



Western Journal of
Orthopaedics 2026
volume XV

T H E U N I V E R S I T Y O F N E W M E X I C O

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Orthopaedics 2026
volume XV

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With thanks to

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Thank You from the Editor



Welcome to the 15th volume of the *Western Journal of Orthopaedics (WJO)* published in conjunction with the Research Division of The University of New Mexico (UNM) Orthopaedics & Rehabilitation Department. This edition updates educational and research activities from the Department and features 16 articles that focus on orthopaedic innovations and cases of interest to the readership. Many of the articles are authored by UNM alumni, faculty, fellows, residents, students, and staff, and we also welcome external submissions from across the nation and around the world that enrich the overall scientific quality of *WJO*. We are delighted to offer authors the opportunity to share their research and perspectives on a wide variety of orthopaedic topics, and we invite you to submit your work to next year's 16th volume.

I would like to extend my heartfelt congratulations to our graduating residents and fellows. Their steadfast dedication and hard work have brought them to this exciting milestone, and we wish them continued success and growth as they embark on the next chapter of their careers as surgeons. I would like to acknowledge the outstanding work of our research team, with special thanks to Dr. Laurie Wells – an expert statistician and clinical researcher whose contributions have significantly shaped many of the articles presented in this year's journal. Her recent retirement has certainly marked a transition, but not a departure. Although Laurie has stepped back from full-time work, she continues to contribute to the department in her new, quarter-time role, ensuring that her presence, insight, and outstanding work remain integral to our department. After years of furthering the department's research and mentoring countless colleagues, Laurie's unwavering commitment to advancing our data-analysis capabilities is deserving of the highest recognition. We are deeply appreciative of Leorrie Watson, our Sports Medicine Research Manager, for her dedication and exceptional support in advancing the department's research endeavors. I would also like to express my sincere appreciation for Gail Case, Administrative Supervisor, for her continued leadership and support of our research efforts. We are all appreciative of our Department Chair, Dr. Gehron Treme, for his leadership and support of the department, and especially for his commitment to advancing our research initiatives.

In this edition, I want to express my deepest appreciation for our dear friend and colleague, Joni Roberts, whom we sadly lost late last year. Her professional and personal contributions to our department will be deeply missed. I am grateful for Arianna Medina, our managing editor, for her publication support in gathering, copyediting, and formatting submissions to *WJO*. My thanks as well to Angelique Tapia, our layout editor, for her work in producing this volume of *WJO*.

I look forward to the work we will all continue to create together in the coming years.

A handwritten signature in black ink that reads "Deana Mercer".

Deana Mercer, MD
Professor
Department of Orthopaedics & Rehabilitation
The University of New Mexico

CALL FOR SUBMISSIONS

WJO 2027; Volume 16

YEARLY DEADLINE: NOVEMBER 15

WJO highlights the following types of articles relevant to orthopaedic surgery and engineering: clinical and basic-science original research, case reports, reviews, technical notes, new technology, pilot studies, education articles, and reflections.



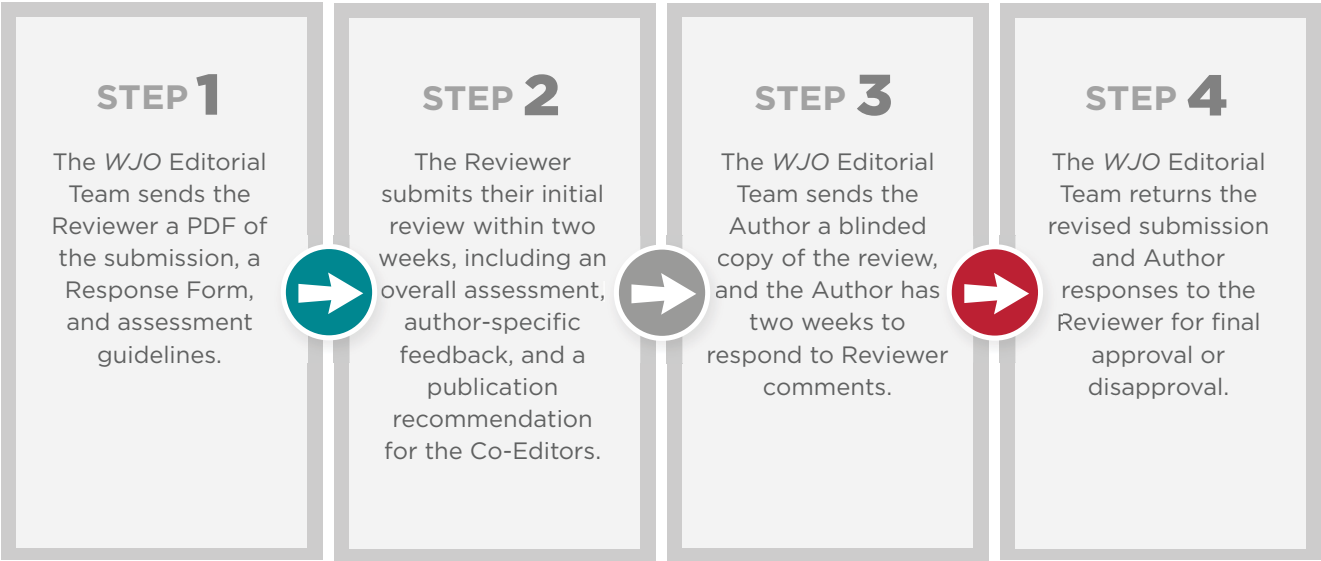
Short (1-Page) Instructions for Authors:
<https://orthopaedics.unm.edu/research/research-journal.html>

Email your Title Page, Blinded Manuscript, Figures, and Tables
to WJO@salud.unm.edu

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INSTRUCTIONS FOR PEER REVIEWERS

WJO follows a double-blind peer review process to maintain the highest standards of academic quality. Reviewers participate in the following steps:



Reviewers will not be asked to review more than two submissions for a given volume. We understand that reviewer’s time is limited and valuable. If the request is not possible, or if you believe that the content does not align with your expertise, please let us know immediately. A prompt review helps encourage authors to submit future work and allows our team to meet printing and publication deadlines.



PEER REVIEWERS: *WJO* 2026

The Co-Editors and Editorial Team of *WJO* extend our thanks to our peer reviewers, whose generous contributions of time, insight, and expertise play a vital role in shaping the scientific integrity and relevance of our content. Your thoughtful reviews uphold the standards of academic excellence we strive for.

Together, we continue progressing on our shared journey toward official indexing in PubMed and expanding the reach and impact of *WJO*.

- | | | |
|----------------------------|---------------------------|---------------------------|
| Camille Aubin-Lemay | Rick Gehlert | Christopher Shultz |
| Tamás Bárdos | Erick Kruger | Gehron Treme |
| Patrick Bosch | Charles Metzger | Andrew Veitch |
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| Shawn Duxbury | Miguel Pirela-Cruz | |
| Katherine Gavin | Dustin L. Richter | |

SHORT INSTRUCTIONS FOR AUTHORS

Western Journal of Orthopaedics

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

The submission deadline for *WJO* volume 16 is November 15, 2026. Manuscripts submitted afterward will be considered for volume 16. Email questions to WJO@salud.unm.edu.

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

General Formatting: Title Pages and Blinded Manuscripts must be submitted as Microsoft Word documents. *WJO* follows the style and format of the *AMA Manual of Style* (11th ed). Use Times New Roman, 12-point typeface, and 1-inch margins. Use continuous line numbering, continuous page numbering in the upper-right corner, and double spacing. Spell out numbers less than 10 except measurements (eg, “4 days”). Use SI metric units. Only include up to 2 significant digits (eg, $P = 0.05$, $P < 0.01$).

Title Page: State the paper’s title. List authors’ names in the desired order of appearance. For authors, include their highest academic degree, current affiliations, and any changed affiliations since the time of the study. Identify the corresponding author’s name, physical address, and email. Include five informative statements: 1) funding, 2) conflict of interest, 3) informed patient consent for case reports *OR* your Institutional Review Board approval number if the research involved humans, 4) preferred subspecialties of reviewers for your submission (eg, pediatric spine), and 5) acknowledgments of any non-authors who contributed.

Blinded Manuscript: Excluding the references, abstract, tables, and figure legends, we will accept ≤ 3200 words for reviews; ≤ 2500 for scientific articles, pilot studies, education articles, and new technology; ≤ 1200 for case reports and technical notes; and ≤ 1000 for reflections. For scientific articles and education articles, include the following headings: Abstract, Introduction, Methods, Results, Discussion, References, and Figure Legends if figures are used. For reviews, use the same headings but replace Discussion with Conclusion. For case reports, the headings are Abstract, Introduction, Case Report, Discussion, References, and Figure Legends. Email us about headings for other submission types. Subheadings may vary but are generally not included in the Introduction, Discussion, or Conclusion sections.

