 1 and 4).

There were also significant differences in regards to inter-observer reliability for each radiographic view. There was 56.67% (34/60) agreement with kappa of 0.64 on AP view, substantial agreement; 45% (27/60) agreement with kappa of 0.51 on oblique view, moderate agreement; and 35% (21/60) with kappa of 0.44 on lateral view, moderate agreement (Tables 2 and 3). Overall, inter-observer reliability was only 10 of 60 (16.67%) for agreement on classification type on all 3 radiographic views. This means that all five observers agreed on the same classification for only 10 patients of the 60 patients and 180 radiographs evaluated.

Further analysis of the data also revealed that the five observers classified one of the patient's fracture as either type 1 or type 2, which shows a large divergence in how this fracture might be classified. There were also six instances where all three different classification types (type 1, 2, and 3) were chosen for the same patient on different radiographs by an observer.

## DISCUSSION

This study demonstrates that the most commonly used classification system for fifth metatarsal base fractures has poor intra- and inter-observer reliability. Orthopaedic surgery residents, radiology residents, attending radiologists with musculoskeletal fellowship training, and an orthopaedic attending with fellowship training in foot and ankle surgery all had poor classification of these fractures.

Not only were the intra- and inter-observer reliability low, there were also instances where the difference was between zone 1 and zone 3, which greatly impacts treatment approach and presumed patient outcomes. This could mean the difference between conservative treatment for a zone 1 fracture versus strict non-weight

**Table 1. Intra-Observer Reliability**

Agreement for all 3 views (%)	
Observer 1	25 (42)
Observer 2	38 (63)
Observer 3	41 (68)
Observer 4	35 (58)
Observer 5	22 (37)

Number of times each observer chose the same classification on all three views and corresponding percentage.

**Table 2. Inter-Observer Reliability**

Radiographic View	5 / 5 Agree (%)	4 / 5 Agree (%)
Anteroposterior	34/60 (57)	52/60 (87)
Oblique	27/60 (45)	39/60(65)
Lateral	21/60 (35)	41/60(68)

Number of times all five observers agreed on each view. Then, number of times four of five observers agreed on each view.

**Table 3. Inter-Rater Agreement**

	Anteroposterior View	Oblique View	Lateral View
% Agreement	56.7	45	35
Fleiss' Kappa	0.643 (Substantial)	0.508 (Moderate)	0.441 (Moderate)
z	21.4	16.4	14
P value	0	0	0

Comparing the 5 raters, 60 subjects for each of 3 views.

**Table 4. Intra-Rater Agreement**

	Observer 1	Observer 2	Observer 3	Observer 4	Observer 5
% Agreement	47.1	63.3	68.3	58.3	36.7
Fleiss' Kappa	0.31 (Fair)	0.57 (Moderate)	0.55 (Moderate)	0.55 (Moderate)	0.31 (Fair)
z	5.25	10.2	9.41	10.2	5.49
P value	1.51x10 <sup>-7</sup>		0		3.99x10 <sup>-8</sup>
	0		0		

Comparing the three different views (computed as 3 raters, 60 subjects).

**Table 5. Kappa Values and Associated Interpretations**

Kappa	Interpretation
<0	Poor agreement
0.01 - 0.20	Slight agreement
0.21 - 0.40	Fair agreement
0.41 - 0.60	Moderate agreement
0.61 - 0.80	Substantial agreement
0.81 - 1.00	Almost perfect agreement

Table is given by Landis and Koch (1977) for interpreting kappa values.<sup>12</sup> There is some disagreement about the validity of this scale.<sup>13</sup> The kappa value will be higher when there are fewer categories.<sup>14</sup>

bearing and possible early surgery for a zone 3 fracture. Improper identification of these fractures can have a considerable negative impact on healing and outcomes. Fracture location is important owing to the blood supply to the fifth metatarsal. The metaphysis is supplied by a complex system of arterioles around the non-articulating surface of the tuberosity, while the blood supply to the diaphysis is via the nutrient artery entering through the middle of the diaphysis. This creates a watershed area at the metaphysis-diaphysis junction, explaining the higher risk of delayed union and non-union of fractures in this area.<sup>9</sup>

In addition to the tenuous blood supply in the region, relatively strong ligaments attach the base of the fifth metatarsal, cuboid, and base of the fourth metatarsal. This makes the proximal most part of the fifth metatarsal relatively stable, while the diaphysis of the fifth metatarsal is quite mobile in contrast. This disparity in stability also gives rise to a propensity for delayed union and nonunion at the metaphyseal-diaphyseal junction.<sup>10</sup> DeVries et al<sup>11</sup> examined proximal fifth metatarsal fractures in 10 cadaveric specimens, specifically the anatomy and mechanics of the proximal fifth metatarsal tuberosity. The lateral band of the plantar fascia, peroneus brevis, and articular surface were identified and separated from their attachments, thereby splitting the fifth metatarsal base into zones A, B, and C. Zone A was found to be the attachment of the lateral band of the plantar fascia, zone B the attachment of the peroneus brevis, and zone C encompassed the articulation of the fifth metatarsal to the cuboid. The authors postulated that the further distal the injury was the increased likelihood of prolonged immobilization and/or internal fixation was for proper healing. Zone A was relatively stable while zones B and C were exposed to the dynamic forces of the peroneus brevis.<sup>11</sup>

There are some shortcomings of this paper. First, each radiograph was characterized individually, and not as a set of three radiographs. In real life, the physician would have all three radiographs to use in conjunction to classify the fracture and make a clinical decision. Yet this is also of utmost importance, highlighting the importance of using all views of radiographs when attempting to classify a proximal fifth metatarsal fracture; a quick classification using a single view will likely lead to improper classification and possible poor clinical outcomes. However, the overall reliability would likely increase if all three views were views simultaneously. Furthermore, in the clinical setting, the treating physician will also have a history with a mechanism of injury to aid in classification of the fracture. Additionally, with poor identification of these fractures, inappropriate treatment may be chosen leading to suboptimal clinical outcome. This study did not investigate what treatment was chosen for each radiograph or the eventual clinical outcomes of each

patient. Finally, the inclusion of residents in this study may skew the results due to their level of training and experience

Lastly, computed tomography is a common imaging modality used in foot and ankle injuries. This is especially used when there are numerous injuries through this area or high-energy trauma to help aid in exact diagnosis and surgical planning. With numerous injured structures in the foot and ankle, plain radiography becomes exceedingly difficult for exact diagnosis and CT can be very beneficial. However, in isolated proximal fifth metatarsal fractures, the risks of excessive radiation and financial costs of CT outweigh any possible benefits that would be gained. It is not the authors' recommendation to routinely use CT for evaluation of isolated proximal fifth metatarsal fractures.

Fifth metatarsal base fractures are common injuries. Understanding the anatomy and location of the fracture is crucial in determining healing potential and appropriate management. The results of this study underscore a potential risk in using a classification system for treatment guidance when there is poor inter- and intra-observer reliability. To the author's knowledge, this is the first study examining the inter and intra-observer reliability of the Lawrence and Botte Classification.

The poor intra-observer reliability showed in the paper underscores the importance of using all radiographic views, as well as clinical history, to make the best-informed assessment of a patient's injury and select the most appropriate treatment. Further study in this area should seek to establish an approach to classifying fifth metatarsal base fractures with better inter- and intra-observer reliability to assist with classification, prognostication, and treatment of our patients.

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# Quantifying Coverage of a Distal Radius Volar Plate Using a Novel Pronator Quadratus Rotational Muscle Flap Technique

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## ABSTRACT

**Background:** Flexor tenosynovitis and tendon rupture are rare, yet serious complications after treatment of a fractured distal radius with a volar plate. The highest incidents of rupture are associated with the plate on or distal to the watershed line of the radius. While studies have shown that reattachment of the pronator quadratus (PQ) following plating does not lead to improved measures in grip strength or range of motion, it may reduce the incidence of these complications. Reattachment of the PQ after a standard approach does not often capture the distal edge of the plate. We report results of a new rotational muscle flap technique for improved coverage.

**Methods:** The PQ of 13 cadaver forearms were exposed. The muscle was then raised and a volar distal radius plate was applied to the forearm. The PQ was repositioned over the plate and photographed to document its initial plate coverage area. Varying amounts of rotational back cutting were utilized to reposition the PQ. The amount of plate coverage was then analyzed.

**Results:** Varying amounts of back cutting of the PQ increased the coverage of the distal radius plate, from a 54% increase from a 25% cut up to an 82% increase from a 75% cut. However, rotation of the muscle flap from larger back cuts will increase distal coverage at the expense of proximal coverage.

**Conclusions:** Repair of the PQ to cover the volar plate after distal radius open reduction internal fixation is often difficult. When utilizing a PQ back-cut technique, surgeons can achieve improved coverage of distal radius plates by the PQ flap.

**Keywords:** Pronator Quadratus, Radius Fracture, Volar Plate, Tendon Injuries, Internal Fixation

## INTRODUCTION

Repair of the pronator quadratus (PQ), after elevation of the muscle for treatment of distal radius fractures, is debated. The utility of this effort has been an area of debate amongst orthopaedic surgeons as it can be difficult to advance the muscle radially due to muscle damage from trauma and surgical exposure.<sup>1</sup> Although each individual patient will have PQ anatomical variances,<sup>2</sup> proximal release of the PQ allows advancement of the muscle distally to cover the exposed volar rim of the volar plate.<sup>3,4,5</sup> The PQ functions not only in wrist pronation, but can also provide a friction pad for the flexor pollicis longus and the flexor digitorum profundus of the index finger.

Flexor tenosynovitis and tendon rupture are serious complications after treatment of a fractured distal radius with a volar plate. These injuries are rare, with a reported incidence of 1%.<sup>6</sup> The highest incidents of rupture are associated with the plate on or distal to the watershed line of the radius. The risk of tendonitis or tendon rupture may be reduced by 1) releasing part of the PQ proximally to improve distal coverage of the distal radial volar plate, and 2) facilitating the repair of the transitional fiber zone.

Implant prominence after distal radius fracture volar plating can lead to flexor tenosynovitis and eventual tendon rupture, with the most common ruptured tendons being the flexor pollicis longus and flexor digitorum profundus of the index finger. Higher rupture rates have been associated with plate placement distal



to the watershed line of the volar distal radius.<sup>3,4</sup> Huang et al<sup>7</sup> performed a technique where the PQ is split in a transverse fashion along the more distal aspect of the PQ, which allows a portion of the PQ to cover the distal aspect of the volar plate. Goorens et al<sup>8</sup> established the value of proximal plate positioning and repair of the PQ in the management of distal radius fractures to maximize the distance between the plate and flexor tendons, thus theoretically decreasing the incidence of flexor tendon injuries.

The PQ is also important in forearm pronation, grip strength, and distal radial ulnar joint stability.<sup>8</sup> It has been found to contribute considerably to pronation and can result in functional deficits if damaged.<sup>8</sup> Furthermore, while PQ repair does not seem to affect clinical outcomes with regards to DASH (Disabilities of the Arm, Shoulder and Hand) scores, some patients have shown improvement in strength postoperatively.<sup>1,2,9</sup>

In this study, we aim to address this issue by using a pronator quadratus back-cut technique, and to further quantify the amount of increased coverage that this technique is able to achieve.

## MATERIALS AND METHODS

Thirteen fresh-frozen cadaver hands with forearms were used in this study. A fellowship-trained hand surgeon exposed the PQ and marked the most proximal and distal aspects of the muscle at the ulnar border. The length of the PQ was measured along the ulnar border, and the PQ was marked at 0%, 25%, 50%, and 75% of its total length. The neurovascular bundle, which is consistently found 1 to 3.5 cm from the proximal ulnar margin of the PQ muscle, was isolated and protected. The muscle was raised off the radial insertion site of the distal radius with an inverted L-shaped incision and elevated off the underlying periosteum per the standard approach to volar plate fixation.<sup>10</sup> A Geminus volar distal radius plate (Skeletal Dynamics, Miami, FL) was positioned on the radius to simulate repair of a distal radius fracture, and it was held in place with a single 3.5 mm x 15 mm screw positioned in the oblong hole along its shaft. A Nikon digital camera was mounted normally to the plate surface to document plate coverage. The plate was photographed on the distal radius for calibration of the software for each specimen and normalization of data across specimens. The camera and specimen were fixed in position for the remainder of each test. The PQ was repositioned over the plate and photographed to document its initial plate coverage area (Figure 1).

A back-cut with rotational muscle flap technique was then implemented to quantify the difference in plate coverage area relative to the initial plate coverage area. Sequential back cuts to 25%, 50%, and 75% of the ulnar border length were made at the proximal, ulnar border of the PQ, radial and volar to the anterior interosseous (AIN) branch of the median nerve. The PQ was repositioned over the plate after each sequential cut

using a rotational flap technique moving the proximal edge of the PQ, radially (Figure 1). The specimen was again photographed to document coverage of the plate. Care was taken during repositioning at each step to optimize total plate coverage area. After the 75% cut was documented, the PQ was translated distally over the plate with the goal of maximizing coverage of the distal end of the volar plate. (Figure 1). An additional photograph was taken to document plate coverage.

Plate coverage area was quantified using ImageJ open source software. Before analysis, the plate was virtually divided into proximal and distal. For all photographs, an outline was drawn encompassing the exposed regions of the volar distal radius plate. With the outline of the exposed plate, ImageJ was used to quantify exposed plate area (total, distal only, proximal only) after coverage by the intact and sequentially sectioned PQ for each specimen. The primary outcome measure was the increase in percentage of plate coverage from intact PQ to 25%, 50%, and 75% of the proximal to distal length of the pronator quadratus muscle compared to un-sectioned specimens, respectively. This allowed for normalization against size and geometrical effects for each specimen. Results are presented as percentage increase in coverage of the distal aspect of the volar plate (DVP) and percentage increase in coverage of the proximal aspect of the volar plate (PVP) as prepared by the ImageJ software. We report the mean and standard deviation (SD) for the thirteen samples.

## RESULTS

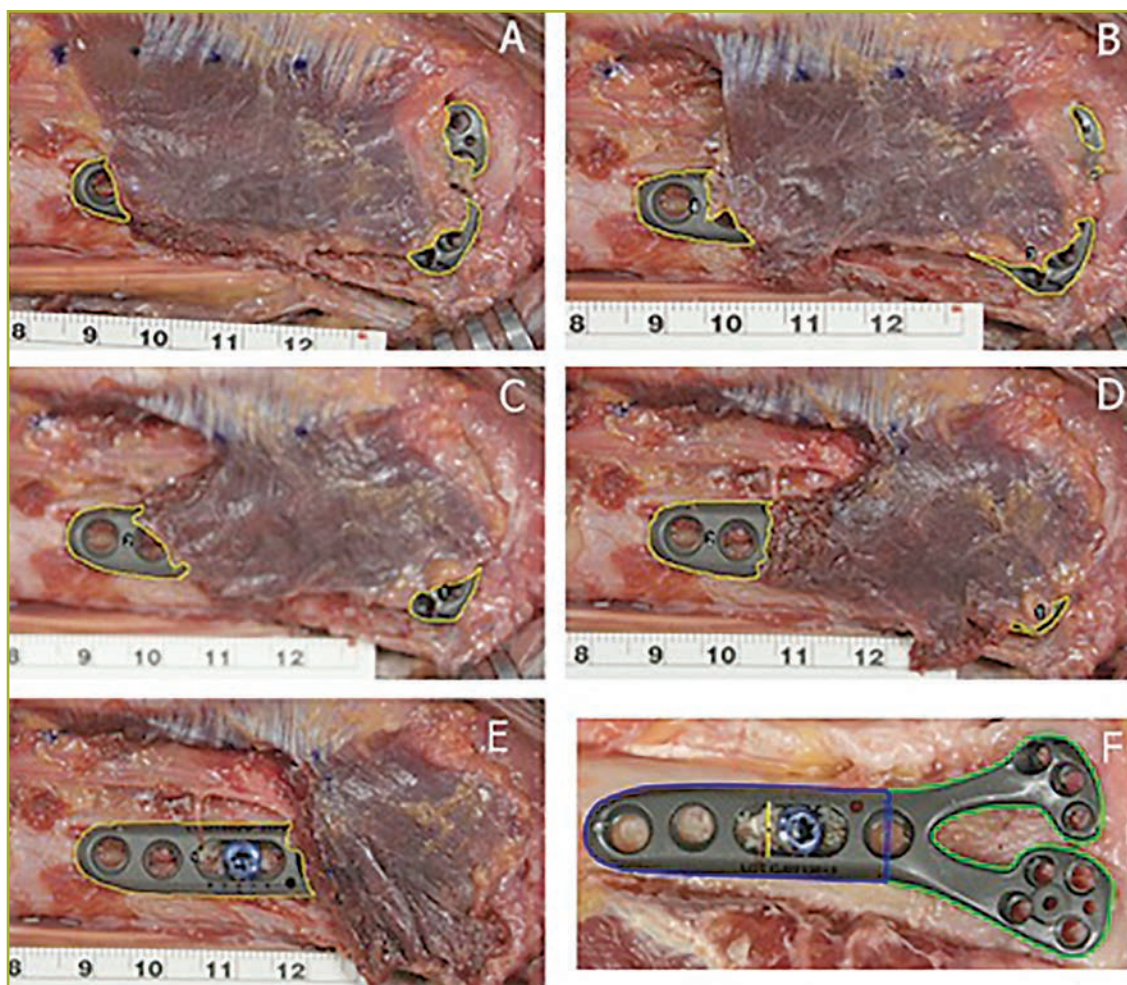
A 25% cut of the proximal aspect of the PQ resulted in an increase in coverage of 54.3% (SD 0.2%) of the DVP and 34.3% (SD 0.5%) of the PVP. A 50% cut increased coverage to 64.7% (SD 0.2%) of the DVP and 42.5% (SD 0.7%) of the PVP. A 75% cut increased coverage to 82.0% (SD 0.2%) of the DVP, but decreased coverage to 11.1% (SD 0.9%) of the PVP.

### Summary

A PQ rotational muscle flap allows for increased excursion to cover the distal aspect of a volar distal radius plate. Rotation of the muscle flap created from a 75% back cut increases distal coverage of the plate, but decreases proximal coverage

## DISCUSSION

In the literature, repair of the PQ is debatable in regard to its impact on functional outcome after distal radius fracture fixation with volar plate. However, a large number of surgeons still consider coverage of the volar plate with PQ to be an essential part of the procedure. This is most likely because its use as a friction pad to protect flexor tendons appears advantageous in order to decrease the risk of flexor tendon injuries and mitigate complications. Creating a muscle flap by transecting the PQ ulnarly would allow establishment of such a friction pad, thus achieving the goal of reduced



**Figure 1.** Sequential analysis of a single specimen using ImageJ. The exposed plate is outlined in yellow. A) Initial coverage of the volar plate. B) Volar plate coverage after a 25% cut, C) 50% cut, D) 75% cut, E) and 75% cut with effort made to cover the entire distal end of the plate and the transitional fibrous zone. F) The outlined proximal half of the plate (blue) and the outlined distal half of the plate (green).

flexor tendon injuries. This technique also preserves the vascular supply of the PQ and careful dissection, with identification of the AIN along the ulnar aspect of the PQ,<sup>11</sup> potentially minimizes neurologic injuries and could preserve motor function in a live subject. While trauma often disrupts the PQ, we find that this disruption usually occurs distally in the PQ muscle belly and the proximal neurovascular anatomy of the PQ is relatively preserved.

Denervation and devascularization of the PQ is a risk. However, anatomical studies have recognized clear landmarks for the AIN branch of the median nerve. The AIN branch of the PQ is 1 to 3 cm proximal to the ulnar styloid process or distal 13% of the forearm length, and it is 2 cm lateral to the medial border of the ulna or 40% of the wrist width on the ulnar side.<sup>12</sup> The normal anatomy of the neurovascular bundle is median to the ulnar origin of the pronator quadratus.<sup>12</sup> Therefore, it is our belief that careful dissection and identification of the AIN branch leads to a minimal risk of neurovascular bundle injury with this muscle flap technique.

#### Limitations

A possible criticism of this technique is whether the muscle will retain its function after this procedure. While we do not yet have studies evaluating the strength and function of the PQ after this technique, the muscle's insertion is reestablished during repair and half of the origin is preserved. The muscle also should retain its vascularity and innervation, given that the neurovascular pedicle is not disturbed. The effect of the strength and function of the PQ would be a possible future area of investigation. In addition, advancing the pronator quadratus distally after 75% back cut places muscle in the region of the transitional fibrous zone, which may not be ideal. This is a cadaveric technique; therefore, the benefit of this technique is theoretical and future studies in vivo are needed to determine benefit in patients.

While the technique illustrated here improves coverage of the plate by the PQ, further studies are needed to determine if coverage of the volar plate using this technique improves clinical outcomes and reduces complications among patients.

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# Measurement of Femoral Notch Type Show Low Inter-Rater Reliability

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**Conflicts of interest** The authors report no conflicts of interest.

## ABSTRACT

**Background:** Preventing first time anterior cruciate ligament (ACL) injury and the devastating sequela of post-traumatic osteoarthritis in the young athlete has attracted efforts to identify risk factors for development of ACL injury. Femoral notch type has been related to risk of ACL injury in previous studies. However, little data exists to support the reliability of assessing this qualitative measurement amongst independent investigators.

**Methods:** Femoral notch type was measured from magnetic resonance imaging sections of 344 injured ACL and control knees by three investigators with different levels of professional experience. Inter-rater reliability was assessed using Cohen's kappa statistic.

**Results:** The simple kappa statistic between investigators 1 and 2 was 0.44 (SE 0.04, 95% CI 0.36 - 0.53); between investigators 1 and 3 was 0.31 (SE 0.04, 95% CI 0.22 - 0.40); and between investigators 2 and 3 was 0.16 (SE 0.05, 95% CI 0.08 - 0.25).

**Conclusions:** There is low inter-rater reliability for measuring femoral notch type.

**Keywords:** Femoral Notch Type, ACL Injury, Reliability, Risk Factor

## INTRODUCTION

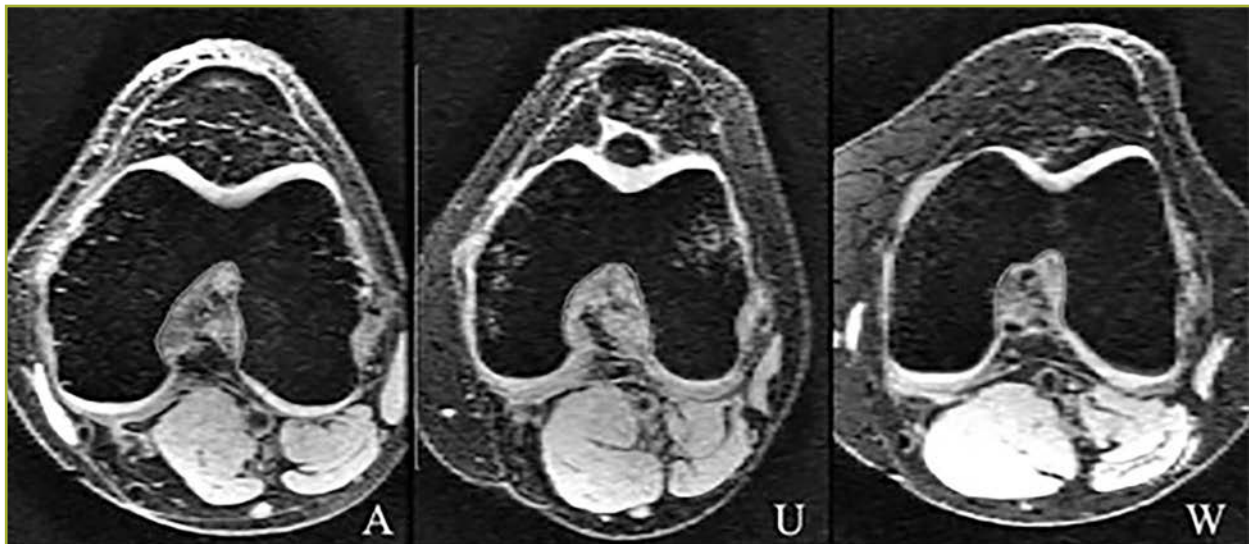
Anterior cruciate ligament (ACL) injuries affect over 200,000 individuals in the United States annually, and they are particularly prevalent in the young athletic population.<sup>1</sup> Estimates of incidence per 1000 exposures have been reported at 0.08% in female athletes and 0.05% in male athletes.<sup>2</sup> ACL disruption is a debilitating injury, and it is especially devastating in the athletic population. These injuries are painful, can prevent athletes from immediate return to play, and are career ending in some instances. ACL injuries are often complicated by concomitant injury to the medial meniscus (0 - 28%), lateral meniscus (20 - 45%), and medial collateral ligament (19 - 38%).<sup>3</sup> These injuries have been shown to alter the biomechanics about

the knee, and they are associated with the onset and progression of post-traumatic osteoarthritis (PTOA).<sup>4</sup> There are currently no effective treatment options for young and healthy individuals with PTOA. As such, there have been an increasing amount of research aimed at identifying intrinsic and extrinsic factors that place an individual at risk of developing an ACL injury.<sup>5-15</sup> Ultimately, the goal of determining risk factors for ACL injury is to identify which individuals may benefit from pre-injury intervention in order to prevent the occurrence of ACL injury and the devastating sequela of PTOA.

The intercondylar morphology of the femoral notch serves as the origin of the ACL, and it has been well studied in relation to ACL injury. Alterations in morphology would logically impact the stress and strain imparted on the ACL during activity. For instance, decreased femoral notch width has been related to increased risk of first time ACL injury,<sup>15</sup> increased risk of contralateral ACL injury following a first time ACL injury,<sup>16</sup> and increased risk of ACL graft injury.<sup>17</sup> Previous studies have investigated the relationship between the shape of the femoral notch (ie, notch type) and the risk of suffering ACL injury; however, the findings from these reports have been inconsistent.<sup>18-21</sup> Femoral notch shape can be assessed via visual inspection at the time of arthroscopy (or, using images acquired at the time of arthroscopy), or with image-based techniques such as computed tomography (CT) or magnetic resonance imaging (MRI).

The inconsistent findings from these previous studies may be attributed, at least in part, to the subjectivity and decreased reliability associated with the qualitative assessment of the femoral notch shape. Qualitative measurements are inherently subjected to measurement bias, calling into question the ability of using notch type as a reliable predictor for assessing risk of ACL injury.

The purpose of our current study was to determine the reliability of measuring notch type morphology between three investigators with different levels of experience. Our hypothesis was that there is low inter-



**Figure 1.** Axial T1-weighted magnetic resonance imaging displaying Type-A, -U, and -W notch types, respectively.

rater reliability for measurements of femoral notch type morphology.

## METHODS

This investigation was approved by our Institutional Review Board (CHRMS #19-0050), and all participants provided informed consent prior to data collection. MRI data of injured ACL and control knees were obtained as part of a previously reported prospective cohort study with a nested case-control analysis.<sup>22</sup> Over the course of 4 years, athletic teams from 36 institutions (ie, 28 high schools and 8 colleges) were monitored to identify patients who suffered an ACL disruption. Participants were included in the study if they had torn their ACL during participation in an organized sport, had no prior ACL injury, and were injured by a non-contact mechanism. At the time of enrollment of the ACL injured participant, a control participant of the same age and sex was selected from the same athletic team. Control patients were also enrolled in the study. For the ACL injured participants, MRI data were acquired within 3 weeks of injury and before surgery. The control participants underwent MRI examination during the same week as ACL injured participants.

Both ACL injured and control participants underwent bilateral MRI with a Philips Achieva 3.0T TX scanner system (Philips Medical Systems, Best, Netherlands). Participants had both knees scanned with the joint placed in an extended position inside an 8-channel SENSE knee coil (Philips Medical Systems, Best, Netherlands) by the same technicians over the course of the study. Sagittal-plane MRI data were acquired with T1-weighted fast-field echo scans with a slice thickness of 1.2 mm and a pixel size of 0.3 by 0.3 mm.

Notch type morphology was measured on axial images at the level of maximal depth of the popliteal groove of the lateral femoral condyle. At this level, the single image was sent to reviewers for measurement of notch type to maximize blinding from injury status.

A total of 344 knees were analyzed by each rater. Of the 344 knees, there were 100 from men (ACL injured and uninjured) and 244 from women (ACL injured and uninjured). Definitions for notch type morphologies were adapted from previous work by Van Eck et al.<sup>19</sup> Notch Type-A was defined as an intercondylar notch that narrowed from base to midsection to apex, Type-U as notch that did not significantly taper from base to midsection, and Type-W as a notch that did not taper from base to midsection and had two apparent apices (Figure 1).

Three independent investigators were asked to characterize notch type morphology. The group of three investigators was composed of a second-year medical student (investigator 1); a post-graduate year-2 orthopaedic surgery resident (investigator 2); and a sports-medicine fellowship-trained, practicing orthopaedic surgeon, with over 20 years of experience with knee surgery (investigator 3). All investigators were blinded to the injury status of the participant and to the measurements made by the other investigators. However, given that ACL fibers could be visualized at the bone-ligament junction at the ACL origin in the femoral notch, it was impossible to completely blind investigators of the injury status of all individuals, as disruption or inflammatory changes within these fibers would suggest an ACL injury.

Reliability of notch type morphology measurements within and between investigators was assessed using Cohen's kappa statistic. A kappa of 0.7 or higher was selected as acceptable reliability for a prognostic measure for risk of ACL injury.

## RESULTS

Patient demographics are discussed in the original publication of this study cohort by Beynon et al.<sup>22</sup> The inter-rater reliability between investigators 1 and 2 yielded a simple kappa statistic of 0.44 (SE 0.04, 95% CI 0.36 - 0.53). When assessed between investigators 1



**Table 1. Results of inter-rater reliability kappa statistics**

Investigators	Kappa value (CI)
1 + 2	0.44 (0.36-0.53)
1 + 3	0.31 (0.23-0.40)
2 + 3	0.16 (0.08-0.25)

CI, confidence interval

**Table 2. Notch type measurements for each investigator**

Notch Type	Investigator 1	Investigator 2	Investigator 3
A	90 (26%)	113 (33%)	164 (48%)
U	235 (68%)	191 (56%)	166 (48%)
W	19 (5%)	40 (11%)	14 (4%)

and 3, the simple kappa statistic was 0.31 (SE 0.04, 95% CI 0.23 – 0.40). For investigators 2 and 3, the simple kappa statistic was 0.16 (SE 0.045, 95% CI 0.08 – 0.25) (Table 1). Stratified data for notch type measurements for each investigator can be seen in Table 2.

## DISCUSSION

Our study revealed low inter-rater reliability for measuring notch type morphology. This study shows that notch type is not a reliable replacement for notch width or other similar characteristics as a predictor of an individual's risk for suffering ACL injury.

Previous studies have investigated notch type morphology as a predictor of risk of ACL injury. Van Eck et al<sup>19</sup> measured notch type morphology in 102 knees undergoing primary arthroscopic ACL reconstruction. Intraoperative arthroscopic photos and videos were acquired and subsequently assessed by two independent orthopaedic surgeons at separate time intervals. The intra-rater kappa statistics for the first and second investigator were 0.513 and 0.610, respectively, with an inter-rater kappa statistic of 0.526. The authors concluded that their results yielded an "acceptable" intra- and inter-rater reliability. The main differences between the study by Van Eck et al<sup>19</sup> and our study were that they measured notch type using arthroscopic photos and videos and did not have a control group. Characterization of femoral notch type at time of arthroscopy or via arthroscopic images may be a more reliable method of measurement, as it allows for visualization of the entire notch simultaneously, compared to assessing only one two-dimensional section via CT or MRI. However, arthroscopy is invasive and costly, and it would not be a reasonable method of assessing notch type morphology for assessing risk of ACL injury. Only ACL injured individuals were included in the report by Van Eck et al; consequently, it is unclear whether notch type can be reliably measured in patients with an intact and normal ACL. Additionally, the authors

did not specify the level of kappa that they considered to be of sufficient reliability. This is concerning because the kappa statistic for both inter- and intra-rater reliability was below the level 0.7, which is what we considered acceptable in our current study.

Retrospective studies by Bouras et al<sup>20</sup> and Al-Saeed et al<sup>21</sup> evaluated MRIs of injured ACL and control knees to determine notch type. Although both studies found a significant association between notch Type-A and increased risk of suffering ACL injury, different criteria were used for defining notch type morphology between the two studies. More importantly, neither study evaluated intra- or inter-rater reliability.

Determining femoral notch type is a qualitative measurement, and there have been different criteria used to define the different notch types reported in the studies.<sup>18-21</sup> When using an axial MRI or CT image to access notch type, the appearance of the distal femur may change from Type U to Type A owing to the image or slice level that is selected. It is often not clear which notch type an individual knee may fall under. As such, it was not surprising to find variance amongst the three investigators in our study.

There are potential limitations of this study. The three investigators differed in training experience. Level of experience could affect the ability to accurately and predictably measure notch type morphology. Thus more consistent results may have been observed if all three raters were practicing orthopaedic surgeons. However, the ultimate goal is to identify risk factors that can be reliably measured by individuals regardless of area of specialty or level of experience. As such, we felt it was appropriate to use raters with different levels of experience in this study.

In conclusion, femoral notch type cannot be measured with sufficient reliability for use as a prognostic indicator of ACL injury risk, at least in part with the MRI planes and knee flexion angles used in this study.

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# Aseptic Nonunion of Long Bones in Children: A Report of Twelve Cases

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## ABSTRACT

**Background:** There are very few reports in the literature that directly address nonunion in children. The current study aimed to present a series of long bones nonunion in children following fractures and corrective osteotomies.

**Methods:** This was a retrospective study that included pediatric patients diagnosed with nonunion following long bone fractures or corrective osteotomies. Patients with nonunion following femoral neck or lateral humeral condyle fractures were excluded. The clinical and radiological records were retrospectively analyzed.

**Results:** Eight patients developed nonunion after fractures, while four patients had nonunion after corrective osteotomies. The mean age at the time of surgical procedure for nonunion was 10.8 years (range, 2 - 18). The tibia was the most common bone complicated by nonunion with 8 cases (66.6%). The mean time to diagnosis of nonunion was 7.9 months (range, 4 - 24). Five patients (41.6%) had multiple fractures or osteotomies. Two patients (16.6%) had a neurological deficit.

**Conclusion:** Pediatric nonunion is a rare entity. Possible risk factors include older children, open fractures, and co-existing neurological disorders. Further studies that include a comparative group and adequate sample size are needed to confirm these findings.

**Keywords:** Pediatric, Long Bones, Osteotomies, Fracture, Nonunion

## INTRODUCTION

Bone healing is a complex physiological process. It includes different stages such as cellular activity, bone callus formation, and bone remodeling.<sup>1</sup> Any disturbances of these stages can lead to impaired healing response and subsequent delay in bone healing or nonunion.<sup>2</sup> Nonunion may have serious effects on the daily activities of children, and can cause loss of limb function, muscle atrophy, and stiffness of the adjacent joints.<sup>2</sup>

Nonunion is considered a rare complication of long bone fractures in the pediatric population. There are few studies in the literature reporting on the topic.<sup>3,4</sup> The studies discussing pediatric nonunion have been

published as either case reports or as isolated entities in a larger series of predominantly adult fractures.<sup>5</sup> Moreover, there is a paucity of literature dealing with pediatric nonunion following corrective osteotomies.<sup>6</sup>

This study aimed to report the cases of nonunion after fractures and corrective osteotomies of long bones in children, and report the treatment plans and outcomes of such cases.

### Patients and Methods

The authors obtained approval from our institution's Human Research Protective Program (HRPP #E18097). Records from over a 9-year span (Jan 2009-Jan 2018) were reviewed for pediatric patients treated for long bone nonunion at our institution. Inclusion criteria included patients younger than 18 years old who experienced nonunion of a long bone after fracture or corrective osteotomies. Exclusion criteria included any case of femoral neck or lateral humeral condyle nonunion or congenital pseudarthrosis of the tibia, because nonunions in these conditions are well documented in multiple studies.<sup>7-10</sup> Nonunion was defined by clinical and radiological factors. Clinical factors included persistent pain at the fracture site and impaired function of the extremity. Radiological factors included lack of bridging callus and persistent fracture lines in at least two of the orthogonal x-ray views. Lack of progressive radiological healing on consecutive radiographic imaging and at least 6 months from the injury were required to diagnose nonunion. Injuries with slow healing but less than 6 months from injury were classified as "delayed union," using the classification system by Weber and Cech.<sup>11</sup> The presence of infection or implant failure were also reported.

The data collected included patient age, gender, comorbidities, fracture characteristics, initial treatment, time to nonunion diagnosis, nonunion type, infection status, management, follow-up, and outcome. The study collected additional information for osteotomy patients, including initial diagnosis and management. Complications of the treatment were also reported.

The primary outcome of interest was the ability to treat the nonunion and achieve clinical and radiographic bone healing. Secondary outcomes were possible risk factors and treatment plans.

**Table 1. Detailed Results of 13 pediatric cases who experienced non-union of long bones in the study**

Patient #	Age	Gender	MOI	Fracture description	Initial treatment	Time from initial treatment to diagnose nonunion	Type of nonunion	Infection	Treatment of nonunion	Time to attain bony union -Follow up in months
1	16	M	MVA accident	Left open G IIB distal both bone leg shaft femur	Ring fixator Antegrade IM nail	5 months United	Atrophic	No	-Ring fixator -IM BG (RIA)	-5 months -34 months
2	12	F	MVA accident	Left closed transverse proximal shaft humerus Left closed transverse midshaft tibia	2 Elastic IM nails 2 IM nails	United 4 months	Hypertrophic	No	-Compression plate -Synthetic, local BG -Fibular osteotomy	-3 months -14 months
3	11	F	Fail	Left open G II highly comminuted distal shaft humerus	Two 2.7 plates and one L. plate (synthes)	6 months	Oligotrophic	No	Posterolateral plate (S&N) -1/3 tubular plate -Synthetic BG	-4 months -6 months
4	8	M	Fail	Right open G II distal ulna Right closed distal radius Right closed SC humerus	One IM k-wire 2 lateral k-wires 2 lateral k-wires	6 months 6 months United	Hypertrophic Hypertrophic	No No	-2 Compression plates -Synthetic and local BG	-3 months -11 months
5	2	M	N/A	Right closed transverse midshaft femur	Plate fixation	8 months With implant failure	Atrophic	No	2 Elastic IM nails	-2 months -10 months
6	16	M	Fail	Right closed subtrochantric femur (Had retrograde Nail)	Retrograde removal and Reconstruction Nail applied	8 months	Oligotrophic	No	-Blade plate with retrograde nail for prophylaxis of distal femur -IM BG (RIA)	-1.5 months -12 months
7	18	M	N/A	Left closed transverse midshaft tibia	Kuntscher nail	2 years (late presentation)	Hypertrophic	No	-Ring Fixator -fibular osteotomy -RIA	-14 months -26 months
8	3	M	Fail	Left closed tibial shaft Multiple ribs	Nonoperative Nonoperative	Exact timing cannot be determined as this is a child abuse case, however, radiologically it seems that it is over 6 months United	Hyper-trophic	No	2 IM elastic nails	-2 month -7 months

This patient did not have congenital pseudo arthrosis of tibia or any manifestations of neurofibromatosis

**Table 1. Detailed Results of 13 pediatric cases who experienced non-union of long bones in the study (continued)**

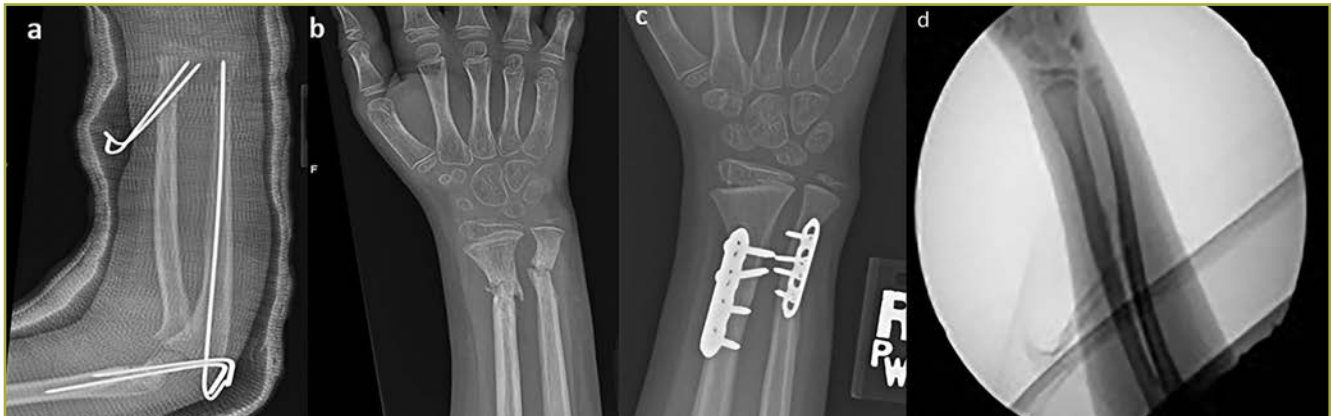
Patient #	Age	Gender	Comorbidity	Initial diagnosis	Initial surgical intervention	Time from initial treatment to diagnose non union	Infection	Type of non-union	Treatment of non-union	Time to attain bony union -Follow up
9	4	M	-Bilateral cleft feet -Developmental delay -Skeletal abnormalities	External rotation deformity of Rt tibia	Internal rotation osteotomy of the Rt tibia 30 degrees fixed by k wires	6 months	No	Hyper-trophic	-Compression plate -Synthetic BG	-5 months -56 months
10	10	F	-Juvenile RA -scleroderma -bilateral genu valgum	Right external tibial torsion	Right supra-malleolar 40-degree derotational osteotomy Fixed by 2.7 plate (Synthes)	10 months	No	Oligo-trophic	-Double plating -Local BG	-3 months -9 months
11	18	F	-Achondroplasia -previous Bilateral femur, tibia and humerus lengthening	Valgus deformity of the Right tibia	Varus producing osteotomy fixed by ring fixator	6 months	No	Oligo-trophic	compression pate and synthetic BG;	-4 months -11 months
12	17	F	-Myelodysplasia -lower limbs neurological deficit	IR Right tibia ER Left tibia	Right ER osteotomy Fixed by IM nail Left IR osteotomy fixed by Plate	United 6 months	No	Oligo-trophic	IM nailing with synthetic BG	-3 months -63 months

Abbreviation: MOI, mechanism of injury; MVA, motor vehicle accident; N/A: not available; IM, intramedullary; TSF, Taylor spatial frame; BG, bone graft; SC, supracondylar; RA, rheumatoid arthritis; IR, internal rotation; ER, external rotation; RIA, reaming irrigation aspiration; G II, IIIB, Gastilo classification for open fractures





**Figure 1.** A) X-ray and computer tomography scan of left closed non-united transverse mid-shaft tibial fracture fixed by intramedullary nailing after 4 months of fixation. Patient was an 11-year-old adolescent girl. B) Intraoperative fluoroscopic image of a nonunion correction by open reduction and internal fixation using a compression plate with screws and bone graft (synthetic and local) with fibular osteotomy. C) Anteroposterior and lateral x-ray views after complete union and hardware removal.



**Figure 2.** A) Anteroposterior x-ray view of right distal both bone forearm (closed radius/open ulna G2), and supracondylar humerus fracture fixed by K-wires in cast. Patient was an 8-year-old boy (case 4). B) Follow up x-ray after 6 months showing non-united both bone forearm fracture. C) Anteroposterior x-ray view showing complete union of previous fracture fixed by 2 compression plates at 4 months postoperative period. D) Fluoroscopic image showing fracture union after implant removal.