Abstract: ≤ 250 words for scientific articles, structured into four paragraphs: Background, Methods, Results, Conclusions. ≤ 150 words for education articles, case reports, technical notes, new technology, and pilot studies (≤ 250 for reviews) in an unstructured paragraph format. At the end, list 3 to 5 keywords using terms searchable in the MeSH database (<https://meshb.nlm.nih.gov/search>).

References: List in order of appearance (not alphabetically) and cite in the text using superscript numbers. Format all references in *AMA Manual of Style* (11th ed). All listed references must be cited in the text and vice versa.

Tables/Figures: Create tables using only the Microsoft Word table function. Number each table and include a descriptive title. Place each table on a separate page after the References section in the Blinded Manuscript. For figures, place each one at the end of the Blinded Manuscript and also email us each one as an EPS, TIFF, PPT, or JPEG file in 300 DPI. Provide a brief description of each figure in the last page of the Blinded Manuscript, under a Figure Legends heading. When submitting a figure published elsewhere, provide information about the obtained permission. All figures and tables must be cited in the text.

We welcome all relevant orthopaedic and engineering submissions. We encourage manuscripts from faculty, fellows, residents, alumni, and colleagues. **For detailed instructions, view <http://orthopaedics.unm.edu/research/research-journal.html>.**

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

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Letter from the Chair of Orthopaedics

It's my pleasure to introduce this year's edition of the *Western Journal of Orthopedics*. My deepest thanks go to our dedicated team whose commitment to editing, review, layout, and publication make this edition possible, as well as to the contributors whose expertise further enriched our journal. It has been exciting to watch this journal grow over the years, and I look forward to engaging once again with the articles and perspectives contained within these pages.

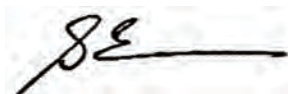
This time of year also marks the close of our academic calendar and the completion of residency training for our five graduating chief residents, along with our five fellowship trainees. I would like to extend special appreciation to our Program Directors, Program Coordinators, faculty, and administrative staff, without whom our training programs would not exist, let alone provide the high-quality educational experiences that we have come to expect for our residents and fellows.

I am honored to recognize our graduating residents: Cesar Cardenas, Colin Carroll, Taylor Gurnea, Kate Parker, and Ryan Price. This group has distinguished itself as outstanding physicians, skilled surgeons, exemplary role models, and wonderful individuals who are now permanent additions to the quilt that is the UNM Orthopaedic family. These residents began their journeys by interviewing for residency amid the restrictions of the COVID-19 pandemic, navigating rotation limitations, the uncertainties of an ever-changing care landscape, and the rapid transition to virtual interviews—changes that significantly altered how programs were evaluated and applicants were considered. Each of them took a leap of faith in choosing UNM, and for that I am deeply grateful. I believe we emerged from that period stronger, more thoughtful, and appreciative of normalcy, and I am proud to have had this class of residents helping to lead us through that time.

While graduation from residency is certainly not the end of training, learning, or professional growth, it does represent the most significant milestone to date. I am proud to call this year's graduating residents colleagues and am sincerely grateful for the many contributions they have made to our program and department. They will be greatly missed, and I look forward to following their future careers with enthusiasm and pride.

We are all so proud of you and happy for you.

Very best regards,



Gehron P. Treme, MD
Professor & Chair
UNM Department of Orthopaedics & Rehabilitation



Orthopaedic Faculty



Camille Aubin-Lemay MD



Attlee Benally DPM



Patrick Bosch MD



David Chafey MD



Tyler Chavez MD



Trevor Crean MD



Thomas DeCoster MD
Professor Emeritus



Rebecca Dutton MD



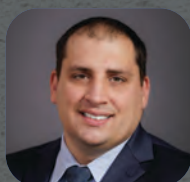
Katherine Gavin MD



Rick Gehlert MD



Samer Kakish MD



John Krumme MD



Gordon Lee MD



Eric Lew DPM



Joanne A Marasigan MD



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Umesh Metkar MD



Elizabeth Mikola MD



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Urvij Modhia MD



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Christina Salas PhD



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Professor Emeritus



Frederick Sherman MD
Professor Emeritus



Christopher Shultz MD



Selina Silva MD



Gehron Treme MD



Andrew Veitch MD



Daniel Wascher MD



Mathew Wharton MD



Meghan Whitmarsh-Brown MD

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Caroline Cook
PA



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Amber West
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David Young
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NOT PICTURED:

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Shannon Lopez CNP
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Patricia Wallace CNP
Dominic Weiler CNP
Abigail Yazzie CNP

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Christina Salas PhD

Staff



Arianna Medina BA



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Laurie Wells PhD

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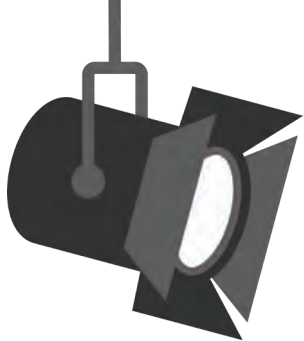
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2025 Alumni Conference Highlights

The 44th annual UNM Orthopaedic Alumni Conference was held on June 13, 2025 at the Sandia Resort Event Center. This annual conference is designed to deliver up-to-date insights on current orthopaedic practices. Our audience includes practicing orthopaedic surgeons, advanced practice providers, therapists, and other professionals working within the orthopaedic realm. This year's conference topic was "Orthopaedic Oncology" with three main objectives as they relate to spine surgery:

1. Understand emerging concepts in orthopaedic oncology & appropriate treatment options
2. Identify pathologic conditions and patients appropriate for surgical intervention
3. Understand emerging concepts in orthopaedics: hand, sports, and trauma

We had the honor of hearing presentations from two distinguished orthopaedic surgeons, Dr. Valerae Lewis, from the University of Texas, and Dr. Erika Garbrecht, from Providence Medical Group. The conference concluded with a graduation dinner for the chief residents and fellows, during which our Chair of Orthopaedics, Dr. Gehron Treme, delivered a thoughtful keynote address.



Valerae Lewis, MD

Valerae Lewis, MD is Professor and Chair of the Department of Orthopaedic Oncology at The University of Texas MD Anderson Cancer Center in Houston. Dr. Lewis earned her undergraduate degree in Psychobiology from Yale University, and her medical degree from Harvard Medical School. Dr. Lewis completed residency at the Harvard combined Orthopaedic Residency Program in Boston, Massachusetts. She then completed a fellowship in musculoskeletal oncology at The University of Chicago. Among her distinguished appointments, Dr. Lewis was named the Endowed Dr. John Murray Professor in Orthopaedic Oncology at The University of Texas MD Anderson Cancer Center in 2010. Dr. Lewis specializes in limb salvage and pelvic sarcoma surgery in adult and pediatric patients.



Erika Garbrecht, MD

Erika Garbrecht, MD is an orthopaedic oncologist practicing in Spokane, Washington. Dr. Garbrecht earned her medical degree from the University of Oklahoma College of Medicine, graduating with honors. She completed her orthopaedic surgery residency at The University of New Mexico, followed by a dual fellowship in traumatology and orthopaedic oncology at the University of Miami and Jackson Memorial Hospital. She is also serves on a sarcoma tumor board in Spokane, where physicians collaborate to develop individual treatment plans for complex cases. Dr. Garbrecht specializes in the management of adult and pediatric benign and malignant bone and soft-tissue tumors.

Letter from the Residency Director



As we celebrate the publication of the 15th edition of *WJO*, I continue to be profoundly impressed by our residents' unwavering dedication to advancing research. Their work extends far beyond the pages of this journal, with many residents publishing in other prestigious journals as well. While our department is home to remarkable talent across all divisions, I want to take this moment to highlight the exceptional achievements within our Residency program.

Our Residency program continues to expand, offering a wide range of research opportunities for faculty, staff, and residents who are excelling in their individual research interests. We take great pride in the number of residents who surpass the two-project minimum required for graduation, with many taking on additional projects that contribute meaningfully to the department. Our mission extends beyond training residents to become skilled surgeons and clinicians; we are equally committed to fostering their personal and professional growth. I am honored to be part of a program that provides residents with the educational and clinical foundation that will guide them throughout their careers as orthopaedic surgeons.

I would also like to recognize the outstanding work of the *WJO* co-editors, Dr. Deana Mercer and Dr. Dustin Richter, our Vice Chair of Research. The co-editors' commitment to project completion, their engagement of medical students, and their support of residents during didactics are truly appreciated. During my 20 years at UNM, I have witnessed tremendous growth within the department, much of which is owed to our outstanding research team. Monthly research meetings, dedicated staff supporting project completion across divisions, and the continued development of *WJO* have all played vital roles in our success. As our department continues to grow and evolve, I am confident that under Dr. Dustin Richter's leadership, our research efforts will continue to thrive.

Thank you to the entire research team and to *WJO* for your unwavering support of our residents and faculty.

Sincerely,

A handwritten signature in black ink, appearing to read 'Selina Silva'.

Selina Silva, MD
Orthopaedic Surgery Residency Program Director
The University of New Mexico School of Medicine

Orthopaedic Residents

PGY
4



Carolyn
Ardizzone MD



Tomas
Holy MD



Hayley
Urreiztieta MD MPH



Kylan
Larsen MD



Nicholas
Newcomb MD

PGY
3



Cory
Alford MD



Mathew
Gremillion MD



Naomi
Kelly MD



Hernan
Lebensohn MD



Lauren
Nun MD

PGY
2



Lorena Fuentes
Rivera Lau MD



Matthew
Gasparro MD



Johnathan
Jensen MD



Hoang
Nguyen MD



Tobi
Odeneye MD

PGY
1



Nicholas
Christopher MD



Kian
Habashi MD



Andrew
Kaler MD



Kendall
Schwartz MD



Jaron
Wilson MD

Chief Residents



Cesar Cardenas, MD

Medical School: University of Washington
Fellowship: Foot and Ankle Surgery, Duke University

I grew up in the small town of Burley in southwestern Idaho, where I spent most of my time playing soccer and enjoying the Snake River. After graduating high school, I attended the College of Southern Idaho for two years as I explored my interests, which eventually led me to pursue a degree in Kinesiology at Boise State University. It was during my time in Boise that I developed a strong interest in musculoskeletal anatomy and medicine.

I went on to attend the University of Washington School of Medicine, where my love for orthopaedic surgery truly took shape. Matching at The University of New Mexico's (UNM) orthopaedic surgery residency has been a dream come true. I will sincerely miss the community and relationships that I have formed here over the past five years.

I did not reach this point on my own. First and foremost, I would like to thank my parents for always encouraging me to dream big. Without their sacrifices, love, and support, I would not be in this position. I am equally grateful to my wife - my best friend - who has stood by me throughout this journey and helped me navigate the most difficult moments of residency. I also want to thank my co-residents and faculty for continually pushing me, supporting my growth, and providing me with the tools necessary to become a successful orthopaedic surgeon.

Outside of work, you can find me spending time outside - hiking, trail running, mountain biking, and snowboarding. I also enjoy spending time with my wife and our dog, whom we rescued during residency. We have loved traveling all around New Mexico, a state filled with beautiful scenery and great restaurants. I am also a sports fanatic and never miss a chance to cheer on my teams.

The next phase of my training will take me to Durham, North Carolina, where I will complete a fellowship in foot and ankle surgery at Duke University. Once again, thank you to UNM Orthopaedics for an incredible five years - years filled with immense professional and personal growth.



Colin Carroll, MD

Medical School: University of Queensland
Fellowship: Sports Medicine, Duke University

I was born in Berwyn, a suburb of Chicago, but moved to Fountain Valley, California, when I was two years old. I completed my undergraduate studies in Southern California at Pepperdine University. I majored in Sports Medicine and played D-1 water polo for the Waves. Before heading to medical school, I worked as an EMT and ocean lifeguard for the City of Huntington Beach. My medical school experience was not typical. I attended the University of Queensland in Brisbane, Australia, for two years followed by rotations at the Ochsner Clinic Foundation in New Orleans, LA. I was fortunate to experience medicine on two different continents and two different health care systems.

In medical school, I met my wife, Caroline. We couples matched at The University of New Mexico (UNM), with Caroline specializing in Pediatrics. Outside of residency, I enjoy concerts, the outdoors, traveling, watching Chicago sports, and spending time with my wife and our son, Caelan, who was born in August.

I am grateful for the opportunity to train at UNM. I am indebted to Dr. Schenck, Dr. Treme, Dr. Silva, and the rest of the staff and faculty at UNM for allowing me to realize my dream of becoming an orthopaedic surgeon. I want to thank my wife for all her love and support through medical school as well as residency. I would also like to thank my mom, Cathy, my dad, Al, and my brothers, Sean and Robert, for their guidance throughout my life, which has helped me reach this point. Following graduation in June, I will be heading to Duke University for a Sports Medicine Fellowship.

Chief Residents



Taylor Gurnea, MD

Medical School: University of Nevada
Fellowship: Spine Surgery, Hoag Orthopaedic Institute, Newport Beach, California

I grew up in Reno, Nevada, a mountain town that shaped much of who I am today. The outdoors were woven into my daily life, and the community that raised me instilled a deep respect for hard work, humility, and caring for others. After graduating from the University of Nevada, Reno, I carried those values with me as I pursued medicine.

My interest in orthopaedics began well before medical school, shaped by my work in search and rescue and by time spent shadowing a trauma surgeon. Those early experiences showed me how timely, decisive surgical care can change the trajectory of a patient's life in their most vulnerable moments. I attended medical school at the University of Nevada, Reno School of Medicine, where that early interest solidified. The blend of problem-solving, anatomy, and the ability to restore a person's function drew me in, and that pull only deepened as I progressed through training. That path ultimately led me to The University of New Mexico for residency, where I have been fortunate to train alongside exceptional mentors and colleagues.

As I reflect on residency, I am thankful for my parents, who laid the foundation that allowed me to pursue this career. I am grateful for my son, whose arrival reshaped my perspective and deepened my sense of purpose in both medicine and life. Above all, I am most grateful for the unwavering support of my wife, Kennedy, whose steadiness and encouragement have carried me through every phase of this journey.

Outside of work, I enjoy hiking, skiing, camping, and spending time outdoors with my family. I have also developed a growing interest in personal finance and investing, an area I have enjoyed exploring throughout residency. These activities help keep me grounded and provide balance amid the intensity of surgical training. I will be pursuing a fellowship in Orthopaedic Spine Surgery, where I hope to continue developing my skills in the diagnosis and surgical management of complex spinal conditions. I am excited for the next step in training and for the opportunity to join a field that continues to challenge and inspire me.



Kate M. Parker, MD

Medical School: The University of Chicago Pritzker
Fellowship: Trauma, Wake Forest University

I grew up in Edmonds, Washington, at the time a sleepy, retirement-leaning town along the Puget Sound, about 30 minutes north of Seattle. I stayed close to home for undergraduate school at the University of Washington, but medical school took me to Chicago. Although I initially assumed I would never live somewhere without mountains, Chicago quickly became my favorite city. Its diverse communities, festivals, music events, lakefront, and incredible architecture made it an unexpectedly impressionable place.

None of my educational endeavors would have been possible without the support of my parents, to whom I owe everything, as well as my closest friends from childhood and siblings, who remain my strongest foundation. Residency at The University of New Mexico has been nothing short of a gift. The combination of amazing staff, co-residents, a unique patient population, and access to the outdoor activities that I love has made it an ideal environment for both professional and personal growth.

This coming year, I will be living farther from home than ever before in Winston-Salem, North Carolina. Although far from home, it already feels familiar, as UNM's strong connection with the program there creates a sense of community within the trauma community. I am forever grateful to everyone who helped make this opportunity possible, and I am excited to continue learning while strengthening the relationship between these two programs. I am forever thankful to UNM and all the people who make this place the best.

Chief Residents



Ryan C. Price, MD

Medical School: The University of New Mexico
Fellowship: Spine Surgery, University of Maryland

I grew up in Farmington, New Mexico, in a rural community on a seven-acre plot that my parents cultivated into a productive hay farm. My brother and I learned to ride horses, weld fences, and enjoy the outdoors. It was an idyllic place to grow up, where effort, compassion, and service were part of daily life. With both of our parents working as teachers, education was always a priority.

The United States Air Force Academy drew me in early, and graduating in 2008 remains one of the most meaningful experiences of my life. I earned a Bachelor of Science in Biology while competing in Division I wrestling and later boxing. After graduation, I completed pilot training at Sheppard Air Force Base in Texas, then spent seven years flying the C-5M Super Galaxy at Travis Air Force Base in California.

My aviation experiences were thrilling, challenging, and humbling. They ranged from flying cargo into combat theaters in Southeast Asia to transporting NASA satellites and supporting presidential travel around the world. During this time, I was selected for the Health Professions Scholarship Program, which set in motion a carefully planned transition into medicine.