#### **Surgical Technique**

Treatment was customized according to nonunion type, presence of infection, and implant failure. Fracture edges were exposed and freshened. All fibrous and sclerotic bone edges were excised. Drilling was applied to open the medulla to restore the medullary blood supply. Cultures were taken to rule out infection as appropriate.

Skeletal fixation was dependent on nonunion type. Eight cases were treated with compression plating of different types, according to fracture site and characteristics. When the compression plating modality could not be applied due to the nature of the fracture or the initial treatment plan, an alternative implant was used as another method of fixation. Two fractures were treated using elastic intramedullary nails, one

osteotomy was treated with an interlocking nail for tibial nonunion, and two fracture nonunions were treated using a ring fixator.

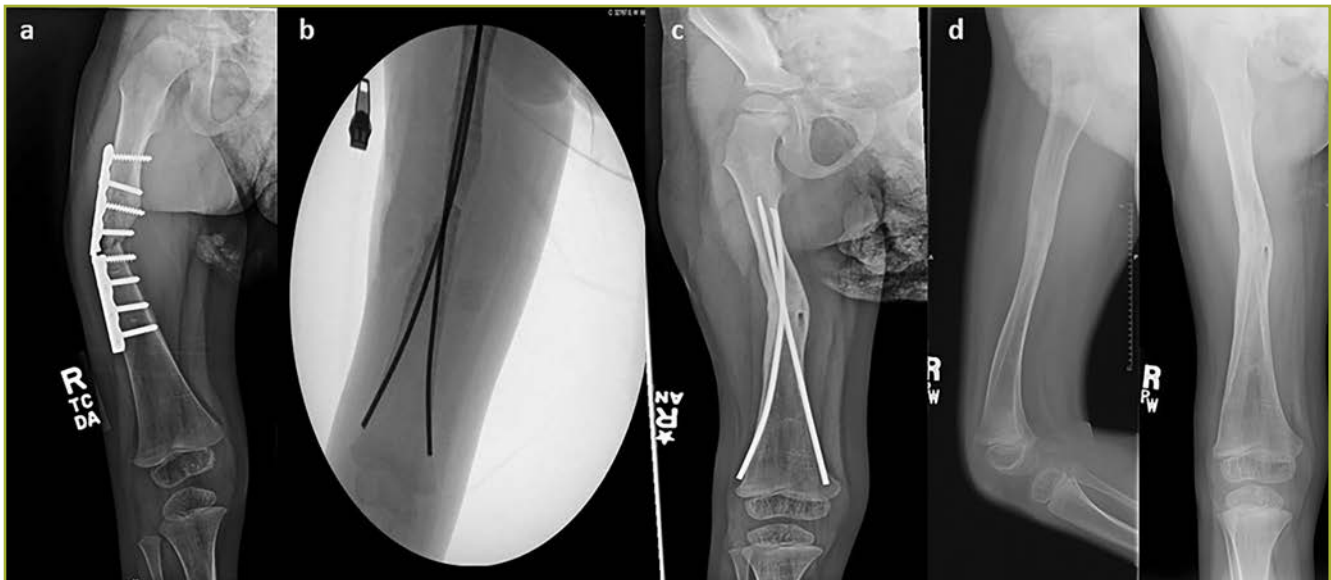
Decortication was done to promote bone healing. Different types of bone grafting were used in eleven of the cases in this series. Demineralized bone matrix (DePuy Synthes Companies, Warsaw, PA) was used as a synthetic bone in five cases. In two cases, a combined local and synthetic graft was used. A local bone graft was used solely in one case. In three cases, intramedullary bone grafting using a reamer irrigator aspirator (DePuy Synthes Companies, Warsaw, PA) was used to harvest an autograft from the intramedullary canals of the femur and tibia.



**Figure 3.** A) Anteroposterior x-ray view of non-united internal rotation osteotomy of the both bone right leg 30° fixed by K-wires. Patient is a 3-year-old boy who had external rotation deformity (case 9). B) Intraoperative fluoroscopic image of reoperation and fixation using compression plate and screws. C) Anteroposterior x-ray view showing complete bony union at 5 months of reoperation. D) Intraoperative fluoroscopic image after hardware removal



**Figure 4.** A) Anteroposterior x-ray view showing non-united varus producing osteotomy fixed by Taylor Spatial Frame for valgus deformity of the right tibia. Patient is an 18-year-old woman with achondroplasia (case 11). B) Intraoperative fluoroscopic image for reoperation and fixation using compression plate and screws. C) X-ray showing complete bony union after 4 months of reoperation. D) Intraoperative fluoroscopic solid union after hardware removal.



**Figure 5.** A) X-ray (one view) of non-united closed transverse fracture of the mid-shaft right femur fixed by plate and screw 8 months postoperatively. Patient is a 2-year-old boy (case 5). Implant failure is evident. B) Intraoperative fluoroscopic image of reoperation using elastic intramedullary nails. C) Anteroposterior x-ray view showing complete bony union at 2 months of reoperation. D) X-ray showing complete union.

#### Statistical Methods

This study used only descriptive statistics calculated using Microsoft Excel (Microsoft, Redmond, VA). Inferential statistics couldn't be used due to small sample size.

## RESULTS

Table 1 details the results of the 12 cases. Eight patients developed nonunion after fracture, and four patients had nonunion following corrective osteotomy. Nonunion of the tibia was the most common, with a total of eight cases (Figures 1, 2, 3, and 4). Of these eight cases, four cases were post-traumatic and the other four cases were after osteotomy. There were two cases of femoral nonunion. The first of these cases was a shaft fracture that was initially treated using plate fixation, and it subsequently developed nonunion and the implant failed (case 5) (Figure 5). The second of these cases was a subtrochanteric fracture nonunion.

None of the patients in this study showed any clinical signs or laboratory findings suggestive of infection. No specific type of nonunion seemed to dominate. Four patients were polytrauma with multiple fractures at the time of presentation, and another patient had multiple osteotomies in the same setting. There were five fractures that were closed, and three open fractures (ie, tibia fracture, grade III B (case 1); distal shaft humerus fracture, grade II (case 3); and ulnar fracture, grade II (case 4). Two patients had an associated neurological deficit. One of these patients had three nerve palsies (ie, radial, ulnar, and partial median) that were associated with an open distal shaft humerus fracture (case 3). The other patient had a history of myelodysplasia with neurological deficit in the lower limbs (case 13). The average time to diagnosis

**Table 2.** Summary of results.

Age	10.8 (2-18)
Gender	7 Males; 5 Females
Fracture/Osteotomy Location	8/12 Tibia [66.6%] 1/12 Both bone forearm [8.3%] 1/12 Subtrochanteric femur [8.3%] 1/12 Shaft femur [8.3%] 1/12 Distal humerus [8.3%]
Nonunion Type	5/12 oligotrophic [41.6%] 2/12 atrophic [16.6%] 5/12 hypertrophic [41.6%]
Open Fractures/Total Fractures	3/8 [37.5%]
Associated Osteotomies/ Total Osteotomy Cases	1/4 [25%]
Associated Multiple Fractures/ Total Fractures	4/8 [50%]
Associated Neurological Deficit	2 /12 [16.6 %]
Method of Fixation	Compression plate 7/12 (58.3%) Elastic intramedullary nails 2/12 Interlocking Nail 1/12 Ring fixator 2/12
Bone Graft usage	Synthetic (DBM): 4 cases Local: 1 case Combined: 2 cases RIA: 3 cases None: 2 cases
Time to Diagnose Union	7.8 Months (4-24)
Follow-Up	21.6 Months (6-63)
Time to Attain Bony Union After Nonunion Treatment	4 Months (1.5-14)

of nonunion was 7.8 months (range, 4 - 24). No complications related to nonunion treatment were recorded in this study. All patients attained bony union within an average of 4 months (range, 1.5 - 14). A summary of results is included (Table 2).

## DISCUSSION

Nonunion in children is a rare complication following long bone fractures and corrective osteotomies.<sup>12</sup> Mills and Simpson<sup>13</sup> estimated the incidence of nonunion in children. Their study examined the overall rate of nonunion in a large population of children and young adults. For patients under the age of 15 years, the risk of nonunion per fracture was approximately 1 in 500 for both boys and girls. For patients in the 15- to 19-year-old age group, the risk of nonunion per fracture was approximately 1 in 500 for girls and 1 in 200 for boys. During the study review, the authors identified only 12 cases of long bone nonunion over a span of 9 years. This reflected the rarity of this complication in the pediatric population. Highly comminuted fractures with or without bone defect, associated severe soft-tissue loss, presence of infection, and prior treatment with open reduction and internal fixation are well known risk factors for nonunion.<sup>3</sup>

Patient age, open fractures, technical errors, infection, polytrauma patients, or neurological disorders were reported as risk factors for nonunion in children. It has been reported that age and fracture pattern have a statistically significant association with developing nonunion. Older children over 12 years old are predisposed to nonunion.<sup>3-12,14</sup> Grimard et al<sup>12</sup> reported 10 cases with delayed union and 7 cases with nonunion, with all patients over 6 years of age. The study found that the age of the patient was a statistically significant factor associated with time to union. The authors reported from 12 years of age and older, and they found that delayed union and nonunion were seen at rates close to those in adults. Similarly, Kreder and Armstrong<sup>14</sup> found that age was a significant factor in the development of nonunion. Arslan et al<sup>3</sup> suggested that the incidence of nonunion increases after the age of 6 years. In a case series of 16 cases of pediatric nonunion, Yeo et al<sup>4</sup> had only one case below the age of 8 years. In our current study, only 3 patients (ie, 23%) were below the age of 8 years, which supports the previously published studies.

In a study by Grimard et al,<sup>12</sup> the authors found that open fractures were also considered a risk factor for delayed union. These authors found that the average union times for Gustilo-Anderson grade III fractures were significantly longer than those for grade I. The current study had three cases of open fractures (ie, 37.5%). Two cases were grade II (cases 3 and 4), which united at 4 and 3 months, respectively. The other case that was grade III B healed at 5 months.<sup>12</sup>

Technical error in surgery was considered another risk factor. In 1976, Weber stated the following statement, "Considerable skill is required to induce

nonunion in a child, and its occurrence always results from a serious error in management."<sup>11</sup> In contrast, Arslan et al<sup>3</sup> disagreed with Weber's statement, and the authors found that it occurred in children despite appropriate treatment. The author's observations suggested that the nonunion in pediatric fractures can occur because of the surgeons using a relatively less stable fixation method, and they feel falsely secured by favorable healing mechanisms present in children (Figures 1 and 3). Lack of sufficient attention to details and failure to achieve adequate fixation may cause nonunion.

The presence of infection adds to the complexity of nonunion. Treatment should include the controlling of the infection as well as treating the nonunion. In this study, we didn't encounter any fracture or osteotomy site infections. In contrast, Arslan et al<sup>3</sup> reported infections associated with pediatric nonunion in their study. However, our study results show that the majority of nonunions in children are not related to infection.

Zura et al<sup>15</sup> found that polytrauma patients were considered a risk factor for nonunion, with a reported odds ratio of 2.65 (95% CI, 2.34-2.99). In this study, four patients were categorized as polytrauma patients with multiple fractures, and another patient had multiple osteotomies in the same setting. The severity of the associated injuries and the fact that they had multiple healing sites may be a contributing risk factor.

Two cases in this study (ie, 15%) had associated neurological deficits, which may support the findings in the study conducted by Aro.<sup>16</sup> In his study, he demonstrated that sciatic denervation accompanying tibial fracture in rats had a negative effect on union.

Nonunion is not a rare occurrence in a child who has osteogenesis imperfecta.<sup>17</sup> Using a population of 52 osteogenesis imperfecta patients, Gamble et al<sup>17</sup> reported 12 nonunions in 10 patients. Similarly, in a case series of 44 osteogenesis imperfecta patients, Agarwal and Joseph<sup>6</sup> reported 9 nonunion in 8 patients, in which 4 nonunions developed at sites of osteotomies. Our study reports one case of proximal femur fracture nonunion in an osteogenesis imperfecta patient.

Bone quality and biology have a direct impact on the healing of bone. In inflammatory arthritis conditions, chronic use of glucocorticoids and immunomodulatory medications result in reduced bone mineral density and compromised bone growth and healing potentials.<sup>18</sup> One child with tibial osteotomy nonunion had an underlying connective tissue disease, scleroderma. This underlying disease, or the treatment of the disease, may have been a risk factor for the nonunion.

Children with the neurological disease myelomeningocele had bone mineral densities one to two standard deviations below the mean of the normal population.<sup>19</sup> Children with neuromuscular disorders, such as cerebral palsy and myelomeningocele, ambulate less than neurologically normal children. Additionally, the lack of the normal muscle tone in



myelomeningocele patients further contributes to osteopenia. Compromised sensation and osteopenia in myelomeningocele patients could lead to an increased risk of hardware failure, malunion, or fracture.<sup>20</sup>

In this study, nonunion treatment consisted of bone edge refreshing, stable fixation using a plate, and bone grafting. These treatment options are similar to treatment for nonunion in adults. To support the poor biologic environment associated with atrophic nonunion, treatment included using a bone graft to ensure mechanical stability. Hypertrophic nonunion was addressed with better skeletal fixation. Bone grafting was used in eleven cases to enhance the union. This study used a reamer irrigation aspiration for autogenous bone grafting to treat pediatric nonunion in three cases without complications.

Despite being one of the largest case series in literature concerning pediatric nonunion, there are some limitations of this study. The small sample size of the study prevented a more advanced statistical analysis. However, the rarity of the aseptic nonunion in pediatric patients precluded obtaining a larger number of cases at one institution. Moreover, there are inherent limitations to the study due to the retrospective nature of this cohort. Further studies with a larger number of cases are needed to establish the risk factors and precautions that can be applied to avoid nonunion among this group of patients. The authors would also like to emphasize that our institution is a tertiary pediatric trauma service, and that these 12 cases represent a small fraction of the pediatric patients whom we treat.

In conclusion, surgeons dealing with pediatric orthopaedists and trauma should not expect successful bone healing in every child without paying attention to the details. Long bone nonunion in children is a rare complication after fractures and osteotomies. The orthopaedists treating nonunion in children should address it appropriately. Care and attention should be paid to the details in order to maintain fracture stability and promote bone healing, especially in patients with poor bone quality due to the associated medical comorbidities. Adequate stable revision fixation in addition to possible bone grafting can achieve union in cases of long bone nonunion in children.

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# The Versatility of Taylor Spatial Frame in Treating Complex Posttraumatic Deformities of The Lower Extremity

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## ABSTRACT

**Background:** The Taylor Spatial Frame (TSF) is a multi-planar external fixator with a computerized web-based program to provide accurate fractures reduction and deformity correction. This study aimed to evaluate our results after the treatment of complex lower extremity injuries with the external fixators including TSF.

**Methods:** This retrospective case series included eight patients with complex lower extremity injuries treated with TSF. The medical records and radiographs were reviewed. The ASAMI score was used as an outcome measure. Statistical analysis used Microsoft Excel descriptive statistics. No inferential statistical tests were done owing to the small sample size.

**Results:** The mean age was 37.5 years (range, 18-70 years). The study included a total of eight patients: seven men and one woman. The anatomic locations were six tibias and two femora. The mean external fixator time (EFT) was 5.2 months (range, 3-6 months). The mean follow-up time was 33.5 months (range, 24-48 months). One patient developed refracture due to premature frame removal (12.5%). Autogenous bone grafting was performed for three patients (37.5%) and was the most common secondary procedure after the index operation. Knee stiffness occurred in two patients (25%). Restoration of limb alignment occurred in all patients. All patients achieved bone union except one who developed nonunion. The ASAMI bony and functional outcome scores were excellent and good in seven (87.5%) and one (12.5%) patient, respectively.

**Conclusions:** TSF can be successfully used to treat various complex fractures, posttraumatic limb deformities, and bone nonunion with high minor complications major rate, intermediate major and 87.5% excellent outcome rate in this series.

**Keywords:** External Fixation Frames, Fracture Malunion, Complex Fractures Nonunion

## INTRODUCTION

The use of circular external fixators have been used effectively in complex lower extremity fractures and posttraumatic deformities. External fixators are successful used for treating acute fractures and late reconstruction after trauma, including bone deformity, nonunion, and segmental bone defects. Furthermore, circular external fixators can be used effectively for high-energy comminuted fractures, fractures with soft tissue envelope, juxta-articular fractures, and fractures with bone loss.<sup>1</sup>

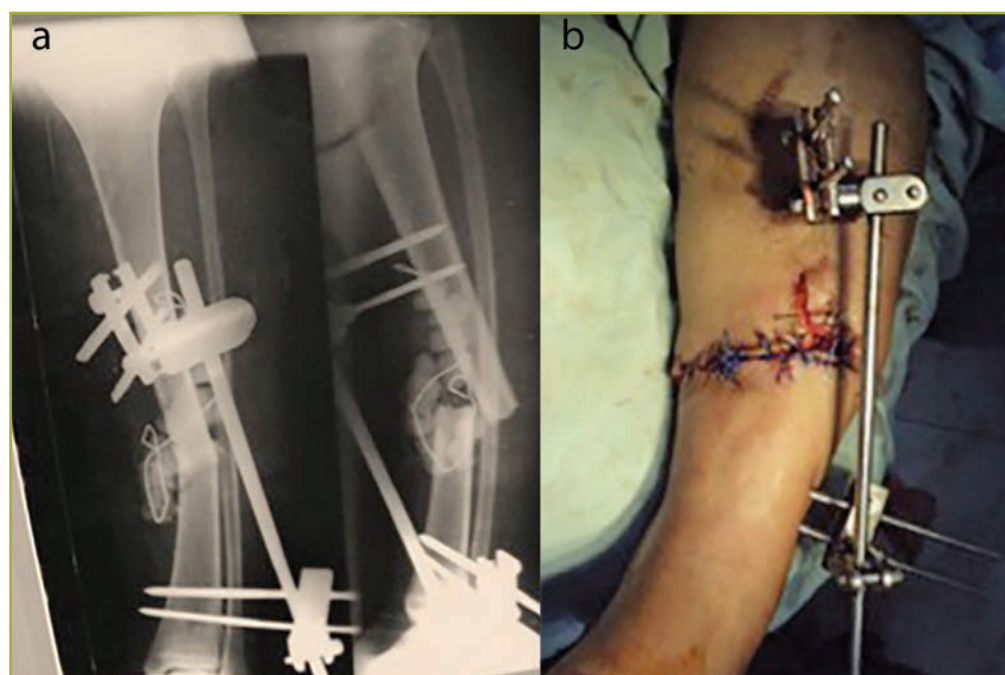
The Taylor Spatial Frame (TSF, Smith and Nephew, Memphis, USA) combines multi-planar fixation, ease of application and computerized accuracy in the reduction of fractures and deformities correction. Furthermore, TSF offers several advantages including reliability, versatility, and accuracy to simultaneously correct deformities in all planes including rotation, angulation, and translation deformities with adjusting only the strut lengths utilizing the virtual hinge concept.

The use of TSF is limited by the cost and other complications, as joints' stiffness and pin site infections. Several studies have demonstrated that the Ilizarov method may be used in conjunction with other treatment modalities to augment healing and corrective techniques.<sup>2-5</sup>

The current study discusses the different ways to use TSF for management of complex lower extremity injuries. The study presents a case series demonstrating the versatility of the TSF as a sole treatment or as an augmentation to other techniques for complex lower extremities injuries.

## METHODS

This retrospective study included eight patients with lower extremity injuries treated with TSF between March 2007 and February 2011. The study was approved by the scientific committee of the Orthopaedic Department, Benha University, Egypt. The medical records and radiographs were reviewed. The ASAMI



**Figure 1.** Case 2 images. A) The fracture position in the uniplanar fixator. B) Primary closure of the wound in the intentional deformity.

**Table 1.** Association for the Study and Application of Methods of Ilizarov (ASAMI) outcome scores

Bony results	
Excellent	Union, no infection, deformity < 7°, limb length discrepancy < 2.5 cm
Good	Union + any two of the following: no infection, deformity < 7°, limb length discrepancy < 2.5 cm
Fair	Union + only one of the following: no infection, deformity < 7°, limb length discrepancy < 2.5 cm
Poor	Nonunion / refracture / union + infection + deformity > 7° + limb length discrepancy > 2.5 cm
Functional results	
Excellent	Active, no limp, minimum stiffness (loss of < 15° knee extension < 15° dorsiflexion of the ankle), no Reflex Sympathetic Dystrophy (RSD), insignificant pain
Good	Active with one or two of the following: Limp, stiffness, RSD, significant pain.
Fair	Active with three or all of the following: Limp, stiffness, RSD, significant pain
Poor	Inactive (unemployment or inability to return to daily activities because of injury)
Failure	amputation

bony and functional scores were used to assess the outcomes, described in detail in Table 1. The treating surgeon used different surgical strategies to address the complexities of the cases. In three patients, TSF struts were used in combination with Ilizarov rings. A uniplanar fixator was used initially followed by application

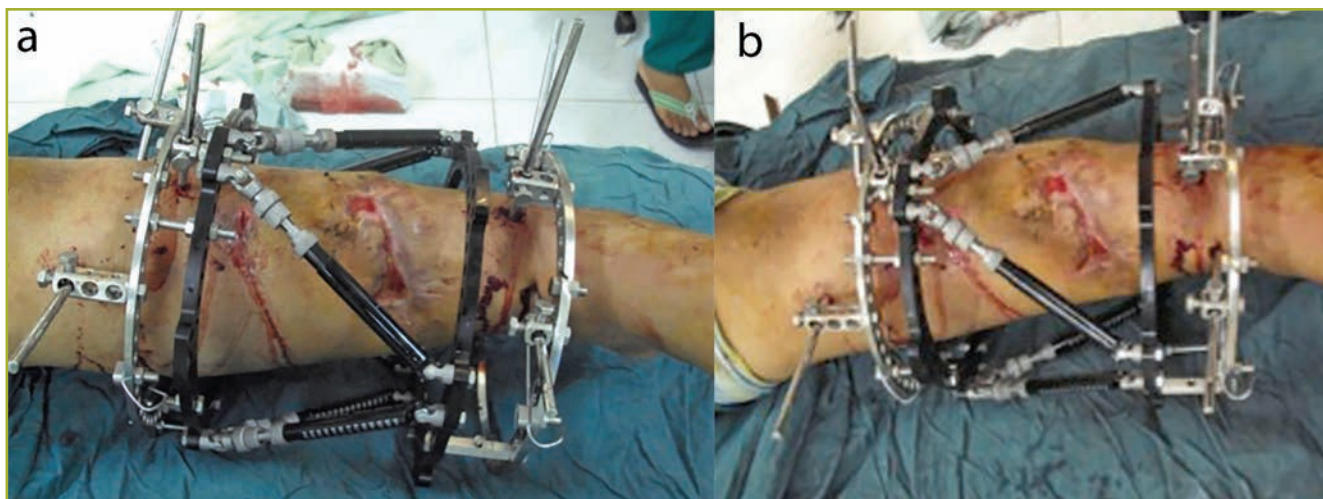
of combined TSF and ilizarov external fixators. The deformity correction was achieved using TSF followed by internal fixation and bone grafting were performed to address the non-union. TSF was used as initial treatment in case 1, definitive treatment in case 2, deformity correction in cases 3 through 5, additional support in case 6, and infection management in cases 7 and 8.

#### Case 1: TSF Used as Initial Treatment

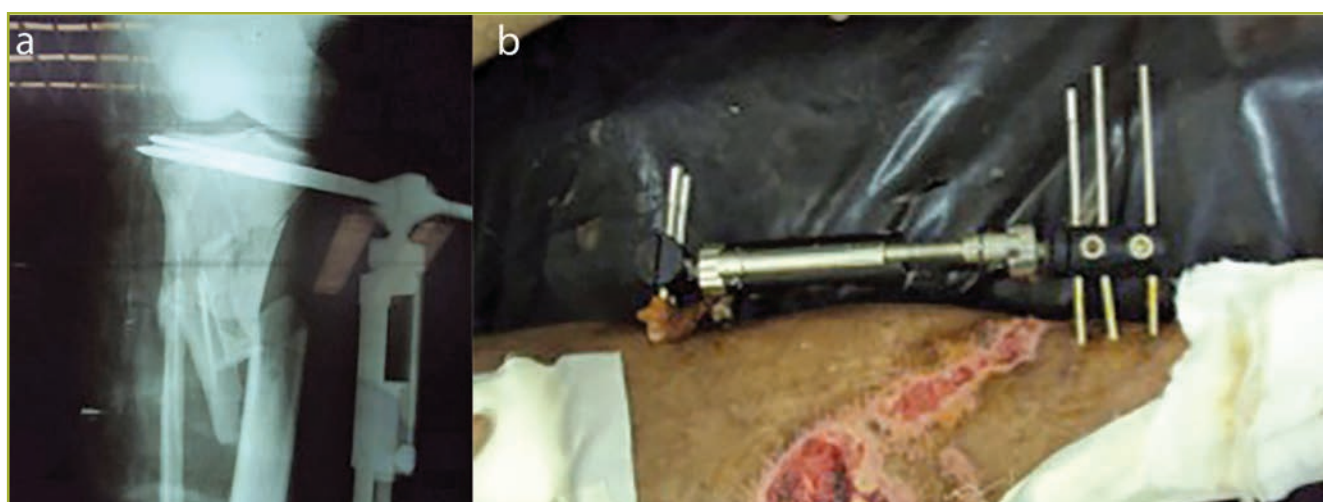
An 18-year-old man sustained a transverse femur fracture shaft. The patient presented 6 weeks after the injury in a mal-reduced position. Combined TSF and Ilizarov construct were used as definitive fixation to gradually to restore the fracture alignment and to achieve bone healing. The fracture went on to healing with normal limb alignment at the final follow-up visit. The ASAMI scores were excellent as follows: active, no limp, full knee and ankle range of motion at final follow up, no reflex sympathetic dystrophy, and insignificant pain reported.

#### Case 2: TSF Used as Definitive Treatment

A 20-year-old woman presented with an open tibial shaft fracture (grade IIIB according to the Gustilo-Anderson classification). Varus, shortening, and internal rotation deformities were intentionally created to assist in wound closure. A uniplanar Hoffman frame (Stryker) was used to hold the fracture, and wound closure was achieved without any plastic surgical intervention (Figures 1A and 1B). After complete wound healing, TSF was applied as the definitive treatment to achieve deformity correction and bone healing (Figures 2A and 2B). The patient developed refracture due to premature frame removal. The refracture was treated with frame reapplication and autogenous bone grafting (ABG),



**Figure 2.** Case 2 images. A, B) Clinical image of the Taylor Spatial Frame combined with the Ilizarov technique after wound healing and correction of the deformity.



**Figure 3.** Case 4 images. A) Radiographic image of the malreduced fracture fixed with the uniplanar fixator. B) Clinical image of the malreduced fracture fixed with the uniplanar fixator.

followed by dynamization of the frame. Bone healing was achieved. The ASAMI bony and functional scores were excellent at the final follow up. .

#### **Cases 3, 4, and 5: TSF Used in Correcting Deformity**

In case 3, a 38-year-old man sustained a medial plateau fracture extended to the proximal tibia, which was treated with screws. The patient developed malunion. The patient presented with varus collapse with knee flexion contracture and medial joint line knee pain. TSF was used to correct varus deformity with lateralization of the mechanical axis to the lateral compartment to achieve pain relief as well as correct the knee flexion contracture by decreasing the knee slope. Knee arthroscopy was performed at the same time to check the internal knee structures and medial knee compartment. The knee ligaments and menisci were intact. At the last follow-up, the patient had complete bony union, deformity correction, full range of motion, and complete pain relief. The ASAMI functional and bony outcome scores were excellent.

Case 4 involved a 32-year-old man who sustained a high-energy fracture of the proximal tibia. Although the patient was treated with a uniplanar frame initially, the fracture was fixed in a mal-reduced position (Figures 3A and 3B). The patient underwent revision fixation with combined TSF and Ilizarov (Figures 4A and 4B). Deformity correction was achieved gradually using the TSF. The patient developed complications of ankle equinus contracture and delayed union. These complications were treated with ABG as a secondary procedure and Strayer gastrocnemius muscle recession to achieve bone union, respectively. Bone healing and restoration of normal limb alignment were satisfactory at the final follow-up.

Case 5 involved a 70-year-old man who presented with proximal tibia fracture nonunion and implant failure. Subsequently, all the hardware was removed and a TSF was applied to achieve deformity correction and bone union. At the final follow-up, normal alignment was restored with good bone healing. The ASAMI functional and bony out scores were excellent.





**Figure 4.** Case 4 images. A, B) Clinical image of the Taylor Spatial Frame combined with the Ilizarov technique after correction of the deformity.

**Case 6: TSF Used as Additional Support in Managing Fragile Bone**

A 62-year-old man presented 6 months after injury with nonunion and deformity of the distal femur (Figures 5A and 5B). The operative plan was to correct deformity using TSF followed by conversion to internal fixation and ABG to achieve healing. The change in the treatment course was enacted to treat the anticipated complication of nonunion, as well as several other reasons: 1) the patient lived in a remote part of the country and could not attend regular follow-up visits during TSF treatment, 2) the patient was not fully compliant with pin care protocol, and 3) the bone quality was poor due to old age. The patient stayed locally during the deformity correction program followed by conversion to plate fixation and ABG. The TSF was held in place for 6 weeks after plate application to increase the stability owing to poor bone quality (Figures 6A and 6B). The author paid attention to the pin sites during the combined period of internal and external fixation. Pins with any suspicious signs of infection were removed immediately to avoid deep infection of the plate. Deformity correction and bone healing were achieved (Figures 7A and 7B).

**Cases 7 and 8: TSF Used in Managing Infection**

In case 7, the patient was a 42-year-old man with a malunited tibial plateau fracture and an infected draining fasciotomy wound. The patient presented with severe varus and internal rotation deformity with a chronic draining wound secondary to fasciotomy. The application of the TSF promoted bone healing while correcting the varus deformity. This patient healed well with acceptable alignment at the final follow-up. The ASAMI functional and bony scores were excellent.

For case 8, an 18-year-old man sustained an ipsilateral transverse femur shaft fracture and open comminuted proximal tibia fracture. The patient presented late with an infected wound of the proximal tibia fracture and non-reduced transverse femur shaft fracture. The mal-reduced femur shaft fracture was treated with a combined TSF and Ilizarov construct. The infected proximal tibia fracture was then treated



**Figure 5.** Case 6 images. A) Anteroposterior and B) lateral radiographic views showing the distal femur fracture nonunion and deformity.

with bone transport after resection of the necrotic bone. A TSF was utilized for fracture reduction. Bone healing and restoration of normal limb alignment were satisfactory at the final follow-up. The ASAMI functional and bony scores were excellent.

**SURGICAL TECHNIQUE**

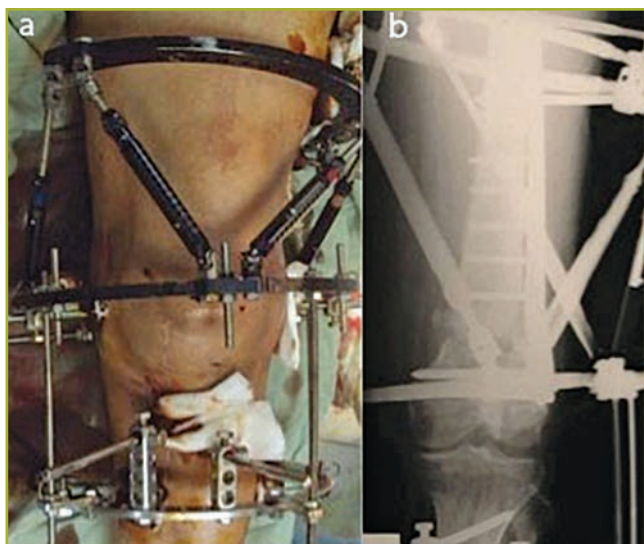
**Preoperative Planning**

Full-length weight bearing lower extremity images as described by Paley and Maar were obtained.<sup>6</sup>

**Operative Technique**

The surgical technique comprised femoral and tibial applications of TSF external fixation with the patient positioned supine. Ring-first technique for TSF application was used in all cases. Intentional bony deformity was created in open fractures to help wound closure followed by gradual deformity correction after wound healing. Extensive soft tissues and bony debridement with or without application of antibiotics beads were done in cases with infection. Femoral arches





**Figure 6.** Case 6 images. A) Clinical image showing Taylor Spatial Frame combined with the Ilizarov after correction of the deformity. B) Radiographic image showing internal fixation with plate and screws combined with external fixation.



**Figure 7.** Case 6 images. A) Anteroposterior and B) lateral radiographic views showing the distal femur fracture healed in the corrected position.

were used in femur frames. The hybrid advanced frame mounting according to Paley et al was used in all cases.<sup>7</sup> The mounting parameters were collected at the end of the surgical procedure.

#### **Postoperative Protocol**

Deformity, frame, and mounting parameters were input into web-based software. A total residual program was used in all cases. Proximal reference was used in four patients and distal reference was used in the other four. Pin site care was done using a daily warm shower. Antibiotics were given to prepare for potential severe pin site infection. Pin removal or irrigation and

debridement were done in case of osteomyelitis at the pin sites. Frames were removed after complete fracture healing as documented by follow-up images. Frame dynamization was done before frame removal. The frame removal was performed in the office, although four patients could not tolerate the pain during removal. The patients were instructed to restrict weight bearing after frame removal to avoid refracture.

## **RESULTS**

The mean age was 37.5 years (range, 18-70 years). The study included a total of eight patients: seven men and one woman. The anatomic locations were 6 tibias and 2 femora. The mean external fixator time (EFT) was 5.2 months (range, 3-6 months). ABG was performed for three patients (37.5%) and was the most common secondary procedure after the index operation. Four patients were treated with only TSF rings and struts and the other four with combined TSF rings and struts attached to Ilizarov rings as the dead frame. Deformity correction and bone healing were achieved in all patients. Seven patients (87.5%) had excellent functional outcomes according to the ASAMI outcome scores. One patient (12.5%) had a good outcome.

#### **Complications**

Pin site infection was encountered in three patients. Pin site infection was grade III and controlled with daily pin care and oral antibiotics. One patient (12.5%) had refracture due to premature frame removal, which was treated with frame reapplication, ABG, and fibular shortening to enhance bone healing. Healing was achieved eventually. Knee stiffness occurred in two patients (25%) and was treated with an intensive physical therapy program after frame removal. One patient (12.5%) in case 4 developed delayed union and ankle contracture, which was successfully treated operatively.

## **DISCUSSION**

TSF has demonstrated its efficacy in treating lower limb deformity.<sup>8,9</sup> The current study results support its efficacy in treating posttraumatic complications. The complexity of these injuries was related to late fracture presentation, bad soft tissue coverage, and initial treatment that complicated with posttraumatic deformities with and without nonunion.

The TSF is a versatile device.<sup>10</sup> In the current study, treatment was customized according to the patient's injury pattern, and TSF was used to achieve reduction followed by conversion to plate fixation and bone grafting. The TSF was left in place around the plate to maximize the stability until complete fracture healing. Complications included grade III pin site infection in three patients (37.5%), refracture due to premature frame removal in one patient (12.5%), knee stiffness in two patients (25%), and delayed union and ankle contracture in one patient (12.5%).

The risk of deep infection when combining both internal and external fixation is serious and well described. Kim et al reported the rate of deep infection in 63 patients with 118 limb segments.<sup>11</sup> Thirteen of the limb segments (11%) developed a superficial infection. The deep infection occurred in six limb segments (5%). The authors confirmed that deep infection of combining internal and external fixation is uncommon but a serious complication.

Wound closure in cases with open fracture can be achieved by the creation of deformity. Sharma and Nuun reported two cases with grade IIIB tibia open fracture.<sup>4</sup> The authors intentionally created bony deformities to help in wound closure. After wound closure, TSF was used to correct the deformity. The authors believed that two factors were important in this technique including soft tissue and bony factors. The soft tissue factors include wounds on the medial side to avoid the stretch of a neurovascular bundle. The unstable fractures with fibula are easier to deform and help in wound closure. Both patients did not need any plastic intervention for wound closure. Other authors have echoed the same results.<sup>12,13</sup>

Correcting deformity, lateralizing the mechanical axis to the lateral compartment, and correcting fixed knee flexion contractures can be done with TSF. The efficacy of TSF in managing posttraumatic deformities is well reported.<sup>14-17</sup> Ganger et al reported 22 patients with posttraumatic deformities treated with TSF.<sup>18</sup> The mean age at time of surgical procedure was 22.7 years (range, 12-48 years) and the mean follow-up was 21.1 months (range, 12-43 months). Deformity correction was achieved in all patients. The authors reported a total of 44 problems, 7 obstacles, and 10 complications during the study period.

Marangoz et al reported 22 femoral deformities in 20 patients treated with TSF.<sup>19</sup> The mean age at the index procedure was 13.9 years (range, 5.9-24.6 years). Deformity and limb length discrepancy correction were achieved in all patients. Infected nonunion is not uncommon after critical bone defects. Circular ring fixators and distraction osteogenesis are useful in this setting for equalizing limb lengths, healing the soft tissues, and eradicating infection.<sup>8,15,20-21</sup> Robinson et al reported the use of TSF for correcting varus deformity and medial compartment osteoarthritis (MCOA) of the knee in nine patients.<sup>9</sup> The mean age at operative procedure was 49 years (range, 37-59 years). Median follow-up was 19 months (range, 15-35 months). The mean Oxford knee score improved from 28.7 preoperatively to 35.4 postoperatively. The survival rate using total knee replacement (TKR) as the endpoint was 88.9%. Alterations in limb length can have significant effects on the patient. After TKR, outcomes of patients having greater than 15 mm of postoperative limb length discrepancy were seen to be lower than those having less than 15 mm of discrepancy.<sup>22</sup> The authors recommended using TSF for correcting varus deformity and MCOA.

Containment of healthcare costs is an important issue especially in institutions with limited resources. Combined TSF and Ilizarov were used to combat the cost of TSF. The costs of TSF rings and struts are expensive. The current study used the combined TSF and Ilizarov in four patients to reduce the TSF costs. The TSF rings were mounted to Ilizarov rings. The Ilizarov rings were attached to the bone with wires and half pins. The TSF program was used to achieve reduction. When reduction was achieved, the TSF rings and struts were removed. Ilizarov was kept in place until fracture healing, allowing recycling and using the TSF in a large number of patients. This protocol greatly helped reduce TSF costs and allowed its use in a large number of patients. This technique has been described in a previous report.<sup>23</sup> The author's institution allowed the recycling of TSF parts. Recycling of external fixators is a controversial topic.<sup>24</sup> Each institution has its policy on reprocessing external fixators. Horwitz et al reported the cost reduction for reusable parts of external fixators at 32% and total saving at 27% for the total external fixator charges.<sup>24</sup> The authors reported no failure of recertified parts during the clinical course of the study. Sung et al conducted a randomized clinical trial of new versus refurbished with consented patients, and the authors reported no statistical differences in the incidence of pin tract infections (46% vs 52%,  $P = 0.32$ ), loss of fixation (4% vs 4%,  $P = 0.70$ ), or loosening of the components (1% vs 1%,  $P = 1.0$ ). The authors found a cost reduction of 25% for all new frames.<sup>25</sup>

The limitations of the current study are the retrospective nature, small sample size, and lack of comparison between TSF and other methods. Despite these limitations, deformity correction and bone healing were achieved in all patients with low complication rates. Further prospective studies with a larger sample size may be needed to show the benefits of TSF over alternative methods. In conclusion, TSF can be effective, accurate, and safe in the correction of posttraumatic deformities.

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# Side-by-Side Comparison of 4-Strand Versus 5-Strand Hamstring Graft Diameters in Patients Undergoing Anterior Cruciate Ligament Reconstruction

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## ABSTRACT

**Background:** Hamstring (HS) graft size is an independent risk factor in determining outcomes related to anterior cruciate ligament reconstruction (ACLR). Although anthropometric correlations with HS tendon size have been studied, a predictable association with resultant graft size has not been established. This study directly compares the difference in diameter between a 4-strand (4S) and 5-strand (5S) HS autograft in the same patient.

**Methods:** A total of 31 consecutive patients undergoing ACLR with HS autograft were included in the study. The gracilis and semitendinosus tendons were harvested for each patient. The diameters and lengths of a standard 4S HS graft followed by that of 5S HS graft with a tripled semitendinosus tendon were measured and recorded for each patient.

**Results:** There were a total of 17 males included in the study, with an average age of 32.7 years. The average 4S HS graft measured 7.2 mm in diameter versus the 5S graft that averaged 9.0 mm in the same patient, with an average increase of 1.8 mm ( $P < 0.001$ ). The calculated cross sectional area for a 4S HS graft was 40.7 mm<sup>2</sup> versus 63.6 mm<sup>2</sup> for a 5S graft ( $P < 0.001$ ).

**Conclusion:** This is the first study to directly compare the difference in diameter between a 4S and 5S HS autograft in the same patient. A 5S graft reliably increases the diameter of a HS autograft in the same patient by at least 1 mm without sacrificing graft or tunnel length to a degree that may be detrimental to the overall quality of the reconstruction.

**Keywords:** Anterior Cruciate Ligament, Anterior Cruciate Ligament Reconstruction, Autograft, Hamstring

## INTRODUCTION

The incidence of primary anterior cruciate ligament reconstruction (ACLR) in the United States rose from an estimated 87,000 to 130,000 cases from 1994 to 2006.<sup>1</sup> Multiple graft options exist for reconstruction, including bone-patellar tendon-bone (BPTB) autograft, hamstring (HS) tendon autograft, quadriceps tendon (QT) autograft, and allograft tissue. Many factors influence graft selection such as surgeon training, experience, and patient factors.<sup>2,3</sup> Although several studies have shown no difference in outcomes between BPTB and HS autografts, some recent literature suggests that HS autografts may be associated with higher rates of failure.<sup>4,5,6,7</sup>

HS graft size has been shown to be an independent risk factor in determining outcomes related to ACLR. In 2012, Magnussen et al<sup>8</sup> reported that use of HS autografts with a diameter greater than 8.0 mm was associated with a lower rate of revision ACLR. Several other studies have confirmed these results, and it has become well established that a graft diameter of 8 mm or greater can play a role in minimizing the risk for graft rupture.<sup>9,10,11</sup>

For HS autografts, it can be difficult to make an accurate preoperative prediction of the size of the harvested tendons and diameter of the eventual graft. Although some studies have correlated certain anthropometric indices to the diameter of the gracilis and semitendinosus tendons, a reliable model to predict the eventual size of the autograft has not been well established.<sup>12</sup> Given these limitations in predicting graft diameter, there has been interest in investigating techniques and methods to increase the overall diameter of the HS graft without compromising its structural integrity.



To our knowledge, no direct comparison has been made of the diameter, cross sectional area, and graft length in the femoral tunnel and tibial tunnels between a 4-strand (4S) and 5-strand (5S) HS graft in the same patient. We hypothesized that a 5S HS autograft, when compared to a 4S HS autograft in the same patient, will increase the diameter significantly to a value of at least 8 mm while providing adequate graft within both the femoral and tibial tunnels for fixation.