My wife and I chose to attend medical school at The University of New Mexico so our six-month-old son, Cameron, could grow up near his grandparents. During this time, I was drawn to orthopaedics, particularly the mechanical problem-solving and technical challenges the specialty demands.

Our family grew during my orthopaedic surgery residency at UNM with the arrival of our daughter, Layla. Over five years, I gained broad clinical experience and found invaluable mentors throughout the department. At home, my wife, Mariam, sustained our family through the demands of training while excelling in her own career. I deeply admire her resilience and support.

Next year, I will pursue a Spine Surgery fellowship at the University of Maryland before returning to active-duty military service. I am grateful for my time at UNM and hope our family may one day return to New Mexico.

Fellows



Matthew Brown, MD

Fellowship: Trauma
Residency: Duke University
Medical School: University of Florida



Bridget Ralston-Ripple, MD

Fellowship: Sports Medicine
Residency: University of Arizona College of Medicine
Medical School: University of Arizona College of Medicine



Gregory Roy, MD

Fellowship: Hand
Residency: University of Vermont
Medical School: University of Vermont



Christina Wassef, MD

Fellowship: Hand
Residency: John Peter Smith Hospital
Medical School: Baylor College of Medicine



Erin Wilson, MD

Fellowship: Sports Medicine
Residency: University of Wisconsin
Medical School: University of Iowa



TOTAL ANKLE ARTHROPLASTY: WHERE ARE WE NOW?

Cesar Cardenas, MD

End-stage ankle arthritis affects approximately 1% of the population and disproportionately impacts younger, more active individuals compared with those who develop hip or knee osteoarthritis. Historically, ankle arthrodesis has been considered the gold-standard surgical treatment. However, alterations in gait and function, as well as the subsequent development of adjacent-joint degeneration, have driven interest in total ankle arthroplasty (TAA).

First-generation ankle replacements demonstrated unacceptably high failure rates due to poor implant design, excessive bone resection, and limited understanding of ankle biomechanics. Second-generation implants showed improved survivorship, but persistent issues with subsidence remained. Modern third- and fourth-generation systems emphasize anatomic design, porous ingrowth surfaces, bone preservation, and improved instrumentation, including patient-specific guides. Recent studies report implant survivorship exceeding 90% at 5 years to 10 years, with

sustained improvements in patient-reported outcome measures and gait parameters. Comparative studies demonstrate that both arthrodesis and arthroplasty improve pain and function, though TAA is associated with greater improvements in motion, gait mechanics, stair negotiation, and health-related quality of life, without a significant increase in complication rates. Revision rates for modern implants are comparable to national joint registry data and are similar between fixed- and mobile-bearing designs.

In conclusion, both ankle arthrodesis and TAA remain viable surgical options for end-stage ankle arthritis. In appropriately selected patients, modern TAA provides reliable pain relief, improved functional outcomes, and preservation of ankle motion, with survivorship approaching that of more established joint replacements. Successful outcomes depend on careful patient selection, correction of deformity, and restoration of a stable, well-balanced ankle joint.



FLYING C-5S TO FUSING C5S: MILITARY LEADERSHIP FOR ORTHOPAEDIC SURGEONS

Ryan C. Price, MD

Physician leadership development has been increasingly recognized as an area for improvement in both medical school and residency training. Orthopaedic surgeons function as de facto team leaders in the clinic and, most critically, in the operating room. Despite this responsibility, leadership behaviors are often acquired informally through observation of role models, and there is limited evidence to support or refute the effectiveness of these approaches. A structured understanding of how and when to employ different leadership styles may help orthopaedic surgeons become more effective leaders.

Dr. Price draws on his military aviation experience to examine leadership through the lens of the Full Range Leadership Model (FRLM). Developed by Bernard Bass and Bruce Avolio in the 1990s, the FRLM provides a comprehensive framework that characterize leadership behaviors along a continuum from passive to highly active engagement. The model integrates three primary styles: laissez-faire (hands-off leadership characterized by avoidance and ineffectiveness), transactional leadership (based on reward-driven exchanges and management by exception), and transformational leadership (focused on inspiration, motivation, and personal development).

Transformational leadership, the most effective end of the spectrum, encompasses four key behaviors: idealized influence (serving as a role model), inspirational motivation (articulating a compelling vision), intellectual stimulation (challenging assumptions and fostering innovation), and individualized consideration (mentoring and developing followers). Transactional leadership includes contingent reward (establishing clear links between performance and reward), active management by exception (proactive monitoring and correction), and passive management by exception (reactive intervention). Laissez-faire leadership reflects minimal involvement and is consistently associated with poor outcomes.

Effective leaders dynamically blend these styles, with transformational behaviors augmenting transactional ones to optimize motivation, performance, and team engagement. Dr. Price illustrates these concepts through practical examples drawn from his residency training and military aviation career, highlighting how leadership behaviors can be deliberately applied in the day-to-day practice of orthopaedic surgery.



SPINAL CORD INJURY

Taylor Gurnea, MD

Spinal cord injury (SCI) is a catastrophic condition with significant neurologic, functional, and socioeconomic consequences. Approximately 18,000 new cases occur annually in the United States, with nearly 300,000 individuals living with chronic SCI. Injuries occur more commonly in males and are most often the result of motor vehicle collisions, falls, violence, and sports-related trauma. Beyond the initial injury, SCI is associated with substantial lifetime healthcare costs and significant long-term morbidity, underscoring the importance of timely diagnosis and evidence-based management.

Evaluation of SCI begins with an understanding of spinal cord anatomy and established classification systems. Neurological assessment is guided by the ASIA impairment scale, which remains central to injury classification, prognosis, and longitudinal assessment. Injuries are broadly categorized as complete or incomplete, with incomplete injuries further characterized by recognizable clinical syndromes, including central cord, Brown-Sequard, anterior cord, and posterior cord syndromes. Structural assessment of the spine relies on biomechanical frameworks such as the Denis three-column model and TLICS/SLIC systems to evaluate stability and guide operative decision-making.

The pathophysiology of SCI supports the principle that neurological injury evolves over time. While the primary injury results from mechanical disruption of the spinal cord, secondary injury mechanisms—including ischemia, breakdown of the blood-spinal cord barrier, inflammatory cascades, and excitotoxicity—contribute significantly to progressive neurological damage. These secondary processes provide the biological rationale for early intervention and aggressive physiological optimization following injury.

Diagnostic imaging plays a critical role in both evaluation and prognosis. Computed tomography is the initial imaging modality of choice for rapid assessment of osseous injury and alignment. Magnetic resonance imaging (MRI) provides superior evaluation of the spinal cord, ligamentous structures, and intramedullary pathology, including edema and hemorrhage. MRI-based findings carry prognostic significance, as intramedullary hemorrhage is associated with poor neurological recovery. Although MRI is valuable for surgical planning, its availability should not delay urgent decompression when clinical indications are present.

Management of acute SCI centers on hemodynamic optimization, selective pharmacologic therapy, and surgical decompression. Maintaining mean arterial pressures above 85 mmHg for the first several days following injury has been consistently associated with improved neurological outcomes. The role of high-dose steroids remains controversial; contemporary guidelines indicate that steroids may be considered within a narrow early window but are not standard of care. Surgical decompression has demonstrated the most consistent benefit, with strong evidence supporting intervention within 24 hours of injury and emerging data suggesting potential advantages to ultra-early decompression in select patients.

Ongoing research continues to explore neuroprotective and neuroregenerative therapies aimed at mitigating secondary injury. Although definitive pharmacologic advances remain limited, continued investigation reflects a growing emphasis on systems-based, time-sensitive care designed to maximize neurological recovery following SCI.



MENISCUS ROOT REPAIRS ARE ASSOCIATED WITH HIGH RATES OF POSTOPERATIVE DEEP VEIN THROMBOSIS

Colin Carroll, MD

Meniscal tears are among the most common soft-tissue injuries of the knee. The meniscus plays several critical roles, including transmitting load across the knee joint, increasing the surface area for congruity and decreasing contact stress, and serving as a secondary stabilizer. Meniscus root tears are a specific subtype of meniscal tear. Many of these injuries occur with minimal or no trauma in middle-aged patients and may represent the progression of an age-related cascade, beginning with coronary ligament insufficiency and ultimately advancing to root tear.

There is limited research specifically evaluating the rates of deep vein thrombosis (DVT) and pulmonary embolism (PE) in patients undergoing meniscal repair. This study examined patients aged 8 to 80

years who underwent arthroscopic meniscal repair or meniscectomy at a single center. These two cohorts were then subdivided into patients older than 40 years and those 40 years or younger. Postoperative rates of DVT PE were then recorded and compared across the four groups, and associated risk factors were analyzed.

Patients who underwent meniscal repair at >40 years of age were found to have significantly higher rates of DVT ($P < .01$) than those who underwent debridement at any age and those who underwent repair at ≤40 years of age ($P = .02$). All DVTs and PEs in the >40 meniscal repair group occurred in patients who had meniscus root repairs, with a DVT incidence of 10.7% and PE incidence of 3.6%. Risk factors for developing DVT included age and a prior history of DVT.



WASTE AND ASSOCIATED COSTS OF AN ORTHOPAEDIC SURGERY OPERATING ROOM

Kate Parker, MD

Operating rooms (ORs) generate a substantial amount of waste, creating both financial and environmental burdens. Hospitals in the United States produce an average of 3,500 kg of plastic waste per day, excluding other forms of waste.¹ An estimated 30% to 70% of this waste originates comes from ORs. In addition, ORs consume up to three times more energy than standard commercial buildings due to ventilation, sterilization, and temperature regulation, making them costly to operate and significant contributors to carbon emissions.² Several studies have identified medical devices and single-use items as the largest sources of greenhouse gas emissions within the OR.³ In a warming world where the effects of climate change are already altering ecosystems, and with each successive year ranking among the warmest on record, mitigating carbon emissions and waste production within the healthcare sector has become an essential professional responsibility for physicians and hospital systems.⁴ Notably, several studies have also demonstrated that implementing environmentally sustainable practices can be associated with significant reductions in hospital operating costs.

In orthopaedic ORs, reductions in cost and emissions can be achieved through decreased waste production, appropriate waste segregation, and streamlining instrumentation trays to lessen the burden on sterilization services. Opened but unused supplies on back tables, such as extra basins, clips, or implants, can account for up to 13% of the total cost of a surgical case and may result in an average of \$1,000 in wasted materials per procedure.⁵ Waste can be further reduced by critically evaluating the necessity of each single-use item placed on the back table, guided by evidence from the literature.

Reports indicate that approximately 61% of biohazard waste is incorrectly discarded as standard waste.⁶ Incineration of medical waste releases five times more CO₂ and up to 105 times more particulate matter than standard waste disposal methods, in addition to releasing carcinogenic compounds harmful to human health.⁷ Inappropriate segregation of non-biohazard waste can be reduced through simple staff-education programs; in fact, studies have shown a 50% reduction in misclassified waste after a single educational session.⁷

Sterilization is also an expensive and energy-intensive process. The energy required to process a single large bone-set tray is comparable to the kW consumed by a small household over a 24-hour period. The instrumentation burden on sterile processing departments can be reduced by streamlining trays and minimizing the opening of unused trays. 'Tray Optimization' practices have been highly effective in lowering CO₂ emissions, with reported reductions

of 40% to 66% per case, equivalent to emissions produced by driving approximately 10 miles.⁸ More systematic tray configurations have also been shown to decrease sterilization time by up to 75 minutes and generate annual hospital savings of \$281,000, without negatively affecting OR efficiency.⁹

Our every day practices as surgeons in the OR carry substantial financial costs and contribute significantly to carbon emissions. Physicians should remain aware of the economic and environmental consequences of their clinical decisions, as well as the strategies available to mitigate the.

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Letter from the Chief of The Division of Physical Therapy



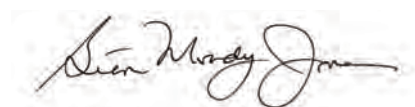
As the Division of Physical Therapy at The University of New Mexico School of Medicine marks its 52nd year, we do so with a deep sense of purpose and progress. This moment offers an opportunity to reflect on the collective efforts that have shaped our program and continue to advance our mission in education, research, and service.

One of our most exciting recent achievements is the full launch of our one-of-a-kind Gait and Motion Analysis Lab. This state-of-the-art facility supports cutting-edge research aimed at understanding how people move and walk. Through advanced camera systems and sensor-based technologies, the lab captures precise muscle, joint, and limb motion to generate detailed biomechanical data. Already, this resource is opening doors to new collaborations, innovations, and research opportunities that were previously out of reach.

I am continually inspired by the talent, dedication, and shared commitment within our division. This was clearly reflected in the Commission on Accreditation in Physical Therapy Education's decision to grant us the maximum 10-year reaffirmation of accreditation. Notably, we were one of only seven Doctor of Physical Therapy programs, out of 293 programs reviewed in Fall 2025, to receive a 10-year reaffirmation of accreditation with no requirement for a compliance update. This distinction reflects the strength of our curriculum, the depth of faculty mentorship, and the unwavering commitment of our learners. These accomplishments underscore the exceptional quality, consistency, and rigor of our program.

I would also like to recognize the scholarly and service contributions of our faculty and students. As a division, we now average more than 12 peer-reviewed publications each year, nearly 20 national and local professional presentations, and active participation in grants totaling more than 3 million dollars. Looking ahead, we remain focused on expanding scholarship support for our students and advancing our research agenda in ways that strengthen our educational mission and service to our community.

Sincerely,



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

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Deborah Doerfler
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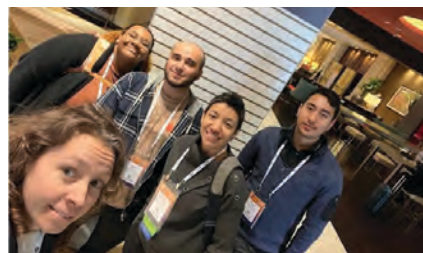
A TRIBUTE TO *Jasmine Jackson*

The UNM Orthopaedic Biomechanics and Biomaterials Laboratory team is writing this tribute in honor of Jasmine Jacklyn Jackson (February 15, 1997 – September 27, 2025), a valued member of our team whose unexpected passing this last year has deeply saddened us. Jasmine was an incredible asset to our team. She was helpful, courteous, kind, and unfailingly thoughtful. Her absence is felt deeply, and we will miss her dearly.

Jasmine, then a junior in the Chemical Engineering Department at UNM, joined our team in October of 2020 as part of the prestigious McNair Scholars Program. She initially reached out with an interest in tissue engineering, but the Covid-19 pandemic had closed our labs for more than a year. While most students were learning remotely and most research laboratories were closed, our team was leading the statewide effort to 3D print masks for emergency medical personnel and communities across New Mexico.

Our primary focus at this time was supporting the Navajo Nation across eastern Arizona and western New Mexico, where the need was especially urgent. We had recently relocated our FEMA-style printing, sterilizing, and packaging facility to UNM's main campus, and we offered Jasmine the opportunity to contribute to this critical work until research activities could resume. She embraced the chance to help New Mexicans with enthusiasm and generosity, quickly becoming a valued member of our team.

Little did we know that it would be more than a year before we could return to our laboratory spaces, delayed both by the pandemic and by our relocation from UNM's main campus to the UNM Center of Excellence for Orthopaedic Surgery and Rehabilitation in Rio Rancho, NM. Under normal circumstances, outgoing team members train incoming team members on the equipment and skills needed for our research. However, because of the extended shutdown, all of our senior lab members graduated before Jasmine was able to get started. This did not phase her. Jasmine devoted herself to learning independently, carefully studying our standard operating procedures and quickly becoming our go-to person for anything chemical-related. She helped us move into our new labs, obtain all certifications, and train incoming lab assistants. Jasmine graduated with honors in Chemical Engineering in 2021 and immediately began her MS in Biomedical Engineering. Her primary research project focused on synthesizing biodegradable polymers for bone tissue engineering applications using 3D printing. She earned her MS degree in 2023 while progressing toward her PhD, which she was expected to complete this year.



To honor her memory, our team created a memory box for her family, which we presented at her funeral.