## METHODS

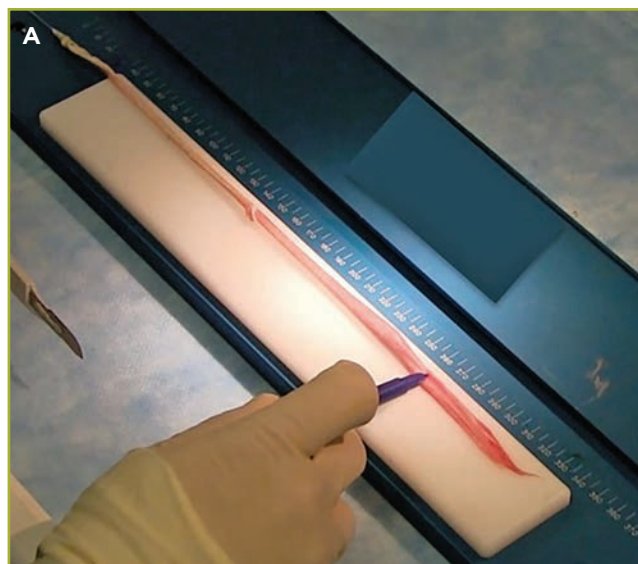
### *Patient Selection*

A total of 31 consecutive patients undergoing ACLR with HS autograft were included in the study. Inclusion criteria included any patient older than 18 years undergoing a primary ACLR with HS autograft. Exclusion criteria included multi-ligament knee injury and history of previous ACLR. The local Institutional Review Board granted exempt status for the study.

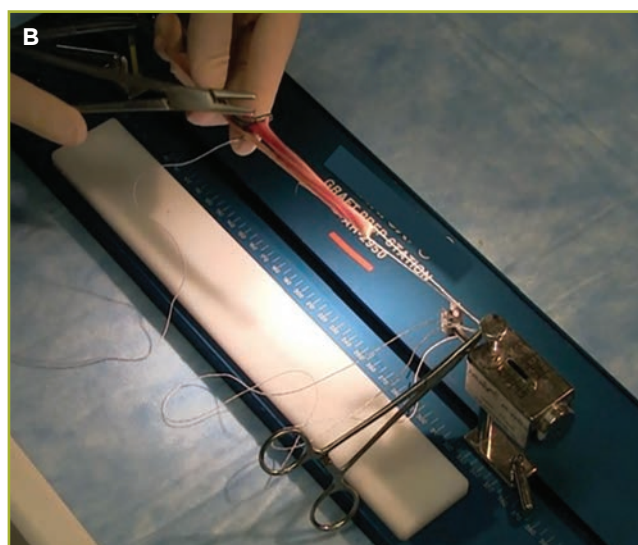
### *Surgical Technique*

All grafts were obtained by a single orthopaedic surgeon proficient in HS tendon graft harvest (GT). The HS tendons were harvested in a standard fashion using a 3 cm oblique incision centered over the pes anserine tendon insertion. The gracilis and semitendinosus tendons were released from their distal attachment on the tibia and sequentially harvested using a closed tendon stripping device. All measurements were obtained after blunt removal of attached muscle and fat, but this was completed before any further postharvest alteration or graft trimming. The 4S HS graft was prepared by folding over (doubling) both the gracilis and semitendinosus tendons. Graft size was measured with a standard non-slotted sizing block (Smith & Nephew, Memphis, TN) that allows measuring differences of 0.5 mm in diameter. The 4S graft diameter was determined when the entire quadrupled graft, including the most distal portions of the HS tendons, fit through the sizing block and would not fit through the next 0.5 mm smaller size.

After sizing of the 4S graft was complete, the 5S graft was constructed. Based on a target graft length of 85 mm for females and 95 mm for males, the musculotendinous junction of the semitendinosus tendon was cut to a length 3 times the desired graft length. Similarly, the gracilis was cut to a length twice the desired graft length. After the tendons were prepared, the semitendinosus tendon was divided into thirds with a marking pen (Figure 1). The proximal one-third of the semitendinosus tendon was then folded back onto itself and secured with #2 Fiberwire (Arthrex, Naples, FL) suture (Figure 2). The graft was then placed under tension to ensure that all tissue was under uniform tension. The looped end of the semitendinosus tendon was secured with a #2 Fiberwire whipstitch. The gracilis and semitendinosus tendons were combined and folded in half, creating the 5S construct (doubled gracilis and tripled semitendinosus) (Figures



**Figure 1.** Using a marking pen, the semitendinosus tendon is divided into thirds based on overall measured



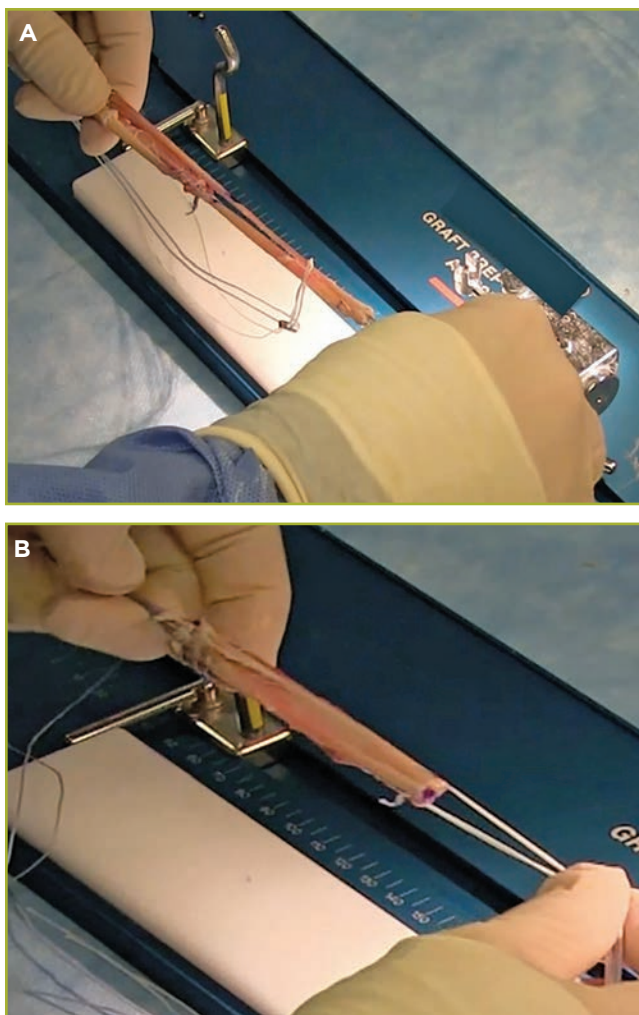
**Figure 2.** Folding one-third of the semitendinosus tendon onto itself, and securing it with a non-absorbable suture.

3A and B). The 5S graft was then measured using the same technique described for the 4S graft.

All patients had an ACLR performed with independent femoral tunnel drilling. The femoral socket was drilled from inside-out with a cannulated drill (Arthrex, Naples, FL). The tibial tunnel was made with a cannulated drill. Both tunnels were made according to the measured graft diameter. Using a modification to the technique previously described by Lavery et al,<sup>13</sup> the graft was then fixed with an ACL femoral Tight Rope (Arthrex, Naples, FL) (Figures 4A and B). Tibial fixation was performed with a Graftbolt PEEK sheath and screw (Arthrex, Naples, FL) for every case.

### *Statistical Analysis*

A student *t* test was used to compare the averages of the diameter and calculated cross sectional area for

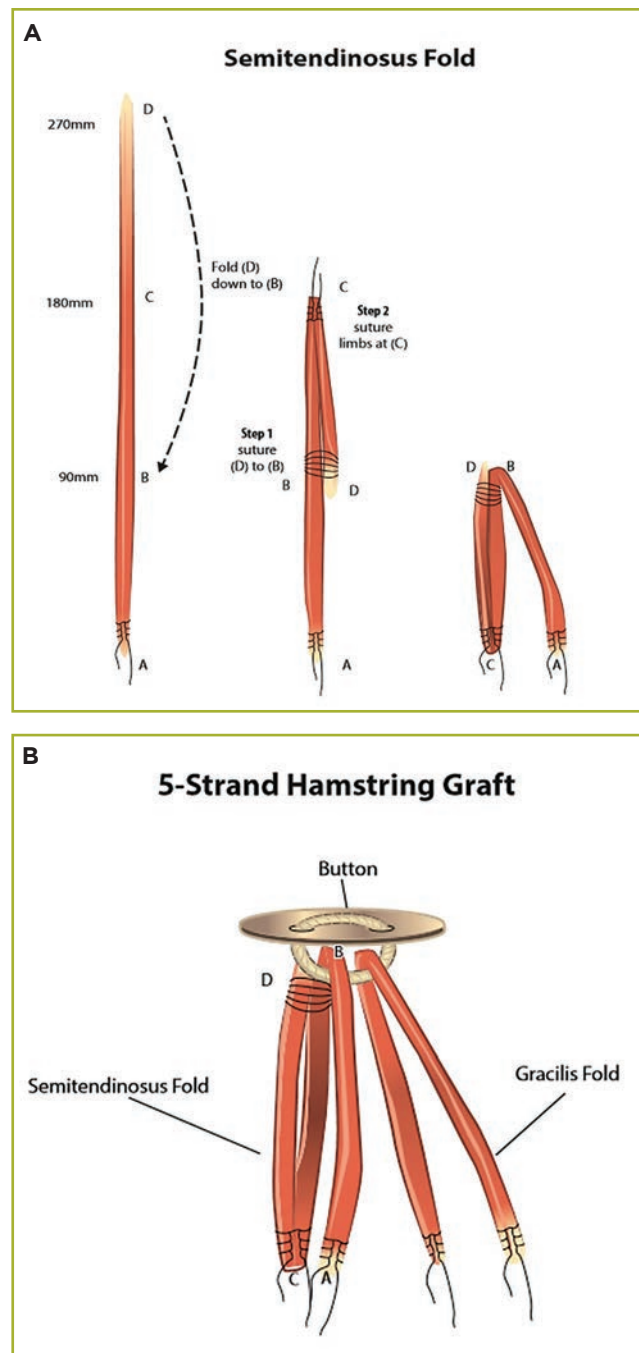


**Figure 3.** A, B) The gracilis and semitendinosus tendons are then combined and folded in half, creating the 5-strand graft (doubled gracilis and tripled semitendinosus).

both the 4S and 5S grafts. Statistical significance was based on an assumed value for the Type I error of 0.05. A linear regression model was utilized to determine if any relationship existed between patient height and weight measurements and patient-specific 4S and 5S graft diameters.

## RESULTS

A total of 31 HS autograft tendon pairs were harvested and analyzed. The average age of the patients was 32.7 years, with 55% of the patients male. The average subject height was 171 cm, with an average body mass index of 28.6 kg/cm<sup>2</sup> (Table 1). The average 4S HS graft measured 7.2 mm (range, 6.5 - 8.0 mm) in diameter versus the 5S HS that averaged 9.0 mm (range, 7.5 - 9.5 mm) in the same patient, with a total of 5 of the 31 5S HS grafts measuring between 7.5 and 8.0 mm. This was a statistically significant increase of 1.8 mm in graft diameter ( $P < 0.001$ ). Similarly, there was a statistically significant increase in calculated cross sectional area from 40.7 mm<sup>2</sup> to 63.6 mm<sup>2</sup> when going from a 4S HS to



**Figure 4.** A) Diagram depicting the technique to triple the semitendinosus tendon. B) The three equal-length tendon strands of the tripled semitendinosus and the doubled gracilis are fixed through the Tight Rope (Arthrex, Naples, FL) to complete the 5-strand HS graft.

5S HS graft, respectively ( $P < 0.001$ ) (Table 2). The average graft length in the tunnel was 26 mm (range, 20 - 30 mm) and all grafts ended at the external tibial aperture distally. There was no association between patient weight and diameter of the 4S or 5S graft. However, there was a weak association noted between patient height and the 4S graft diameter [ $P = 0.002$ , 95% confidence interval (CI) (0.0085, 0.033)] as well as the 5S graft diameter [ $P = 0.0001$ , 95% CI (0.017, 0.047)].

**Table 1. Patient characteristics**

<b>Mean age at time of surgery</b>	32.7 (15-68)
Years (range)	
<b>Sex</b>	
Males (%)	17 (55)
Females (%)	14 (45)
<b>Anthropometric Measures</b>	
Mean Height, cm (range)	171.0 (152.4-188.0)
Mean Weight, kg (range)	83.2 (58.8-123.6)
Mean body mass index, kg/cm <sup>2</sup>	28.6

**Table 2. Intraoperative 4-strand and 5-strand graft dimensions**

	<b>4-Strand</b>	<b>5-Strand</b>
Graft diameter, mm (range)	7.2 (6.5 - 8.0)	9.0* (7.5-9.5)
Graft calculated cross-sectional area, mm <sup>2</sup>	40.7	63.6*
Graft length, mm		
Male	Not available <sup>a</sup>	96.5
Female	Not available <sup>a</sup>	84.3
Graft in femoral tunnel, mm (range)	Not available <sup>b</sup>	26 (20-30)

\*Indicates significance with *P*-value of <0.001

<sup>a</sup>Graft length was not measured for the 4-strand graft as this has not historically been a concern after 4-strand graft preparation

<sup>b</sup>All anterior cruciate ligament reconstructions were completed with the 5-strand hamstring graft, thus 4-strand graft in femoral tunnel was not measured and similarly has not been a historical concern.

## DISCUSSION

ACL HS autograft size has been established as an important variable in improving biomechanical properties and clinical outcomes related to ACLR. This study shows that despite known physiologic variability in HS tendon size and length, there is a significant increase in HS autograft diameter of at least 1 mm when utilizing a 5S versus a 4S HS tendon graft in the same patient. Perhaps more importantly, the average cross sectional area of the graft increased by 56.2%, from 40.7 to 63.6 mm<sup>2</sup>. This illustrates the exponential relationship of cross sectional area to the radius of the graft and correlates to an increased strength of the graft. For solid cylindrical materials, the strength is proportional to the radius to the 3<sup>rd</sup> power, and stiffness is proportional to the radius to the 4<sup>th</sup> power. The average graft length in the femoral tunnel for the 5S HS graft was 26 mm, with an absolute minimum of 20 mm for the 31 patients evaluated.

Inadequate ACL graft size has been implicated as a cause of ACLR failure. Some failures have been attributed to insufficient graft diameter, with several studies providing convincing evidence that a diameter greater than 8 mm may be optimal.<sup>8</sup> The Multicenter Orthopaedic Outcomes Network (MOON) study group retrospectively reviewed 263 consecutive patients and found that a younger patient age and smaller HS

autograft size was a predictor of poorer subjective patient outcomes.<sup>9</sup> However, when young patients (< 20 years old) underwent reconstruction with grafts larger than 8 mm diameter, the failure rate in the MOON study reduced from 18.3% to 0%, a finding similar to outcomes in the study by Magnussen. In a recent systematic review, there was a 6.8 times greater relative risk of failure of HS autograft ACL reconstructions for graft diameters equal to or less than 8 mm.<sup>10</sup> Furthermore, Spragg et al<sup>11</sup> found that grafts ranging from 7 to 9 mm in diameter have a 0.82 times lower likelihood of requiring revision surgery with every 0.5-mm incremental increase in diameter.

It has been shown that a quadrupled HS tendon has greater initial biomechanical strength than a matched patellar tendon and is sufficient for use in ACLR.<sup>14</sup> However, there is recent evidence suggesting that tensile strength is highly dependent on graft diameter.<sup>15</sup> Boniello et al<sup>15</sup> showed that there was a statistically significant increase in tensile strength with increasing graft diameter for quadrupled HS tendon grafts measuring between 6 and 9 mm in diameter. They also noted that increasing HS graft diameters by 1 mm may dramatically affect graft strength. Calvo et al<sup>16</sup> showed that converting to a 5S graft in patients with diameters less than 8 mm resulted in re-rupture rates no different than those patients with 4S grafts greater than 8 mm.

Although several studies have attempted to predict HS tendon autograft size prior to harvest,<sup>12,17,18</sup> a reliable model to predict the eventual size of the quadrupled HS autograft tendon does not exist. Patient height and weight have been proposed as surrogate markers for HS tendon length and size; however, this is not a universally accepted model. The current study showed that 1) no relationship existed between HS graft diameter and patient weight, and 2) there was only a weak correlation for graft diameter and patient height. Graft configurations that exceed the 8 mm threshold decrease the need for such predictions. Several approaches have been examined for grafts measuring less than 8 mm in diameter, including allograft supplementation, contralateral HS harvest, and graft preparation configurations that triple or quadruple one or both of the tendons. Techniques for 5S HS graft reconstruction have been discussed in the literature.<sup>13</sup> Tutkus et al<sup>19</sup> collected data on 122 adult patients undergoing ACLR and found that preparation of a 5- or 6-strand HS graft yielded graft diameters larger than 8 mm in 98.4% of cases.

Furthermore, it has been recognized that graft preparation can change tendon size and dimensions. In a recent study, Cruz Jr. et al<sup>20</sup> investigated how the size of HS tendon allograft changes as they are prepared for ACLR. They found that the average diameter of HS ACL grafts decreases by almost 1 mm after being subjected to both tension and circumferential compression within a standard cylindrical sizing block. The measurements found in the current study likely



fall on the lower end when compared to retrospective studies in the literature. The tendons were first passed and compressed through the sizers for the 4S measurements prior to preparation of the 5S construct and then further compressed and tensioned. Further, grafts were passed through sequentially smaller sizers until they would not fit, resulting in the lowest possible number being reported for each graft. Despite this, the current study grafts averaged 9.0 mm in diameter, which we believe compares favorably with the existing data from retrospective studies. Additionally, most patients increased their graft diameters by more than 1.0 mm when going from a 4S to 5S construct. We did have one patient with a 5S graft diameter of 7.5 mm. This patient had a 4S graft diameter of 6.5 mm, and a 5S graft was used for this patient. However, a 6S graft can be created with tripling of the gracilis tendon in the same fashion described for the semitendinosus, further increasing the graft diameter.

Other than graft diameter, the available graft length for fixation in the femoral tunnel has been cited as a potential source of failure. Some critics have noted that the overall HS graft length is decreased by increasing the HS graft diameter, thus the amount of graft in the femoral and/or tibial tunnels may be compromised. Qi et al<sup>21</sup> published a series of 40 adult canines that underwent ACL reconstruction with Achilles tendon grafts with varying graft lengths in the tibial bone tunnels. They found that the histologic maturity and biomechanical strength of the bone-tendon junction after ACL reconstruction were delayed if the intra-tunnel graft length was less than 15 mm. Mariscalco et al,<sup>22</sup> studied this question and showed no difference in 2-year patient-reported outcome scores between patients with graft length in the femoral tunnel less than 25 mm and those with graft length in the femoral tunnel of at least 25 mm. They concluded that as little as 15 mm of intra-tunnel length in the femur can be used without adverse consequences. All patients in the current study had 5S grafts that averaged over 25 mm in the femoral tunnel, with a minimum intra-tunnel length of 20 mm, and had adequate length to reach the external tibial aperture distally.

#### **Limitations**

One limitation of this cross-sectional cohort study is that only graft diameter, length, and calculated cross-sectional area were evaluated. Although previous research has illustrated crucial concepts that could be inferred and extrapolated to this study, the design of the study is such that long-term clinical outcomes still need to be performed and thus no clinical conclusions can be drawn. Standard surgical measuring methods with a simple surgical hand ruler and standard graft-sizing block were used for all measurements rather than digital calipers with micrometer increments; therefore, the measurements are subject to some variability. In addition, a single fellowship-trained orthopaedic surgeon performed all graft measurements, thus inter-

and intra-rater reliability was not performed. However, previous studies show excellent to near-perfect inter-rater reliability when measuring these variables.<sup>20,23</sup> Although gender was recorded, the analysis of different subgroups with respect to gender should be based on large samples to objectively reveal reliable differences. Since this study was based on consecutive patient encounters, it was difficult to control for potential confounding variables that may influence the final data interpretation.

To our knowledge, this is the first study to directly compare the difference in diameter between a 4S and 5S HS autograft in the same patient. Assuming that larger graft diameters and surface area leads to improved clinical outcomes and biomechanical properties, a 5S graft can reliably increase the diameter of a HS autograft in the same patient by at least 1 mm without sacrificing graft or tunnel length to a degree that may be detrimental to the overall quality of the reconstruction. Further studies are needed to determine if this translates into improved clinical outcomes with lower risk of graft failure and need for subsequent revision.

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# COVID-19: The New Mexico Experience and Background

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## ABSTRACT

**Introduction:** The novel Coronavirus Disease 19 (COVID-19) identified in December 2019 and the associated pandemic has temporarily changed the way that we conduct medicine, allocate resources, and educate resident and fellows. The present investigation is a summary of The University of New Mexico clinical experience managing the sudden surge of critical patients, personal protective equipment management (PPE), and resident education.

**Methods:** We evaluated and analyzed the data related to the COVID-19 pandemic patient load and management in New Mexico, the formation of teams to protect the providers from simultaneous exposure, the resident experience, the PPE management, and the change in trauma load due to social distancing.

**Results:** The timeline of infection was as expected, with the slowing of infection as social distancing measures increased. The hospital census and availability of intensive care unit (ICU) beds to care for COVID-19 patients was maximized, and the management of this situation was immediate and effective with conversion of hospital floors to non-COVID ICUs. The trauma census decreased during this time as compared to the same time period the year prior. The resident experience in education continued to be positive with zoom patient sign out and continued education conference with faculty members. There was a considerable emphasis shift towards provider wellness and safety.

**Conclusion:** The COVID-19 pandemic will leave long lasting effects in the way we educate, manage patient care, and utilize resources. The experience, albeit

difficult with significant negative impacts, will likely lead to improvement in the way we conduct ourselves in the various aspects of medical care and training.

**Keywords:** COVID-19, Personal Protective Equipment, Orthopaedics, Resident Education

## INTRODUCTION

On December 31, 2019, the Chinese government received the first reports of patients suffering from pneumonia-like symptoms out of the city of Wuhan.<sup>1</sup> Since that time, the causative pathogen, severe acute respiratory syndrome Coronavirus 2 (SARS-CoV-2) and its associated illness Coronavirus Disease 19 (COVID-19), has spread to over 200 countries and has infected almost 4 million people.<sup>2</sup> Mathematical models predicted that the infection toll will rise to 3 million in the United States alone.<sup>3</sup> The large, swift increase in cases necessitated the cooperation of government and healthcare leadership to introduce measures for slowing the spread of the disease and making available resources to adequately treat those afflicted and to protect caregivers.

SARS-CoV-2 is an enveloped, positive-sense, single-stranded ribonucleic acid virus. It is thought to be shed from its host through bodily fluids (eg, saliva, feces, urine, and respiratory droplets) and subsequently transmitted via fomites, droplets, and the feco-oral route.<sup>1</sup> Once it enters the new host, it is thought to infect pneumocytes through the angiotensin-converting enzyme 2 receptor.<sup>1</sup> The ensuing lung tissue destruction and cytokine storm then produces the classic symptoms of COVID-19 (ie, fever, cough, dyspnea, and in severe cases, respiratory failure).<sup>1</sup> Many patients also exhibit bilateral patchy infiltrates on chest x-rays, further

clarified as ground-glass opacities on chest computed tomography (CT) scans.<sup>4</sup> Although many early patients showed the expected symptoms, evidence of unusual presentations began to emerge as testing became more widely available. Asymptomatic patients and patients with olfactory and gustatory changes, diarrhea, and headaches began testing positive for the virus or showing suspicious findings on chest CT.<sup>5</sup> The incubation period for SARS-CoV-2 is estimated to range from 2 to 14 days, during which the asymptomatic carrier is still able to actively shed the virus.<sup>1</sup> This range is considerably longer when compared to those of recent epidemics, including Severe Acute Respiratory Syndrome Coronavirus 1 (SARS-CoV-1), Middle East Respiratory Syndrome Coronavirus (MERS-CoV), H1N1 influenza, and seasonal influenza.<sup>1</sup> The variety of presentation symptoms, including asymptomatic infection combined with the lengthy incubation period, results in high infective potential.<sup>1</sup> Interestingly, the basic reproductive number  $R_0$ , defined as the number of new cases generated by one existing case, is reported to be 2 to 2.5 for COVID-19, which is almost double the  $R_0$  of influenza (1.3).<sup>1</sup>

Of the 3.9 million people that have been infected worldwide, approximately 270,000 have died.<sup>2</sup> Mortality rates are not distributed equally across age groups, with those older than 60 years and those with underlying comorbidities suffering disproportionately higher rates of death and disability.<sup>1</sup> The burden of disease has been felt around the world. Orthopaedic surgeons in hard-hit nations, such as China and Italy, have been forced to restructure their daily operations to continue giving necessary care to orthopaedic patients while rationing finite resources.

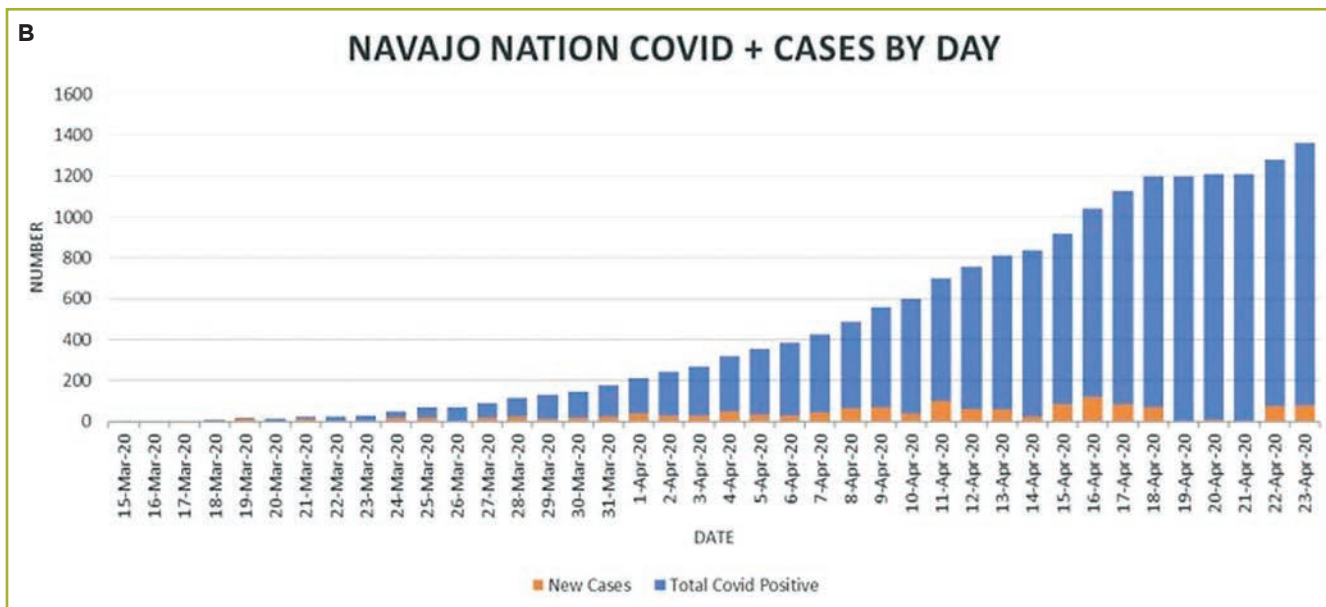
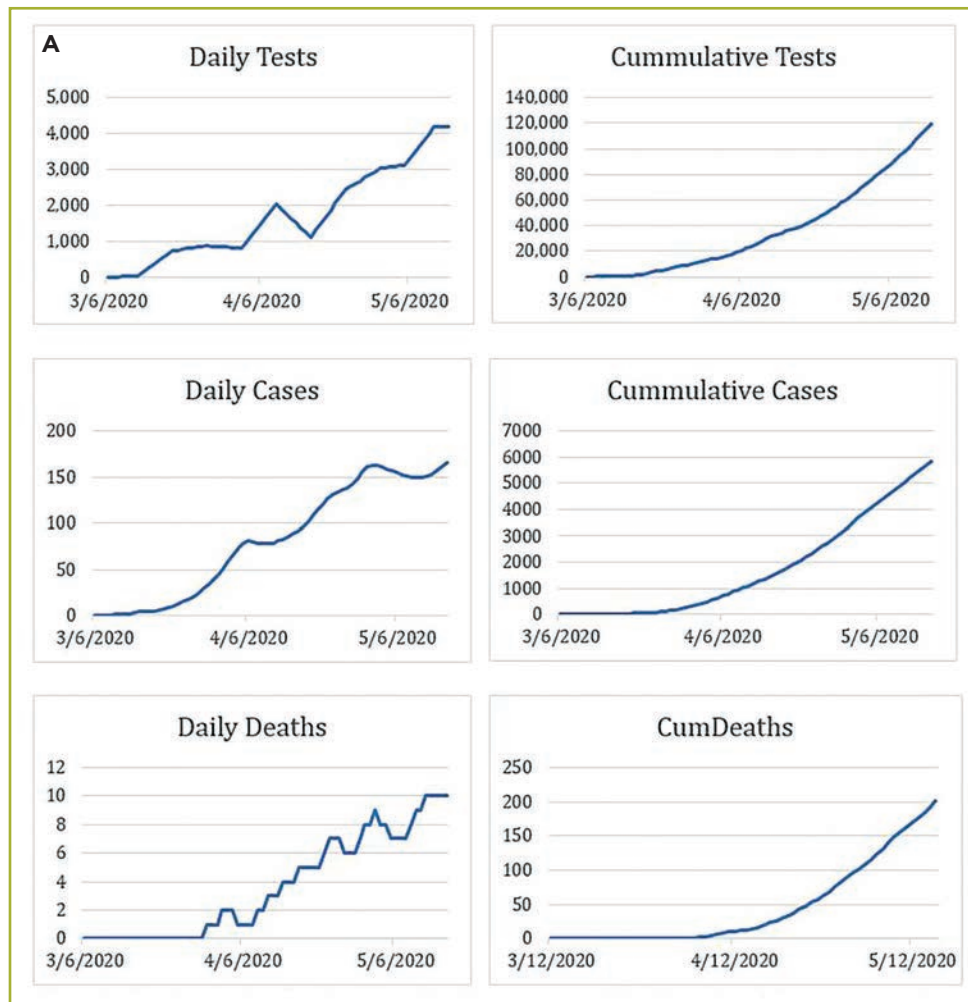
Although the healthcare infrastructures of China, Singapore, and Italy are all different from each other, all have adopted similar management strategies to deal with the COVID-19 pandemic. Each has initiated testing and subsequent segregation of suspected COVID-19 patients. The first widely available test was a reverse transcription polymerase chain reaction (RT-PCR) test of oropharyngeal specimens (reported sensitivity of 66 to 80%).<sup>1</sup> Due to the low sensitivity rate and initially lengthy turnaround time of the test, ground glass opacities on chest CT scan and recent (ie, within 3 weeks) febrile or respiratory symptoms were also criteria used to place patients in suspected COVID-19 isolation.<sup>6,7</sup> One study in Thailand reported three consecutive negative RT-PCR tests as their benchmark of downgrading isolation protocol.<sup>7</sup> Another commonality was the formation of a multidisciplinary overseeing board that included orthopaedic, anesthesiology, and hospital leadership.<sup>8,9</sup> With the input of all involved parties, decisions were made on parameters of preoperative respiratory clearance, current hospital needs and resources, and conditions of discharge from the hospital.<sup>8</sup> All elective procedures were cancelled or postponed, although the scope of the word “elective” is at the discretion of the overseeing multidisciplinary board.<sup>9</sup>

Cases that could tolerate spinal or regional anesthesia were performed under such to prevent possible virus aerosolization during intubation and further respiratory demand placed by general anesthesia.<sup>4,8,10</sup> This underlined the importance of personal protective equipment (PPE) for healthcare workers and was repeatedly stressed. For orthopaedic surgeons, assistants, and any operating room staff, full PPE (ie, N95 masks, eye protection, disposable gowns and gloves) was initially recommended for all case types. However, this was modified to interacting with any patient who had suspicious examination findings for COVID-19, or could not participate in screening due to unconsciousness or altered mental status.<sup>6,7,10</sup> Confusion occasionally persisted as Guo et al<sup>11</sup> recommended inpatient orthopaedists donning N95 masks at all times while in the hospital.

In China, the most common fracture sustained after the onset of the virus and government-enforced quarantine was proximal femur fracture resulting from a fall from standing.<sup>6</sup> Recommendations for fracture care from the Hubei province included opting for nonoperative fracture management if possible; negative pressure operating rooms for those undergoing surgical management; and close postoperative monitoring for acute decompensation, given the higher risk of COVID-19-related morbidity and mortality in elderly patients with fractures.<sup>6</sup> Orthopaedists in the Lombardy region of Italy recommended that elderly patients with hip fractures undergo operative treatment if they could tolerate surgery, stating that the improvement in respiratory parameters observed postoperatively is likely due to better upright positioning and decreased opioid use.<sup>4</sup> To relieve the burden on the main hospital and free up intensive care unit (ICU) beds, medical groups in northern Italy set up an orthopaedic hospital for patients with time critical elective procedures and those with minor orthopaedic traumas that did not require multidisciplinary care.<sup>8</sup> Singapore adopted methods to limit the number of people physically in the hospital. More time was encouraged between non-urgent outpatient follow-up appointments.<sup>12</sup> Rotating, segregated orthopaedic teams were deployed to decrease disease spread amongst the department.<sup>12</sup> Residency training was restructured to include online procedure videos and virtual lectures and meetings.<sup>12</sup> This tactic was employed world-wide and was introduced locally at the end of March. The following timelines are representative of our regional experience.

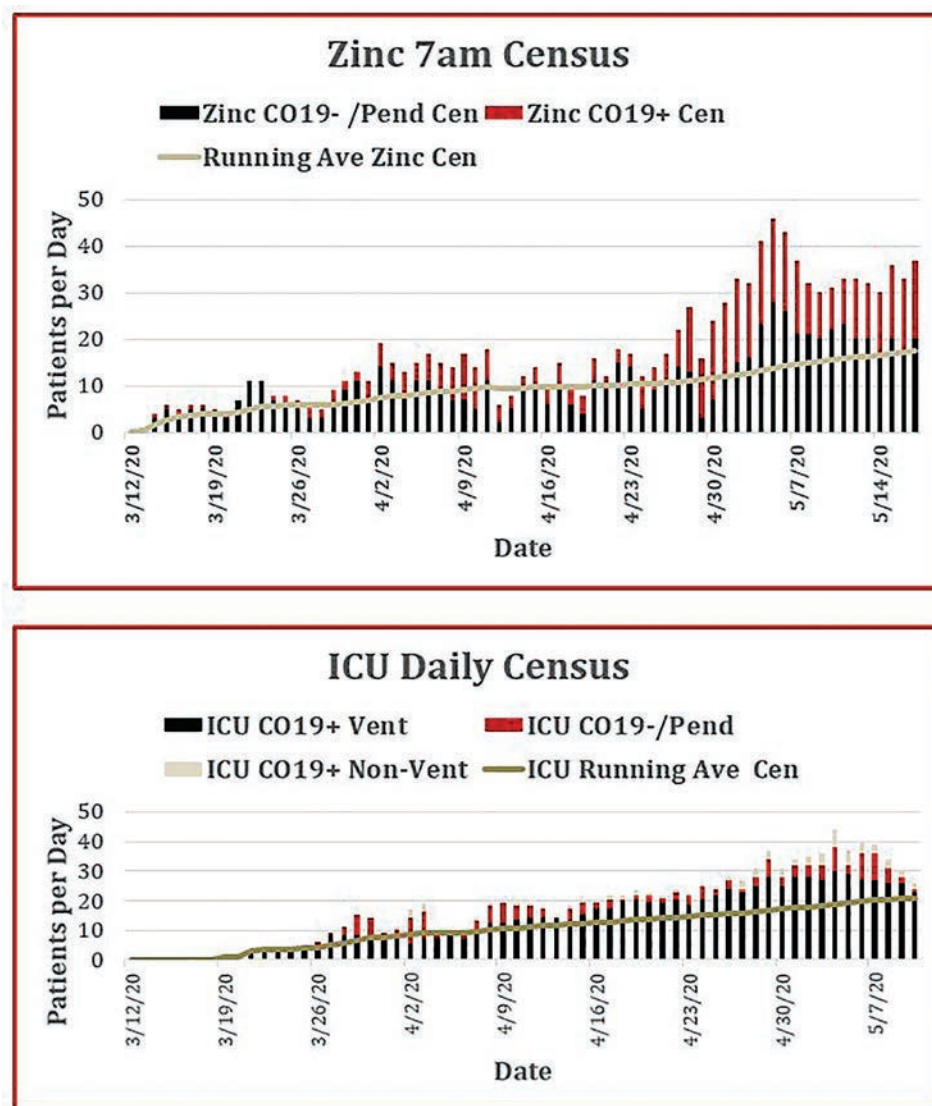
#### ***Timeline in New Mexico***

March 6:	Testing began
March 10:	First positive result
March 12:	Gatherings restricted
March 13:	Educational facilities closed
March 16:	Some businesses closed
March 23:	First reported death in New Mexico from COVID-19
March 24:	All non-essential businesses closed



**Figure 1.** A) Charts showing the timeline of testing, cases, and deaths in the state of New Mexico. B) The Navajo Nation hot spot changed the time line in New Mexico. Data was taken from: <https://covid19.healthdata.org/united-states-of-america/new-mexico>.





**Figure 2.** Charts showing the timeline of cases at The University of New Mexico Health Science Center. Reprinted with permission.

Charts of the number of tests, number of positive COVID-19 cases, and deaths in New Mexico from March 6, 2020 to May 6, 2020 are shown in Figure 1.

**Timeline at The University of New Mexico Health Sciences Center (UNM HSC)**

- March 12: First COVID-19 patient admitted to UNM HSC
- March 16: UNM HSC non-medical staff work from home
- March 20: Medical appointments and elective surgeries at UNM HSC cancelled

Charts of the daily census of COVID-19 patients and ICU patients at UNM HSC are shown in Figure 2.

**PROVIDER SAFETY AND PATIENT CARE**

In response to the COVID-19 pandemic, The University of New Mexico’s Department of Orthopaedics implemented a “team-based” approach to COVID-19, with provider safety, patient care, and preservation

of the resident educational experience as the primary goals. As the only level one trauma center in New Mexico, it was vitally important to protect our most important asset, our healthcare providers and support staff, in an effort to be able to continue excellent care to the citizens of our state.

Based on information provided from the Orthopaedic Trauma Association and information gleaned from experiences in New York, China, Singapore, and Italy, the department was divided into four main teams comprised of faculty from various subspecialties and an appropriately-sized resident workforce. This team-based approach was carefully planned and vetted weeks before the COVID-19 pandemic became a threat. Two teams each were assigned to either UNM hospital or Sandoval Regional Medical Center. One team covered call responsibilities at their respective hospitals while the other team stayed “home.” Every 7 days, the teams would switch roles. This worked to separate the individual providers to minimize the risk of large

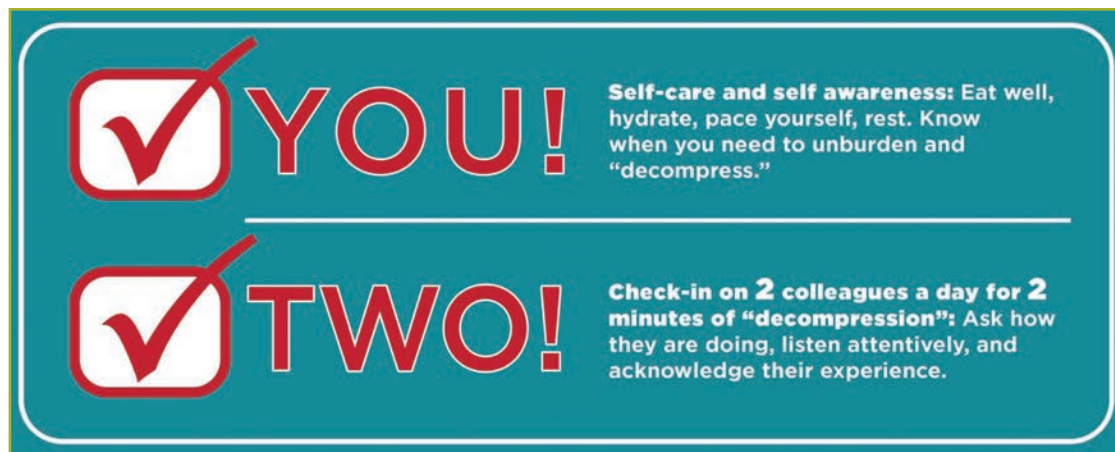


Figure 3. Check You, Check Two. Reprinted with permission from The University of New Mexico Wellness.

group exposure, which had the potential to quarantine or infect a large number of providers at one time. It also allowed for some down time to monitor from symptoms and to mentally recover from providing 7 straight days of acute care for fractures and infections. Additionally, hand, spine, and pediatric divisions were relegated to their own divided teams due to the specific requirements of these specialties. This worked to keep the providers adequately distanced from each other to ensure that we would be able to continue offering complex hand surgeries, microvascular cell and spinal surgeries, and pediatric fracture and infection care, should one provider become quarantined or infected.

Elective cases were canceled, and the surgeons worked diligently to reassure their patients that they would receive timely care once the viral infection threat was under control. Orthopaedic leadership worked with the hospital to ensure timely care of trauma patients to minimize hospital stay and surgical delays. The available trauma surgeon was increased from one surgeon to three surgeons via team approach, with care provided 7 days a week to ensure prompt treatment of orthopaedic trauma patients.

### RESIDENT EXPERIENCE

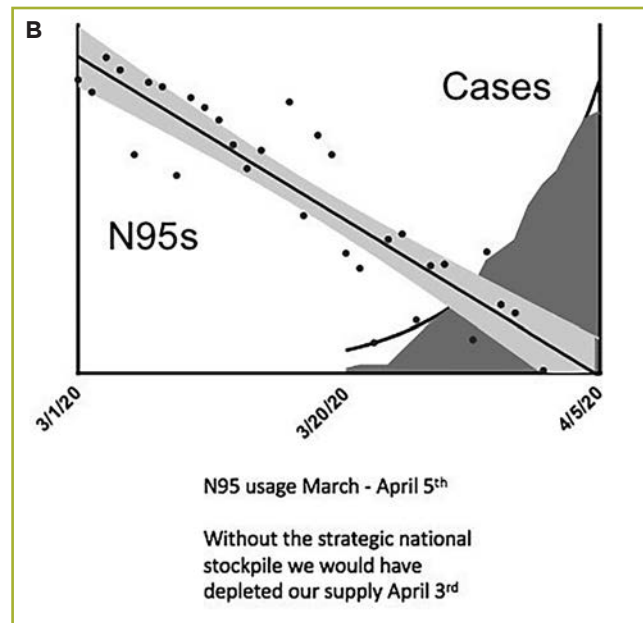
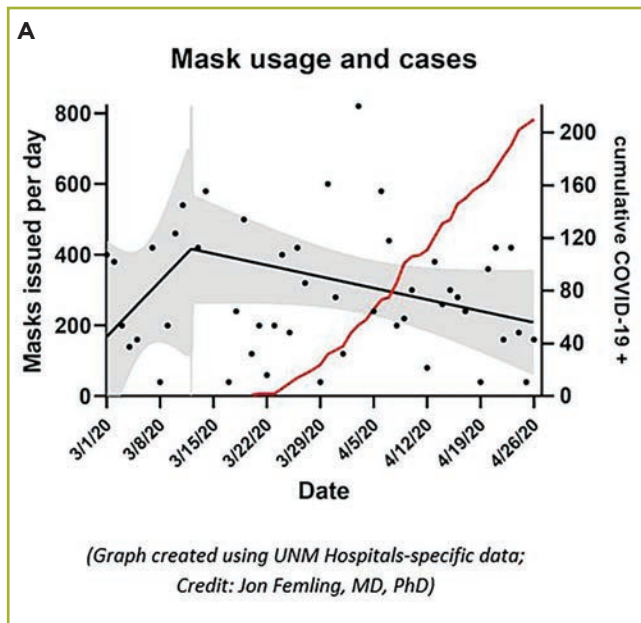
Residents continued to participate in the care of trauma patients in both the inpatient and outpatient setting. The resident education format changed but was continued throughout the COVID-19 pandemic, and the new format continues to date. There was first a 10-person limit followed by 5-person limit in group gatherings, which led to the initiation of video conference meetings. The password protected video conference platform was used for both education and patient care. The video conferencing was well accepted by residents and carried several advantages, including national and international thought leader involvement in education. Peer publications were shared in real time to support the discussion. Additionally, the opportunity to collaborate on research publications presented itself as case cancellation and surge-team free-time occurred on many levels.<sup>13,14</sup>

### PERSONAL PROTECTIVE EQUIPMENT

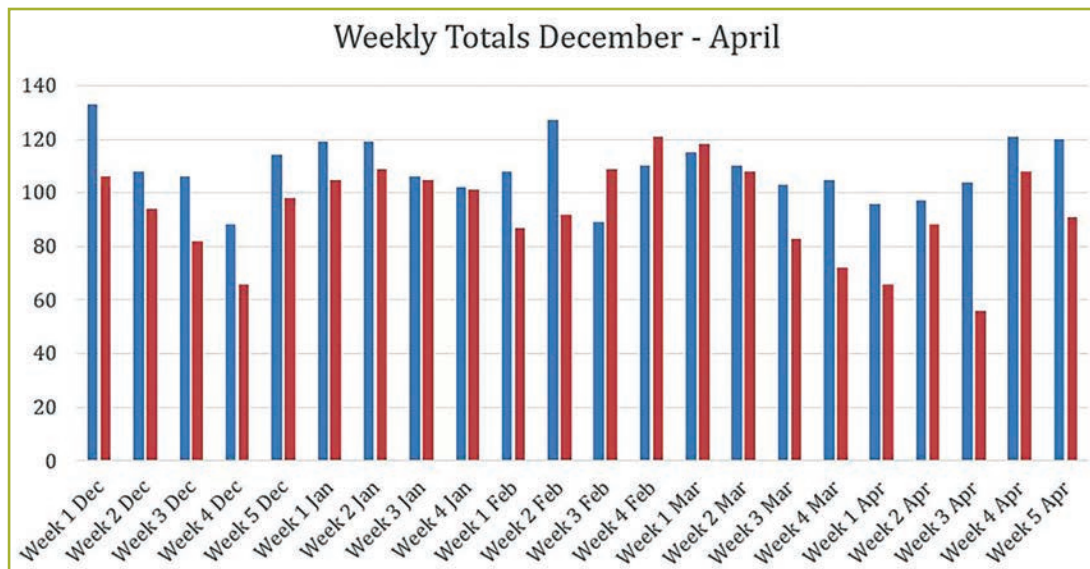
A personal protective equipment (PPE) committee was formed as a subcommittee by The University of New Mexico Emergency Operations Committee (EOC) in an effort to define appropriate PPE for use in the various clinical settings. This committee consisted of broad representation from various clinical groups within the hospital including Emergency Medicine, Hospital Medicine, Critical Care, Infectious Disease, Infection Control, Logistics, Nursing, and Anesthesia, among others. One individual from the Department of Orthopaedics was appointed to this committee and functioned as the sole representative for surgical specialties.

The PPE committee reviewed Center for Disease Control (CDC), World Health Organization (WHO), Occupational Safety and Health Administration (OSHA) guidelines, and guidelines developed from institutions that were affected much earlier throughout the course of this pandemic. The committee was ultimately responsible for delivering guidance to the EOC, recommending specific PPE for use in a variety of clinical situations. Included in the PPE committee's role was development and monitoring of N95 respirator decontamination for reuse. It was also responsible for keeping up to date on the hospital's PPE burn rate, supply chain, and PPE stockpile. Dr. Matthew Wharton, PGY-4, was the only resident representative in the UNM Hospital PPE committee as recommended by his Chair, Dr. Robert C. Schenck, Jr. Dr. Wharton proved to be an excellent leader and a powerful resident voice and advocate during these uncertain times.

Initially, the appropriate and specific use of PPE for orthopaedic surgery cases was in flux. This mostly surrounded the use of N95 masks versus standard surgical masks for orthopaedic trauma cases. Based on available literature, the PPE committee developed formal guidelines to maximize provider safety and conserve the PPE supply. Procedures were categorized by their risk based on knowledge of viral transmission, and orthopaedic procedures were deemed low risk due



**Figure 4.** A) Effect of mask utilization and re-sterilization protocols in avoiding depletion of stockpile and B) available PPE supplies. Graph created using The University of New Mexico Hospitals-specific data. Credit: Jon Femling, MD, PhD.



**Figure 5.** Weekly Orthopaedic Consult Totals for December 2018 through April 2019 and December 2019 through April 2020. There was a drop in orthopaedic trauma during social distancing.

to the lack of evidence showing viable virus present in blood. Using the knowledge that aerosol-generating procedures (eg, intubation) incur the highest risk of transmission, operating room practices were changed. Particularly, non-anesthesia providers were to leave the room for 15 minutes during intubation or extubation to allow for 99% air turnover, based on our facilities' air exchanges per hour. Standard approaches to avoid burn through of N95 PPE were the use of surgical masks and leaving the operating room during intubation and extubation. If splints were needed to be held during extubation, orthopaedic surgeons were required to wear N95 PPE. By doing these, we were able to curb

the utilization of PPE, and with the addition of the PPE stockpile, enough PPE was available throughout the peak period of infection (Figures 4A and 4B).

### CHANGES IN ORTHOPAEDIC CONSULTS FROM THE EMERGENCY DEPARTMENT

We looked at the number of orthopaedic consults per week from the emergency department for four time periods: 15 weeks pre-social distancing, 7 weeks post-social distancing, and the same two periods for the previous year as controls. The data were tested for normality using the Shapiro-Wilk Test in R. The data were found to be normal. The weekly totals for the



**Table 1:** Mean number of consults per week for each period and standard deviation of averages for each period

Time Period	12/2/18 - 3/16/19	3/17/19 - 5/4/19	12/1/19 - 3/14/19	3/15/19 - 5/2/19
Reason for collecting	Previous Year Control	Previous Year Control	Pre-Social Distancing	Post-Social Distancing
Weekly Average	110	107	101	81.5
Std Deviation	12.1	10.1	13.9	17.4

periods of interest are shown in Figure 5. Table 1 shows the time periods, the mean number of consults per week for each period, and the standard deviation of the mean for each period.

The data were compared with a Welch Two Sample *t*-test in R. The difference between the samples from the previous year control periods was not significant ( $P = 0.4665$ ). The difference between the samples from pre-social distancing and post-social distancing were significant ( $P = 0.02328$ ). We conclude that the social distancing and lockdown requirements in New Mexico led to a 20% drop in orthopaedic emergency department consults.

## CONCLUSION

The recent COVID-19 pandemic has led to a transformation in care provided worldwide. This has often been fraught with fear and anxiety. However, in the scenario of UNM HSC, there were constant reminders to remain calm, flexible and positive. Daily testing, reports of positive tests, intubations, and deaths were all a central focus of healthcare providers (Figure 1). Leadership during this time was certainly tested, redefined, and critical for our successes. UNM Orthopaedics allowed faculty and residents to be leaders, which was evidenced by a very cohesive and well-informed approach to the COVID-19 crisis. Part of the communication process was a daily message by Dr. Robert Schenck, which eventually morphed into a two member message with Dr. Mathew Wharton discussing what we know, what to expect, and what our concerns were. The messaging on a daily basis to the UNM Orthopaedic Team/Family from both an attending and resident proved to be a unique and powerful approach. Furthermore, mental health and wellbeing of all the department became a continued focus and source of inspiration for all working during the trying times. Use of recommendations from outside sources for mental health, such as Rutgers' "Check You, Check Two," was suggested during daily messages. The "Check You, Check Two" initiative urged all to attend to their own needs and then touch base with two colleagues daily by phone, text, or a brief message (Figure 3). We liken this concept to "a string of compassion" in that when you think of someone, regardless how random, check in on them and see how things are going. The pressure of the crisis for providers, patients, and families was a large determinant in making mental health a priority for UNM Orthopaedics.

COVID-19 infections have occurred among UNM HSC healthcare workers during this pandemic. Out of 660

healthcare personnel tested through mid-May 2020, thirty (4.6%) workers have tested positive for COVID-19 infection. Most of the exposures that lead to infection were not from direct patient care, but instead from work meetings or spending time with colleagues. Some were acquired from travel to areas with known community spread of COVID-19 infection. Two healthcare personnel acquired COVID-19 infection from patient exposures; however, these happened early on during the pandemic when COVID-19 infection was not clinically suspected, thus appropriate PPE had not been worn. These events have been reviewed and other protections have since been put into place to lessen the risk to healthcare personnel, including universal masking of patients and healthcare personnel and the testing of all inpatients upon admission to the hospital.

Research is still needed to define specific transmission risks. To date, the science hasn't shown how much infection transmission is mediated by droplets versus aerosols, how much virus leads to infection, or what type of mask affords the best protection in different scenarios when working with COVID-19 infected individuals. What is known about SARS-CoV-2 transmission is that more prolonged exposure to COVID-19 infected patients (eg, greater than 10 to 30 minutes), and performing aerosol generating procedures on infected patients imposes the greatest risk of transmission. It's important to have N95 masks available for those in healthcare who do more prolonged, face-to-face work in COVID-19 dedicated units and those performing procedures that generate aerosols.

Unfortunately, SARS-CoV-2 surged across the globe and caught the world unprepared. Hospitals all over the globe experienced shortages of PPE as the demand did not cease. As we and many other hospitals have found, previous levels of PPE use are poor predictors of PPE use during a pandemic. If we had continued to use our N95 masks as we had in March, we may have run out of N95 masks by early April.

We were able to use our UNM HSC pandemic supply, a supply that was put into place after the 2009 H1N1 influenza pandemic, to bridge many key PPE items as we looked for other sources to procure PPE. We have also updated our PPE practices to provide N95 masks for those at greater risk. We now extend and reuse our N95 masks so that our current supply lasts longer per updated CDC guidance. We continue to seek out alternatives to N95 masks and evaluate all leads for other types of PPE. Since we have changed our practices related to PPE, we're ensuring that we're not



only protected today but also pacing ourselves to have an adequate PPE supply as this pandemic ameliorates, and more importantly, for our next pandemic.

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# Prevalence of Prolonged Sitting Among Orthopaedic Residents

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## ABSTRACT

**Background:** There is a plethora of data regarding the negative health consequences of sitting, including increased cardiometabolic risk factors and all-cause mortality. Correctable actions should be identified.

**Methods:** A literature review was performed to examine articles that identified sitting prevalence and health consequences. A survey querying average hours per day spent sitting was distributed to orthopaedic residents at a single institution. Statistical analysis of the data was performed using a 2-tailed *t* test.

**Results:** A total of 25 orthopaedic residents were surveyed, and 20 responses were received. The average time spent sitting was 5.38 hours per day. There was equal representation among year in residency, with no statistically significant difference between year and sitting.

**Conclusions:** The average orthopaedic resident sits less than the average American adult, yet may be at risk for increased all-cause and cardiometabolic mortality. Programs using standing desks should be considered as an intervention to decrease sitting time.

**Keywords:** Sitting, Health, Longevity

## INTRODUCTION

There is an increasing amount of data emerging on the effects and negative health consequences of prolonged sitting. Prolonged sitting increases cardiometabolic risk factors and all-cause mortality.<sup>1</sup> Literature has shown an increase in all-cause mortality (46%) and cardiovascular-related mortality (80%) in those that sit more than 4 hours a day.<sup>2</sup> Owen et al<sup>3</sup> found that 1 in 4 adults will spend 70% of their day sitting, while other studies determined that the average American adult sits a little over 7 hours per day.<sup>4</sup> Prolonged sitting can alter health directly and increase negative physiologic consequences such as cardiovascular risks.<sup>5,6</sup> Prolonged sitting equates to decreased skeletal muscle contraction, lower energy expenditure, lower overall vascular flow, and vascular pooling.<sup>7</sup> These risks appear to occur in a dose-response relationship, with

those sitting more than 10 hours per day having the worst biomarkers for cardiometabolic risks.<sup>1,4</sup>

Although literature is increasingly emerging on the topic, the authors are not aware of any data showing the relationship between prolonged sitting and physicians. This purpose of this study was to examine the prevalence of sitting behavior of orthopaedic residents at a single institution.

## METHODS

We received approval from our Human Research Review Committee (HRC #18-803). A literature review was performed on PubMed and Google Scholar to identify studies that examined sitting prevalence and health consequences. A survey querying the average hours per day spent sitting was distributed to orthopaedic residents at a single institution, The University of New Mexico (UNM). Using resident recall, sitting time was measured based on the average sitting time per day over an average week during the resident's current year. Statistical analysis of the data was performed using a 2-tailed *t* test.

## RESULTS

Of the 25 orthopaedic residents surveyed, there were 20 responses in total. On average, the respondents spent 5.38 hours per day sitting (Table 1), with the majority sitting between 4 to 6 hours a day (Figure 1). There was equal representation among post-graduate year (PGY) in residency. There was no statistically significant difference between time spent sitting and program year, nor a statistical difference between lower (PGY 1, 2, and 3) and upper level (PGY 4 and 5) residents and sitting time (71 hours per week vs 36.5,  $P = 0.82$ ).

## DISCUSSION

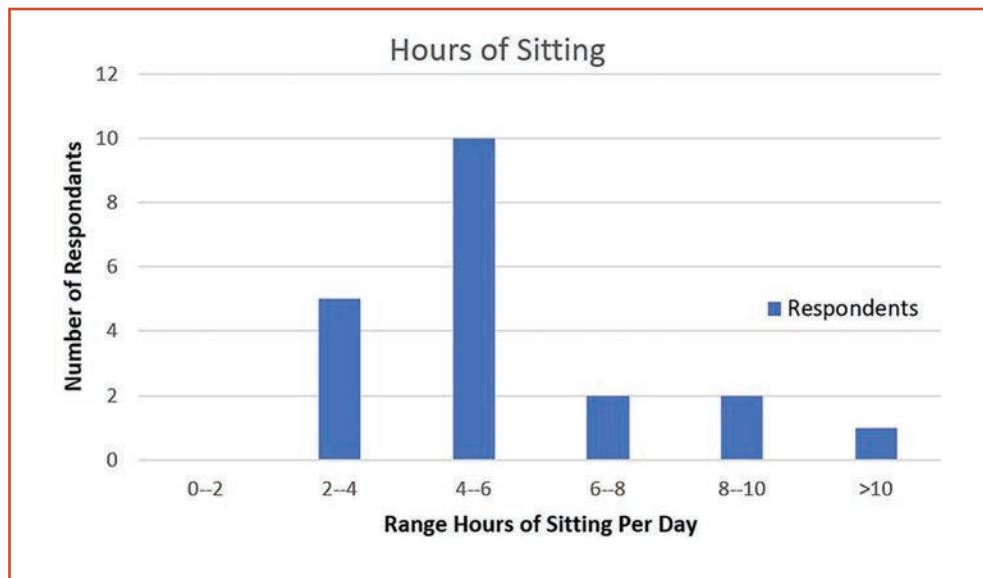
Prolonged sitting, also known as sedentary activity, is defined as any behavior while awake that involves little or no energy expenditure (ie, 1-1.5 metabolic equivalents) while in a sitting or reclining posture.<sup>1</sup> Prolonged sitting has a real impact on health and longevity. Although sitting is not the new smoking as shown by Vallance et al,<sup>8</sup> prolonged sitting still has

**Table 1. Average Resident Sitting Time Per Day**

PGY Year	A	B	C	D	E	Avg.
1	5	5	8	4	4	4.8
2	10	4.5	8	3	-	6.38
3	3	5	3.5	10	-	5.38
4	5	5	5	-	-	5
5	5	7	5	3.5	6	5.38

PGY, post-graduate year

Free hand response by each resident, divided by PGY year. The values represent residents' expected average hours of daily sitting.



**Figure 1.** Hours of sitting per day as described by a range. Each value represents the range options residents could choose.

destructive health consequences. The study showed heavy smoking caused more than 2000 excess deaths from any cause per 100,000 persons compared to 190 excess deaths for prolonged sedentary activity.<sup>8</sup>

Sitting reductions can be helpful and incite change. One study showed that cardiometabolic risk factors (ie, diastolic and systolic blood pressure, body fat, weight, cholesterol, and insulin) were considerably reduced when implementing sitting reduction.<sup>9</sup> Shrestha et al<sup>10</sup> showed a sit-stand desk, with no requirements or instructions to stand, reduced sitting time by 2 hours daily. Ergonomic workstations can be implemented by adding a standing desk to an already present desk. Standing mats can also be added to help with fatigue. Redfern and Cham<sup>11</sup> showed that softer floors provided more comfort than harder floors, especially for the lower back and extremities.

To help reduce sitting, Winkler et al<sup>12</sup> created an institution-wide program for their desk-bound employees and coined the phrase “Stand Up, Sit Less, Move More.” *Stand Up* is a reminder to break up periods of prolonged sitting, especially anytime over 30

minutes. The goal is not necessarily to remain standing for the entirety of the day, but rather to ensure no prolonged periods of sitting (ie, over 30 minutes). *Sit Less* aims to reduce overall, cumulative sitting time by various means such as using standing desks. *Move More* promotes formal physical activity that focuses on a select and discrete time and emphasizes the inclusion of daily movement, including walking breaks, taking the stairs, or stepping in place. Long-term (ie, 12-month) sitting reductions that were created by this program showed reduced cardiometabolic risk, triglycerides, total-cholesterol-to-HDL ratio, diastolic blood pressure, weight, body fat, and waist circumference. Formal physical activity has also shown to be moderately beneficial in decreasing cardiovascular risk factors.<sup>13</sup>

There are limitations in this study. Not all residents who were given the survey responded, which caused an incomplete representation of the orthopaedic residency at The University of New Mexico. The results of this survey are subjective and retrospective. There is a large risk of recall bias with respondents unable to give specific and accurate data to their length of sitting.

We did not use technological devices to collect data nor measured data in real-time. Nonetheless, Boudet et al<sup>14</sup> conducted a systematic review of 154 articles that examined sedentary activity, and they found 91 articles that used self-reported questionnaires with sufficient results. Wearable technology can cost over \$400 with each device; thus the use of this technology can vastly increase the cost of a study. The purpose of the current study was to determine the subjective prevalence of sitting amongst orthopaedic physicians, to gauge a baseline for the population in hopes of a secondary study, in which subjects would be examined with wearable technology. Additionally, sitting time was not stratified by specific rotation, which may change depending on specific rotations. Likely, residents spend the majority of their time sitting in the office dictating notes or at a clinic; however, the questionnaire did not specifically address where and when each resident spent their time sitting.

To the authors' knowledge, this is the first study examining the relationship between sitting prevalence and orthopaedic physicians. Although the average orthopaedic resident at The University of New Mexico sits less than the average American, 5.38 hours compared to 7 hours, they may still be at risk for increased all-cause and cardiometabolic mortality. Programs using standing desks, ergonomic workstations, and the teaching of deleterious effects of sitting should be considered. Measures taken to decrease sitting time may improve the short- and long-term health outcomes of orthopaedic residents. An inexpensive intervention of standing desks can be used to evaluate whether sitting routines of orthopaedic residents can be modified.

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# 3D Printing of Face Masks and Face Shields to Address the Coronavirus Public Health Crisis in New Mexico

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**Conflict of Interest** The authors report no conflicts of interest.

**Funding** The United States Space Force provided rapid startup funding for purchase of the 3D printers and supplies used in this project. We are still in the midst of the coronavirus public health emergency in New Mexico. If you are interested in supporting this effort, please consider donation to our UNM Foundation 3D Printing Fund (<https://www.unmfund.org/fund/3d-printing-fund/>).

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## ABSTRACT

Shortages of personal protective equipment (PPE) in the State of New Mexico (NM), particularly in regions with limited access to healthcare facilities, led to exploration of 3D printing options for PPE production. Open-source Version 2 Wiles COVID Pandemic Masks, a 3-part design (mask, filter box, and filter), are printed with thermoplastic polyurethane (TPU), a pliable filament material. Printing with TPU makes our masks contourable to the face and provides a tight seal during use. Filter boxes for the masks and 3DVerkstan 3D printed face shield headbands are printed using polylactic acid polymer filament. Filters consist of two layers of hospital grade, high efficiency particulate air filters that we tested and found to be 95% efficient at capturing particles 270 nm (0.27 mm) and larger. To date we have distributed 3,679 face masks and

2,395 face shields. We effectively created a system for fabrication and distribution of 3D PPE for NM.

**Keywords:** COVID-19, 3D Printing, Personal Protective Equipment, Corona Virus, Additive Manufacturing

## INTRODUCTION

New Mexico (NM) has seen disproportionate effects of Coronavirus Disease 19 (COVID-19) in the northwest region of the state, particularly the eastern part of the Navajo Nation (NN) and the surrounding cities providing healthcare to that territory. As of May 18, 2020, the NN has the highest infection rate per capita in the United States (US) according to John Hopkins University.<sup>1</sup> As of May 26, 2020, the county most affected by COVID-19 in NM is McKinley County, with 3,064 cases per 100,000 people. For perspective, Cook County, Illinois has the highest number of COVID-19

infections in the US with 1,411 cases per 100,000 people. The three counties that service the eastern part of NN are remote locales with only 52 intensive care beds and limited access to running water and electrical power.

There have been local personal protective equipment (PPE) shortages, particularly in regions of NM with limited access to healthcare facilities. Subsequently, multiple groups at The University of New Mexico (UNM) began exploring 3D printing options to readily mass-produce PPE for community and healthcare providers. Logistically, it is very difficult to provide disposable PPE and continuous replenishment of these supplies to the remote regions of our state in a timely manner. We aimed to provide reusable, sterilizable face masks and face shields to healthcare providers, first responders, and residents of remote NM communities disproportionately affected by COVID-19. The Dean of the School of Engineering at UNM appointed the senior author to lead the institution's efforts toward



**Figure 1.** The Version 2 Wiles COVID-19 Pandemic 3D printed face masks with filter boxes, including a modification to use thermoplastic polyurethane filament to provide flexibility, comfort, and a tight seal for wearers. We print them in four sizes to allow for wide community, first responder, and healthcare provider use - small narrow (purple), small wide (green), large narrow (orange), and large wide (red).

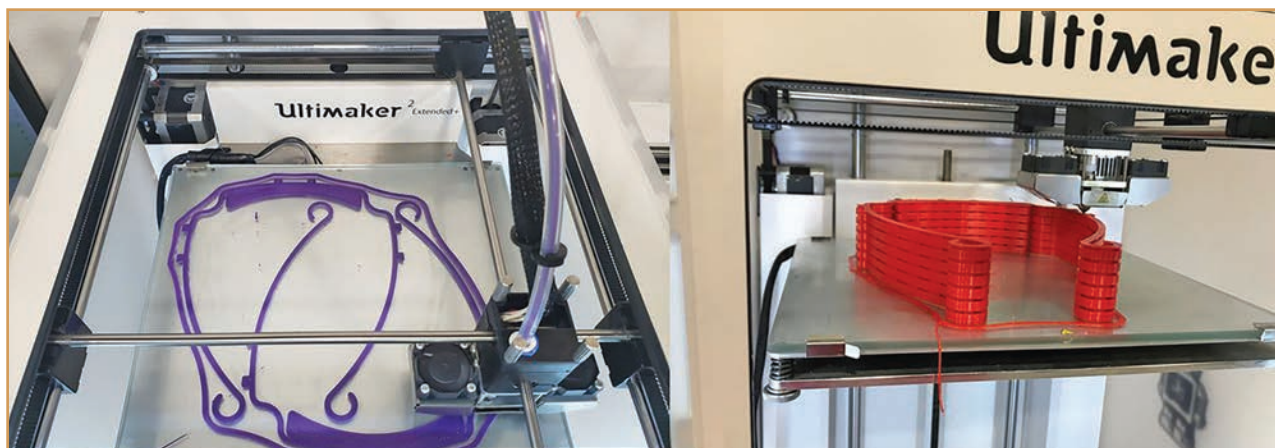
this aim. Using US Food and Drug Administration (FDA) guidance, particularly the "Enforcement Policy for Face Masks and Respirators During the Coronavirus Disease (COVID-19) Public Health Emergency" issued on March 25, 2020,<sup>2</sup> we began fabricating 3D printed face masks and shields.

This article describes the materials and methods used to fabricate PPE, testing completed on PPE, distribution strategies of PPE, and the lessons learned for future response of subsequent pandemics. All face masks and face shields were fabricated at the UNM School of Engineering COSMIAC (Configurable Space Microsystems Innovations and Applications Center) research facility.

### FACE MASK AND SHIELD DESIGN SELECTION INCLUDING FDA CONSIDERATIONS

We explored multiple mask designs on the National Institutes of Health (NIH) open source 3D print exchange website under the COVID-19 Supply Chain Response link.<sup>3</sup> After consideration of nearly ten mask designs, we decided to use the Version 2 Wiles COVID Pandemic Mask designed by Dr. Christopher Wiles, an anesthesiology resident from the University of Connecticut.<sup>4</sup> This face mask is a simple 3-part design (ie, mask, filter box, and filter), with files for the mask available in multiple sizes to accommodate different face sizes, including large narrow, large wide, small narrow, small wide (Figure 1). At the time of this publication, the Wiles design has been tested and cleared for community use when fabricated as instructed in the design specifications, but designers have not completed outgassing tests to meet full requirements for use in a clinical setting.

Using the NIH 3D print exchange, we selected the 3DVerkstan 3D printed face shield headband design<sup>5</sup> developed by a group in Sweden. This is a simple, headband frame for holding plastic protective sheets and is universal in size to accommodate many head



**Figure 2.** The 3DVerkstan 3D printed face shield headband design printed with polylactic acid filament. This design is universal in size and was primarily distributed to first responders and healthcare providers. (Left) A single layer of two headbands printed simultaneously. (Right) A modified stereolithography (.stl) to print stacked headbands for increased productivity and print efficiency.

*Table 1. Onsite 3D print range parameters for face masks, filter cartridges, and headbands for face shields.*

Item	Printer Type	Material	Filament Size (mm)	Slicer	Layer thickness (mm)	Nozzle temp (°C)	Bed temp (°C)	Print Speed (mm/min)	Fill pattern	Outline Overlap (%)	Extrusion Multiplier	Extrusion Width (mm)	Retraction Distance (mm)	Fan (%)
<b>Mask</b>	Lulzbot Taz Pro	TPU	2.85	Simplify 3D	0.25	250	65	4000		40	1.00	0.55	1.7	0
<b>Filter Cartridge</b>	Lulzbot Taz Pro	PLA	2.85	Simplify 3D	0.25	215	60	4000		20	1.0	0.70	1.9	0
<b>Filter Cartridge</b>	Lulzbot Taz Workhorse	PLA	2.85	Simplify 3D	0.35	215	70	4000		20	1.0	0.70	1.9	0
<b>Filter Cartridge</b>	Ultimaker 2e	PLA	2.85	Cura	0.2	210	60	2400	line	25	1.0	0.70	2.0	100
<b>Filter Cartridge</b>	Ultimaker 3	PLA	2.85	Cura	0.2	210	60	3000	line	25	1.0	0.70	2.0	75
<b>Headband</b>	Ultimaker 2e	PLA	2.85	Cura	0.2	210	60	2400	line	25	1.0	0.70	2.0	100
<b>Headband</b>	Ultimaker 3	PLA	2.85	Cura	0.2	210-215	60	3000	line	25	1.0	0.70	2.0	75

PLA; Polylactic Acid; TPU; Thermoplastic Polyurethane

sizes (Figure 2). At the time of this publication, this design has undergone a review in a clinical setting and is deemed appropriate when fabricated according to the specifications on the website.

According to the FDA guidance mentioned in the previous section, our 3D printed masks fall under the definition of a “face mask,” which is defined as a mask, with or without a face shield, that covers the user’s nose and mouth and may or may not meet fluid barrier or filtration efficiency levels. This classification required us to adhere to guidelines<sup>2</sup> in section C, which states that face masks are intended for medical purposes and are not intended to provide liquid barrier protection. This guidance requires product labeling as a face mask as opposed to a surgical mask or respirator, contains a list of body contacting materials, includes recommendations against use in surgical settings or where risk of infection is high, and does not include particulate filtration claims (although this testing was completed and included in a later section). We opted to maintain classification as a face mask to expedite distribution to the communities most affected in our state.

Per the aforementioned FDA guidance, our 3D printed shield headbands fall under the definition of a “face shield,” which is defined as device used to protect the user’s eyes and face from bodily fluids, liquid splashes, or potentially infectious materials. This classification required us to adhere to guidelines<sup>2</sup> in section D, which states that face shields are intended for a medical purpose. This guidance requires adequate labeling as a face shield, includes a list of body contacting materials, and does not contain flammable materials.

### FACE MASK 3D PRINTING

Masks are printed on LulzBot Taz Pro 3D printers (Aleph Objects Inc, Loveland, CO) with thermoplastic polyurethane (TPU), a filament material that is pliable and can easily and comfortably fit to the contours of each individual’s face. The use of TPU makes our masks unique. Most other designs utilize rigid polymer filament that cannot contour to the user’s face and requires additional interfacing material such as foam or weatherproofing rubber to provide a secure and comfortable fit. The filter boxes are printed on a variety of 3D printers using a rigid polylactic acid (PLA) polymer filament. The filter boxes snap directly to the masks upon assembly. We use Cura (open-source software) and Simplify3D (Simplify3D, Cincinnati, OH) slicer software to convert the stereolithography (.stl) files to g-code files for each printer type. Due to the large print beds on the LulzBot Taz Pro models, five to eight masks can be fabricated per printer in a 12-hour window depending on the mask size. Additionally, we can print twelve filter boxes at a time on the larger printers and four on the smaller print beds. A team of engineering students, staff, and faculty are working 8 hour shifts, 7 days a week, 24 hours per day, which amounts to more than 600 masks and more than 700

filter boxes printed weekly. The printed components are then sanded down using belt and Dremel sanders, and head straps (tourniquet material) are added. Table 1 provides details of printer specifications used for fabrication of face masks, filter boxes, and headbands for the face shields printed at the COSMIAC research facility.

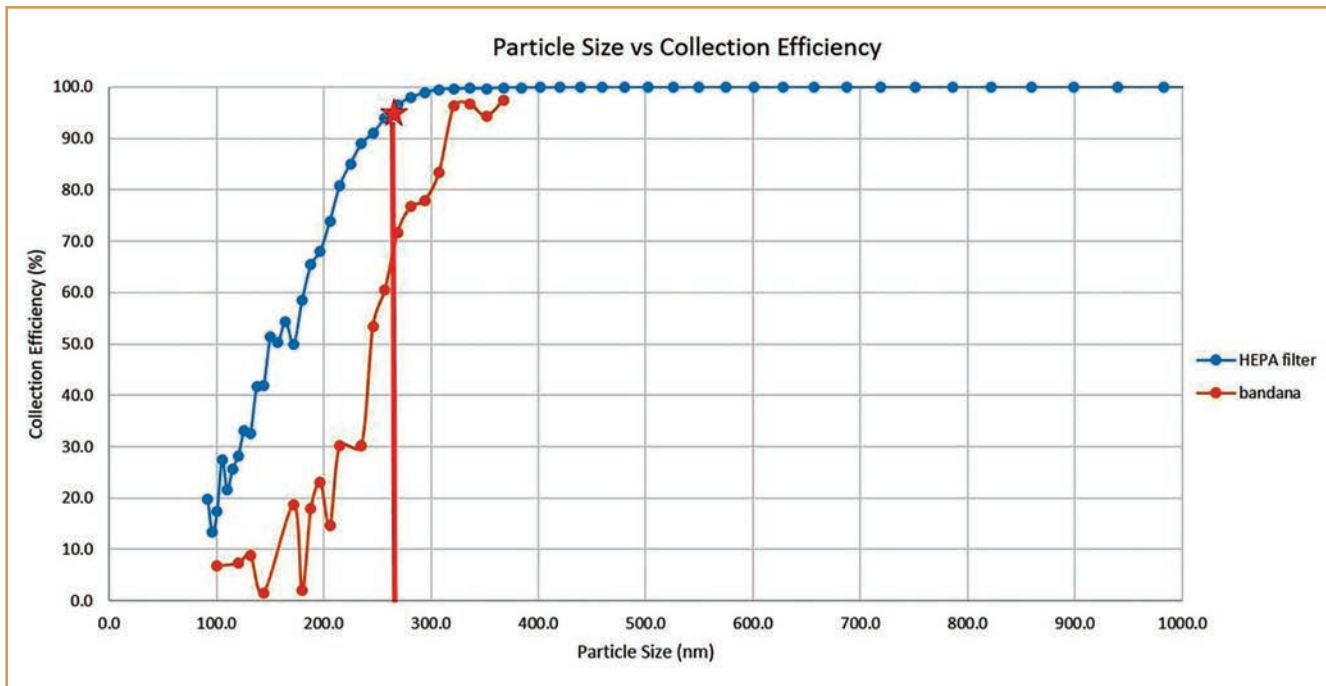
### FACE SHIELD 3D PRINTING

Headbands for face shields are printed on a variety of 3D printers using rigid PLA and n-gen polymers. The 3D printing specifications enable printability with nozzles up to 1 mm and layer heights up to 0.5 mm. We can print two headbands per printer in a single layer setting, but we have created files that allow stacks of up to ten headbands per print. Because of the simple design, widely used polymer filament types, and broad printer specification that can be used, we have enlisted help from our community to print headbands for this purpose; we provide printer filament and the g-code files, and they return printed headbands. This partnership enables us to reduce production of headbands and increase production of masks. Our printers are among the only printers in the state currently 3D printing PPE that are capable of printing with TPU, thus enabling us to increase face mask production from our facility.

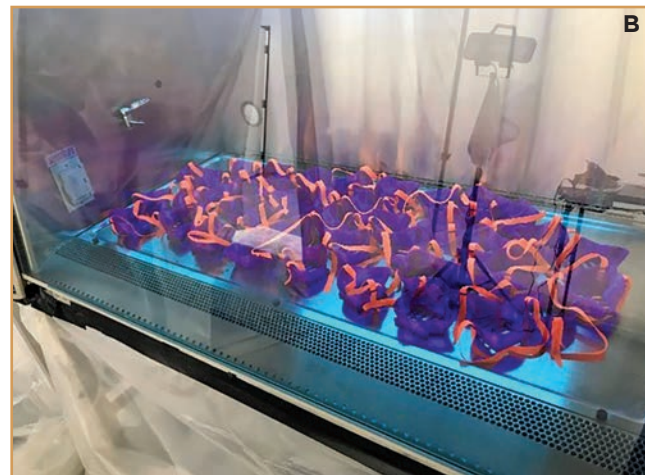
### FACE MASK HIGH EFFICIENCY FILTRATION

Filters consist of two layers of hospital grade, high efficiency particulate air (HEPA) filter material without fiberglass: a flat 3M Filtrete MPR 1500 layer and a Honeywell Elite Allergen Pleated FPR 10 layer folded in an accordion manner to increase filtration surface area. Each layer has a minimum efficiency reporting value of 13, which captures large particles like dust, small particles like bacteria, and other virus carrying particles. Particle filtration efficiency testing has been completed on the sandwiched filters. Kaolin (clay mineral) aerosol was generated using a fluid bed generator (Model 3400A, TSI Inc, Shoreview, MN) and delivered to a mixing chamber. A real time aerosol monitor (Model 8533 DustTrak DRX, TSI Inc, Shoreline, MN) measured chamber concentration. A probe delivered the Kaolin to a 47 mm filter holder containing the sandwiched filters. Samples from the filter holder were extracted upstream and downstream and measured using an aerosol particle spectrometer (Model 3340 Laser Aerosol Spectrometer, TSI Inc, Shoreview, MN). Filter collection efficiency was calculated as: Efficiency (%) = 100\*[1-(downstream conc./upstream conc.)]. Results of efficiency testing are shown in Figure 3. The filters achieved a particle capture efficiency of 95% at 270 nm (0.27 microns). For comparison, N95 respirators that are recommended in COVID-19 aerosolizing environments are commonly tested to ensure 95% particle capture efficiency at 300 nm (0.3 microns).





**Figure 3.** Particle capture efficiency testing of the HEPA filters used in the face masks. The two filters were sandwiched together for testing. Upstream and downstream data were used to calculate capture efficiency of a range of aerosolized Kaolin particles from 100 to 1000 nanometers (0.1 to 1.0 microns) in size. A reference plot was generated from data collected of particle efficiency testing of a household bandana folded in half (2 layers) in order to show the effectiveness of the filters. Note that the red star indicates 95% particle capture efficiency of the filters at approximately 270 nanometers.



**Figure 4.** A) Clean room facility modeled after disaster relief and emergency response shelters. This facility was used for sterilization, assembly, and packaging of face masks and shields. B) Biosafety cabinet with ultraviolet light used for post-processing sterilization of masks, filter boxes, and headbands for face shields. C) Nurses, paramedics, and other volunteers (primarily from the healthcare industry) staffed the clean room to ensure an aseptic environment.



**Figure 5.** Packaged masks and face shield headbands with appropriate labeling as directed by the United States Food and Drug Administration.

### FACE MASK STERILIZATION, ASSEMBLY, AND PACKAGING

Completed 3D printed masks, filter boxes, and headbands for shields are then transferred to a room for sterilization, assembly, and packaging. Using four adjacent 10 ft x 10 ft canopies completely enclosed in large plastic sheeting, we developed a portable “clean room” facility modeled after temporary emergency response and disaster relief shelters (Figure 4). Inside this facility, we maintain two Biosafety Level 1 cabinets with HEPA filtration and ultraviolet germicidal lamps with 40  $\mu\text{w}/\text{cm}^2$  intensity. The clean room is staffed by volunteers, primarily nurses and paramedics, employed in New Mexico at various hospitals and healthcare companies. We specifically selected trained medical personnel to work in this capacity because they are most familiar with working in an aseptic environment that was necessary for these tasks. Volunteers work 4 to 8 hours per day, comply with strict PPE requirements in the clean room, and assist with distribution of supplies across the state.

3D printed materials are first exposed to 15 to 20 minutes of ultraviolet light per side using the biosafety hoods. At the next station, volunteers hot glue the flat filter against the inner surface of the filter box ensuring a proper seal across all edges. At the third station, the accordion layer of filter material is added to the filter box. Mask and filter boxes are then snapped together and vacuum sealed in packs of four to six with FDA labeling corresponding to the mask (Figure 5). Headbands for face shields are exposed to ultraviolet light and then vacuum sealed in packs of 20 to 25.

### AUTHORIZATION FOR DISTRIBUTION AND LESSONS LEARNED

As a state institution, it was necessary for us to ensure that anything fabricated by our students, staff, or faculty was safe for external distribution. The Governor of New

Mexico, Michelle Lujan Grisham, requested that we complete three tasks prior to distribution:

1) ensure adherence to the FDA guidelines described in prior sections, 2) prepare a memorandum of agreement (MOA) with all FDA guidelines clearly delineated for any recipients, and 3) obtain approval from the state Medical Advisory Team (MAT). We consulted our university’s legal team in order to prepare tasks 1 and 2. The legal team enlisted the assistance of an external lawyer with FDA experience to ensure we met all FDA guidelines. With the FDA instructions clearly defined and after a series of drafts and revisions, the university approved an MOA for external distribution of our masks and shields. Exactly 2 weeks from the fabrication of our first mask, on April 24, 2020, the state MAT approved the MOA, the FDA guidance, and the design of our masks. On April 28, 2020, the first MOA was approved by the McKinley County, NM manager, and we completed our first distribution to McKinley County Fire Department that day. We quickly faced a limitation on widespread distribution of our masks and shields. In order for the MOA to be official, a notary was required to witness signing of the document remotely online. Due to the lack of electrical power and limited Internet access of the most affected communities in our state, we were unable to complete this essential task. For the following week, we dispatched a notary to various regions of our state for in-person signing of the MOA. This enabled us to increase distribution to more regions, but unnecessarily risked exposure to our notary. We sought an alternative path toward widespread distribution. On May 5, 2020, we received broad approval from the New Mexico Department of Homeland Security (DHS) Secretary, Kelly Hamilton, to distribute our masks and shields freely across NM and in states adjacent to NM, with the only requirement to track the dispensing of our PPE and notify the DHS of these distributions.



## IMPACT ON THE STATE OF NEW MEXICO

To date we have distributed 3,679 face masks and 2,395 face shields to the eastern parts of NN in NM (Newcomb, San Juan, Upper Fruitland, Burnham, Hogsback, Nenahnezad, and Crownpoint) and Arizona (Fort Defiance and Chinle); to other Native American pueblos in NM (Zuni, Zia, and Santo Domingo); and to the community and healthcare providers in cities that serve these Native American communities (Rehoboth McKinley Medical Center and Miyamura Alternate Care Facility in Gallup, NM). These distributions also included delivery to the Field Operations Officer for Emergency Operations for the Eastern NN, which covers Red Mesa, Arizona and Shiprock, Tohachi, Crownpoint, Torreon, and Tohajiilee, NM.

Furthermore, we have partnered with the New Mexico COVID-19 Emergency Supply Collaborative ([www.nmccovid19.org](http://www.nmccovid19.org)) to increase understanding of the needs of communities, first responders, and healthcare providers in our state. We have planned distributions to San Felipe Pueblo and to all remaining chapters of the eastern parts of NN. Our aim is to continue to provide masks and shields to the communities disproportionately affected in NM and Arizona and to areas that continue to lead the entire US in per capita infections. We hope to saturate these communities with enough masks that we will only need to provide replacement filter boxes and filters to satisfy the 3 month suggested lifespan of the HEPA filters.

## CONCLUSION

After identifying a need within our state during the COVID-19 pandemic and concluding that utilization of 3D printing resources could help this cause, we were able to effectively create a system for production, fabrication, and distribution of 3D printed face masks and shields by collaborating across institutions and governing bodies within our state. Although our efforts have resulted in distribution of 3D printed PPE to regions of NM and surrounding areas in great need, there continues to be a disproportionate rate of infection and death in northwestern NM counties. Despite this trend, NM is moving forward with the gradual reopening of businesses and restaurants in various regions of the state and decreasing restrictions on travel and mandatory stay at home quarantine. It is essential during this return to normalcy, that all NM citizens, first responders, and healthcare workers

have access to proper PPE including N95 masks. Our hope is that the knowledge we have learned and the connections we have made throughout this ordeal, both advance technologies for 3D printed PPE and better prepare us for helping with a similar situation, should it arise, in the future.