Along the sides of the box, our lab members laser-engraved personal messages to her and about her. A few of these messages are shared below:

"Jasmine was a sweet person and left too soon. She will be missed and the impact she had on everyone will remain forever." -Marissa

"Jasmine was such a bright presence in the lab. I'm really grateful for the time all of us had together." -Ethan

"Thank you, Jasmine, for believing in me when I felt lost joining a new lab. You saw effort and patiently taught me when I felt alone. Your kindness and quiet strength made me better. I'll never forget how you carried me when I struggled. You left too soon, but your impact stays." -Chioma

"I am grateful for the time was spent together and will carry that with me always. Your kindness, insight, dedication, and smile will never be forgotten. Thank you for being the best you every day. I miss you, Jasmine." -Natalia

"When I first met Jasmine, her kindness stood out immediately. She was always there to support others, never hesitating to put her own tasks aside to lend a helping hand." -Bryan

Distal Adding-On as a Complication of Posterior Spinal Fusion in Adolescent Idiopathic Scoliosis: A Scoping Review of Contemporary Evidence

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ABSTRACT

Distal adding-on (DAO) is a complication of spinal fusion characterized by postoperative deformity progression distal to the fusion construct. DAO after posterior spinal fusion for adolescent idiopathic scoliosis (AIS) is variably defined and inconsistently managed. This scoping review synthesizes evidence on DAO detection, management, and outcomes. A PRISMA-ScR-guided search identified relevant studies. Thirty-one studies (2,998 patients; median follow-up, 30 months) met inclusion criteria. Reported DAO incidence ranged from 3.5% to 62.5%, reflecting heterogeneity in definitions, patient factors, surgical constructs, and follow-up duration. Revision surgery was infrequent and typically delayed. When performed, it was most often prompted by progressive coronal decompensation rather than radiographic changes alone. Patient-reported outcomes were largely preserved; deterioration was observed primarily in younger adolescents and in those meeting stricter DAO criteria. Overall, DAO is most often a radiographic finding managed with surveillance. Significant symptoms develop in a minority of patients, and revision, typically distal extension of fusion, is reserved for progressive coronal imbalance or symptomatic deformity.

Keywords: Revision Surgery; Scoliosis; Spinal Fusion; Spine; Vertebra

INTRODUCTION

Distal adding-on (DAO) is a recognized postoperative phenomenon, commonly defined as a progressive distal extension of the primary curve with ≥ 5 mm deviation from the center sacral vertical line (CSVL) and/or $\geq 5^\circ$ increase in distal disc angulation, as originally described by Wang et al.¹ Adolescent idiopathic scoliosis (AIS) is a three-dimensional spinal deformity and the most common form of scoliosis in adolescence.² Surgical treatment is typically indicated for curves exceeding 45° to prevent progression and restore alignment, with selective thoracic fusion correcting the primary curve while preserving lumbar compensation.²

DAO is a postoperative complication characterized by progressive distal coronal curve extension below the lowest instrumented vertebra (LIV), including coronal plane distal disc wedging/angulation and lateral (coronal) translation of the first unfused vertebra (typically LIV+1) relative to the central sacral vertical line (CSVL), and may be accompanied by distal junctional kyphosis (DJK) in the sagittal plane.³⁻⁵ Reported DAO incidence ranges from 12.9% to 51.1% across studies, reflecting variability in definitions, patient populations, and follow-up duration.^{2,6} Recognized

risk factors include younger skeletal maturity (eg lower Risser grades) and selection of an LIV that is too proximal, such as constructs ending proximal to the last substantially touched vertebra (LSTV) or other distal stable reference levels.^{2,6} Stopping the fusion proximally may leave an unfused compensatory segment exposed to postoperative coronal correction forces, promoting distal disc angulation and vertebral translation as the spine rebalances below the LIV. DAO has been associated with coronal imbalance, distal degeneration, aesthetic dissatisfaction, and revision risk, although some cases may represent adaptive compensation.^{7,8}

Despite its clinical relevance, DAO remains poorly standardized, with definitions varying across studies and including distal Cobb angle progression, distal disc angulation, and LIV+1 translation relative to the CSVL.⁹⁻¹¹ Follow-up duration and timing of assessment also differ across studies, further limiting cross-study comparability.

Definition choice directly influences reported incidence and perceived clinical relevance. Broader radiographic criteria, such as distal Cobb progression alone, generally yield higher reported incidence, whereas composite or

stricter definitions incorporating distal disc angulation and/or LIV+1 translation relative to the CSVL produce more specific, and often lower, estimates. This variability complicates interpretation of outcomes and affects evaluation of fusion-level selection strategies, as differing DAO definitions influence how postoperative distal progression is assessed when determining the appropriateness of the preoperative LIV.

AIM OF THIS REVIEW

This scoping review synthesizes contemporary evidence on the detection, management, and outcomes of DOA following posterior spinal fusion (PSF) for AIS. A scoping methodology was selected to map the breadth and heterogeneity of DAO definitions, radiographic criteria, and management. Unlike systematic reviews or meta-analyses that address narrowly defined questions and focus on effect estimation, this approach allows comprehensive characterization of DAO across diverse study designs.

Secondary objectives include identifying reproducible risk factors and characterizing definitional heterogeneity as a limitation of current practice. The most commonly applied radiographic definition of DAO is that described by Wang et al,¹ in which DAO is defined as progressive distal curve extension accompanied by either a >5 mm increase in deviation of the first vertebra below instrumentation from the CSVL or >5° increase in angulation of the first disc below the instrumentation at follow-up. Wang-type criteria incorporating distal disc angulation and/or LIV+1 translation relative to the CSVL were therefore used as the primary reference framework for comparison across studies.^{1,12}

METHODS

Study Design

This scoping review followed the Arksey and O'Malley framework, and is reported in accordance with PRISMA-ScR guidelines. No formal risk-of-bias assessment or certainty-of-evidence grading was performed, consistent with the objective of mapping current literature rather than estimating pooled effects.

Search Strategy

A comprehensive search of MEDLINE (PubMed), Embase, Scopus, Web of Science, and Cochrane CENTRAL was conducted from database inception to March 15, 2025. The strategy combined controlled vocabulary and free-text terms related to AIS, PSF, DAO (including distal add-on and distal curve progression), and the LIV. Reference lists of included studies and relevant reviews were manually screened. No date restrictions were applied. Only studies in English or with adequate English translation were included. Full search strategies are provided in Appendix 1.

Eligibility Criteria

Eligibility was defined using a Population–Concept–Context framework.

Population: Studies included patients with AIS, defined as ≤21 years at surgery or explicitly described as adolescent cohorts. Mixed-etiology studies were included only if AIS-specific data were extractable.

Concept: The primary concept was DAO after PSF, defined as distal curve progression below the LIV, postoperative distal extension of the primary curve, or progression involving LIV+1 or adjacent distal disc spaces. DAO definitions relied on objective radiographic parameters including Cobb angle change, disc wedging, vertebral translation, and/or changes in touched or end vertebra alignment. Studies without numeric thresholds were retained when reproducible measurement methodology was described.

Context / Intervention: Studies were included when PSF was the primary intervention; mixed or hybrid approaches were eligible only if PSF outcomes were reported separately.

Outcomes: Eligible studies reported at least one of the following: radiographic DAO definition; DAO incidence or severity; predictors or risk factors; postoperative alignment changes; or management strategies (surveillance, revision, or fusion extension).

Study Design: Included designs were randomized or non-randomized comparative studies, prospective or retrospective cohort studies, case-control studies, registry-based studies, and case series ≥10 patients with defined radiographic endpoints. Exclusions comprised non-idiopathic scoliosis, growth-friendly constructs (eg VEPTR, MAGEC), vertebral body tethering, anterior-only fusion when PSF outcomes were not isolatable, proximal adding-on only, revision-only cohorts without index surgery data, case reports or series <10 patients, biomechanical or simulation studies, editorials, reviews, conference abstracts without full text, and studies lacking extractable distal radiographic progression data.

Study Selection

Records were imported into Covidence for deduplication and screening. Two reviewers independently screened titles/abstracts; records mentioning “adding-on” without direction were retained for full-text review. Full texts were then independently assessed by two reviewers with documented exclusion reasons. Disagreements were resolved through discussion or third-reviewer adjudication. The process is summarized in a PRISMA-ScR flow diagram.

Data Extraction

A standardized extraction form was developed and piloted on five studies. Extracted data included study characteristics, population demographics, curve and alignment features, surgical details (including LIV selection), DAO definitions and radiographic criteria, incidence and timing, predictors, management strategies, revision details, radiographic follow-up, and patient-reported outcomes. Two reviewers extracted data independently with consensus resolution.

Data Synthesis

Given substantial heterogeneity in design, DAO definitions, and outcome reporting, a descriptive synthesis was performed. DAO definitions were mapped by radiographic parameters, anatomical reference points, and timing of assessment. DAO incidence was compared across definitions and follow-up schedules. Management strategies were synthesized narratively. When multiple DAO definitions were used within a cohort, data were extracted separately when available; otherwise, the primary operational definition was used. No quantitative meta-analysis was undertaken.

RESULTS

Revision Timing and Burden

Thirty-one studies were included, comprising predominantly retrospective single-center, multicenter, and registry-based cohorts (Appendix 1). The sample sizes ranged from 22 to 253 patients, with most cohorts including adolescents aged 12 years to 16 years. The majority of studies assessed Lenke 1-2 curves, while smaller groups investigated Lenke 5C and more complex curve patterns. Fusion strategies varied widely, with the LIV commonly anchored to the last touched or LSTV. However, some studies used neutral-vertebrae and CSVL-based methods. The mean follow-up ranged from two years to ten years, with several studies reporting long-term outcomes exceeding five years. Appendix 1 summarizes key study characteristics.