Specifically, we aim to evaluate the face masks to determine whether they meet the classification requirements to be designated a “surgical mask intended to provide liquid barrier protection.” These requirements include: standard test method for resistance of medical face masks to penetration by synthetic blood per ASTM F1862; flammability requirements per 16 CFR 1610 (unless labeled with a recommendation against use in the presence of a high intensity heat source); labeling that accurately describes the product as a surgical mask; and labeling that does not include uses for antiviral protection or particulate filtration claims. The addition of a liquid barrier fabric to the inner surface of the filter boxes, such as that used for surgical sterilization, would enable a reclassification of these masks. This would allow us to distribute them to a greater number of healthcare facilities for use in areas where liquid exposure is a risk. At this time, the FDA has not issued guidance for 3D printing devices meant to be classified as “filtering face piece respirators,” even in the presence of this continued healthcare crisis.

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# Pronator Quadratus Rotational Muscle Flap Technique for Coverage of Hardware After Distal Radius ORIF

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## ABSTRACT

Flexor tenosynovitis and tendon rupture are rare. Yet these occurrences can be serious complications after treatment of a fractured distal radius with a volar plate. The highest incidents of rupture are associated with the plate on or distal to the watershed line of the radius. Although studies have shown that reattachment of the pronator quadratus (PQ) following plating does not lead to improved measures in grip strength or range of motion, it is possible that doing so may reduce the incidence of flexor tendon irritation or rupture. Reattachment of the PQ after a standard approach does not often capture the distal edge of the plate. We present a new technique for a rotation muscle flap of the PQ muscle that improves coverage of the volar distal radius plate.

**Keywords:** Pronator Quadratus, Distal Radius Fracture, Volar Plating, Tendon Rupture

## INTRODUCTION

Repair of the pronator quadratus (PQ), in the context of volar plating for distal radius fractures, has been challenged in recent years. The pronator quadratus is a trapezoid-shaped muscle that originates from the volar distal fourth of the ulna, and inserts into the volar lateral border of the distal fourth of the radius. It is composed of two heads with different functions: (1) a superficial and distal head mainly involved with pronation, and (2) a deep proximal head that stabilizes the distal radioulnar joint (DRUJ).<sup>1,2,3</sup> Although evidence for repair of the PQ is still ambiguous,<sup>4,5</sup> many surgeons still routinely repair the PQ in their practice. This practice is typically performed to prevent plate irritation and possible postoperative rupture of the flexor tendons.<sup>6</sup> Distal radius fractures can be associated with high-energy trauma, leading to partial destruction of the PQ and making primary repair challenging. In order to overcome this problem, various authors

have developed innovative techniques. Huang et al<sup>7</sup> performed a technique where the PQ is split along its more distal aspect in a transverse fashion. This technique allows a portion of the muscle to cover the distal aspect of the volar plate, which is at the highest risk for flexor irritation. Most recently, Hohendorff et al<sup>8</sup> published a technique where part of the brachioradialis muscle is included during the PQ muscle dissection, thus facilitating primary repair. To overcome the disruption of the PQ muscle altogether, some authors have suggested the use of pronator quadratus-sparing approaches for distal radius fracture fixation.<sup>9,10</sup>

Repair of the PQ can be difficult owing to individual anatomical differences, destruction secondary to trauma, and poor suture retention by muscle tissue.<sup>11</sup> To allow for appropriate advancement of the muscle tissue to cover the volar and most distal aspect of the plate, we propose releasing the pronator quadratus proximally and ulnarly after volar plating of the distal radius for fracture or osteotomy. The muscle functions as a biological gliding pad, allowing for the flexor pollicis longus (FPL), flexor digitorum profundus (FDP), and flexor carpi radialis (FCR) tendons to glide over the muscle without direct contact with the plate.<sup>11</sup> The pronator quadratus is also important in forearm pronation, grip strength, and DRUJ stability.<sup>11</sup> It has been found to contribute considerably to pronation, and it can result in functional deficits if damaged.<sup>11</sup> Although PQ repair does not seem to affect clinical outcomes in regard to DASH (Disabilities of the Arm, Shoulder, and Hand) scores, some patients have shown improvement in strength postoperatively.<sup>11,12,13</sup>

The anterior interosseous nerve (AIN) innervates the PQ muscle after supplying the FPL and FDP. The AIN and anterior interosseous artery (AIA) follow the same course between the interosseous membrane and the deep aspect of the PQ muscle. The entry zone of the AIN branch to the PQ is 3 cm proximal to the ulnar



styloid process, and covers the distal 13% of the forearm length.<sup>2</sup> The AIA and AIN enter the muscle centrally and dorsally, thus ulnar-sided back cutting will not devascularize or denervate the muscle.

This procedure can be used as an adjunct for plate coverage during volar plating of the distal radius for both fracture fixation and osteotomy. This procedure is useful in trauma cases where the PQ muscle is damaged, limiting its use for coverage of the volar plate. The exposure of the entire PQ muscle is generally required for volar plating of the radius, thus there is no increase in needed exposure. There is no absolute contraindication to this technique. However, considerable damage to the anterior interosseous artery could preclude its use, because the creation of the flap could alter the muscle's blood supply and lead to necrosis.

## TECHNIQUE

The distal radius is approached using the extended FCR approach.<sup>6</sup> The pronator quadratus is raised off the volar aspect of the distal radius to obtain adequate exposure. The dissection starts distally at the lunate facet and moves to the radial aspect of the radius (Figure 1). At this point, the ulnar attachment of the



**Figure 1.** Appearance of the pronator quadratus (PQ) muscle after dissection for volar plating. The neurovascular bundle is indicated by the blue arrow. The PQ spans from the 8 to 13 cm markings.

muscle is left untouched and the muscle is reflected ulnarly. After completion of the distal radius fixation, the pronator quadratus muscle is addressed (Figure 2). In order to obtain complete coverage of the distal aspect of the plate, the ulnar aspect of the muscle is transected from proximal to distal. This incision is done on the ulnar aspect of the PQ muscle tendon insertion to ensure preservation and inclusion of the neurovascular bundle into the flap. An incremental increase of the ulnar sided incision will allow more mobility of the muscle flap, thus providing better plate coverage distally (Figures 3 and 4). Transection of more than 75% will result in further distal plate coverage, but proximal plate coverage will begin to be sacrificed.

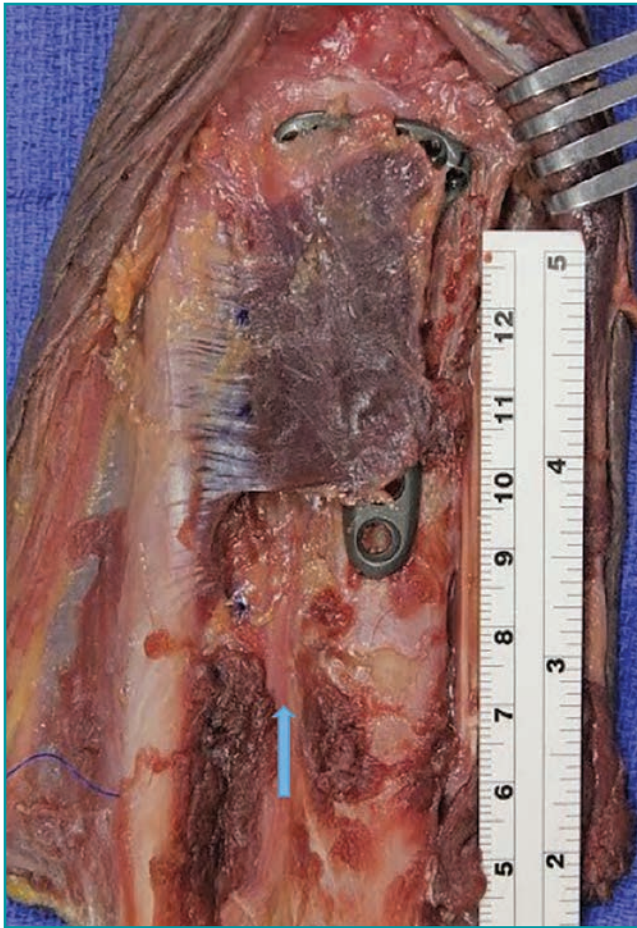
## DISCUSSION

The key objective of this technique is to obtain coverage of the volar plate in order to reduce irritation of the flexor tendon. The creation of a back cut should allow adequate mobilization of the PQ muscle, thus creating a flap that will preserve its function and place vascular muscle as padding between the plate and overlying flexor tendons. Other authors have described the distal radius approach with pronator sparing technique, but

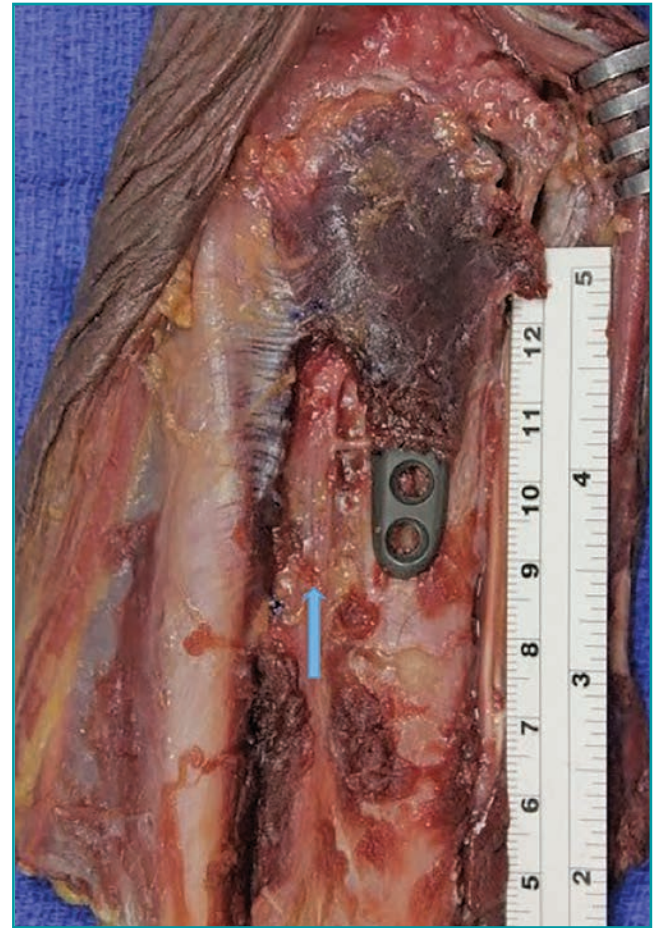


**Figure 2.** Appearance of pronator quadratus (PQ) muscle once volar locking plate is in place. The blue arrow indicates the neurovascular bundle. The PQ was raised radially for the exposure and is able to be mobilized distally by about 1 cm.





**Figure 3.** Creation of the muscle flap with back-cut of 25% of the ulnar side of the muscle. The blue arrow indicated the neurovascular bundle. The pronator quadratus is able to be mobilized distally by about 2 cm.



**Figure 4.** Muscle flap created with incision of 50% of the ulnar side of the pronator quadratus. Note the increased reach of the muscle flap distally.

few reports of muscle flap have been published so far.<sup>7,8</sup> Descriptions of minimally invasive plate osteosynthesis utilization have been increasingly published in the literature. However, acceptance by upper-extremity surgeons is limited due to the technical complexity.<sup>9,10</sup> This technique is straightforward and offers an adjunct to standard PQ repair.

The main complication associated with this procedure is injury of the neurovascular bundle during flap elevation, which could lead to paralysis secondary to anterior interosseous nerve injury with subsequent loss of pronator function. Likewise, injury to the anterior interosseous artery can cause muscle necrosis with loss of plate coverage as an end result. However, this complication can be prevented if the muscle dissection is performed with the known anatomic landmarks of the neurovascular bundle in mind.

A possible criticism of this technique is whether the muscle will retain its function after the procedure. Although we do not yet have studies evaluating the strength and function of PQ after this technique, the muscle's insertion is reestablished during repair and half of the origin is preserved. The muscle also should

retain its vascularity and innervation, given that the neurovascular pedicle is not disturbed. The effect of the strength and function of PQ would be a possible future area of investigation.

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# Hallux Rigidus: A Technique for Reliable, Safe, and Reproducible Cheilectomy Excision

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## ABSTRACT

Hallux rigidus is a common cause of foot pain involving the hallux; however, the etiology is yet to be elucidated. There are many different treatments that have been described, including cheilectomy. Taking too much bone can cause joint instability and altered joint mechanics, whereas taking too little bone may not relieve pain. We present a reliable, safe, and reproducible technique for cheilectomy in the hallux rigidus.

**Keywords:** Hallux Rigidus, Cheilectomy, Technique, Excision

## INTRODUCTION

Hallux rigidus (HR) is a condition that involves arthrosis of the first metatarsophalangeal joint (MTPJ). The exact cause of this condition remains unclear; however, studies suggest HR is caused by anatomic variations such as contracted medial plantar fascia contracture, first metatarsal head shape, metatarsus adductus, hallux valgus, inflammatory arthropathy, and repetitive trauma.<sup>1,2</sup> Some studies have hypothesized trauma as the primary mechanism, while others have found no relationship between HR and trauma, elevated first ray, Achilles tendon tightness, or shoe wear.<sup>3,4</sup> HR is relatively common and has been reported in 2.5% of all people,<sup>5</sup> has a higher incidence in women than in men, and most commonly presents in the fifth decade of life. Approximately 79% of all people diagnosed with HR will present with bilateral HR. Furthermore, nearly two-third of affected patients will report a family history of HR.<sup>1,2</sup>

Patients with HR will present with pain of the first MTPJ. Radiographs vary but often present with a large dorsal osteophyte and degenerative arthritis of the joint (Figure 1). Patients will likely have concerns of pain that is most noticeable at the extremes of motion especially during toe-off. The first MTPJ may be swollen with redness compared to the contralateral side. As the disease progresses, patients may have concerns of pain with certain shoe types, especially on the dorsal aspect of the foot. If an osteophyte become large enough, a patient may have concerns of numbness on the medial



**Figure 1.** Preoperative x-ray of foot with dorsal osteophyte and first metatarsophalangeal space narrowing.

border of the great toe owing to compression of the dorsomedial cutaneous nerve.<sup>6</sup>

Before any surgical management, patients should undergo extensive nonsurgical treatment, including NSAID (nonsteroidal anti-inflammatory drug) therapy, activity modification, stiff-soled shoes to prevent dorsiflexion, and orthotics with a Morton's extension. Surgical intervention is reserved for those who have unsuccessful nonoperative treatment. Early in the disease process, a cheilectomy may provide reliable pain relief in patients who exhibit pain with direct pressure on osteophytes or during the toe-off phase of gait, with less successful outcomes as the disease grade progresses.<sup>4</sup> In patients who require significant dorsiflexion, a cheilectomy with a dorsal closing wedge osteotomy of the proximal phalanx is a surgical option.<sup>7</sup> Resection arthroplasty has been advocated for patients with severe disease and who are low demand and anticipate return to less vigorous activity. Interpositional arthroplasty has shown varying success, with noted increased range of motion and increased functional outcomes scores.<sup>8</sup> Surgeons have turned to implant arthroplasty, including hemiarthroplasty,





**Figure 2.** Preoperative photograph showing the dorsal incision used for a cheilectomy.

total arthroplasty, silastic arthroplasty, and polyvinyl alcohol hydrogel implants. The majority of these types of implants have been studied in relatively small numbers, with only short-to mid-term follow-up available.<sup>9-11</sup> Further information is needed regarding their longevity. Total arthroplasty and hemiarthroplasty have been met with mixed results, but most studies recommend arthrodesis.<sup>4</sup> Having been found to have unacceptable complication rates, silastic implants are mostly historical. Arthrodesis is the gold standard for the treatment of grade III and IV HR, and patients routinely report high satisfaction and have no activity restrictions.<sup>12,13</sup>

Cheilectomy is a procedure often involved in the treatment of HR. It was originally described in 1959 by DuVries.<sup>14</sup> A case series by Mann<sup>15</sup> includes the classical description of the excision of the osseous rim that interferes with the motion of the first MTPJ. It begins with a dorsal midline incision over the first MTPJ. The extensor hallucis longus (EHL) is then retracted either medially or laterally, and is opened midline with a sharp incision after exposure of the joint. Proliferative synovial tissue, debris, and loose bodies are removed. Using either osteotome or rongeur, the large dorsal osteophyte on the head of the first metatarsal and the occasional dorsal based spur on the first proximal phalanx are removed. Any large medial or lateral osteophytes are excised if present. The medial, lateral, plantar capsular, and ligamentous restraints are then released, followed by the resection of the degenerative articular portions of the first metatarsal head. Range of motion of the joint is then checked with a goal of 70° of



**Figure 3.** The first metatarsal head is translated dorsally until the first toe is in neutral dorsiflexion and plantarflexion.

dorsiflexion. The capsule is then closed followed by the skin.<sup>15</sup> Since the publication of the original description, additional authors have suggested the addition of microfracture of the subchondral plate in areas of articular cartilage degeneration.<sup>16</sup>

Technical mistakes can result in failure of the procedure. Joint instability and altered joint mechanics can result from over resection of the metatarsal head. To avoid this complication, recommendations for cheilectomy advocate resecting no more than 40% of the metatarsal head. Other common complications include failure to relieve pain, which is typically a result of under resection of the metatarsal head and failure to remove the symptomatic osteophytes.<sup>7</sup> Mann's original description suggested resection of one-third of the head.<sup>15</sup> We present a reliable, safe, and reproducible technique for cheilectomy in the hallux rigidus, which seeks to set the appropriate resection level to avoid these complications.

## TECHNIQUE

A longitudinal incision is created just medial to the EHL tendon (Figure 2). Dissection is deepened to the MTPJ capsule, which is incised longitudinally and elevated off of the dorsal aspect of the MTPJ. The capsule is elevated dorsomedially and dorsolaterally. After exposure of the MTPJ, the metatarsal head is manually pushed dorsally until the great toe lies in a neutral position of dorsiflexion and plantarflexion (Figure 3). A sterile marking pen is used to mark the junction of bone covered by the proximal phalanx and the exposed dorsal bone (Figures 3 and 4). All bone is removed dorsally with an osteotome. If the metatarsal



**Figure 4.** A sterile marking pin is used to mark the junction of the phalanx and the metatarsal head. All bone dorsally is removed with an osteotome.



**Figure 5.** Intraoperative radiographs taken after the dorsal bone is excised with an osteotome.

head is not pushed up in this position, the great toe is too extended and not enough bone is removed. After removal of the dorsal osteophyte, the dorsomedial and dorsolateral edges of the metatarsal head are then rounded with a rongeur (Figure 5).

## DISCUSSION

HR is classically described in grades as originally proposed by Coughlin and Shurnas (Table 1).<sup>3</sup> It has been discussed that cheilectomy is ideal for patients with grade I and grade II early HR, with many successful outcomes as noted in a retrospective reviews. Easley et al<sup>17</sup> performed cheilectomy in 68 cases of HR encompassing all grades of disease with 5-years follow-up.<sup>17,18</sup> Most patients had up to a 90% degree of satisfaction; however, nine feet remained symptomatic. There were eight feet found to be symptomatic at the midrange of motion, which was then proposed as a poor prognostic factor. The benefits of cheilectomy include its safety and efficacy as well as its ability to be amenable to revision surgery. Complications of cheilectomy include infection, neuroma formation, transient paresthesia of the hallux, and reflex sympathetic dystrophy. Owing to the favorable results seen in early HR (grade I and II), it currently has a grade B recommendation by the Foot and Ankle Society.<sup>18</sup> The above technique is reliable, safe, and reproducible for cheilectomy in hallux rigidus.

**Table 1.** Grading of HR as described by Coughlin and Shurnas<sup>3</sup>

Grade	Exam Findings	Radiographs
0	Stiffness	Normal
1	Mild pain at extremes of motion	Mild dorsal osteophyte, normal joint space
2	Moderate pain with range of motion	Moderate dorsal osteophyte, < 50% of joint space narrowing
3	Significant stiffness, pain at extremes of range of motion, no pain at midrange	Severe dorsal osteophyte, > 50% of joint space narrowing
4	Significant stiffness, pain at extremes of range of motion, pain at midrange	Severe dorsal osteophyte, > 50% of joint space narrowing

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# Mesh Plate Fixation for Complex Patella Fractures: A Surgical Technique

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## ABSTRACT

Different types of low-profile plates have been designed for fixation of complex patellar fractures. Plate fixation of patella fractures provides stable fixation and allows earlier mobilization. This report describes three cases of complex patellar fractures. The report includes a detailed description and tips of the surgical technique.

**Keywords:** Patella, Fractures, Mesh plates

## INTRODUCTION

Fractures of the patella account for about 1% of all skeletal injuries.<sup>1</sup> Tension-band wiring and cannulated screws have been the most commonly used techniques for the management of most patellar fractures.<sup>2</sup> Although tension band wiring techniques allow for dynamic compression at the fracture site, the rate of failure and hardware removal in more complex fractures can be unacceptably high.<sup>3-6</sup> Comminuted fracture patterns can be more challenging and often require more complex surgical techniques.<sup>7</sup>

Lower profile mesh plates provide stable fixation and less prominent hardware. This mode of fixation opened a new horizon for the treatment of complex patellar fractures.<sup>5,8-12</sup> Several case series of patellar plating and biomechanical studies have demonstrated equal or superior fixation strength with plates as compared to tension banding.<sup>9,12-17</sup> This report describes case-based technical tips and tricks to implement and achieve the desired clinical outcomes for patellar mesh plating.

Institutional Review Board approval (#E20016) was obtained to conduct this study.

## CASE REPORT

### Case 1

The patient was a 17-year-old man with a comminuted right patellar fracture with multiple fragments associated with contusion to the chondral surface. The fracture was preliminary reduced using multiple interfragmentary Kirschner wires (Figure 1A). The



**Figure 1.** A) Preoperative anteroposterior (AP) and lateral radiographs of Case 1. B) Intraoperative lateral fluoroscopic images showing provisional stabilization with Kirschner wires. C) Lateral, skyline, and AP radiographic views showing united fracture and knee flexion at 7-month follow-up, respectively.

mesh plate was then contoured and applied to the dorsal surface of the patella, and fixation of fracture fragments was performed using multiple screws through the mesh plate (Figure 1B). The patient was compliant with postoperative protocol. The fracture healed without complication. The patient achieved full knee range of motion (ROM) without pain at 7-month follow-up (Figure 1C).





**Figure 2.** A) Preoperative anteroposterior and skyline radiographs of Case 2. B) Intraoperative lateral fluoroscopic images showing large fragment fixation with Kirschner wires, and compression of the fracture site with a reduction clamp after application of the Mesh plate. C) Anteroposterior and lateral images of united anatomically reduced patellar fracture at 6-months follow-up.

### Case 2

The patient was a 46-year-old man with a complex right patellar fracture and comminuted distal pole (Figure 2A). Fracture reduction was performed using interfragmentary Kirschner wires. Reduction clamping was used to anatomically reduce the large fragment and restore the articular surface (Figure 2B). The patient was compliant with postoperative protocol. Imaging showed fracture healing without complication at 7-month follow-up. The patient had full ROM of the knee without pain (Figure 2C).

### Case 3

The patient was a 95-year-old man with a transverse patellar fracture in his knee with osteoarthritis (Figure 3A). The decision was made to fix the fracture with cannulated screws and suturing, as well as a mesh plate due to the poor quality of the bone (Figure 3B). The patient followed postoperative protocol; however, ROM was limited due to the knee joint osteoarthritis. The patient achieved bony union. At the last follow-up visit at 18 months postoperatively, the patient showed no complications (Figure 3C).



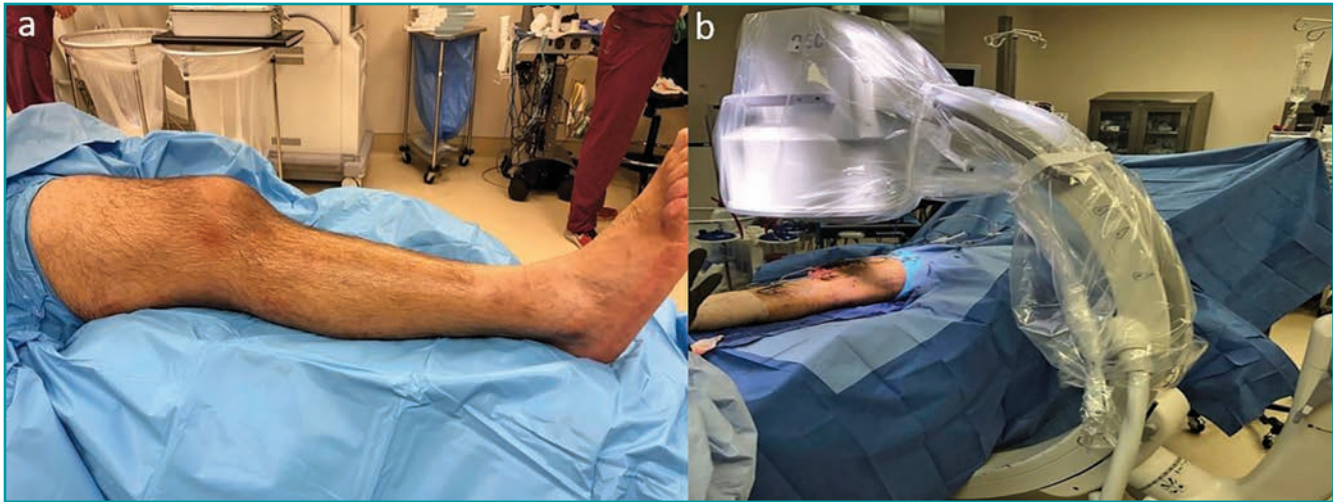
**Figure 3.** A) Preoperative anteroposterior and lateral radiographs of Case 3. B) Postoperative lateral fluoroscopic images showing the initial fixation with cannulated screws and combined fixation using screws and mesh plate. C) Anteroposterior and lateral images of the united fracture at 12-months follow-up.

## SURGICAL TECHNIQUE

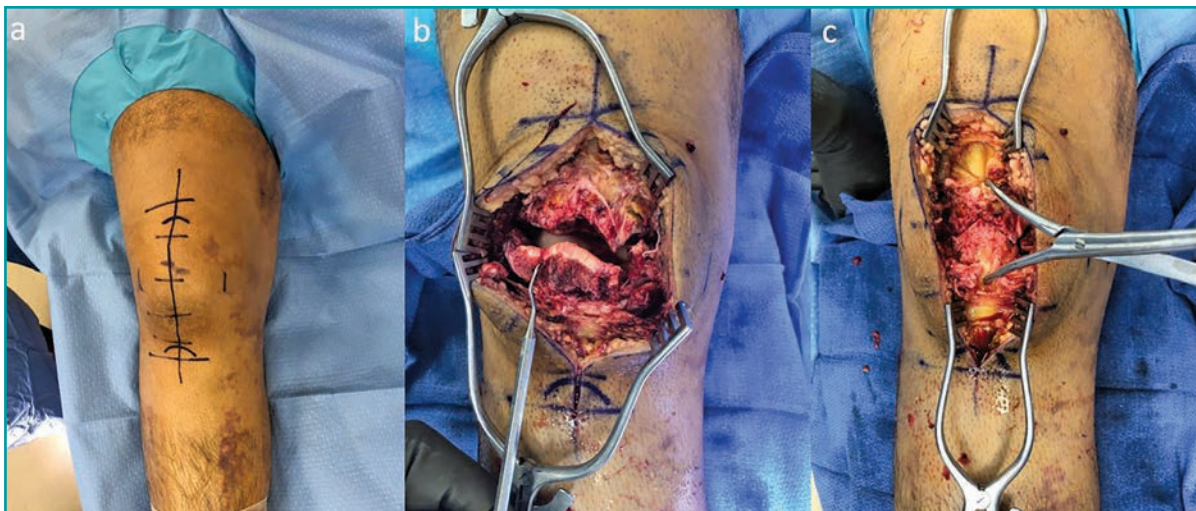
The patient was positioned supine on the flattop table (Figure 4A) and was anesthetized with endotracheal intubation. A regional nerve block was used when appropriate. The injured extremity was ramped with bone foam for x-ray visualization, and the C-arm was positioned on the opposite side (Figure 4B). A non-sterile tourniquet was applied around mid-thigh.

A longitudinal incision was made for fracture exposure (Figure 5A), along with the traumatic rent of the retinaculum. The fracture fragments were identified and reduced with two-point large bone clamps. The clamps were then used to compress the fracture into a transverse fracture (Figures 5B and 5C), and multiple Kirschner wires were used in comminuted fractures. The fracture was then provisionally fixed using multiple Kirschner wires, as seen in (Figure 6A), and the measurement of the plate was obtained (Figure 6B).

The articular congruency was visualized and palpated through the arthrotomy incision using fluoroscopy. The wires were positioned away from the footprint of the plate, and the temporary reduction was checked using



**Figure 4.** A) Patient was positioned supine on the flattop table. B) The C-arm position in relation to the surgical site.



**Figure 5.** Intraoperative photograph showing A) longitudinal incision used for fracture exposure, and B,C) the fracture fragments identified and reduced with two-point large bone clamps.

fluoroscopy in two orthogonal views. A low profile 2.3 mm titanium mesh plate (Stryker, Mahwah, NJ) was cut to fit, and then it was fixed to the anterior surface of the patella using non-locking 2.3 mm screws (Figure 7A).

Further customization through contouring of the plate onto the bone may be performed before placing the screws. Fixation was continued using 2.3 mm self-tapping mini screws. Each screw was pre-drilled, with length measured using the depth gauge (Figure 7B). Care was taken to space the screws according to the fracture pattern and bone integrity. After placing a few screws to gain provisional stability, levering down the plate and further contouring were performed to bring the plate down to the bone. A total of four to six points of fixation were used in each fragment. Small bony fragments needed fewer screws for fixation. Reduction, length of screws, and positioning of the plate were rechecked with fluoroscopy,

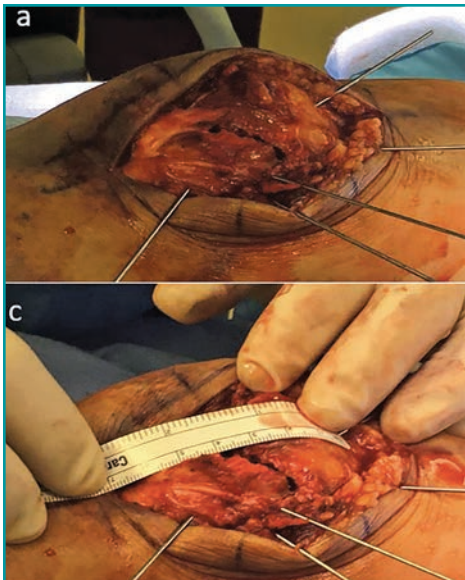
The articular surface was examined under direct visualization by inverting the patella to ensure that

there were no penetrating screws. Alternatively, fluoroscopy may be used to confirm the length of the screws. The Kirschner wires were removed after screw fixation. If the fracture pattern was markedly comminuted, a cerclage using a non-absorbable suture (Ethibond No. 5) and curved needle was passed all around the patella and through the patellar and quadriceps tendons, with care not to evert the patella. A combined suture tension band and mesh plate construct can be used in revision and nonunion cases. The fracture stability was then tested intraoperatively through a full range of flexion and extension.

#### **Postoperative Follow-Up**

Immediately after surgery, patients were mobilized in a hinged knee brace locked in full extension and instructed to bear weight as tolerated. The ROM was conducted through three phases.





**Figure 6.** A) Intraoperative photograph showing temporary fixation of an AO/OTA 34-C3 patellar fracture using Kirschner wires (fracture was highly comminuted). B) Intraoperative photograph showing patellar fracture fixed provisionally using Kirschner wires, and measurement of the patella to adjust the mesh plate (fracture was highly comminuted).

**Phase 1 (Weeks 2-6):** Postoperative hinged knee brace in full extension locked during weight bearing. Knee brace unlocked only for ROM exercises. Begin active ROM in a prone position, active assist ROM as tolerated, quadriceps muscle strengthening in brace immediately.

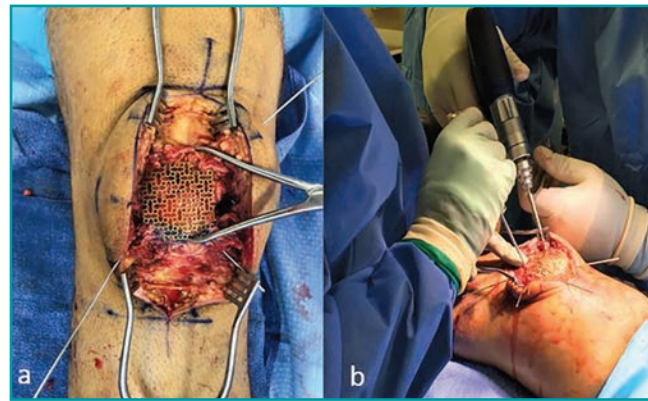
**Phase 2 (Weeks 6-10):** Hinged knee brace unlocked, and the patient is weaned from the brace. Scar massage, passive ROM, and increased strengthening exercises were performed.

**Phase 3 (Week 10):** Begin aggressive ROM exercises, strengthening gradual return to higher-level activity once quadriceps muscle strength returns, with typically no restrictions starting week 12. Evaluate for osseous union and functional outcomes with routine physical and radiographic examinations until full fracture healing.

## DISCUSSION

Mesh plate fixation of patellar fractures has shown excellent rates of union with fewer revision operations in complex patellar fractures (Table 1).<sup>8,13-15,17</sup> A single prospective cohort study by Lorich et al<sup>9</sup> compared a mesh cage plate versus tension band wiring, and they found superior functional outcomes and considerably decreased anterior knee pain in the plate cohort.

Singer et al<sup>14</sup> conducted a study that included nine patients with closed displaced comminuted patella fractures that were fixed using a mesh plate and 2 mm mini screws. The authors found that a low profile mesh plate was an effective method of fixation in the management of comminuted patella fractures with good



**Figure 7.** A) Intraoperative photograph of trimming of low profile 2.3 mm titanium mesh plate to adjust to the size of the fractured patella. B) Intraoperative photograph of definitive fixation of patellar fracture using low profile 2.3 mm titanium mesh plate and non-locking screws.

clinical outcome. The study added a new alternative fixation method to treat the comminuted fractures.

Symptomatic implant is the most common complication reported following patellar fracture fixation. Hoshino et al<sup>3</sup> conducted a retrospective study that included 448 surgical patellar fractures fixations. The authors reported symptomatic hardware removal in 22.6% of the patients fixed by cannulated screws and in 36.8% of patients treated by Kirschner wires and cerclage. LeBrun et al<sup>5</sup> echoed these same findings and found that the removal of symptomatic implant was required in 52% of the patients treated with osteosynthesis. Singer et al<sup>14</sup> reported no hardware complications or removal of patellar fractures when using low profile 1.5 mm mesh plates. Volgas and Dreger<sup>17</sup> reported irritation in several patients when using 2.7 mm mesh plates. Additionally, five patients needed hardware removal, which may be due to the relatively larger plate size and profile.

Several published biomechanical studies have compared the stability and strength of a mesh plate construct to that of a tension band wiring technique.<sup>16,18,19</sup> These studies demonstrated either equal or superior strength and stability achieved by plate constructs. Karakasli et al<sup>19</sup> compared fracture displacement after cyclic loading in two groups of cadaveric knees receiving either titanium plate or tension band-wiring fixation. Cadaveric knees treated with plate fixation showed a considerable reduction in fracture displacement, and the study concluded that fixation with curved titanium plates provided satisfactory stability under cyclical loading, similar to the loading encountered during the postoperative rehabilitation period.<sup>22</sup> Additionally, Dickens et al<sup>18</sup> found that the augmented titanium mesh construct is equal to tension-band wire augmentation concerning the ultimate force required for failure.

A minor complication seen in tension band wiring is a loss of knee ROM due to postoperative stiffness. In one

case series,<sup>20</sup> up to 71% of patients treated with tension band wiring and cast immobilization reported a lack of full extension. The authors proposed that the stability and rigidity of the mesh plate construct allowed earlier weight bearing and ambulation, resulting in decreased stiffness and improved recovery of ROM. Long-term and larger cohort follow-up is not available; however, it is needed to determine the actual efficacy of the plating construct and thus a limitation to this technical trick narrative.

In conclusion, mesh plates appear to be advantageous in the treatment of complex and comminuted fractures by providing stability and allowing fixation of bone fragments with lower rates of hardware removal. Larger comparative studies with long-term follow-up are needed between mesh plate and tension band fixation of patellar fractures to demonstrate whether one is clinically superior to the other. Additional studies comparing various types of mesh plates would be useful in establishing their best clinical uses.

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# Foreign Bodies in the Hand: A Case Report, Review of Literature, and Guidance for Acute Management

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## INTRODUCTION

Penetrating injuries of the hand and fingers are among the most common reasons patients present to the emergency department.<sup>1</sup> Nearly one-third of the 11 million patient visits to emergency departments in the United States involve the hand or wrist.<sup>2</sup> In more than 10% of these injuries, a retained foreign body is discovered.<sup>3</sup> Current literature recommending the ideal method and setting to remove foreign bodies in the hand is sparse and mixed. Some authors support foreign body removal in the emergency department or primary care setting.<sup>4</sup> Despite the failure to diagnose or treat retained foreign bodies being the fifth leading cause for claims against emergency physicians,<sup>5</sup> some authors recommend identification and delayed or non-treatment.<sup>6</sup>

When treating patients with foreign bodies in the palmar aspect of the hand, it is important to collaborate with a hand specialist to avoid complications when exploring adjacent to at-risk neurovascular structures.

## CASE REPORT

An 18-year-old man presented to the emergency department with right hand pain after sustaining a penetrating wound to the hypothenar eminence while cutting chicken wire. On physical examination, the patient endorsed tenderness to palpation over a puncture wound of the hypothenar eminence. He showed full range of motion of the right hand and wrist, and he had negative Froment's sign. The patient was able to abduct and adduct his fingers, and he had 5 of 5 strength to the abductor digiti minimi, interossei, and adductor pollicis. He was neurovascularly intact and no other injuries could be identified. Right hand radiographs confirmed the presence of a foreign body located at the volar aspect of the base of the

fifth metacarpal (Figure 1A and 1B). Foreign body removal utilizing a volar incision was attempted by the emergency physician with concern of persistent symptoms or additional injury given its location. A 2-cm longitudinal incision was made along the ulnar aspect of the hypothenar eminence, which was performed under routine sterile conditions and while using a



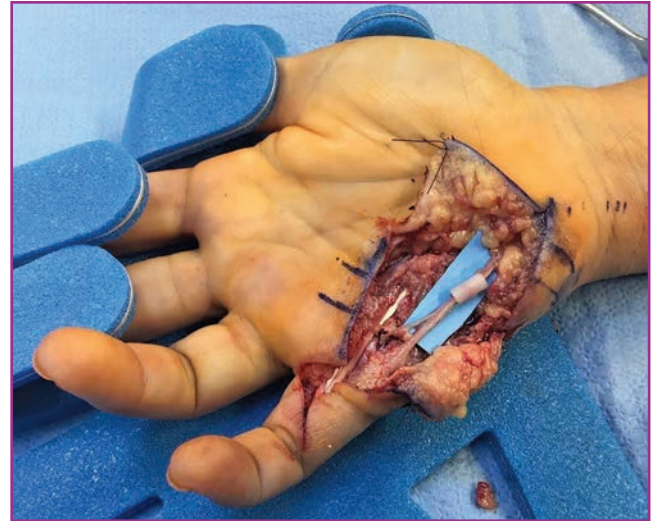
**Figure 1A.** Foreign body at the volar aspect of base of the fifth metacarpal.



**Figure 1B.** Foreign body at the volar aspect of base of the fifth metacarpal.

median and ulnar nerve block. Removal was attempted using fluoroscopic guidance and was unsuccessful. Localization with fluoroscopic guidance suggested that the foreign body was in a deep location not easily accessible from the incision made. Attempted retrieval was thus terminated.

At this point, the orthopaedic service was consulted for assistance. Due to the nerve block, neurological examination was unable to be performed at this time. Given that the foreign body was still near important neurovascular structures, the patient was indicated for formal exploration. In the operating room, antibiotics were administered; a time-out, prepping, and draping were performed; the arm was exsanguinated; and a tourniquet was insufflated. The previous incision that was made by the emergency physician was extended over Guyon's canal. During exploration, the motor branch of the ulnar nerve was found to be sharply transected. The ulnar artery, branching superficial palmar arterial arch, ring and small finger flexor digitorum superficialis, and profundus tendons were intact. A neurolysis of the ulnar nerve and its motor branch was performed. Guyon's canal was decompressed by releasing both the superficial palmar carpal ligament and the flexor retinaculum. The foreign body was located against the base of the fifth



**Figure 2.** Tension free primary repair of motor branch of ulnar nerve reinforced with epineural interrupted simple stitches then covered with nerve conduit.

metacarpal and removed. A tension free, epineural primary repair of the motor branch of the ulnar nerve was performed using a 9-0 non-absorbable suture, and then it was reinforced with interrupted simple sutures (Stryker, Michigan, USA) (Figure 2). A thorough irrigation was performed, followed by skin closure.

## DISCUSSION

Penetrating injuries to the hand are common.<sup>6</sup> The appropriate treatment option and setting for these injuries remain debatable. Complications have been described, including pain, infection, inflammation, neurovascular injury, and unplanned secondary procedures.<sup>7</sup> Indications for foreign body exploration and removal include neurovascular injury, tendon laceration, cosmetic deformity, functional impairment, and chronic pain. Furthermore, contraindications include inaccessibility, unacceptable risks to neurovascular structures during the retrieval process, minute size, inert material, and asymptomatic presentation.<sup>2</sup> Potini et al<sup>6</sup> suggest that a trained hand surgeon perform the safe removal of hand foreign bodies that are accessible or as a part of an exploration procedure to an injured structure.

It is pertinent to obtain an accurate history and physical examination, including a thorough neurovascular examination and wound assessment.<sup>8</sup> To facilitate this assessment, it is important that all penetrating wounds be inspected with proper lighting, sedation, and local anesthesia.<sup>1</sup> Plain radiography and ultrasound can be used to help localize foreign bodies. While plain radiographs identify only radiopaque material (eg, metal, glass, and some plastics), sonographs can be used to identify radiolucent foreign bodies.<sup>4,9</sup>

Understanding the palmar anatomy of the hand, specifically the anatomy of the hypothenar eminence, is essential for safe foreign body retrieval. The main trunk

of the ulnar nerve is adjacent to the flexor carpi ulnaris, superficial to the fascia and skin at the level of the wrist, putting it at risk for penetrating injuries or aberrant explorations.<sup>10</sup> The ulnar nerve and artery then enter Guyon's canal distally, a longitudinal space bordered by the pisiform radially, the hook of the hamate ulnarly, the superficial palmar carpal ligament volarly, and the deeper flexor retinaculum and hypothenar muscles dorsally. Within Guyon's canal, the ulnar nerve divides into the superficial and deep branches.<sup>11</sup> Between the pisiform and the hook of the hamate, the deep branch passes dorsal to the origin of the hypothenar muscles. As the deep branch runs ulnar to the hook of the hamate and radial to the pisiform, an injury localized to this region could disrupt the branch to abductor digiti minimi, resulting in isolated loss of abduction of the fifth digit and an isolated abductor digiti minimi palsy.

We recommend that removal of a foreign body from the palmar aspect of the hand be performed by an appropriately trained hand surgeon in the operating theatre. Adequate anesthesia and meticulous hemostasis in an operating theatre is required.<sup>12-15</sup> An exception to this would be very superficial foreign bodies that are readily visualized through the presenting wound, and do not require imaging guidance or extension of the wound for access. Nevertheless, given the potential difficulty of foreign body removal in the palmar aspect of the hand, as well as the risk to important anatomical structures, hand service consultation is also recommended.

We report the case of iatrogenic transection of the deep branch of the ulnar nerve during hypothenar eminence wound exploration in the emergency department. This case illustrates the challenges of treating these difficult injuries. It should be the primary role of the emergency physician to carefully evaluate wounds for evidence of foreign bodies or damage to deep structures such as nerves, tendons, or arteries. Documenting and discussing these findings with appropriate consultation can limit iatrogenic injury and provide optimal patient outcomes. It is our recommendation that foreign body removal from the palmar aspect of the hand be performed by an appropriately trained hand surgeon in the operating theatre.

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# Isolated Proximal Fibula Fractures in Young Athletes Mimic Lateral Collateral Ligament Injury

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## ABSTRACT

Lateral knee injury is common among adolescent athletes in both contact and non-contact sports. Injuries in this population deserve special consideration regarding diagnosis and treatment due to the presence of open, closing, or recently closed physes. We describe two cases of isolated proximal fibula fractures with knee pain and laxity to varus stress in young athletes. Isolated proximal fibula fractures can mimic lateral collateral ligament injuries in the knee. Treatment for these injuries is conservative with bracing, protected weight bearing, and delayed or protected return to activity.

**Keywords:** Fibula, Fracture, Lateral Collateral Ligament

## INTRODUCTION

Lateral knee pain in the pediatric population elicits a rather short classical differential diagnosis list, including lateral meniscus, lateral collateral ligament (LCL), and iliotibial band injury.<sup>1</sup> A thorough look at the patient's history, including mechanism and timing of the injury, can often narrow the differential to a single diagnosis.

We describe two cases of isolated proximal fibular head fractures in the pediatric population that involve findings consistent with all three classical diagnoses, including popping sensations with activity, pain with varus stress, instability, and lateral joint line tenderness. Although this injury is rare and not well-described in the literature, it should be considered in young patients with lateral knee pain with or without instability so that appropriate treatment can be initiated.

## CASE 1

A 14-year-old adolescent girl presented to our clinic with a 1-day history of knee pain. She felt a pop in her knee with subsequent swelling after accidentally stepping into a hole while playing soccer. She now feels pain with activities and weight bearing. She denied any catching

or locking of the knee, but stated that her knee "pops" with motion.

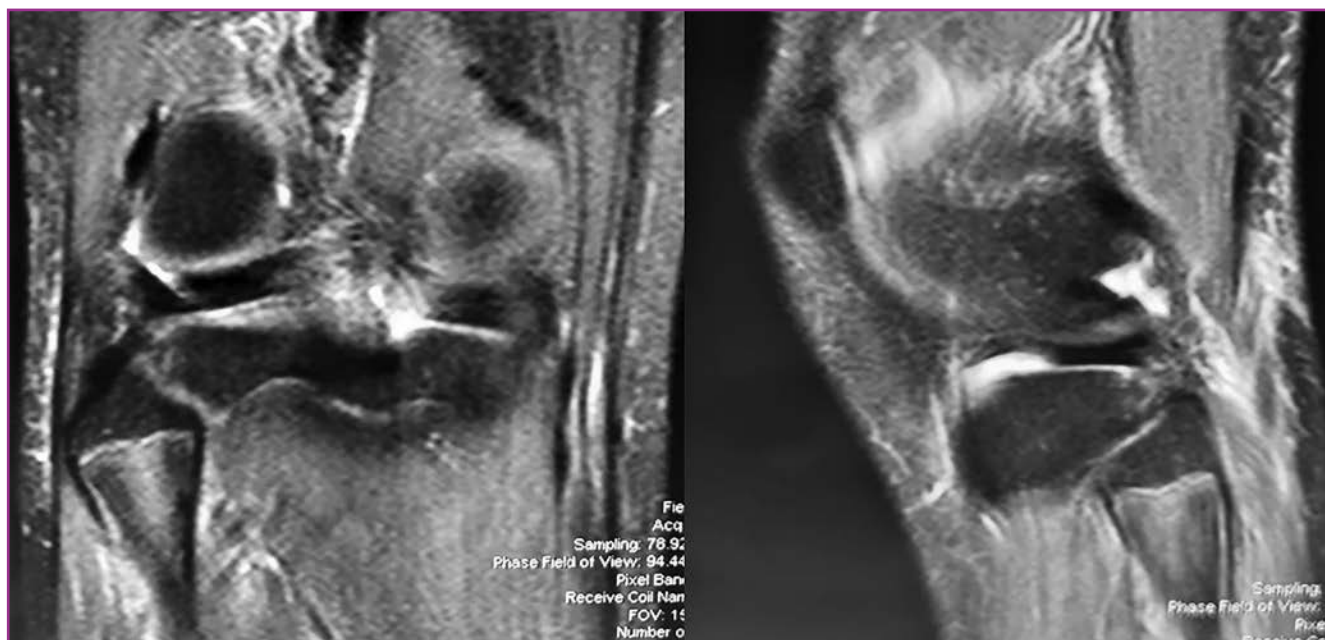
Results of physical examination revealed pain with axial loading, provocative flexion, and varus stress at 0° and 30° knee flexion with grade 1 (< 5 mm) lateral knee opening at 30°; maximal tenderness along the posterior lateral joint line; mildly positive Lachman with a firm endpoint, compared to the left side; exquisite focal tenderness at the fibular head; and mild tenderness along the LCL. Knee radiographs showed a well-aligned Salter-Harris (SH) type II fracture of the proximal fibular head with mild physeal widening (Figure 1).

The patient was placed in a hinged knee brace and made partial weight bearing with crutch use. Owing



**Figure 1.** Right knee radiograph of patient 1 at 4 weeks post-injury. Arrow depicts Salter Harris II fracture of the proximal fibula physis.





**Figure 2.** Coronal and sagittal T2 magnetic resonance imaging of the right knee of patient 1 at 2 days post-injury. Note the bony edema in the proximal fibular head.

to the patient's mechanical symptoms and instability, a magnetic resonance image (MRI) was recommended to rule out lateral meniscal injury and to assess the integrity of the anterior cruciate ligament. Although x-rays showed a proximal fibula fracture, they were unable to rule out a concomitant LCL injury. The patient had a grade I laxity at 30° flexion, which is a finding consistent with LCL injury. An MRI was thus necessary to fully evaluate the integrity of the LCL and posterolateral corner (PLC). MRI revealed no injury to the LCL or PLC and edema in the proximal right fibular head consistent with the SH type II fracture previously identified (Figure 2).

At follow-up (4 weeks after initial injury), there was resolution of tenderness at the posterior lateral knee, fibular head, and at LCL. X-rays were grossly unchanged since the initial visit. It was recommended that the patient continue with activity modifications for 3 weeks. The hinged knee brace was discontinued.

At 9 weeks after initial injury, the patient was full-weight bearing without pain or instability. Physical examination was grossly negative with no focal tenderness. Radiographs revealed new bone formation in the right proximal fibular neck.

## CASE 2

A 15-year-old adolescent boy presented 3 days after injuring his right knee. He was tackled by another player while playing football and felt immediate right lateral knee pain. He had pain with weight bearing and knee range of motion. He did not finish practice the day of injury, but he did return to practice the next day with discomfort.

Results of examination of the knee showed no effusion or swelling. There was mild tenderness to the posterior lateral knee, tenderness over the fibular head

and at the anterior lateral aspect of the patella, and pain with varus stressing. The knee was noted to have good stability in all planes. All other examination maneuvers were unremarkable. Knee radiographs showed a cortical defect at the level of the physeal scar of the proximal fibular, which was indicative of a proximal fibula fracture versus an LCL avulsion fracture (Figure 3). Advanced imaging was not obtained.

Treatment included use of a hinged knee brace for all weight-bearing activity and the continuation



**Figure 3.** Right knee radiographs of patient 2 at 3 days post-injury. Arrow depicts cortical defect at the level of the physeal scar.

of activities as tolerated. Telephone follow-up was obtained 10 years later. He recalls knee pain for 1 to 1.5 months after injury and made a full recovery. He continued to play football for 4 more years and recalls additional knee injuries. He denies any lingering or daily knee pain, but endorses occasional painless popping and clicking. He is able to fully participate in all activities.

## DISCUSSION

Isolated fractures of the proximal fibular head or physis are quite rare, accounting for an estimated 0.09% of all children's fractures and 2.05% of all fibular fractures.<sup>2,3</sup> One previous case of such injury involved a 15-year-old female gymnast who sustained a fall from a balance beam. In contrast to this case series, the patient had no evidence of mediolateral instability.<sup>4</sup> It has been reported that proximal diaphyseal fracture of the fibula can lead to lateral knee laxity in isolation or in the setting of a stabilized associated tibia fracture.<sup>5</sup>

This case series of two patients uniquely describes the variability of lateral knee instability secondary to isolated fracture of the proximal fibula. At presentation, the patients experienced pain with weight bearing, mild swelling about the knee, and no obvious effusion. In aggregate, physical examination findings included maximal tenderness at the fibular head, pain and instability with varus stressing, pain with provocative flexion, and pain with axial loading. We hypothesize that the varus instability and mild opening in case 1 represented gross motion at the fracture site rather than injury to lateral knee structures. Initially, these findings were concerning for isolated or associated LCL injury, which should be among the initial differential diagnosis in patients presenting with lateral knee pain and mild varus opening on stress. However, LCL injuries in young athletes are extremely rare and often involve portions of the PLC or the anterior cruciate ligament.<sup>6,7</sup> One case showed varus instability and both patients had pain with varus stress, consistent with a grade I or II LCL sprain. Although rare, isolated LCL injury can present with focal tenderness over the fibular head if the distal insertion avulses.<sup>8</sup> In both cases, plain films or MRI were able to identify the proximal fibular fracture.

Careful examination of the lateral structures of the knee will aid in a more accurate diagnosis. The LCL becomes isolated and maximally loaded at 30° of knee flexion.<sup>9</sup> Therefore, increased laxity to varus stress at 30° of flexion implies injury to the LCL, whereas increased laxity at full extension implies injury to the cruciate ligaments.<sup>10</sup> The dial test is useful in testing for injury to the PLC and posterior cruciate ligament (PCL). To perform, the patient is placed prone and the knees flexed to 30° and 90°. External rotation of both knees is tested at both degrees of flexion. Increased external rotation of the injured extremity greater than 10° with 30° of knee flexion compared to the non-injured contralateral side implies injury to the PLC.<sup>9</sup> Increased

external rotation at 90° of knee flexion implies injury to the PCL. However, this manuscript shows that proximal fibula fractures can lead to similar positive examination maneuvers, and that imaging in the form of plain radiographs and MRI is warranted for definitive diagnosis.

The routine use of MRI in diagnosing SH fractures, whether radiographically proven or occult, is not currently recommended. MRI in the setting of a suspected SH fracture with negative x-ray findings yields a positive finding in about 0 to 34.8% of patients.<sup>11-13</sup> Furthermore, the authors do not believe that MRI would change the course of management in the setting of an x-ray positive isolated proximal fibula fracture. An MRI should be considered in the presence of associated mechanical symptoms; positive physical examination findings indicating an associated soft-tissue injury, including lateral opening and laxity suggesting true LCL injury; or in the setting of negative x-rays with knee instability.

All patients were treated with partial weight bearing in a hinged knee brace with activity modification for the first 1 to 2 weeks post-injury. Patients were tolerating full weight bearing while in brace at 4 weeks post-injury. For the next 4 weeks, patients were full weight bearing with either a hinged knee brace or laterally stabilized brace, and they were instructed to continue with activity modification. Activity modifications included no competition play, no contact practice, and no cutting or pivoting. At 8 weeks, patients had radiographic evidence of fracture healing and no focal tenderness over the proximal fibular head. Brace wear was continued as needed with activities only. This protocol closely mirrors conservative treatment for isolated grade I and II LCL and medial collateral ligament sprains, bracing for 6 to 8 weeks, graduated weight-bearing status, early range of motion, and return to full activities in 6 to 8 weeks with or without bracing during activity.<sup>14,15</sup>

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# Femoral Diaphysis Fracture in a Collegiate Male Hockey Player: A Case Report

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

## ABSTRACT

Femoral diaphysis fractures represent a small subset of sports-related orthopaedic trauma, accounting for less than 1% of all sports fractures. We describe a 22-year-old male ice hockey player who slid and crashed into the boards during practice. Radiographs revealed fracture of the femoral diaphysis, necessitating surgical intervention to insert an intermedullary nail. Rehabilitation was a hybrid of an anterior cruciate ligament reconstruction and hip labrum repair protocols. There was emphasis on rotator cuff strengthening and lower-extremity rehabilitation owing to a pre-existing shoulder dislocation that occurred during the same season. He returned to skating at 16 weeks, and at 20 weeks he returned to full, unrestricted hockey activity.

**Keywords:** Femoral Fracture, Rehabilitation, Return to Sport, Athletic Injuries, Sports Medicine

## INTRODUCTION

Femur diaphysis fractures are uncommon occurrences in sports. According to a general population study in Edinburgh, Scotland, femur diaphysis fractures account for 0.09% of all sports fractures in adults and children (ie, 1 in 1169 fractures).<sup>1,2</sup> The National Collegiate Athletic Association (NCAA) collects injury data using Injury Surveillance Program, but they do not report statistics on injuries accounting for less than 1% of all injuries. Given this limitation, there are no reported statistics on diaphyseal femoral fractures in any sport, including collegiate ice hockey. NCAA literature does describe a category for “fracture, dislocation, and subluxation” as 5.7% of practice injuries and 7.1% of game injuries, in which 17 to 25% of these injuries require emergency transport.<sup>3,4</sup>

A femur fracture in a professional ice hockey athlete was previously described in the *Journal of Athletic Training*<sup>5</sup>; however, no data were presented for return to baseline performance. Although there is previous description of the injury, it is important to

continue to investigate return-to-play and performance interventions to better describe the recovery and rehabilitation after emergent, traumatic injury.<sup>6</sup>

## CASE REPORT

The patient is a 22-year-old male ice hockey athlete. He reported occasional smokeless tobacco and alcohol usage. The patient had no considerable history of lower-extremity injury. Earlier that year, the patient sustained a traumatic anterior shoulder dislocation that was managed nonoperatively and braced for all on-ice participation. He had planned on operative management of the shoulder at the end of the season, but he has since elected to forgo surgery based on a positive nonoperative outcome. The patient was participating in normal practice activity when he had lost an edge when making a tight turn and violently crashed into the boards. He remained down on the ice, and loudly stated that he broke his leg. The athletic trainer attended to the patient on the ice; his thigh was soft to palpation, and he could not tolerate a log roll. The emergency action plan was activated, and emergency medical services responded promptly. The patient had no decreased pedal pulses or loss of foot function or sensation. There was no evidence of bleeding or concern for open fracture. A vacuum splint was applied, and he was transported to the emergency room. Radiographs showed a displaced femoral diaphysis fracture (Figure 1). He underwent urgent closed reduction and internal fixation with an anterograde intermedullary nail (Figures 2 and 3). The patient remained in the hospital overnight before being discharged in the morning. He was given crutches and allowed to weight bear immediately as tolerated.

Three days after the initial injury, the patient began rehabilitation that focused on soft-tissue massage of all thigh and hip musculature; range of motion of the knee and hip; and isometric progressing to concentric hip, knee, and thigh strengthening.<sup>6</sup> The patient progressed during the first 8 weeks of rehabilitation, which





**Figure 1.** X-ray of fracture showing extent of injury.



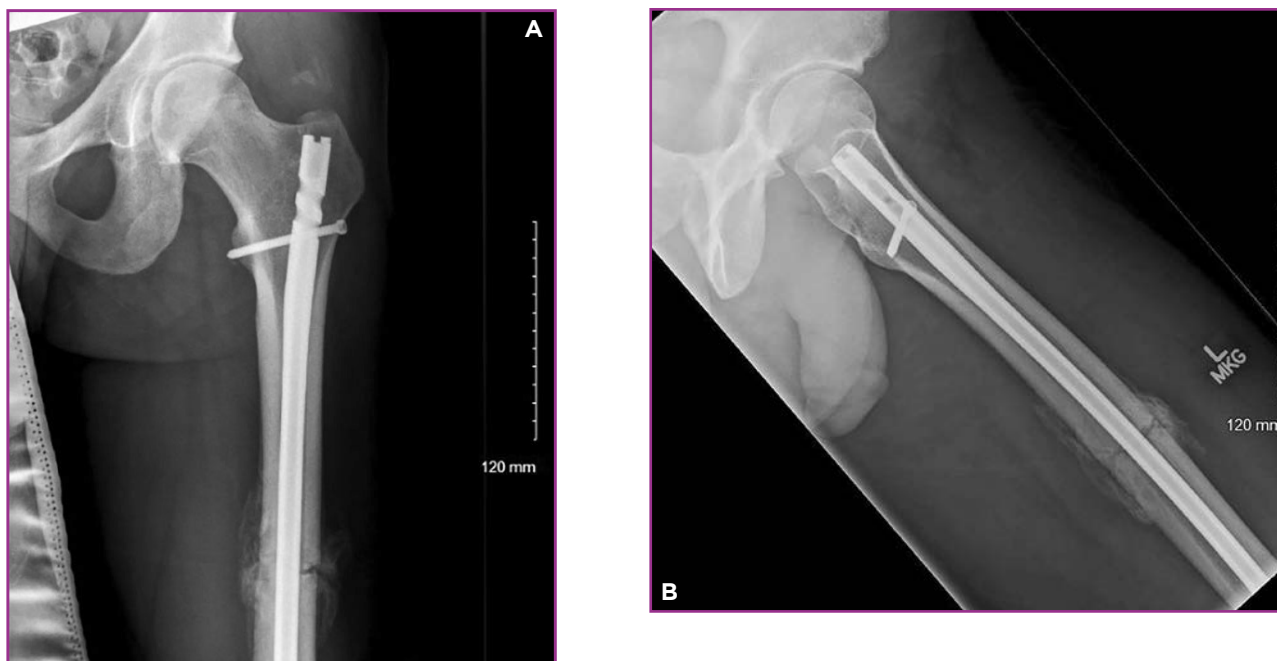
**Figure 2.** Postoperative intramedullary nail placement and fracture alignment showing surgical procedure.



**Figure 3.** Proximal intermedullary nail fixation showing hardware positioning around soft tissues.

**Table 1.** Rehabilitation Progression Weeks 0 - 8

Weeks 0 - 2	Weeks 2 - 4	Weeks 4 - 6	Weeks 6 - 8
<p>Neuromuscular Re-education electrical stimulation targeting the vastus medialis</p> <p>Hip and knee isometrics progressing to concentric table-based exercise including straight leg raises, glut/hamstring bridges, short and long arc quads</p> <p>Quadruped rocking</p> <p>Weight shifting</p> <p>Manual Therapy</p>	<p>Add mini squats (2 weeks) and leg press (3 weeks)</p> <p>Blood Flow Restriction for table exercises at 4 weeks (thigh laceration and incision healing)</p>	<p>Bike warm up daily</p> <p>Band walking – lateral and retro walking</p> <p>Retro stairs, assisted step downs</p> <p>Side planks</p>	<p>Undulating program – strength, functional, core, pool</p>



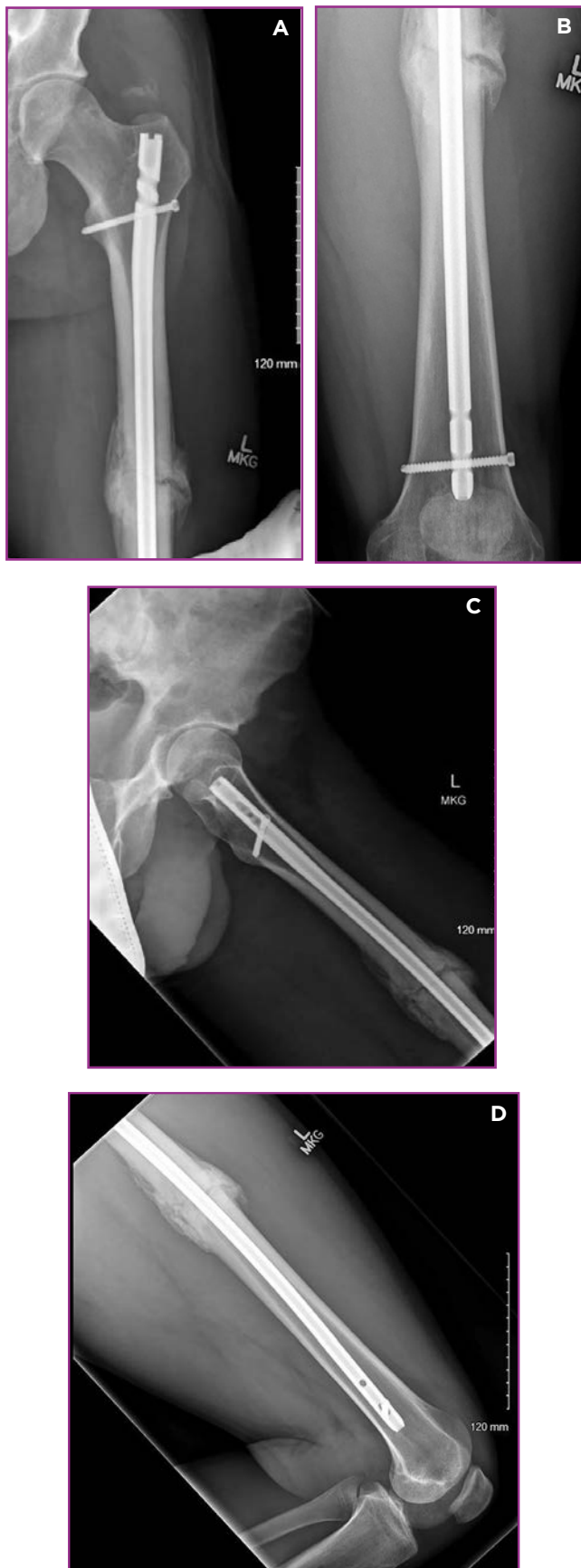
**Figure 4.** A) Anteroposterior and B) lateral femur radiographs showing progressive healing.

combined labral repair and anterior cruciate ligament reconstruction protocol with no range of motion or weight-bearing considerations (Table 1). Previous case reports<sup>5,6</sup> have shown long-term patient concerns of patellofemoral or hip abductor weaknesses as far out as 1 year after internal fixation. Restoration of muscle firing at both the hip and knee was emphasized, especially the gut complex and vastus medialis. At 1 year post injury, the patient subsequently showed no symptoms of hip or knee dysfunction.

Blood flow restriction (BFR) using the “B Strong” modality ((B)Strong, Park City, UT) was applied for all concentric exercise during week 4 onward. The patient was no longer taking Lovenox and there was concern for comorbidity such as deep vein thrombosis. Thus, approval to begin BFR training was obtained from the orthopaedic surgeon. The BFR cuff was applied to pool workouts, including strengthening and plyometric activity. Pressure was estimated using the “B Strong” application, and applied at 310 mm Hg to each leg for up to 30 minutes at a time. The primary goal of the BFR modality is improved muscle hypertrophy, allowing the patient to regain strength rapidly and progress easily back to high-level performance lifting. Although there are many studies showing benefits for muscle hypertrophy, there is not strong evidence to support BFR to modulate bone remodeling.<sup>7</sup> Until BFR was discontinued at 16 weeks postoperation, the patient continued strength training, including step-ups, squatting, and lunging.

At 16 weeks, he began running and returned to plyometric activity. At 18 weeks postoperatively, he resumed limited strength and conditioning activity. Radiographs were obtained at 8 and 16 weeks

postoperatively (Figures 4 and 5). Complete healing was determined to be at 16 weeks. Force plate data were compared to his pre-injury levels. He showed an increased laterality discrepancy, especially in the braking phase immediately prior to the countermovement explosive phase. This represents a shift from his left leg into his right leg at the bottom of the loading phase of jumping. Modifications were made to strength and conditioning activity, with a specific emphasis on unilateral eccentric plyometrics, including reflexive split squat drops and mini hurdle deceleration drills 3 times per week. He resumed full on ice training at 24 weeks postoperation. His only remaining concern was occasional gluteal fatigue, which was resolved with z-axis hip and core integration training. A preseason assessment using an InBody 570 (InBody USA, Cerritos, CA) showed increased muscle mass in his left leg compared to pre-injury levels the previous preseason. Measurement of his vertical jump using a Hawkins Force Plate (Hawkins Dynamics, Westbrook, ME) showed a 17% difference in his left versus right side in the braking phase of a jump, improved from 27% 12 weeks prior (Figure 6). His pre-injury difference was 0.2%. At 30 weeks postoperatively, he showed a 9.5% difference, which represents an improvement of 17% compared to initial testing post injury. His vertical jump height also improved to at or above baseline by 20 weeks postoperatively. Performance lifting testing of trap bar dead lift showed a decrease in 25 lbs from 400 lbs prior to injury to 375 lbs at 22 weeks postoperatively. He also showed a one repetition maximum of 425 lbs for each leg in a rear foot elevated split squat with no available pre-injury testing available.



**Figure 5.** Anteroposterior A) proximal, B) distal C) proximal lateral, and D) distal lateral femur radiographs at 16 weeks showing near complete healing. These are the final radiographs tracking callus formation and healing.

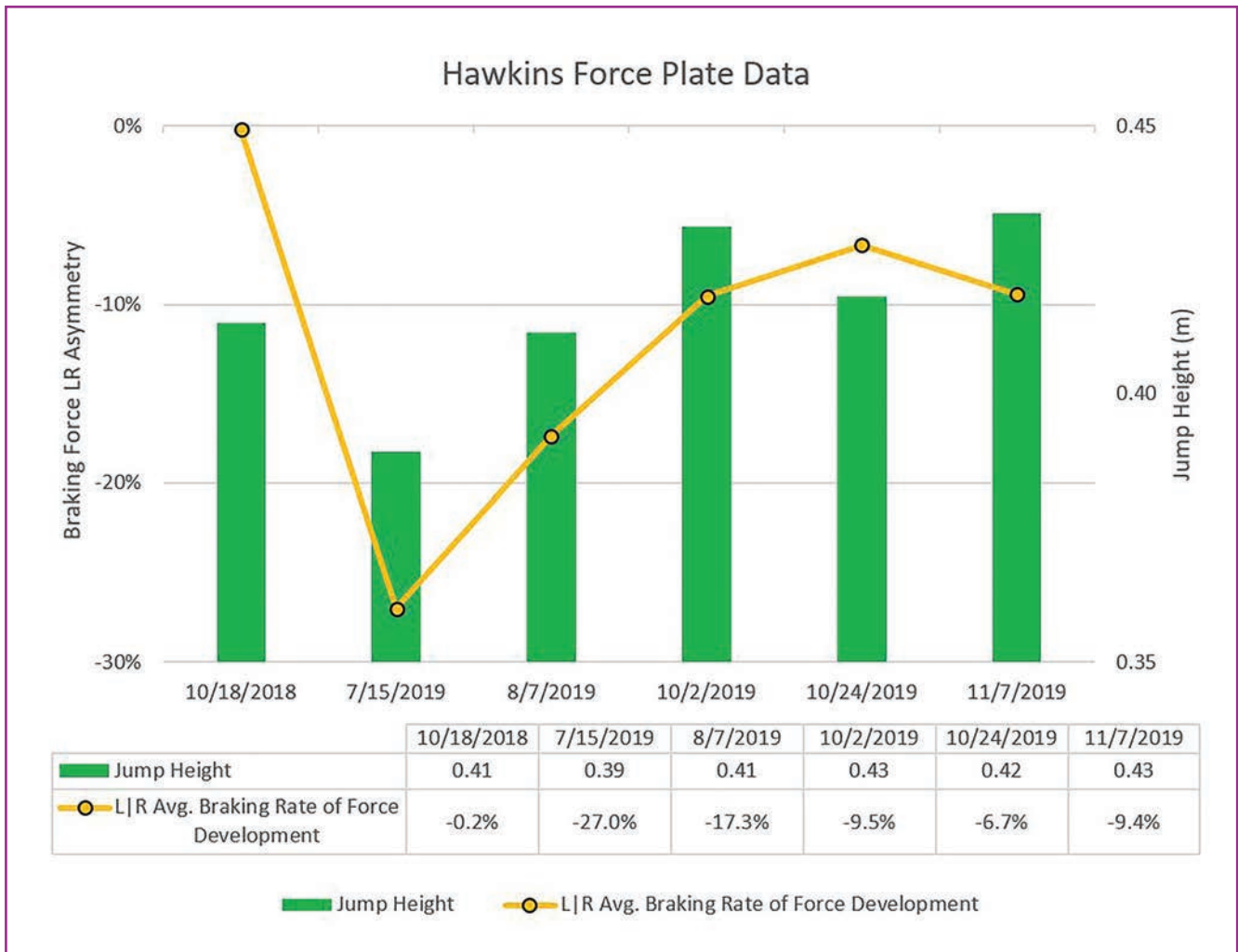
## DISCUSSION

Proper assessment and transport are crucial to obtaining a positive outcome with femur fractures. Failure to recognize the pathology and immobilize the patient prior to extraction may result in additional complications, including propagating neurovascular compromise or failure to recognize a compartment syndrome. It is important to assess distal pulses and sensation when evaluating lower-extremity trauma in order to rule out either pathology prior to transport. Standard anterior-posterior and lateral radiographs are adequate to assess femur fracture, with additional imaging to include joint above and below. Postoperatively, initial rehabilitation should focus on restoring range of motion in the knee and hip and the strengthening of all hip and thigh musculature. The intermedullary nail allows for immediate weight bearing as tolerated. If the fracture pattern and bone quality permits, then all attempts should be made to allow the patient to ambulate fully without assistance as soon as they can do so safely with a relatively normal gait.

Although fracture of the femoral diaphysis is rare in athletic competition, it should also be considered when assessing traumatic injury to the thigh. Skating velocities may be as high as 30 mph and sliding velocities as high as 15 mph.<sup>8</sup> The speed, environmental risks of fixed boards around the ice surface, and rapid deceleration all contribute to the potential for high-velocity collisions in the sport of ice hockey. This combination of factors creates a considerable risk for injuries, and may explain why the injury described in this case occurred despite a previously limited documented description.

Once proper diagnosis has been made, it is necessary to work with multiple disciplines in order to ensure complete recovery. Early involvement of the strength and conditioning staff will help ensure safe and appropriate maintenance of cardiorespiratory fitness. Close collaboration with the certified athletic trainer, surgeon, and strength and conditioning staff creates an environment for long-term patient success as well as a decreased risk of complication.

Overall, successful return to play will be largely dictated by proper diagnosis and collaborative care between physician, athletic trainer, and strength and conditioning coach. In order to best optimize patient outcomes, future investigation of fracture to the femoral diaphysis should work to focus on development of a more complete rehabilitation protocol.



**Figure 6.** Jump Countermovement Laterality Difference. A negative number indicates a bias to the right side, while a positive difference would indicate a bias to the left side. This phase of the jump specifically identifies a discrepancy when the patient squats down and the instant immediately prior to propulsion, capturing a loading bias.

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# A Case of Osteosarcoma and its Presentation in a Division I Collegiate Athlete

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

## ABSTRACT

Primary bone and soft-tissue tumors may present by mimicking common sports injuries. Their diagnosis is contingent on maintaining a broad differential. We report a case of a 20-year-old male athlete who sustained a twisting injury to his planted right knee while playing college lacrosse. He was unable to bear weight or fully extend his knee. The team's orthopaedic surgeon was concerned for a locked knee secondary to a possible flipped meniscal tear. Radiographs and magnetic resonance imaging were performed that led to the discovery of an expansile, sclerotic lesion arising from the posteromedial aspect of the distal femur. Biopsy of the lesion showed an intracortical osteosarcoma. The patient underwent curative knee-sparing *en bloc* resection with an intercalary allograft and reconstruction of the medial collateral ligament. At 2 years postoperatively, the patient returned to play, but not at the previous level.

**Keywords:** Osteosarcoma, Sports, Knee, Athlete

## INTRODUCTION

Early and accurate diagnosis of primary bone tumors in young and healthy patients can be difficult. Symptoms of primary bone tumors often present insidiously and may overlap with those of an overuse or sports-related injury.<sup>1</sup> A missed or delayed diagnosis can have devastating limb- and life-threatening consequences, especially if an inappropriate or invasive procedure is carried out as part of the diagnostic work-up.<sup>2</sup> Thus a comprehensive history and physical examination is warranted in all patients, regardless of how clear the initial diagnosis may seem. We describe the case of a Division I National Collegiate Athletic Association (NCAA) lacrosse player who sustained an injury during practice, and whose initial diagnosis was focused on sports-related pathology. The purpose of this case report is to emphasize the overlapping demographics and symptomatology of sports-related injuries and primary bone tumors, particularly around the knee,

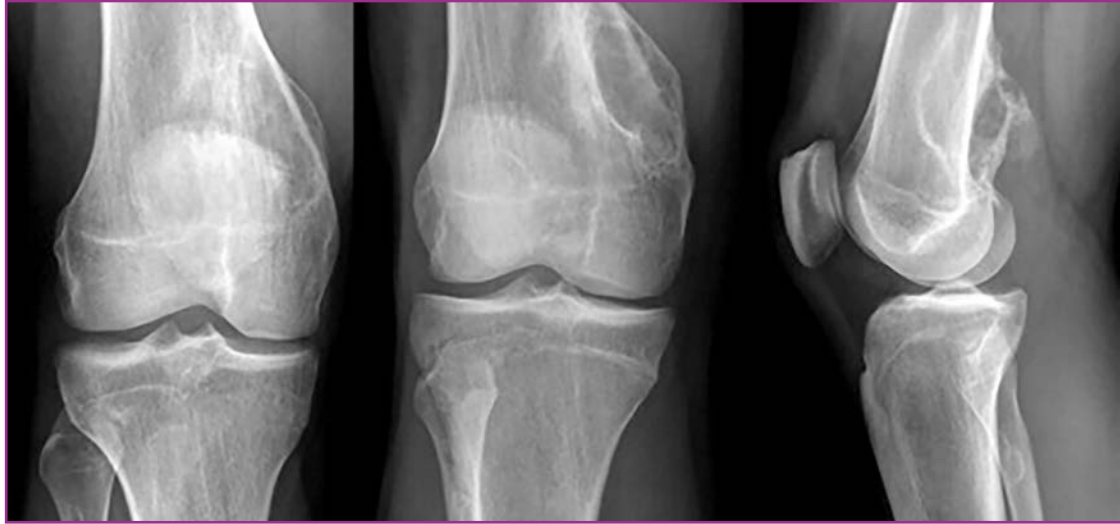
and to bring awareness of salient features that can be crucial in differentiating between the two.

## CASE REPORT

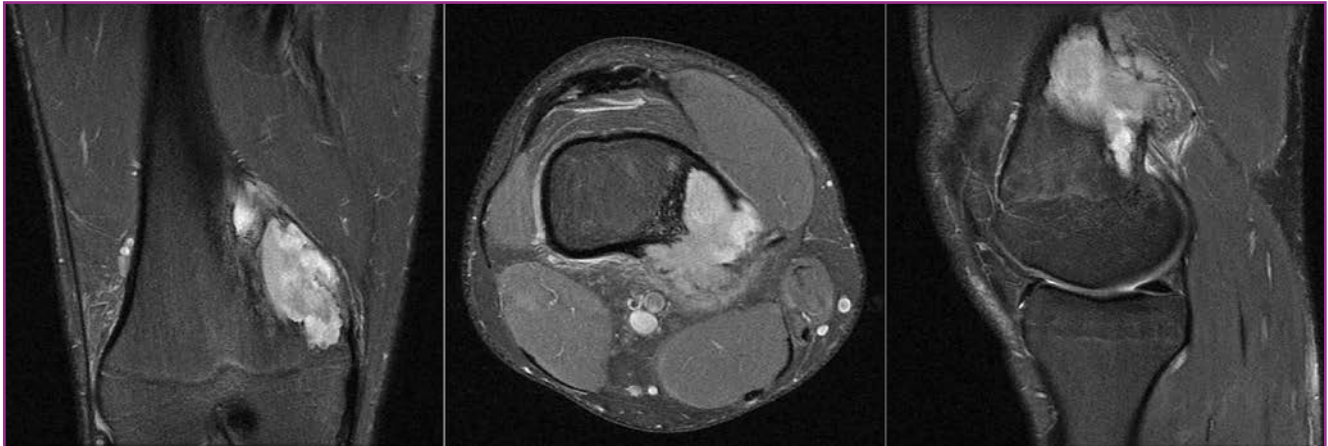
A 20-year-old healthy man, with no significant past medical history, was participating in a Division I lacrosse practice when he sustained a twisting injury to his right knee while defending another player. He had immediate pain on the medial aspect of his knee and was unable to bear weight. Shortly after practice, he was evaluated in the athletic training room by a certified athletic trainer and fellowship-trained, sports-medicine orthopaedic surgeon. On initial examination, the patient was found to have localized medial joint line tenderness, a mild effusion, a 20° extensor lag, and an inability to tolerate flexion beyond 50°. Anterior cruciate ligament, posterior cruciate ligament, medial collateral ligament (MCL), and lateral collateral ligament testing showed stable and firm endpoints. The patient did report pain with MCL valgus stress testing and was unable to tolerate a McMurray test. Based on these symptoms and the situation in which the injury occurred, the suspected diagnosis was a locked knee secondary to an entrapped medial meniscus tear blocking full extension.

Urgent radiographic and magnetic resonance imaging (MRI) evaluations were obtained (Figures 1 and 2). Although the menisci appeared healthy and intact, an expansile, eccentric lesion in the posteromedial portion of the distal femur was identified. The lesion demonstrated several benign radiographic features, including a sclerotic and narrow zone of transition that did not cross the physis. However, there were more aggressive features, including an area of transcortical extension and central enhancement of the tumor. The tumor was adjacent to, but did not involve, the neurovascular bundle traversing the popliteal fossa. Coincidentally, the patient was also noted to have benign and fibrous cortical defects in the proximal fibula.

Consultation with an orthopaedic oncologist was made and the patient was seen the next day, less than one week after the original injury. At this visit, the



**Figure 1.** Anteroposterior and lateral radiographs of the right knee. An 8 x 3.3 cm expansile, eccentrically located sclerotic lesion in the posteromedial aspect of the distal femoral metaphysis. The lesion does not cross the physis and does not have any appreciable matrix mineralization. Note, there are benign fibrous cortical defects involving the proximal fibula.



**Figure 2.** Anteroposterior and lateral T2 and axial fat saturated magnetic resonance imaging slices showing a heterogeneous, hyperintense lesion in the distal femoral metaphysis with transcortical soft-tissue extension

patient's pain had largely resolved, and he had regained full extension. Additional history revealed that the patient had been having episodic, activity-related knee pain for the last year that improved with rest. He did not report any pain that woke him up or worsening pain at night. However, he did report progressive difficulty with activities of deep flexion, including getting into and out of a low car. Biopsy of the lesion was performed and sent to multiple centers for interpretation. The final diagnosis after full work-up was that of a nonmetastatic, low-grade intracortical osteosarcoma.

The patient was referred to a large regional cancer center where he ultimately underwent a knee-sparing *en bloc* resection with an intercalary allograft (Figure 3). The resection was performed through a medial approach and involved meticulous soft-tissue dissection to avoid violating the tumor margins. Hemicortical *en bloc* resection of the tumor was performed using computed tomography-based computer guidance and

an intraoperative O-arm. The distal extent of the tumor was proximal to the physis, and it was adequately resected in a manner that spared the femoral condyles. An identical set of cuts were then performed on a freshly frozen osteoarticular allograft, which was further sculpted to fit the defect and secured in place with a large locking plate (Figure 4). The medial epicondyle, and thus the origin of the MCL, was partially transected during the resection. The remaining intact portion of the patient's MCL was then imbricated with an allograft.

Postoperative pathology on the specimen was interpreted as being an intermediate grade osteosarcoma. Thus the patient received six cycles of adjuvant chemotherapy with cisplatin and doxorubicin. Immediately after the procedure, the patient was touchdown weight bearing on the operative leg. This was gradually progressed, and by 7 months postoperatively he was full weight bearing. No formal postoperative protocol was utilized.

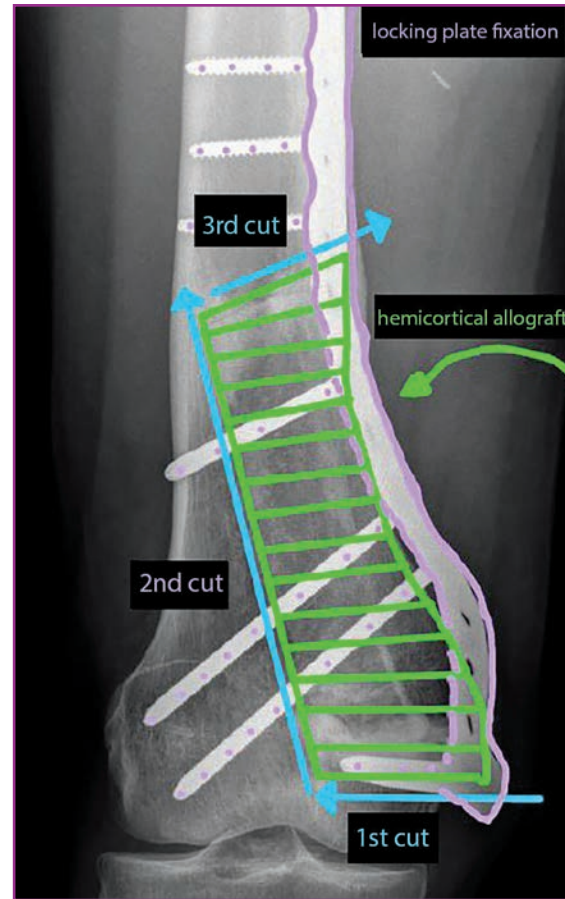


**Figure 3.** Anteroposterior and lateral radiographs taken approximately 2 years after the joint-sparing en bloc tumor resection and reconstruction with an intercalary allograft. There has been radiographic union at the host and allograft interface.

Roughly 1 year following the procedure, the patient began to lose his knee range of motion, but he did not have any evidence of tumor recurrence. He underwent an open exploration with allograft trimming, quadriceps adhesion takedown, and knee manipulation. Following this, he underwent extensive physical therapy and strength training with the hopes of returning to lacrosse. The patient's rehabilitation focused initially on knee range of motion, with subsequent therapy targeted at functional leg strengthening for the high conditioning demands needed for play. Approximately 2 years from the date of diagnosis, the patient returned to lacrosse and was able to participate in light competition. However, the patient did not return to his preoperative level of play. The disease had not recurred at the time of his last clinical follow-up, which was roughly 4 years from the date of the procedure.