Across all the studies, DAO-directed revision surgery was uncommon and consistently delayed. Revision rates ranged from 0% to 19%, with most cohorts noting <5% DAO-specific revisions. Furthermore, the majority of patients with radiographic DAO did not undergo reoperation.

Revision was performed for progressive coronal decompensation, structural distal curve failure, or mechanical complications rather than for radiographic DAO. The median time to revision exceeded 12 months in all cohorts that reported temporal data. The most common revision technique was distal fusion extension.¹³⁻¹⁵ Skeletally immature definitive-fusion cohorts had the highest revision burden, with radiographic DAO reaching 62.5% but only 18.8% requiring surgery.¹⁴ Implant-related reoperations were reported in several studies but were not classified as DAO-directed.

MANAGEMENT STRATEGIES

Management was predominantly nonoperative, with observation and serial radiographs serving as the primary strategy in more than 90% of cohorts. DAO was treated as a radiographic surveillance finding without defined interventions. Nonoperative escalation, such as temporary bracing or exercise-based therapy, was documented in a small number of progressing patients, but these measures did not prohibit positive clinical results or necessitate surgical revision. Appendix 2 summarizes the primary management strategies.

Only a small number of studies documented selective delayed revision, which was reserved for patients with increasing deformity, mechanical failure, or clinically evident coronal imbalance. No study supported routine early revision, prophylactic distal extension, or algorithmic escalation based solely on radiographic DAO.

RADIOGRAPHIC AND PATIENT-REPORTED OUTCOMES

Radiographically, DAO presents as a distal disc angulation, LIV/LIV+1 translation, and loss of lumbar compensation. Despite the high DAO incidence in some cohorts (up to 62.5%), most patients remained under monitoring without requiring revision. Multiple cohorts reported radiographic progression of unfused distal disc degeneration without deterioration in patient-reported outcomes.

Based on SRS-22/SRS-30 outcomes across multiple studies, DAO was not associated with clinically significant deterioration in pain, function, self-image, or mental health at follow-up. However, clinically significant impairment was limited to skeletally immature definitive-fusion cohorts and long-term Cho-defined subgroups.^{14,15} Pulmonary function remained unaffected. Although distal disc degeneration progressed radiographically over time when evaluated, it did not translate into increased pain, impaired function, or a higher likelihood of revision during mid-term follow-up.

DETECTION FRAMEWORKS AND THRESHOLDS

DAO detection was almost entirely determined by radiographic criteria. Wang-type definitions (≥ 5 mm translation and/or $\geq 5^\circ$ distal disc angulation) predominated, although disc-only, Cobb-based, and composite definitions were also used.^{1,12} No study employed a uniform radiographic threshold as a mandatory trigger for surgery; radiographic progression generally resulted in increased surveillance rather than intervention. Jamnik and Han reported explicit clinical triggers for surgery (progressive trunk imbalance and symptoms of mechanical failure).^{14,16} Appendix 3 presents a comparative summary of DAO definition types.

RISK FACTORS

DAO risk was determined by a consistent set of biological, curve-related, and surgical factors across studies. These factors influenced the intensity of postoperative surveillance rather than serving as independent indicators for revision. Table 1 summarizes the direction of repeatable DAO risk factors across studies.

PREOPERATIVE FACTORS

Skeletal immaturity was the most consistent predictor of DAO. Risser grade 0-2 was consistently associated with increased DAO incidence and progression across cohorts.^{6,14,17-19} Curve morphology also influenced risk: highly flexible thoracic curves, atypical low-apex Lenke

Table 1. Key Risk Factors for Distal Adding-On (DAO) After Posterior Spinal Fusion in AIS.

Risk Factor	Direction of DAO Risk	Evidence Consistency	Surgical Interpretation
LIV proximal to LSTV / LTV	↑↑	High	Avoid stopping proximal to LSTV; fusion to LSTV or LSTV+1 recommended in high-risk patients
Low skeletal maturity (low Risser grade)	↑↑	High	Immature patients have limited distal compensation; consider longer fusion or closer surveillance
High lumbar or thoracolumbar curve flexibility	↑	Moderate-High	Excess flexibility predisposes to distal disc wedging after thoracic correction
Excessive thoracic correction / hypercorrection	↑	High	Overcorrection increases distal junctional stress; aim for balanced, not maximal, correction
Residual or progressive LIV tilt / translation	↑↑	High	Ensure horizontal LIV and minimal CSVL offset intraoperatively
Large preoperative lumbar curve magnitude	↑	Moderate	Larger lumbar curves have reduced spontaneous correction potential
Intraoperative distal disc angulation (>3°–5°)	↑↑	High	Distal disc obliquity is an early and strong predictor of DAO
Poor sagittal alignment (thoracic hypokyphosis, low T1 slope)	↑	Moderate	Sagittal imbalance alters distal load sharing and compensation
Inadequate rotational correction at LIV	↑	Moderate	Residual rotation promotes distal curve propagation
Coronal imbalance or trunk shift postoperatively	↑	Moderate-High	Persistent imbalance drives distal compensatory curvature
Atypical curve patterns (low apex, Lenke variants, CMS)	↑	Moderate	These curves are less tolerant of short fusion strategies
Stopping fusion based on non-standardized LIV criteria	↑	High	Adherence to validated criteria (Wang, Qin, Suk, Parisini) reduces DAO risk
Long thoracic curve length (high NV–MTC distance)	↑	Moderate	Longer curves transmit corrective forces distally
Postoperative shoulder imbalance / sacral slanting	↑	Low-Moderate	Likely compensatory mechanisms rather than primary drivers

LIV, Lowest Instrumented Vertebra; LSTV, Last Substantially Touched Vertebra; LTV, Last Touching Vertebra; CMS, Coronal Malalignment Score; NV, Neutral Vertebra; MTC, Main Thoracic Curve

patterns, and hypermobile lumbar compensatory curves were more prone to distal progression.^{13,20–22}

INTRAOPERATIVE FACTORS

Fusion-level selection relative to the LSTV emerged as the most modifiable risk factor. Constructs terminating at or proximal to the LSTV (LIV ≥ LSTV–1) conferred a 7–14-fold increased DAO risk, whereas LSTV-based LIV selection reduced risk by approximately 70% to 80%.^{11,12,18,21,23} Additional contributors included excessive thoracic correction, distal disc obliquity or angulation, and postoperative LIV tilt or translation.^{20,24–27}

POSTOPERATIVE FACTORS

Residual global malalignment was associated with distal progression, including thoracic hypokyphosis, low T1 slope, residual coronal deviation, shoulder imbalance, and sacral slanting.^{12,16,21,28} Larger preoperative curves and longer fusion constructs further increased susceptibility.^{17,29} Overall, these factors functioned as risk stratifiers that guided follow-up intensity rather than serving as triggers for surgical revision, reinforcing DAO as a surveillance phenomenon rather than an operative diagnosis.

SECONDARY OUTCOMES: DEFINITIONAL AND RADIOGRAPHIC VARIABILITY

The majority of studies defined DAO using a Wang-type framework based on distal curve extension with ≥5 mm translation of LIV+1 relative to the CSVL and/or ≥5° increase in distal disc angulation.^{1,11–13,17–19,23,26,30–32}

Despite this predominance, significant definitive variance remains. Alternative constructs included disc-only definitions, hybrid Cobb-disc frameworks that excluded CSVL translation, and multi-definition composite systems applied within the same cohort.^{6,15,33–35} Roye et al¹⁵ highlighted the clinical complications of this variability, demonstrating that DAO incidence ranged from 0% to 26% depending solely on the diagnostic definition used, independent of patient characteristics or surgical technique. This underscores that reported DAO incidence and its perceived clinical relevance are strongly definition-dependent rather than biologically fixed.

Radiographic assessments were typically anchored to the LIV, with LIV+1 and the first distal disc serving as reference points. Although the LSTV was used for risk stratification and fusion-level selection, it was rarely incorporated into

DAO definitions, creating inconsistency between predictive frameworks and diagnostic classification.

The timing of assessments also contributed to variability. DAO was most commonly evaluated at approximately two years postoperatively; however, some studies reported it as an early postoperative finding, while others assessed late outcomes extending up to 10 years.^{13,36,37} Infrequent reporting of measurement reliability further limited cross-study comparability as a diagnostic criterion.