## DISCUSSION

Osteosarcoma is uncommon in the United States, with approximately 500 cases diagnosed in children and young adults annually.<sup>3</sup> This condition also makes up a small fraction of all knee tumors.<sup>4</sup> The two most common malignant knee tumors are osteosarcoma and Ewing's sarcoma. Most tumors around a young athlete's knee are benign, with the majority of symptomatic lesions being an osteochondroma, osteoid osteoma, aneurysmal bone cyst, or nonossifying fibroma.<sup>5</sup> The knee is one of the most frequently imaged structures in the body, and many benign and malignant lesions are



**Figure 4.** Using computed tomography-based navigation, the tumor was resected en bloc. A fresh osteoarticular allograft was then sculpted to match the defect and secured in place with a locking plate.

found incidentally through work-up of nononcologic pathology, including fractures, degenerative conditions, and sports-related injuries. In these instances, the nononcologic diagnosis can arise independently as a result of the tumor or as a misdiagnosis; however, the bone lesion is the true causative agent.<sup>6</sup> In their review of over 650 knee tumors, Muscolo et al<sup>1</sup> found that 3.7% of the tumors were treated with an intra-articular procedure owing to being misdiagnosed as a sports injury. In 60% (15/25) of these cases, definitive oncologic surgical treatment was altered.<sup>1</sup>

For both sports-related injuries and bone tumors, the most common concern is pain. Pain-related symptoms that should raise suspicion include pain at rest, pain at night, and pain that does not follow the typical recovery of what otherwise would be expected from the initial diagnosis.<sup>7</sup> Additionally, prodromal symptoms can help differentiate between tumor pain and injury-related pain when both may be present. In this case, the patient had been having episodic knee pain and mechanical symptoms for nearly 1 year before the acute injury.

Differentiating between benign and malignant pathology may ultimately require a histologic diagnosis,

but that consideration requires the recognition that not all knee pain is actually *knee pain*. Furthermore, nononcologic orthopaedists will almost assuredly encounter osseous lesions in their work-up of acute and chronic conditions. Although many of these lesions are ultimately benign, it is through this pathway that many patients with aggressive and life-threatening neoplasms get the care they need.

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# Treatment of Both Column Acetabular Bone Loss in Multiple Myeloma Patient with Custom Triflange Acetabular Component: A Case Report

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

## ABSTRACT

Massive acetabular bone loss with pelvic discontinuity remains a challenging obstacle with few arthroplasty solutions. We present a case of a 61-year-old man with multiple myeloma who suffered a pathologic acetabular fracture resulting in acetabular protrusion and eventually extensive acetabular bone loss. His prognosis was initially poor; however, he ultimately responded to his radiation and chemotherapy and was limited in his mobility by his extensive acetabular bone loss. Given his complex presentation, it was decided to go forward with total hip arthroplasty utilizing the Zimmer-Biomet custom triflange acetabular component. His outcome at 9 months is fair.

**Keywords:** Hip Replacement Arthroplasty, Joint Revision, Multiple Myeloma, Pathologic Fracture, Total Hip Replacement

## INTRODUCTION

Extensive acetabular bone loss remains a difficult problem for adult reconstruction surgeons. This setting is challenging owing to inadequate bone-for-device implantation and bone integration of the construct placement, which is further complicated by neoadjuvant chemoradiotherapy. Antiprotrusion cage, cup cage, custom triflange, and porous metal constructs are the modalities that are often considered for reconstruction. Szczepanski et al<sup>1</sup> found in a recent meta-analysis of the aforementioned constructs, utilized during pelvic reconstruction in the setting of revision arthroplasty, found custom triflange and cup-cage constructs as having the overall lowest mechanical failure rate. All sampled constructs were found to most likely fail in the midterm, with an average mechanical failure rate of 14.2% versus a 2.6% rate for custom triflange constructs.<sup>1</sup> As seen with other constructs, custom triflange constructs are developed with porous metals that help promote bone growth integration.

In the case presented below, we describe a unique scenario of a 61-year-old man who developed massive acetabular bone loss and a pathologic acetabular fracture with protrusion as a result of multiple myeloma. To our knowledge, this is the first case in the literature to use a custom triflange acetabular component in a primary setting.

## CASE REPORT

A 61-year-old man presented after tripping over a broomstick and sustaining an acetabular fracture. Imaging was obtained, and the patient was found to have a lesion suspicious for malignancy. He was thus transferred to our facility. Initial pelvis films found a large lucent lesion involving the left acetabulum and extending into the inferior pubic ramus. Computed tomography (CT) scan with contrast showed a 10.1 x 10.2 x 11.5 cm expansile mass centered at the left acetabulum, and an associated pathologic fracture through the left ischium and posterior acetabular wall with left acetabular protrusion. Metastasis to the T6 vertebrae was also apparent.

The lesion was biopsied and identified as multiple myeloma. The patient also had multiple medical comorbidities, including supraventricular tachycardia, poor dentition, and acute pulmonary embolism. Initially, the patient was treated with radiation at a dose of 30 Gy over 10 fractions. The patient was deemed not a surgical candidate until he was in remission and a positive prognosis was available. He then received systemic chemotherapy for 1 year and 3 months.

After a positive prognosis was available and the patient was in remission, a discussion was had regarding reconstruction of the left hip. His bone loss was quite complex at this point. Reconstruction would be surgically complex and would require multiple revision components (Figure 1). A CT scan was obtained, and it

showed severe medial and superior protrusion of the hip with only a thin rim of bone keeping the pelvis in continuity (Figure 2). The combination of bone loss and lack of medial wall integrity made reconstruction with simple revision components a poor choice. It was thus decided that a custom triflange acetabular component would provide the most fixation to the pelvis.

The implant selected was the Zimmer-Biomet custom triflange acetabular component (Biomet Orthopedics, Warsaw, IN). The CT scan seen in Figure 2 was used to create the implant with preoperative planning diagrams seen in Figure 3. A 3D printed model of the patient's pelvis with the proposed component can be seen in Figure 4. This process took approximately 8 weeks before the final implant was created and ready to be implanted. This component utilizes Porous Plasma Spray™ coating (Biomet Orthopedics, Warsaw, IN) to improve bone integration through ingrowth.

A posterolateral approach to the hip was utilized. To allow for safe elongation of the leg, the sciatic nerve

was identified and released circumferentially. He was approximately 2.5 cm short radiographically on the operative extremity. The head could not be dislocated independently, and thus a femoral cut in situ was performed. The head was extracted using piecemeal technique due to its depth within the pelvis. A reamer was used to remove the diseased cartilage off the anterior column. The tumor tissue was removed and sent to pathology. A reamer-irrigator-aspirator (RIA) was inserted into the femoral canal to obtain bone graft for the acetabulum. The femur was then reamed for the stem, and the modular component was left off to place the acetabular component. The custom triflange was rotated into place, but it was initially difficult to position owing to the size of the flanges. However, once shown to be in an adequate position with proper version as intended, it was secured using both non-locking and locking screws. The locking screws on the periphery were shown to be secure. The autograft from the RIA was mixed with allograft chips prior to securing the screws, which was backfilled into the cavity defect. The screws in the acetabular cup were then secured. The hip did require considerable soft-tissue release to allow reduction into the acetabulum. Once reduced, the hip was stable up to a combined 90° of flexion and 30° of internal rotation. The surgery was completed without noted complication. Postoperative radiographs showed well-seated implants in the desired locations, with the operative extremity now about 1.5 cm longer than the contralateral side.

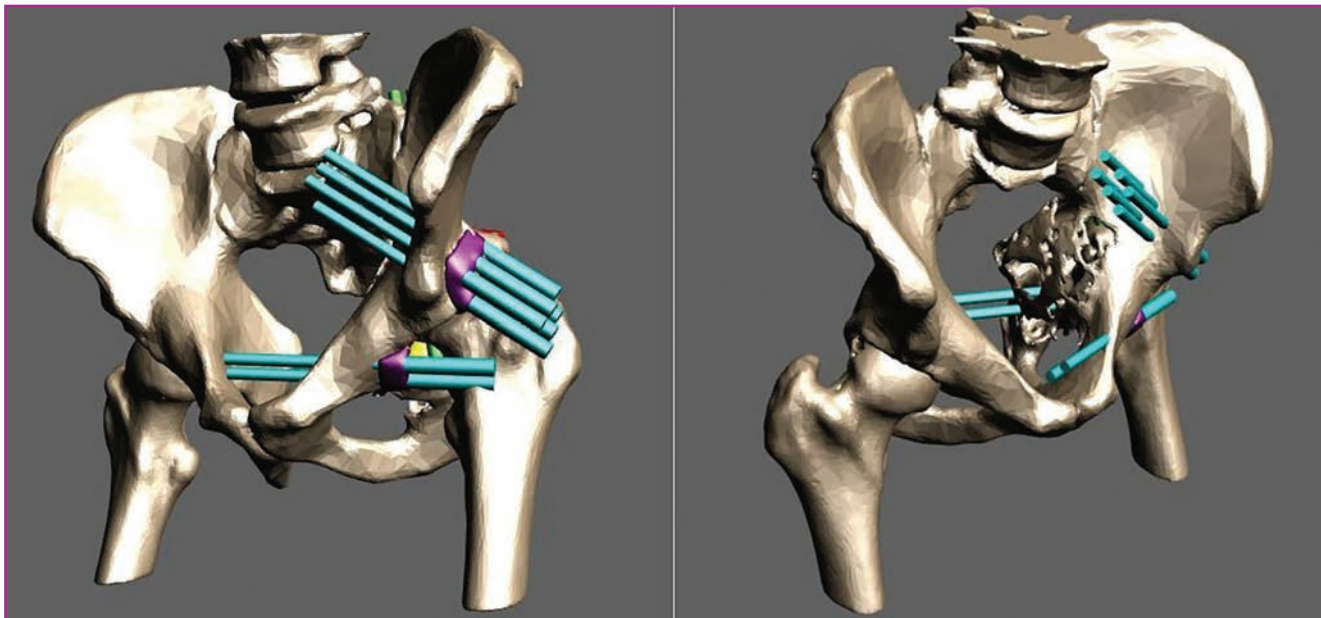
For the first 2 months postoperatively, the patient was limited to touchdown weightbearing to allow for bone integration into the component. He developed a sciatic nerve palsy over the first few days postoperatively, resulting in a foot drop and requiring an ankle-foot orthosis. The patient was ambulatory with a walker at his 3 week follow-up, and he stated he had no pain in his hip at 2 months postoperatively. His component incorporated adequately on postoperative radiographs (Figure 5). At his most recent visit at 7 months postoperatively, he is using a cane only and is



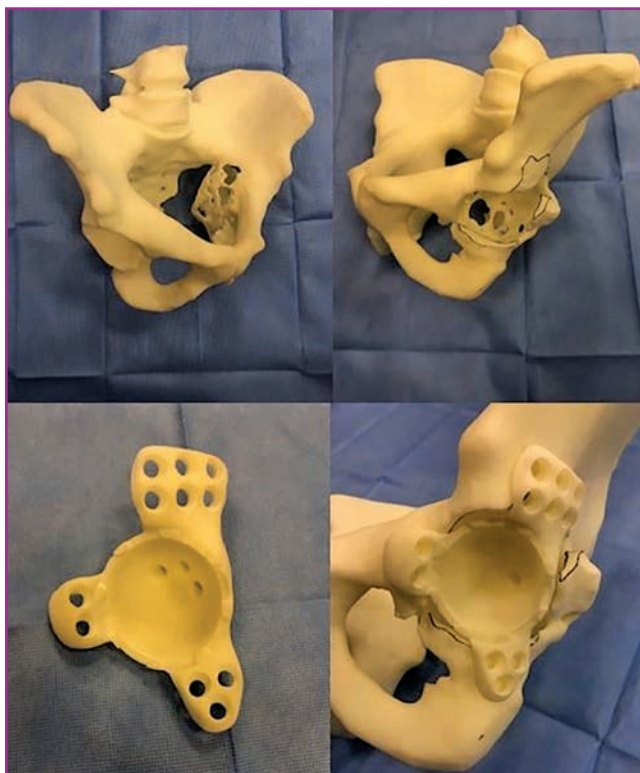
**Figure 1.** Preoperative anteroposterior pelvis radiograph



**Figure 2.** Axial and coronal cut from preoperative computed tomography scan showing thin shell of remaining acetabular bone



**Figure 3.** Preoperative plan showing screw position and hip center of new component



**Figure 4.** 3D model of the patient's pelvis with planned component

able to dorsiflex his ankle against gravity. Maintenance Revlimid (Celgene Corporation, Summit, NJ) was administered throughout this time, and the patient is still in remission.

## DISCUSSION

Massive acetabular bone loss is a difficult problem when attempting total hip arthroplasty. To our knowledge, the case presented is the first to use a custom triflange acetabular component in a primary



**Figure 5.** Postoperative anteroposterior pelvis radiograph

total hip arthroplasty setting. The patient had extensive acetabular bone loss from multiple myeloma and a pathologic acetabular fracture with protrusio. Although this is certainly not a straightforward primary case, it does suggest that the custom triflange component can be used outside of revision arthroplasty and has use in the musculoskeletal oncology specialty. This component has already been shown to have favorable short and midterm results in the revision setting, and here we present a multiple myeloma patient doing excellent at 9 months postoperatively.<sup>2-6</sup> In revision hip arthroplasty cases, the large cavitory bone defect combined with a very thin medial wall is not commonly seen.

This case was unique given the extent and type of bone loss to the acetabulum. The large cavitory bone defect combined with a very thin medial wall is not commonly seen. There are several treatment options,



including conventional options such as jumbo cups, augments, cage constructs, and reinforcement rings. However, these options have less favorable outcomes because the amount of bone loss is so dramatic that there is simply not enough host bone to seat the implant reliably with any hope of bone integration.<sup>7,8</sup> This leaves the cup-cage construct and custom triflange acetabular component, which offer a more stable construct, especially in the setting of a pelvic discontinuity.<sup>1</sup> The cup-cage construct relies on the ability to seat an acetabular component on the host bone, and then fix it in place with a cage that sits within the cup. It is then secured using screws in the remaining host bone. Although this technique works quite well and has favorable outcomes, the cage constructs are limited in screw placement and still rely on the acetabular component to have bone integration at its implanted position. When presented with this degree of bone loss and change of hip center, the custom triflange acetabular component offered the best combination of screw placement and amount of porous material in contact with host bone for increased chances of on-growth.

To our knowledge, there have been no studies comparing the outcomes of cup-cage constructs to custom triflange acetabular components directly. The results of this component have been studied in both the short and midterm range in revision arthroplasty. Overall, survivorship up to a minimum of 2 year follow-up has been shown to be as high as 83 to 100%.<sup>2-4,6,9</sup> Gladnick et al<sup>6</sup> reported midterm results at a 5 year follow-up minimum to be quite favorable, with only 1 of 73 hips (1.4%) deemed radiographically unstable at final follow-up.<sup>6</sup> Long-term data are still lacking in the literature. Complications following implantation are still quite high. Instability is the most common complication with some articles reporting up to 30%. Nerve injury to the superior gluteal and sciatic nerves is also reported as high as 10%.<sup>9,10</sup>

The biggest disadvantage to the custom triflange component is the preoperative planning that must take place. Cup-cage constructs can be used as a back-up plan in most revision scenarios; however, a custom triflange must be decided on before surgery and requires close interaction with the manufacturer to ensure proper specifications are met. It also relies on the acetabulum not changing significantly from the time of CT to the operating room. The cost of the two constructs, surprisingly, were found to be quite similar. Taunton et al<sup>4</sup> found implant cost to be \$12,500 for the custom triflange and \$11,250 for the cup-cage construct. The biggest advantage of the custom triflange is realized in the operating room. Regarding the custom implant, it is a matter of exposing the host bone surfaces and implanting based on the preoperative plan.

Custom triflange acetabular components offer a potential solution for the most difficult cases of acetabular bone loss. As seen in this case, its use

can be a viable option in the setting of metastatic disease. Long-term data are still lacking, but short and midterm data is promising. Its cost is relatively similar to that of the cup-cage construct when dealing with massive acetabular bone loss. The relatively extensive preoperative leg work results in a custom monoblock component designed to take full advantage of remaining host bone with a porous surface and options of locking screws. In this patient with an irradiated acetabulum, massive bone loss, and a relatively good prognosis from multiple myeloma, the custom triflange acetabular is a viable option as a robust and sturdy arthroplasty component.

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# Tibial Lengthening Using A Magnetic Lengthening Intramedullary Nail in an HIV-Positive Patient: A Case Report and Review of Literature

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## ABSTRACT

Limb lengthening can be affected by poor bone healing in patients with human immunodeficiency virus. This is a case report of a 56-year-old man with 6.1 cm leg length discrepancy and end-stage arthritis in the hip. The patient had total hip arthroplasty prior to his lengthening procedure. The patient was human immunodeficiency virus positive. This case report describes the experiences of using a motorized intramedullary magnetic lengthening nail in equalization of limb length discrepancy. Treatment for the patient included tibial lengthening with a motorized nail to correct the limb length discrepancy, with adequate bone healing in a patient with an human immunodeficiency virus infection.

**Keywords:** Leg Lengthening, HIV-Positive Patient, Motorized Tibial Nail, Leg Length Discrepancy, Limb inequality

## INTRODUCTION

Leg length discrepancy (LLD) can result in considerable disabilities such as limping, back pain, and joint arthritis.<sup>1</sup> Gradual limb lengthening using distraction osteogenesis is a well-established technique that equalizes LLD. Reasonable operative options include external fixation, lengthening over the nail, lengthening and then nailing, or lengthening with a fully implantable motorized nail such as the PRECICE Nail (NuVasive, San Diego, CA).<sup>2-4</sup> Each surgical technique has its advantages and limitations.

In recent years, motorized nailing has become the more popular method of treating LLD for several reasons, including transcutaneous activation, short consolidation time, high-quality bone regeneration during lengthening, and early functional rehabilitation.<sup>3</sup>

<sup>5-11</sup> The advantages of using motorized nails compared to external fixation include earlier weight bearing, reduced refracture or regenerate bending after external fixators removal, less pain during lengthening, lack of pin-site infection, and rapid restoration of joint range of motion.<sup>12</sup> Disadvantages to using motorized nails include increased risk of blood loss, fat emboli, mechanical failures, and intramedullary infection.<sup>5-7</sup>

Human immunodeficiency virus (HIV) disrupts the normal inflammatory process, leading to delayed wound healing, osteopenia, and osteoporosis.<sup>13,14</sup> For patients with HIV, the incidence of contracting infection is higher during external fixation for open fractures.<sup>15,16</sup> Poor bone mineral density compromises the post-surgical healing process of fractures in patients with HIV.<sup>17</sup>

This case describes a complex case of a 6.1 cm LLD of the right femur in an HIV-positive patient treated with tibial lengthening with a motorized nail.

## CASE REPORT

A 56-year-old man was referred to clinic for management of an LLD owing to shortening of the right femur. The patient reported remote history of a right femur shaft fracture that was treated nonoperatively during childhood. He had concerns of pain and limping. The pain was aggravated by exercise and walking. Preoperative images confirmed end-stage osteoarthritis of the hip and LLD. The patient underwent arthroplasty of the right hip for the end-stage right-hip osteoarthritis. The surgery was performed by a different surgeon. Total hip arthroplasty (THA) was uneventful; however, the patient continued to have pain and limping after THA due to LLD. The patient was referred to our center for further evaluation and treatment of LLD.

The patient was evaluated clinically and radiologically for the amount and source of LLD, ankle and knee



**Figure 1.** Preoperative radiograph showing leg length discrepancy with shortening of the right lower extremity.

range of motion, and limb alignment. The LLD was 6.1 cm in the right femur (Figure 1). The femoral stem of the ipsilateral THA extended down to the mid-shaft. The plan was to lengthen the right tibia 6 cm to compensate for the 6.1 cm shortening of the right femur. The patient was counseled about other treatment options and their complications (ie, left femur shortening and external fixators), and he consented for implantation of a PRECICE Nail in the right tibia to correct the LLD.

### SURGICAL TECHNIQUE

The procedure began with a fibular osteotomy and prophylactic stabilization of distal tibia-fibular joints with 3.5 mm screws to allow lengthening of both the tibia and fibula. Before reaming, a single venting hole at the presumed osteotomy site was made to minimize the risk of fat embolism during reaming. This single hole was purposefully located in the medial border of the tibia and opened into the subcutaneous tissue to be an exit for excess reaming material, and avoid the extravasation into the closed anterolateral leg compartment. This technique was used to reduce the risk of the acute postoperative compartment syndrome. The tibia was then progressively reamed to 13 mm and implanted with a 305 x 10.75 mm PRECICE Nail. Additional drill holes were made at the presumed osteotomy site using a 4.8 mm drill bit. The nail was then advanced just short of the osteotomy. Completion of osteotomy was then performed using a sharp osteotome (DeBastiani technique). The completion of osteotomy was verified using two orthogonal fluoroscopic images. The nail was then carefully advanced through the tibia. Advancing of the nail was monitored using fluoroscopy.

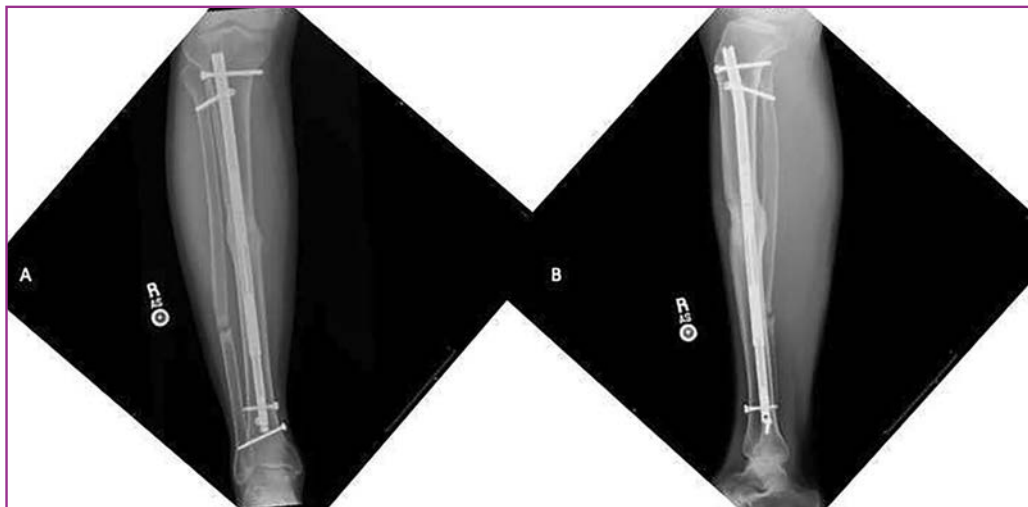
The fixation of the superior tibiofibular joint was achieved with one of the proximal locking screws of the nail (Figure 2). The screws passed from medial to lateral through the nail and through the proximal tibiofibular



**Figure 2.** A,B) Anteroposterior and lateral radiographs of implantation of PRECICE nail at 1 week postoperatively.



**Figure 3.** A,B,C) Images at 12 months follow-up showing correct leg length discrepancy of right lower extremity and range of motion of the affected extremity.



**Figure 4.** A,B Anteroposterior and lateral radiographs of PRECICE nail implantation at 12 months follow-up showing union of the tibial osteotomy site and nonunion of the fibula.

joint. The distal locking screws were inserted using a perfect circle technique. Intraoperative lengthening of 1 mm was applied by the PRECICE nail to verify its mechanical properties using the external remote controller, while the patient was still under general anesthesia.

#### **Postoperative Course**

The patient was admitted for pain control and received intravenous antibiotics for 24 hours. The patient wore a controlled ankle motion boot during the night to protect against ankle equinus contracture. He was referred to physical therapy immediately after surgery.

After a latency period of 2 weeks, tibia lengthening began at a rate of 0.75 mm per day for three increments per day. Partial weight bearing of 40 lb was allowed during the distraction phase. Follow-up appointments were scheduled regularly every 1 to 2 weeks. The patient reported trouble scheduling physical therapy appointments due to his insurance. At 3 months postoperatively, gastrocnemius recession

(Strayer procedure) was performed for ankle equinus contracture. Ankle range of motion was fully restored postoperatively.

Radiographs showed poor-quality bone regeneration. The rate of distraction was slowed to induce normotrophic regeneration. The slower rate (ie, 0.25 mm per day) improved bone regeneration quality, and the patient consolidated without further interventions. Before stopping the distraction, a final LLD evaluation was performed clinically and radiographically. Clinical evaluation was performed using wooden blocks, and radiographic evaluation was performed using a weight bearing, full-length scanogram. A total of 6.1 cm of lengthening was achieved over 9 months for a lengthening index of 0.68 cm per month. At the final follow-up at 28 months postoperatively, the patient reported ambulation without assisted devices or pain. The patient maintained a full range of motion in the knee and ankle (Figure 3). The radiographs confirmed the full healing of the regenerate and equalization of



**Figure 5.** Radiograph at 12 months follow-up showing corrected leg length discrepancy of right lower extremity

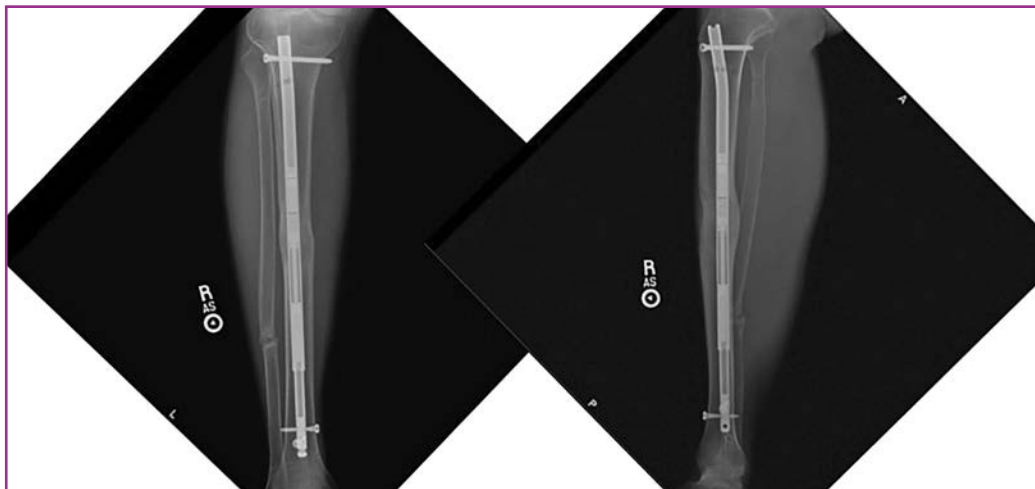
LLD (Figures 4 and 5). Removal of screws across the superior and inferior tibiofibular joints were performed owing to pain and screw loosening (Figure 6).

## DISCUSSION

LLD with associated end stage arthritis is a challenging clinical scenario and adds to the complexity of primary THA. Dysplastic hip joints associated with femoral shortening were well-known examples. There is no consensus in the literature about the proper timing of limb lengthening whether before or after THA. In this report, the patient had THA before the limb lengthening procedure. The lack of the co-ordination with arthroplasty surgeon limited the options for the limb lengthening procedure.

The patient's factors and surgeon's skillset should be considered when deciding on appropriate treatment. In this case report, the patient's factors included the poor bone quality, increased risk of infection secondary to HIV and the presence of femoral stem in the femur. The treating surgeon discussed all operative options with the patient. Additionally, the treating surgeon thoroughly discussed that equalization of LLD can be achieved through shortening of long limb (left femur) or lengthening of the short leg. The patient declined shortening of left femur due to height reduction, loss of muscle strength and risk of vascular compromise.

The various limb lengthening techniques were discussed as well, including whether to lengthen the femur or tibia and the best device to be used for bone lengthening. In this case, the treating surgeon always preferred to lengthen the short bone (femur), which has a better bone regenerate and short consolidation time after lengthening.<sup>18</sup> Despite these advantages of femoral lengthening, there were multiple concerns about femoral lengthening in this patient. The surgeon did the preoperative planning and radiographic measurements. The available lengths of the retrograde femoral nails would leave either a small area of the femur unprotected between the tips of the nail and



**Figure 6.** Radiographic images after removing the loose proximal locking screw from the superior and inferior tibiofibular joints.



femoral stem. The unprotected segment of the femur poses a significant risk of stress riser and increased risk of periprosthetic fracture, or the insertion of the nail will be stopped by the stem of the prosthesis becoming prominent in the knee. The risk of periprosthetic fracture is significant in this HIV patient with poor bone quality and impaired bone healing. Additionally, the amount of available nail stroke was another concern. The patient needed 6.1 cm of lengthening. The shorter nails allowed only 5 cm of lengthening. This might leave the patient with residual LLD. The external fixator was an option; however, it was not optimum in this HIV patient owing to increased risk of pin-site infection and knee joint stiffness due to muscle tethering.

The outcome of limb lengthening using motorized nails is well-documented in the literature. Hawi et al<sup>19</sup> showed that the intramedullary nailing lengthening (PRECICE system) had better results compared to an external fixator in controlling limb alignment during lengthening, less pain, and early weight bearing. However, the use of the intramedullary lengthening nail is contraindicated in different conditions such as infection, open physis, patients with small medullary canal, and patients who are not compliant to lengthening instructions.<sup>19</sup>

Leg lengthening can be complicated with soft tissue contractures. Knee flexion and iliotibial band contractures were well-reported during femoral lengthening in the literature. On the other hand, ankle equinus contracture was common in tibia lengthening.<sup>20</sup> Intensive physical therapy for muscle stretching and joint range of motion exercises helped to prevent soft-tissue contractures. Protective splints were very helpful to avoid soft-tissue contractures. Surgical soft-tissue release may be needed in fixed contractures that were not responding to nonoperative measurements.<sup>21</sup> In our case, the patient developed ankle equinus contracture owing to lack of access to physical therapy due to insurance issue. The equinus contracture was successfully treated with gastrocnemius recession.

To our knowledge, there is no clear published protocol in the literature to treat patients with end-stage hip arthritis and large LLD. Performing limb lengthening before or after THA, the amount of acute lengthening during THA, and whether to use external fixators or motorized nails for lengthening are questions remained to be answered. Harkin et al<sup>22</sup> reported a case series of three patients with THA who underwent ipsilateral femoral lengthening. The LLD in those patients were treated safely and accurately with intramedullary femoral lengthening. The treating surgeon used a motorized nail for tibial lengthening over an external fixator in this case for two reasons.

First, external fixators had higher risk of pin tract infection in HIV patients. The infection may spread to the femoral stem. This might cause a serious periprosthetic joint infection. Ferriera et al<sup>23</sup> examined 229 patients as well as the incidence of pin-site infection in HIV-positive patients versus their HIV-negative counterparts. Although HIV infection has been independently implicated in the development of pin-site infection, this study found no significant difference between the two groups in the incidence of the infection.<sup>24-26</sup> This is in contrast to the historical belief that HIV infection results in increased incidence and increased severity of the pin-site infection, as well as the general recommendation against their usage in these patients.<sup>25,26</sup> However, these studies were not limited to limb lengthening procedures and encompass all orthopaedic trauma. The second reason for lengthening using motorized nail was the reduced risk of secondary fracture or regenerate bending after external fixators removal.<sup>27</sup>

The asymmetry of the knee levels was an obvious limitation of using tibial lengthening for femoral shortening. However, our patient reported no functional limitation related to the asymmetry of knee height. The authors were not aware of any published report of the gait analysis study showing gait disturbance due to asymmetry of knee height. Despite this, the authors admitted the cosmetic concerns of the asymmetry of the knee height, the patient was extremely satisfied with the final outcome.

This is the first reported case of bone transport with a motorized nail in an HIV-positive patient. Although there have been studies examining the complications associated with HIV-positive patients and orthopaedic injuries, none have been conducted to measure the success of bone lengthening with a motorized nail. In this case, a decreased distraction rate was needed to accommodate the poor bone formation seen in this subset of patients. Implantation of a motorized nail controlled via external remote controller allowed rate and rhythm adjustments during lengthening and the achievement of a desirable outcome in our patient.

In conclusion, motorized nails can be used effectively to equalize LLD correction in HIV-positive patients. Slowing the rate and rhythm allows more time for bone healing and consolidation. Preoperative coordination between arthroplasty and limb lengthening surgeons is critical to increase the available treatment options in patients with combined LLD and hip osteoarthritis.

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# Intra-Articular Osteoid Osteoma of the Elbow: A Case Report

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

## ABSTRACT

A 24-year-old woman, with 5 years of left elbow pain, was given a preliminary diagnosis of focal pigmented villonodular synovitis based on magnetic resonance imaging. She underwent arthroscopic debridement and was found to have an intra-articular bony mass. Histopathology was consistent with an intra-articular osteoid osteoma. The mass was removed arthroscopically with excellent symptomatic improvement. There was no recurrence of symptoms at 1 year follow-up.

**Keywords:** Osteoid, Osteoma, Elbow, Arthroscopy

## INTRODUCTION

Osteoid osteoma is a benign lesion most commonly found in the diaphysis of lower-extremity long bones.<sup>1</sup> Intra-articular pathology is uncommon and accounts for only 5 to 12% of lesions.<sup>1,2,3</sup> Classic symptoms, such as night pain relieved by non-steroidal anti-inflammatory drugs (NSAIDs), may be altered or absent when the lesion occurs within a joint.<sup>2,3,4</sup> Traditional radiographic imaging does not provide a clear visualization of reactive sclerosis, which is typically seen in extra-articular locations.<sup>5</sup> Subsequently, lesions located within the joint capsule are frequently missed. Furthermore, magnetic resonance imaging (MRI) may fail to show the central nidus. Computed tomography (CT) scans remain the most specific for diagnosis.<sup>6,7</sup>

Delay in diagnosing an intra-articular osteoid osteoma is often due to patients presenting with non-classic symptoms and the failure to obtain a CT scan of the involved joint.<sup>5,8-10</sup> When compared to extra-articular lesions, which have a mean time to diagnosis of 8.5 months, intra-articular lesions have a mean time to diagnosis of 26.6 months.<sup>2</sup>

Osteoid osteomas are often treated with radiofrequency ablation. However, with intra-articular osteoid osteomas, radiofrequency ablation treatment risks thermal injury to articular cartilage.<sup>11,12</sup> For this

reason, treatment shifts towards surgical excision, which can be performed in either an open or arthroscopic fashion.<sup>13</sup> This treatment also provides histology for diagnostic confirmation.<sup>14</sup>

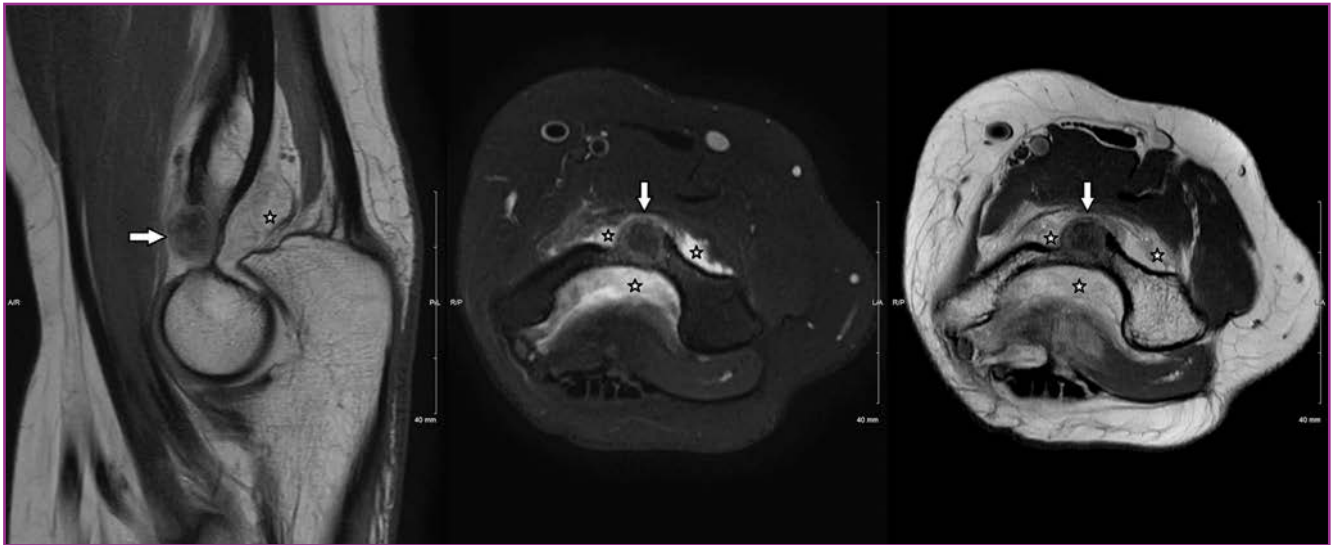
Intra-articular osteoid osteoma of the elbow joint is not often described in the literature.<sup>2,15,16</sup> As such, the differential diagnosis of chronic elbow pain rarely includes this pathology. This case highlights the atypical presentation of an intra-articular osteoid osteoma, expected diagnostic delay, and successful arthroscopic treatment.

## CASE REPORT

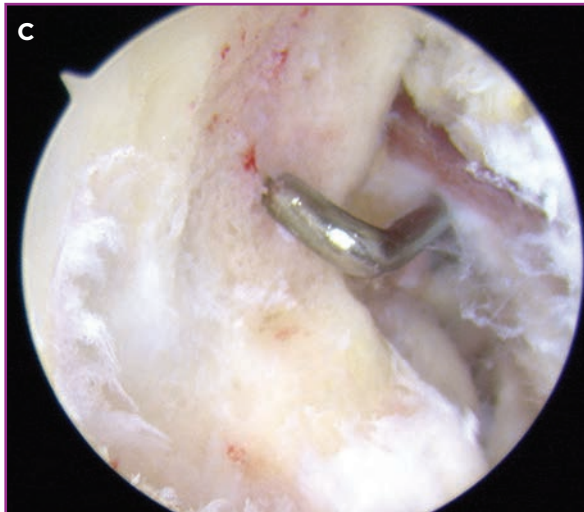
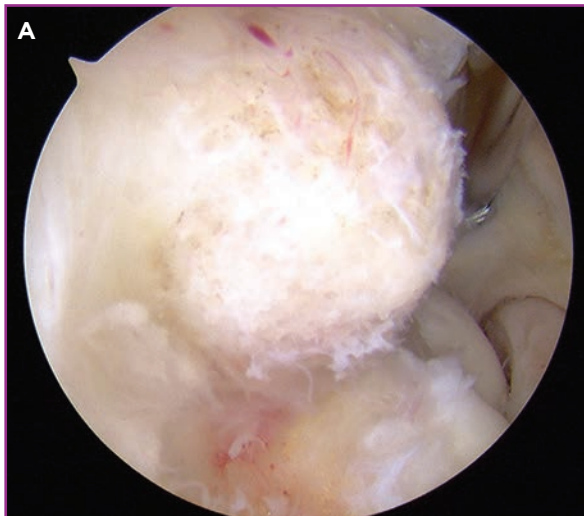
A 24-year-old, right-hand dominant woman presented with 5 years of left elbow pain that had been unresponsive to treatment. Seven years preceding her presentation, she sustained an ipsilateral radial head fracture that was treated nonoperatively with a sling. Within a year, she had full resolution of symptoms with this treatment. Five years later, she hyper-extended her elbow, resulting in severe pain. Radiography and ultrasonography revealed no clear cause. Based off her examination at that time, she was given a presumptive diagnosis of biceps tendinitis, which was treated with a compression sleeve and 5 weeks of physical therapy. The treatment resulted in no symptomatic relief.

The patient subsequently presented to our facility for a second opinion. At that visit, she reported that her symptoms were worse when waking up in the morning and late in the evenings. She had no relief of symptoms with NSAIDs. She could not flex her elbow when pain occurred, and thus described the pain as functionally limiting. The patient denied any other medical history, and her family history was noncontributory. Physical examination was significant for 0 to 135° of motion compared with 0 to 155° at the contralateral, and tenderness to palpation both anteromedially and posterolaterally about the elbow. Her examination was otherwise unremarkable.





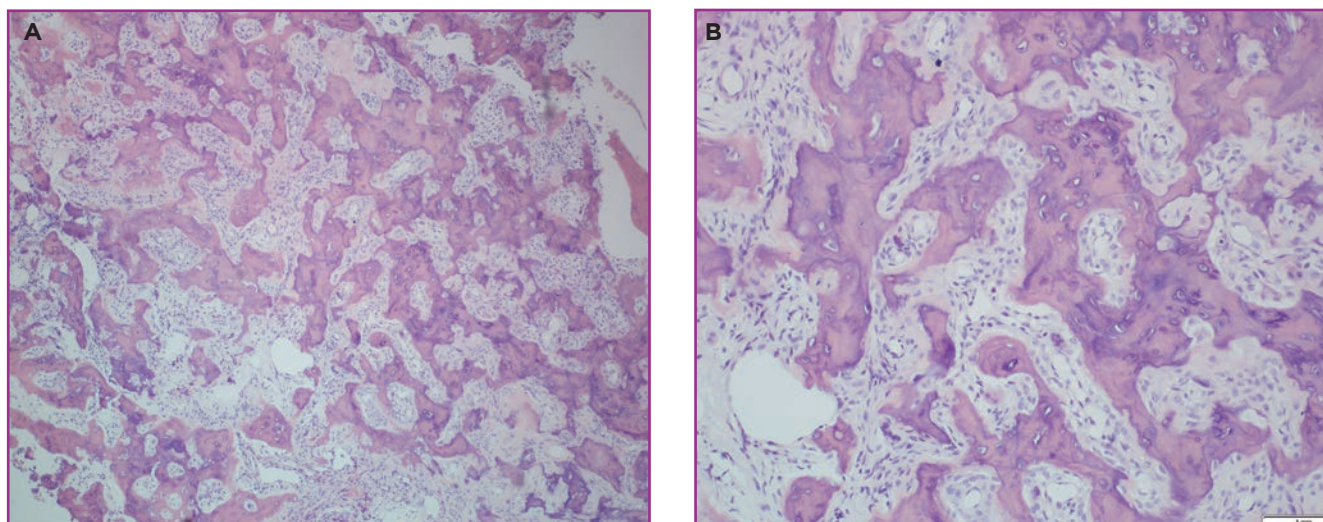
**Figure 1.** Magnetic Resonance Imaging. Sagittal Proton Density (PD) no fat sat, axial T2W fat sat and axial PD no fat sat images of the elbow show an expansile, somewhat rounded, osseous lesion on the distal humerus with intermediate signal and a more focal internal region of low signal on all sequences (arrows). There is an associated elbow joint effusion with evidence of synovitis (stars).



**Figure 2.** Arthroscopy showing A, B) a round and bony lesion identified in the coronoid fossa using a 5 mm probe, and C) the lesion excised to its base.

Dedicated x-rays of the elbow showed no abnormality. MRI localized a 10 mm x 10 mm x 10 mm amorphous mass with significant cortical erosion into the anterior aspect of the mid supracondylar humerus (Figure 1). The mass had heterogeneous, low signal intensity on T1- and T2-weighted imaging without blooming artifact. A preliminary diagnosis of pigmented villonodular synovitis (PVNS) was given, and histologic confirmation was recommended. Anterior elbow arthroscopy was performed through a viewing, proximal anteromedial portal and a working, mid-anterolateral portal. Synovial debridement revealed a round bony mass adherent to the coronoid fossa that appeared inconsistent with PVNS (Figures 2A and 2B). An excisional biopsy was performed (Figure 2C). A pituitary rongeur was used to excise a majority of the mass, and the base was then excised with an arthroscopic burr. Posterior arthroscopy was also performed to inspect the synovium for signs of PVNS or additional masses.





**Figure 3.** A) Histopathology showing osteoid osteoma (4x). There are irregular spicules of partially mineralized woven bone with intervening cellular and hypervascular stroma. B) Histopathology showing osteoid osteoma (20x). The stroma in between the lace-like spicules of mineralized osteoid is composed of a proliferation of bland-appearing, plump osteoblasts and increased numbers of small capillaries.

Gross histology revealed a yellow and focally white piece of hard bone with abutting areas of softer white tissue. Sectioning and histopathologic examination revealed nodular proliferations of bland-appearing osteoblasts with immature trabeculae and an osteoid matrix that were focally surfaced by reactive synovitis (Figure 3A and 3B). A diagnosis of osteoid osteoma was made and confirmed by an outside institution. At 2 and 6 week follow-up, the patient reported resolution of her preoperative pain. Her elbow flexion reached 145° (within 10° of the contralateral) by 6-weeks postoperatively. No formal therapy was utilized. There were no recurrences at 1 year postoperatively.

## DISCUSSION

This case demonstrates the challenge of accurately diagnosing and treating intra-articular osteoid osteomas. Unlike extra-articular osteoid osteomas, intra-articular pathology may be unresponsive to NSAIDs and present with different imaging findings than what is classically expected.<sup>2,3,4</sup> In our case, the patient's pain did not improve with NSAIDs. Her radiographs and ultrasound were negative for pathology, while her MRI demonstrated erosive changes and synovitis more consistent with a diagnosis of PVNS.

This highlights the importance of maintaining a broad differential, which includes osteoid osteoma when patients have chronic joint pain without obvious arthritic changes. In this case, our patient had a discrete mass noted on MRI, but because a central nidus and osseous sclerosis were not identified, osteoid osteoma was not within the differential diagnosis. Furthermore, a CT scan was not obtained given the presumptive diagnosis of PVNS.

This work highlights that arthroscopy can be used to resect an osteoid osteoma from the coronoid fossa. Arthroscopy offers the surgeon adequate access to the area without the need for a more extensile, open approach. Given the benign nature of osteoid osteomas, a limited surgical dissection for their excision is appealing. Success of this treatment was demonstrated by the resolution of our patient's symptoms and the improvement in her postoperative range of motion. Therefore, arthroscopic excision is a successful way to treat osteoid osteomas of the coronoid fossa and should be considered when planning a resection.

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# A Rare Case of Pediatric Radial Neck Fracture with Medial Dislocation of the Radial Head Treated with Open Reduction and Pinning

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## ABSTRACT

Radial neck fractures are common injuries in the pediatric population. Open reduction has classically been associated with poor outcomes, but it is sometimes required for adequate reduction. We describe a 7-year-old patient with a radial neck fracture and far-medial radial head dislocation through the interosseous membrane. Open reduction and pinning was performed, and we were able to follow-up with the patient for 5 years. The patient had minor loss of range of motion and early physeal arrest. However, she did not go on to avascular necrosis and radii asymmetry, and she did not have any functional deficits. When closed reduction is unsuccessful in displaced radial neck fractures, open reduction should be performed. To give the best chance for a positive outcome, the patient should be followed for elbow deformity.

**Keywords:** Pediatrics, Radius, Elbow

## INTRODUCTION

In the pediatric population, radial head and neck fractures make up 5 to 10% of all elbow fractures.<sup>1</sup> The most common mechanism of injury is a fall onto an outstretched arm with the elbow in extension and a valgus force across the joint.<sup>2</sup> The radial head is perfused in a retrograde fashion.<sup>3</sup> Unfortunately, up to 33% of these fractures result in a poor outcome, including avascular necrosis (AVN), premature physeal closure, elbow stiffness, heterotopic ossification, nonunion, radioulnar synostosis, and radial head overgrowth.<sup>4,5</sup> Children over the age of 10 years have been found to have worse outcomes, and 30 to 50% of these fractures are associated with other injuries.<sup>2,6</sup> Open reduction has been associated with worse outcomes, including up to 25% osteonecrosis, and it is generally reserved for irreducible fractures with unacceptable angulation and displacement.<sup>7-10</sup>

There are two case reports describing four cases of radial neck fractures with medial displacement of the radial head in the literature, which were treated using open medial incisions.<sup>11,12</sup> All patients had loss of range of motion, and two patients had associated ulnar nerve injury.

We describe a 7-year-old girl with a radial neck fracture and a medial dislocation of her non-dominant extremity, treated using a lateral approach, open reduction, and pinning.

## CASE REPORT

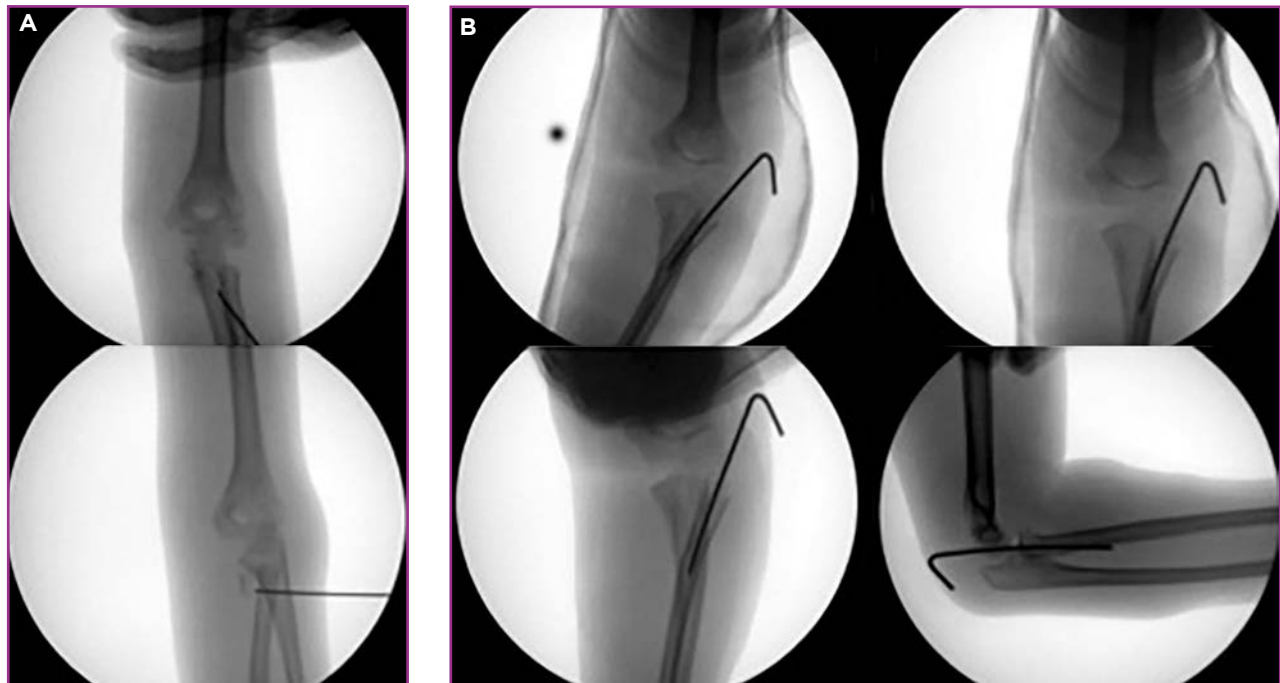
A 7-year-old, right-hand dominant girl was pushed off a 6-foot-high slide. She presented to the emergency department and was found to have a closed Salter Harris II radial neck fracture and dislocation of the radiocapitellar joint (Figure 1). Attempted closed reduction under sedation was unsuccessful. Owing to the severe medial displacement of the radial head, the decision for surgery was made.

The following day, the patient was brought to the operating room. While the patient was under anesthesia, three unsuccessful closed and percutaneous reduction attempts were made using Kirschner wires (Figure 2A). The elbow was grossly unstable to valgus stress. A lateral incision was made, and the interval between extensor carpi ulnaris and anconeus was identified. The capitellum and annular ligament tear were visualized. The radial head was retrieved through a small, pre-existing, traumatic hole in the interosseous fascia. The fracture was reduced and pinned with a 5/64 inch pin from the capitellum to the radius. The reduction was verified using fluoroscopy (Figure 2B). The annular ligament was repaired before skin closure. Patient was placed into a bivalved cast with the elbow in neutral position.

At 2 weeks postoperatively, radiographs confirmed maintained reduction (Figure 3). At 4 weeks



**Figure 1.** Injury radiographs of the left elbow. Lateral, anteroposterior, and oblique views showing a metaphyseal Salter-Harris two radial neck fracture with radiocapitellar dislocation.



**Figure 2.** Intraoperative fluoroscopy images. (A) Anteroposterior (AP) and lateral views with Steinmann pin directed toward the radial head dislocated medially. (B) AP, oblique, and lateral images with the radial head reduced and pinned.



**Figure 3.** Anteroposterior, oblique, and lateral radiographs of left elbow at 2 week postoperative visit. Pins are intact and patient is in long-arm bivalved cast.



**Figure 4.** Anteroposterior, oblique, and lateral radiographs of left elbow at 8 week postoperative visit. The radial head is reduced and bridging callus is present across the fracture.

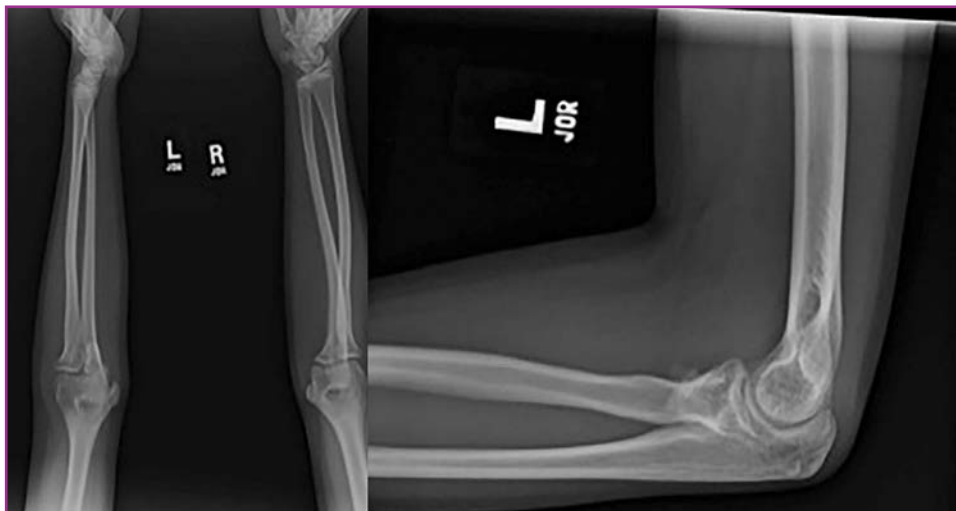




**Figure 5.** Radiographs at 7 months from surgery. Webb view of both forearms, anteroposterior left elbow, and lateral left elbow.



**Figure 6.** Radiographs at 1 year from surgery. Webb view of both forearms, and lateral of the left elbow. A small amount of heterotopic ossification is present over the proximal radius and she has mild cubitus valgus.



**Figure 7.** Webb view of both forearms, and lateral of the left elbow at 5 years from surgery. There are no signs of avascular necrosis or radioulnar synostosis. The patient has symmetric forearm lengths.

postoperatively, the pin was pulled in clinic and the patient was re-casted for an additional 2 more weeks. At 6 weeks postoperatively, she was placed in an unlocked Bledsoe elbow brace. She began physical therapy for range of motion. After 8 weeks, her elbow was stable on examination and range of motion was 80 to 100° with no pronation and supination. Radiographs showed reduction of the radial head with bridging callus and no early signs of AVN (Figure 4). At 12 weeks, the patient improved to a range of motion of 50 to 110° with 20° pronation and supination. The patient weaned herself out of the brace with physical therapy. At 7 months postoperatively, she showed signs of physeal arrest, and Webb views of the right and left arms showed radii measuring 18.3 cm and 18.1 cm, respectively (Figure 5). At 12 months postoperatively, she had 18.4 cm radii lengths, a small bump over her proximal radius, mild cubitus valgus, and almost completely symmetric range of motion (Figure 6). The patient was seen again at 2 years, 3 years, and 5 years postoperatively. At 5 years postoperatively, her contralateral proximal radial physis had closed, and both radii measured 23 cm (Figure 7). She had no signs of AVN or radioulnar synostosis.

## DISCUSSION

Radial neck fractures are common elbow injuries in the pediatric population and are associated with poor outcomes, especially with open treatment.<sup>5,7,8,10</sup> We described a radial neck fracture in a 7-year-old girl with a far-medial dislocation of the radial head, treated with open reduction and pinning. Our patient did have premature closure of the proximal radial physis but did not develop distal ulna instability. To our knowledge, this is the only reported case of this fracture and dislocation in a pediatric patient with long-term follow-up.

El-Ghawabi<sup>11</sup> was the first to describe this type of injury in adults. He treated three patients with radial head excision through a medial incision. All three patients had various degrees of loss of terminal extension, while two patients had marked decreases in pronation and supination. To our knowledge, Poduval et al<sup>12</sup> reported the only other case of this type of injury in a pediatric patient. The patient was a 12-year-old boy treated with open reduction internal fixation using a small fragment T-plate after the radial head was delivered through a medial incision. For 6 months, they were able to follow-up with the patient who maintained good range of motion; however, he was lost to follow-up after implant removal. Of these two studies, two of the four patients had associated ulnar nerve injury. Neither of the patients were explored in the operating room, and one of the patients recovered. At 5 years postoperatively, our patient had full symmetric range of motion and no signs of neurologic deficit.

Although open reduction of radial neck fractures has been associated with higher complication rates, it is

nevertheless sometimes indicated. More severe injuries usually require open reduction. Several studies found that poor outcomes were related to initial displacement and theoretical damage to blood supply from the initial injury as opposed to open treatment.<sup>13,14</sup> Our patient did not go on to AVN, and while she did have some loss of range of motion at early stages and early physeal closure, she had no functional deficits at final follow-up. She did have slight overgrowth of her radial head (Figure 7). However, overgrowth has been found in the majority of healed radial neck fractures, and does not correlate with functional deficit.<sup>7</sup> We made sure to follow-up with her until her radial and ulnar physes were closed bilaterally. Additionally, using the lateral approach for open reduction prevented potential ulnar nerve injury, which was seen in the cases described in the literature where a medial approach was used.

Although Poduval et al<sup>12</sup> chose plate fixation, Kirschner wire fixation was adequate in our patient. She did not need to return to the operating room and the pin was pulled in clinic. Poduval et al<sup>12</sup> and El-Ghawabi<sup>11</sup> proposed one possible mechanism of injury: the elbow dislocation, with or without radial neck fracture, spontaneously reduced with elbow movement. However, this leaves the radial head behind medially. In our case, the patient's elbow was very unstable to valgus stress in the operating room, which could support this theory.

Although complications in displaced radial neck fractures may be severe, especially when associated with open reduction, they do not all lead to bad outcomes. If these fractures cannot be closed reduced, they should be brought to the operating room for open reduction. Our patient presented with an uncommon far-medial dislocation of the radial head, and she was treated successfully with lateral open reduction and pinning. She showed excellent range of motion with no deformity on long-term follow-up.

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# Arthroscopic Management of Focal Pigmented Villonodular Synovitis in the Scaphotrapeziotrapezoidal Joint

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

## ABSTRACT

A 43-year-old man presented with persistent wrist pain and loss of range of motion after nonoperative therapy. Magnetic resonance imaging showed features consistent with pigmented villonodular synovitis (PVNS) of the scaphotrapeziotrapezoidal joint. He underwent arthroscopic excision and synovectomy. At 2 years postoperatively, he had no symptomatic recurrence. This case shows the importance of considering PVNS for chronic pain of small joints, and it highlights the viability for arthroscopic synovectomy as a treatment option.

**Keywords:** Synovitis, Pigmented Villonodular, Wrist Joint, Arthroscopy

## INTRODUCTION

Pigmented villonodular synovitis (PVNS) is a rare and proliferative condition of the synovium that is associated with painful inflammation and recurrent atraumatic hemarthrosis.<sup>1</sup> PVNS predominately appears in larger joints, thus the mainstays of surgical treatment include both open and arthroscopic synovectomy. Recurrence rates are as low as 0 to 9% for complete synovectomy of localized or diffuse disease, but rates can be as high as 56% with arthroscopic partial and subtotal synovectomy.<sup>2</sup> Although both arthroscopic and open synovectomy are performed at larger joints such as the hip and knee, case reports have only described open debridement for PVNS at the wrist.<sup>3-6</sup>

## CASE REPORT

A 43-year-old, right-hand dominant man presented with right-wrist pain occurring after a mechanical fall onto an extended wrist. The pain gradually worsened over 1 year and rendered him unable to complete his physical fitness tests or perform tasks required for his job as a military field technician. He described the pain as a

“dull ache,” and it did not improve with non-steroidal anti-inflammatory drugs (NSAIDs). Nonoperative treatment, including separate courses of physical therapy and wrist immobilization, did not result in lasting improvement of his symptoms. The patient denied pertinent medical or family history. Physical examination was significant for tenderness at the dorsal aspect of the scaphotrapeziotrapezoidal (STT) joint, between the second and third dorsal compartments. His examination was otherwise unremarkable.

Dedicated x-rays of the wrist were without abnormality. Magnetic resonance imaging (MRI) localized a 17 mm x 10 mm x 8 mm mass to the dorsal aspect of the scaphoid, adjacent to the STT joint. The mass appeared with low to intermediate intensity on T1- and T2-weighted images, with blooming artifact on T2-gradient echo sequences and heterogeneous enhancement after intravenous contrast administration, consistent with PVNS (Figure 1).

The patient underwent arthroscopic excision of a mass from the dorsal aspect of the STT joint. A diagnostic arthroscopy of the radiocarpal joint was first performed through the 3-4 viewing portal. A 6R portal was established, and a limited debridement was performed. No significant synovitis was appreciated. Attention was then turned to the midcarpal joint. A radial midcarpal portal was established, and a diagnostic arthroscopy was performed. A dark yellow mass was identified about the dorsal aspect of the STT joint. An ulnar midcarpal portal was then established, and the arthroscope was positioned through the portal to view the mass. The shaver was advanced through the radial midcarpal portal, and limited debridement of connecting synovial tissue was performed to allow for a marginal resection of the entire mass. The shaver was removed, and the dorsal radial midcarpal portal was extended proximally and distally to allow removal





**Figure 1.** Coronal T2W fat sat, coronal proton-density no fat sat, and coronal T2\* gradient-echo images of the wrist showing a mass-like lesion centered in the scaphotrapeziotrapezoidal joint, with intermediate to low signal intensity on all sequences (arrows). The adjacent osseous structures are grossly unremarkable.



**Figure 2.** Arthroscopic images showing A,B) a rubbery, tan-yellow mass identified in the scaphotrapeziotrapezoidal joint. Arthroscope in the ulnar midcarpal portal, 2 mm probe in the radial midcarpal portal. C) The lesion was removed intact.

of the entire mass with use of a grasper. After removal of the mass *en bloc*, the shaver was re-inserted and an arthroscopic synovectomy and debridement were performed (Figure 2).

The mass measured 25 mm x 13 mm x 10 mm at the time of excision, with pale yellow, brown, and mottled cut surfaces. The mass showed active, hemosiderin-laden zones as well as areas of histologic latency

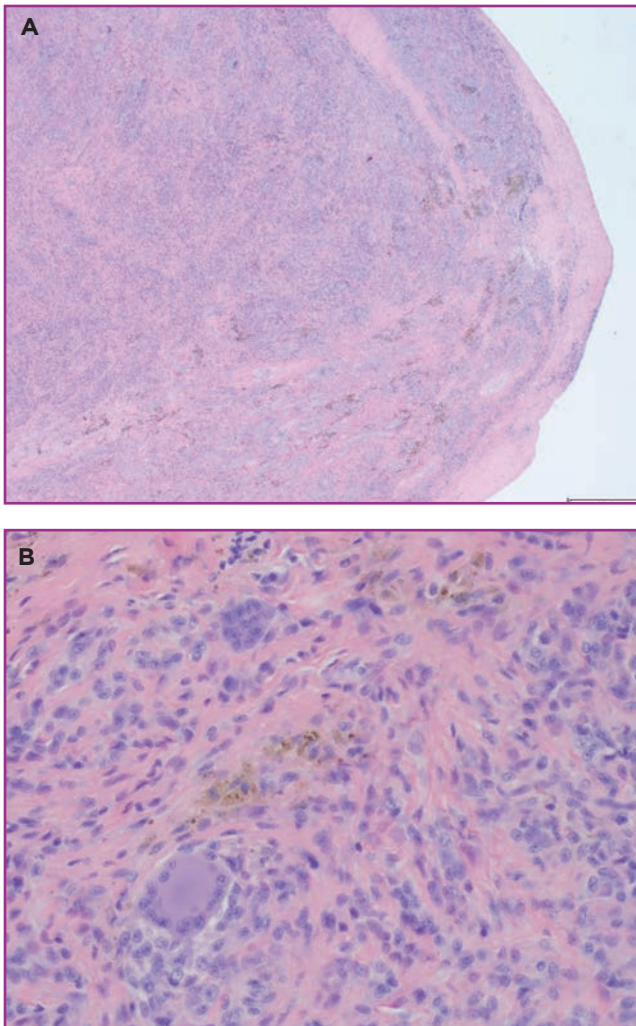
hallmarked by foamy, cholesterol-filled histiocytes. A diagnosis of localized PVNS was made (Figure 3).

At 2 and 12 week follow-up, the patient reported considerable improvements in his preoperative pain level. The patient was advised to return at 1 year postoperatively, but he was lost to follow-up. Just over 2 years postoperatively, the patient presented to our orthopaedic sports clinic for chronic right-hip pain and consented to a follow-up wrist examination. His preoperative tenderness at the STT joint had resolved, and his radial and ulnar deviation were within 5° of the contralateral side. He was without subjective complaints at that time, and he had returned to full duty with the military.

## DISCUSSION

PVNS is a benign though aggressive neoplastic disease that is associated with the abnormal proliferative growth of villi and nodules within the joint synovium.<sup>1</sup> It is classified as either diffuse or localized, with a respective prevalence of 11.5 and 44.5 per 100,000 persons, respectively.<sup>7</sup>

Diffuse PVNS exists as a global joint synovitis with a large effusion and pressure-based erosions on both the proximal and distal aspect of the joint.<sup>8</sup> Commonly termed "giant cell tumor of tendon sheath (GCTTS)," localized PVNS exists as a solitary and pedunculated



**Figure 3.** Findings of histopathology showing A) localized-type tenosynovial tumor (2x). Well-circumscribed and encapsulated polymorphous proliferation of mononuclear cells admixed with osteoclast-like giant cells and hemosiderin pigment deposition. B) Localized-type tenosynovial tumor (40x). The mononuclear cells are bland and include a mix of spindled cells with uniform oval nuclei, and larger, histiocytoid cells with more abundant eosinophilic cytoplasm and reniform, vesicular nuclei. Also present are multinucleated giant cells and associated hemosiderin pigment.

mass, occurring either intra-articularly or extra-articularly intimate with a tendon sheath.<sup>9,9</sup> Although the most commonly affected joint is the knee, joint involvement at various sites has been described.<sup>10</sup>

The exact cause of PVNS is unknown. Proposed mechanisms include *de novo* development from joint inflammation, via unregulated cell growth and proliferation or by prior trauma.<sup>10-12</sup> For this reason, patient history alone may not implicate PVNS as a cause of joint pain. Classic symptoms are less severe at smaller joints and nondescript, including joint swelling, pain, and loss of range of motion.<sup>10,12</sup> Diagnosis thus depends on radiology and histopathology. X-rays may show

soft tissue swelling and bony erosion; however, erosive changes are often a later finding and typically found in diffuse disease. For this reason, MRI can be particularly helpful, as it will show low to intermediate uptake on both T1- and T2-imaging, and gradient echo sequences will show a pathognomonic blooming susceptibility artifact of low signal intensity owing to the presence of hemosiderin.<sup>13</sup> Histologic specimens are grossly nodular in appearance with characteristic microscopic features, including hypertrophic villi, multinucleated giant cells, and hemosiderin-laden foamy macrophages.<sup>9,13</sup>

The treatment of PVNS includes open versus arthroscopic synovectomy for both diffuse and localized disease. Radiation therapy may be used in place of surgery or as an adjunctive therapy in PVNS and GCTTS.<sup>14</sup> Complete excision is advised to decrease the chance of postoperative recurrence. This entails a total synovectomy for diffuse disease, and the removal of the entire lesion for localized disease.<sup>9,15</sup> This is particularly important, because even after reported total synovectomies, recurrence rates between 9 to 44% have been reported.<sup>14</sup>

This case highlights the diagnosis and treatment of intra-articular localized PVNS of the STT joint. Despite its location in an atypical joint, classic symptoms of pain and range of motion loss were reported by our patient. Despite normal x-rays, MRI showed the blooming artifact associated with the presence of hemosiderin, thus increasing the likelihood that the patient's pain was secondary to PVNS. This was confirmed on histopathology when the specimen showed all the key features of PVNS.

The current case also shows that arthroscopic excision and synovectomy for PVNS at a small joint (eg, STT joint) remains a viable treatment option. Our patient lacked symptomatic recurrence 2 years postoperatively. Arthroscopy allows for access and complete visualization of smaller joints, including magnification that may improve upon the resolution of loupe magnification used with open synovectomy. In this way, local recurrences may be diminished.

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# Osteomalacia in a Young Adult Male Presenting as Chronic Wrist Pain: A Case Report

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## ABSTRACT

Chronic wrist pain is a common problem encountered by orthopaedic surgeons, yet osteomalacia is rarely considered in the differential diagnosis in the United States. We present a case involving a 37-year-old man who experienced bilateral wrist pain and weakness for more than 2 years. Further investigation revealed a history of chronic leg pain, low serum 25-hydroxy vitamin D levels, and decreased bone density. He was diagnosed with osteomalacia and treated with vitamin D supplementation and increased sun exposure. At 6 months follow-up, the patient had resolution of his pain and normalized vitamin D levels. To our knowledge, the literature has not previously reported on osteomalacia in a young adult presenting with chronic wrist pain. Although uncommon, osteomalacia should be considered in the work-up for chronic wrist pain.

**Keywords:** Osteomalacia, Vitamin D, Wrist

## INTRODUCTION

Osteomalacia is a metabolic bone disease defined by abnormal mineralization of osteoid, and it is most commonly caused by a vitamin D deficiency and hypophosphatemia.<sup>1,2</sup> Chronic wrist pain, defined as pain lasting greater than 6 months,<sup>3</sup> is a common concern encountered by hand specialists. Yet osteomalacia is not typically considered in the differential diagnosis.<sup>4</sup> Symptoms of osteomalacia are often non-specific, including vague body aches and limb weakness, making diagnosis difficult.<sup>5</sup> Osteomalacia is thought to be uncommon in the United States.<sup>5</sup> However, recent evidence from Europe suggests that osteomalacia is often subclinical and goes undiagnosed, thus it may be more prevalent in the United States than initially thought.<sup>6</sup> There seems to be an overall lack of awareness about osteomalacia among clinicians, thus frequently delaying diagnosis.<sup>4</sup>

## CASE REPORT

A 37-year-old man presented to the orthopaedic hand clinic with chronic wrist pain and weakness. As a software engineer, he had experienced wrist pain for the previous 2 years. The wrist symptoms occurred randomly and did not correlate with activities. He denied a history of trauma. Prior treatments were unsuccessful, including wrist bracing, workstation modifications, and cortisone injections. His medical history was significant for well-controlled hypothyroidism, childhood tuberculosis, and immigration to the United States at the age of 20 from India. On review of systems, he reported intermittent pains involving his forearms and legs with associated diffuse weakness. Physical examination of the upper extremities was within normal limits.

Prior evaluation by the rheumatology service was negative for laboratory evidence of inflammatory arthritis. The rheumatologist ordered magnetic resonance imaging of both wrists, which were found to be only abnormal for diffuse cystic bone changes. Owing to his persistent wrist pain without a diagnosis, he was referred to a hand surgeon for further evaluation.

After consultation, radiographs of bilateral wrists were obtained. The radiographs were concerning for osteopenia. Based on these abnormal findings, a vitamin D level and a dual-energy x-ray absorptiometry (DEXA) examination were ordered to evaluate for metabolic bone disease. The DEXA scan was consistent with osteopenia, with a T-score more than two standard deviations below the mean. His serum 25-hydroxy vitamin D level was 30 nmol/L, with less than 30 nmol/L being considered vitamin D deficient.<sup>5</sup> Given the findings of low vitamin D levels, osteopenia on the DEXA scan, and history of chronic wrist pain and diffuse extremity pain, a preliminary diagnosis of osteomalacia was made.



Endocrinology was consulted for treatment to evaluate for other causes of vitamin D deficiency. The endocrinologist ordered additional laboratory testing, including parathyroid hormone (PTH), thyroid stimulating hormone, total calcium, and celiac antibody. All tests were found to be within normal range. The patient was diagnosed with osteomalacia owing to nutritional vitamin D deficiency. He was started on 5000 units of daily vitamin D3 supplementation, and increased sunlight exposure was encouraged. Six months after starting treatment, his symptoms had resolved, and his serum 25-hydroxy vitamin D level had risen to 43 nmol/L.

## DISCUSSION

We described a young adult patient (< 50 years old) with an uncommon case of osteomalacia as a result of a vitamin D deficiency. In the described case, chronic wrist pain was refractory to common treatment modalities. The patient's symptoms resolved after following dedicated treatment for osteomalacia; however, the diagnosis was considerably delayed. We believe that several factors contributed to the delay in diagnosis, including the patient's atypical symptoms, young age, and clinicians overall lack of awareness about osteomalacia. The purpose of this paper is to raise awareness of osteomalacia in this patient population.

Osteomalacia is a metabolic bone disease that poses a considerable diagnostic challenge for clinicians. Osteomalacia is considered rare when compared to osteoporosis, the most common metabolic bone disease. However, the prevalence of osteomalacia may be higher than what is reported owing to frequently missed or delayed diagnoses.<sup>2,5</sup> In the literature, the majority of osteomalacia cases describe patients younger than 18 years and greater than 50 years of age,<sup>2,5</sup> suggesting that the age of the patient in this case (ie, 37 years old) is atypical for osteomalacia.<sup>7</sup> This may be true, or it may be that the diagnosis is more frequently missed in this age group, as it was in this case. Further studies are needed to better characterize osteomalacia in this population.

The most common presenting concerns of osteomalacia are non-specific, including whole-body pain, bone pain, generalized muscle weakness, and multiple fractures.<sup>1,2,8</sup> In this case, the patient had concerns of chronic bilateral wrist pain not associated with activities. We did not find any previously reported cases of osteomalacia presenting as chronic wrist pain in the literature, which makes this case unique. We believe osteomalacia should be considered in the differential diagnosis for chronic wrist pain.

Although there are many known causes of osteomalacia, we focused on vitamin D deficiency, which is the most common cause. The prevalence of osteomalacia due to vitamin D deficiency is unknown. Recent literature from Europe showed that 13.0%

of Europeans, irrespective of age, were vitamin D deficient.<sup>9</sup> Postmortem studies conducted in Germany reported on populations with a high prevalence of vitamin D deficiency,<sup>6</sup> in which they found that 25% had histological evidence of osteomalacia.<sup>6</sup>

Major risk factors for vitamin D deficiency include limited exposure to sunlight, inadequate nutrition, and intestinal malabsorption.<sup>8</sup> In this case report, the patient spent the majority of the daytime hours inside as a software engineer, and thus had decreased exposure to sunlight. It is well accepted that increased sunlight exposure can improve a patient's vitamin D levels; however, there are currently no strong recommendations for the appropriate amount of sun exposure.<sup>10</sup>

Adequate nutritional vitamin D is important for maintaining healthy levels. The current guidelines recommend 600 to 800 IU per day of vitamin D.<sup>11</sup> Additionally, the patient in this case report had dark skin pigmentation and was a non-western immigrant, which have both been identified as risk factors for vitamin D deficiency and osteomalacia.<sup>11</sup>

Once the diagnosis of osteomalacia due to vitamin D deficiency is suspected, the diagnosis can be supported with laboratory testing. Typical findings in osteomalacia due to vitamin D deficiency include low 25-hydroxy vitamin D, decreased serum calcium, elevated alkaline phosphatase (ALP), and elevated PTH.<sup>8</sup> In this case, the patient's vitamin D was low, but the serum calcium and PTH were within normal limits. ALP was not collected.

Treatment recommendations for vitamin D deficiency consists primarily of oral vitamin D supplementation in the form of 50,000 IU of vitamin D once per week or 6000 IU daily of vitamin D. The goal of treatment is a serum 25-hydroxy vitamin D greater than 30 nmol/L.<sup>10</sup>

In summary, orthopaedic surgeons will encounter patients at risk for vitamin D deficiency and osteomalacia. Raising awareness of these problems could potentially help clinicians identify these patients early and thus improve patient outcomes.

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# Single-Event Multilevel Surgery of the Upper Extremity: A Case Report

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**Informed Consent** The patients were informed that the data concerning their cases would be submitted for publication, and they provided verbal consent.

## ABSTRACT

Single-event multilevel surgery has been used successfully to treat pediatric patients with cerebral palsy for decades; however, it has not been widely used to treat adult patients. Tendinopathies of the arm often coexist, and performing single event surgery to correct one joint pathology may further exacerbate coexisting tendinopathies. Accordingly, performing single-event multilevel surgery in the appropriate patient allows for the correction of multiple conditions of the same limb in a single surgery. Single-event multilevel surgery offers many benefits, including cost savings, convenience for the patient, less potential complications owing to a single anesthetic and hospitalization event, and a shorter overall rehabilitation period. We present an adult patient with multiple tendinopathies of the left upper extremity, including subacromial impingement syndrome, bicipital tendinitis, lateral epicondylitis, and trigger finger. He underwent single-event multilevel surgery for all mentioned musculoskeletal pathologies, resulting in successful surgical correction without complications or adverse outcomes.

**Keywords:** Tendinopathy, Upper Extremity, Orthopaedic Procedures

## INTRODUCTION

Single-event multilevel surgery has been used for decades to treat pediatric patients with cerebral palsy (CP), and it is considered by many to be the standard of care.<sup>1</sup> Single-event multilevel surgery allows for multiple musculoskeletal pathologies to be corrected at the same time, resulting in a single anesthetic event, hospitalization, and rehabilitation period.<sup>1,2</sup>

There is a paucity of literature evaluating the role of single-event multilevel surgery in adult patients without CP, and it is common for orthopaedic patients to have multiple, concurrent upper-extremity pathologies within the same limb.<sup>3,4</sup> Walker-Bone et al<sup>3</sup> reported that patients with shoulder pathology (eg, rotator cuff tendinitis, bicipital tendinitis, subacromial bursitis,

and acromioclavicular joint dysfunction) were often found to have coexisting pathologies, including lateral epicondylitis, medial epicondylitis, De Quervain's tenosynovitis, and carpal tunnel syndrome. At times, these coexisting pathologies can be exacerbated if not addressed during the initial surgery. For example, a 72-year-old man presented to our clinic 6 weeks after undergoing a right-rotator cuff repair. He had signs and symptoms of acute exacerbation of chronic carpal tunnel syndrome that ultimately required a second surgery for its resolution. This is consistent with findings from Harada et al,<sup>5</sup> who examined complications of the fingers and hands after 41 arthroscopic rotator cuff repairs. The authors reported that twelve (29%) of the patients reported hand and finger symptoms after arthroscopic rotator cuff repairs, including pain, numbness, edema, and joint stiffness.<sup>5</sup> Of the 12 patients, flexor tenosynovitis was diagnosed in 10 patients, carpal tunnel syndrome in 3 patients, and cubital tunnel syndrome in 2 patients.<sup>5</sup>

Our experiences with exacerbations of coexisting pathologies in the same extremity after arthroscopic shoulder surgery prompted us to 1) evaluate for coexisting conditions in all patients before surgery, and 2) perform single-event multilevel surgery in appropriate patients when multiple pathologies of the same limb are identified.

We present a case report of one patient and case series of two additional patients who underwent single-event multilevel surgery.

## CASE REPORT

A 63-year-old man presented to our institution with pain in his left anterolateral shoulder, radiating posteriorly for several months. No traumatic injury was reported; however, the patient, an electrician by trade, stated that the pain was aggravated by overhead motion. His physical examination findings were concerning for subacromial impingement syndrome. An x-ray of the left shoulder was unremarkable except for mild arthritis of the acromioclavicular joint.

**Table 1.** Upper Extremity Single-Event Multilevel Surgeries Performed in 2018\*

Gender/Age	SEMLS Performed	Complications
Male, 63	Left shoulder distal clavicle excision, Left shoulder subacromial decompression and acromioplasty, Left shoulder arthroscopic-assisted subpectoral bicep tenodesis, Left open debridement of extensor carpi radialis brevis, Left index trigger finger release	None
Male, 74	Right arthroscopic rotator cuff repair, Right subacromial decompression and acromioplasty, Right arthroscopic-assisted subpectoral bicep tenodesis, Right open carpal tunnel release, PRP supplementation to rotator cuff	None
Female, 51	Right open debridement of extensor carpi radialis brevis and common extensor origin, Right open release of the carpal tunnel	None

PRP, Platelet Rich Plasma

\*The above surgeries were performed as expected, without any delays in healing, complications, or need for further physical therapy

The patient was treated conservatively with a home exercise program and a corticosteroid injection into the subacromial space. The patient returned to the clinic approximately 4 weeks later with less shoulder pain; however, he now reported pain and catching of his left index finger and left lateral elbow pain. He was treated conservatively for lateral epicondylitis with a corticosteroid injection, counterforce brace, and physical therapy. He was also diagnosed with index trigger finger and treated with a corticosteroid injection. He returned to the clinic 4 weeks later with recurrent waxing and waning left shoulder pain, persistent lateral epicondylitis, and trigger finger. Three months later, a platelet rich plasma (PRP) injection was administered at the point of maximal tenderness of the lateral epicondyle and in the extensor carpi radialis brevis tendon under ultrasound guidance. Although the PRP provided some relief, the patient continued to have residual lateral pain in the elbow, adjacent to the lateral epicondyle.

Ultimately, magnetic resonance imaging (MRI) of the left elbow and left shoulder were ordered owing to pain refractory to corticosteroid injection, PRP, nonsteroidal anti-inflammatory drugs, rest, counterforce bracing, physical therapy, and home exercise program. The MRI of his left elbow confirmed a partial tear of the common extensor tendon origin. The MRI of his left shoulder showed bicep tendinitis, a superior labral tear, and acromioclavicular joint degenerative joint disease.

A couple of weeks after the MRI of the left shoulder (6.5 months after initial presentation), the patient returned to the clinic with concerns of an acute exacerbation of his left shoulder pain while lifting, in which he sustained a traction type injury and felt a tearing sensation. He also reported that his left elbow and left index finger continued to cause pain. Based on worsening symptoms despite extensive conservative treatment, the patient was consented for arthroscopic subacromial decompression of the left shoulder,

distal clavicle excision, bicep tenodesis, left elbow debridement of extensor carpi radialis brevis origin, and left index trigger finger release.

A month and a half later (8 months after initial presentation) the surgeries were performed as a single-event multilevel surgery without complications. The patient was given a standard physical therapy protocol, with restrictions limiting active range of motion of the elbow until 4 weeks postoperatively and limiting strength training until 3 months postoperatively.

At his 6-week follow up, the patient had minimal shoulder pain. He showed 170° of forward flexion and 60° of external and internal rotation to the level of the thoracic spine, comparable to the contralateral side. He also showed full range of motion at the left elbow and left index finger without any pain or tenderness to palpation. At 3 months postoperatively, the patient continued to show promising results. He was cleared to transition to strength training and released to follow-up as needed.

## DISCUSSION

Multilevel surgery has been used successfully in pediatric patients with CP for more than 30 years; however, its role in other patient populations has remained largely unexplored. Based on our experience and supporting literature, surgical correction of one joint can result in exacerbations of orthopaedic conditions of the same extremity.<sup>5</sup> Although the pathology underlying this relationship is not well understood, possible explanations include proximal nerve irritation, joint swelling, joint immobility, and activation of inflammatory mediators after surgery.

This case showed that a single-event multilevel surgery is an effective strategy for managing coexisting musculoskeletal pathologies of the upper extremity in a suitable patient. We performed two additional single-event multilevel surgeries, which also showed successful healing without complications (Table 1). In appropriate patients, the benefits of single-event multilevel surgery



are quite pronounced, including convenience for the patient, less potential complications owing to a single anesthetic and hospitalization event, less overall healing time as patients are healing concomitantly, and cost savings. A recently published study<sup>6</sup> examined 302 California hospitals for the cost of care in the operating room, in which they found the average cost per minute to be approximately \$37. There is an opportunity for substantial cost savings by combining several surgeries into one.

A possible disadvantage of single-event multilevel surgery is increased pain with recovery because of the involvement of multiple joints. This case report emphasizes 1) the benefit of appropriately interviewing and examining patients for coexisting pathologies prior to surgery, and 2) the importance of selecting appropriate patients for single-event multilevel surgery.

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		Stan Griffiths (ID)	1989	Charlotte Orr (IN)	2014	Jeffrey Yaste (NC)	2009
		Speight Grimes (TX)	2004	Andrew Paterson (NM)	2004		
		Christopher Hanosh (NM)	2001	L. Johnsonn Patman (NM)	2012		
		Gregg Hartman (CA)	1997	William Paton (AK)	1977		
		Robert Hayes*	1975	Matt Patton (NM)	2002		
		William Hayes (TX)	1996	Tony Pedri (WY)	2018		
		David Heetderks (MT)	1990	Chris Peer (MO)	2005		
		Thomas Helpenstell (WA)	1991	Eugene Pflum (CO)	1976		
		Fredrick Hensal (AL)	1982	Dennis Phelps (CO)	1985		
		Bryon Hobby (MT)	2012	Gregg Pike (MT)	2004		
		Daniel Hoopes (UT)	2013	Brielle Plost (LA)	2018		
		Mischa Hopson (TX)	2016	Ian Power (NM)	2017		
		David Huberty (OR)	2005	Mario Porras (NV)	1977		
		Sergio Ilic (CA)	1977	Julia Pring (PA)	2009		

### Residents

Alexander Aboka (VA)	2011	Joseph Newcomer (IL)	1998	Drew Newhoff (NM)	2017	Jay Wojcik (FL)	2019
Christopher Achterman (OR)	1977	Lockwood Ochsner (LA)	1986	Charlotte Orr (IN)	2014	Heather Woodin (AZ)	2015
Brook Adams (TX)	2011	Charlotte Orr (IN)	2014	Andrew Paterson (NM)	2004	Jeffrey Yaste (NC)	2009
Zachary Adler (WA)	2007	Andrew Paterson (NM)	2004	L. Johnsonn Patman (NM)	2012		
Amit Agarwala (CO)	2002	L. Johnsonn Patman (NM)	2012	William Paton (AK)	1977		
Owen Ala (AK)	2013	William Paton (AK)	1977	Matt Patton (NM)	2002		
Lex Allen (UT)	2002	Matt Patton (NM)	2002	Tony Pedri (WY)	2018		
Alan Alyea (WA)	1986	Tony Pedri (WY)	2018	Chris Peer (MO)	2005		
Frederick Balduini (NJ)	1981	Chris Peer (MO)	2005	Eugene Pflum (CO)	1976		
Christopher Bankhead (VA)	2019	Eugene Pflum (CO)	1976	Dennis Phelps (CO)	1985		
Adam Barmada (OR)	2001	Dennis Phelps (CO)	1985	Gregg Pike (MT)	2004		
Jan Bear (NM)	1991	Gregg Pike (MT)	2004	Brielle Plost (LA)	2018		
Jeremy Becker (NM)	1997	Brielle Plost (LA)	2018	Ian Power (NM)	2017		
Kambiz Behzadi (CA)	1994	Ian Power (NM)	2017	Mario Porras (NV)	1977		
Robert Benson (NM)	1973	Mario Porras (NV)	1977	Julia Pring (PA)	2009		

\*Deceased