To conclude, these findings indicate that although a dominant detection framework exists, substantial definition variability persists, contributing to wide variation in reported incidences and outcomes. This should be regarded as a significant limitation of the current literature and underscores the need for standardized, outcome-linked DAO definitions.

DISCUSSION

DOA should be interpreted within the broader spectrum of distal junctional changes following spinal fusion. Similar to DJK and adjacent segment degeneration, DAO represents postoperative progression occurring at or immediately below the distal end of the construct. However, DAO is defined primarily by coronal-plane distal curve extension, disc angulation, and vertebral translation, whereas DJK is characterized by sagittal-plane deformity and angular kyphotic change at the distal junction. Unlike DJK, which is often associated with mechanical failure or sagittal imbalance that may require intervention, DAO more commonly presents as a radiographic progression with variable clinical significance and a lower rate of revision. Although both phenomena share risk factors related to fusion-level selection, construct termination relative to stable vertebrae, and postoperative alignment, they differ in their predominant plane of deformity and in the frequency of surgical escalation.

Principal Findings

This scoping review highlights that the development of DOA following PSF for AIS is managed primarily as a radiographic surveillance finding rather than an immediate surgical indication. Across cohorts, the dominant strategy was observation with serial imaging, while revision surgery for DAO was uncommon, delayed, and reserved for a small subset of patients with progressive coronal decompensation, structural distal failure, or mechanical complications. Despite wide variability in reported DAO incidence, most patients remain clinically stable and did not require reoperation, indicating that DAO primarily reinforces monitoring intensity rather than prompting surgical intervention.

Radiographic–Clinical Dissociation and Definition Dependence

A persistent dissociation between radiographic progression and clinical impact was observed. The most frequently

reported changes included distal disc angulation, LIV/LIV+1 translation, and distal curve extension; however, these findings rarely resulted in clinically meaningful deterioration or the need for surgical revision. Dominant patterns of translation often stabilized or partially compensated over time, supporting adaptive remodelling rather than inevitable mechanical failure.

The clinically relevant consequences were confined to biologically or temporally high-risk patient groups, particularly skeletally immature patients undergoing definitive fusion and those meeting stricter DAO definitions at long-term follow-up. Despite low revision rates, these cohorts reported worse appearance, satisfaction, or activity scores. These findings demonstrate that the clinical relevance of DAO is strongly definition-dependent and caution against pooling heterogeneous radiographic criteria under a single diagnostic label.

Surgical Indications for Distal Adding-On

In the current literature, there are no consistent radiographic criteria that independently mandate surgical revision for DAO following PSF. Progression of distal Cobb angle, distal disc angulation, LIV/LIV+1 translation in isolation, when lacking clinical imbalance, was not used as a sole indication for reoperation in any study included. As detailed in Appendix 2, revision was rarely supported by radiographic findings alone; escalation was steadily influenced by worsening coronal imbalance, structural failure, or symptom deterioration.

When revisions were performed, the indications were consistently clinical rather than purely radiographic. Reported triggers included progressive coronal trunk shift, worsening global coronal decompensation, mechanical or implant-related complications, and failure of distal compensation. Revisions were described in patients with clinically apparent imbalance in studies by Andre, Jamnik, and Roye, whereas the presence of DAO alone was not sufficient to prompt intervention.^{12–14} Finally, no study identified a reproducible numeric threshold for Cobb angle progression, disc angulation, or trunk shift that mandated surgery.

Revision surgery was consistently delayed, with time to reoperation exceeding 12 months in all cohorts reporting temporal data. This pattern reflects an initial strategy of observation to distinguish adaptive remodelling from progressive mechanical failure.

Implications for Surgical Practice

These findings support a surveillance-based approach to postoperative DAO in the absence of progressive deformity or symptoms. They highlight the importance of fusion level selection, particularly extending to at least the last touched vertebra in skeletally immature patients or in those with hyperflexible lumbar compensatory curves

where compensatory capacity may be limited. Finally, the absence of clinically relevant intervention thresholds suggests that DAO alone should not prompt prophylactic revision. Overall, the presence of DAO functions as a risk-stratifying tool that guides the intensity of follow-up rather than prompting surgical escalation, aligning with best-practice patterns across geographic regions.

Quality of Evidence and Limitations

The evidence is limited by retrospective designs, heterogeneous DAO definitions, variable follow-up durations, and inconsistent reporting of measurement reliability. In several studies, early reoperations were excluded from long-term registries, leading to an underestimation of revision burden, and blinding radiographic adjudication was uncommon, increasing the risk of misclassification. A majority of included studies originated from East Asia, which may reflect differences in fusion philosophy and follow-up practices, thereby limiting generalizability. No study directly compared observation versus revision strategies for DAO, and no comparative-effectiveness data exist to guide management decisions.

Future Directions

Future studies should prioritize prospective designs using standardized, outcome-linked definitions of DAO applied at fixed postoperative intervals, with appropriate reporting of measurement reliability. Based on the prevailing criteria across included studies, a reproducible working definition of DAO for future research would incorporate progressive distal curve extension accompanied by ≥ 5 mm translation of the first vertebra below the LIV relative to the central sacral vertical line and/or $\geq 5^\circ$ increase in distal disc angulation. Standardized assessment timepoints at approximately one year postoperatively, followed by evaluation at two years and longer-term follow-up when available, would improve comparability across studies and better capture both early progression and late clinically significant changes.

Prospective evaluation comparing surveillance versus selective revision strategies in higher-risk populations, particularly younger adolescents and patients with proximal fusion termination relative to distal stable vertebrae, is needed to establish evidence-based management thresholds.

Clinical Perspective

From a clinical standpoint, radiographic finding of DAO alone does not indicate intervention. Serial imaging for observation is safe and appropriate for the majority of patients in the absence of progressive trunk shift, symptomatic imbalance, or mechanical failure. In high-risk patients, such as those who are skeletally immature or who have limited distal compensatory capacity, radiographic DAO carries greater clinical relevance and justifies prolonged follow-up rather than early prophylactic revision. Until outcome-based thresholds are established, operative

decision-making will continue to rely on individualized clinical judgement informed by curve behavior, global alignment, and biological maturity.

CONCLUSION

DOA following PSF for AIS is most commonly managed through radiographic surveillance, with surgical revision reserved for a small subset of patients demonstrating progressive coronal decompensation, mechanical failure, or symptomatic deterioration. Despite frequent radiographic progression, most patients remain clinically stable with preserved health-related quality of life. The clinical impact of DAO is strongly modulated by biological maturity, curve behavior, and, critically, the radiographic definition applied. DAO should therefore be interpreted primarily as a radiographic marker rather than an automatic surgical indication. Future prospective studies should apply standardized, CSVL-based definitions incorporating distal disc angulation and LIV+1 translation at fixed postoperative timepoints (eg 24 months), and explicitly compare surveillance versus revision strategies to establish evidence-based management thresholds.

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Appendix 1. Characteristics of Included Studies Evaluating Distal Adding-On After Posterior Spinal Fusion in Adolescent Idiopathic Scoliosis.

Study	Country	Design	Sample Size	Age (Years)	Curve Type	Complications	Follow-up Duration (Years)
Chan ⁶	Malaysia	Retrospective cohort	100	15.9 ± 4.4	Lenke 1-2	LSTV-based	2.6
Li ⁸	China	Retrospective cohort	84	14.53 ± 1.95	Lenke 1A-2A	LSTV-based	2
Mitchell ⁹	USA	Prospective registry	253	14.7 (10-20)	Lenke 1-2	CSVL-based	2
Park ¹¹	South Korea	Retrospective cohort	145	14.8 ± 2.6	Lenke 1A-1B	Multi-criteria LIV	6.9
Li ¹²	China	Retrospective cohort	152	NR	Lenke 1-2	LSTV ±1	≥2
Andre ¹³	France	Registry cohort	105	14 ± 2	Lenke 1-2	LTV-Based	3.1
Jamnik ¹⁴	USA	Retrospective case series	32	12.2 ± 1.3	Lenke 1-6	Variable vs LTV	7
Roye ¹⁵	USA	Retrospective multicenter	118	14.6 ± 2.1	Lenke 1-2	Variable	10
Han ¹⁶	China	Retrospective cohort	22	14.0 ± 2.1	Not specified	SV-1	2.6
Guo ¹⁷	China	Retrospective (nomogram)	213	12.9-14.7	Lenke 1-2	Not standardized	≥2
Qin ¹⁸	China	Retrospective cohort	94	4.4 ± 2.2	Lenke 1A-2A	LSTV-1	3.1
Yin ¹⁹	China	Retrospective cohort	78	14.4 ± 1.8	Thoracic AIS	LSTV-based	3.5
Abe ²⁰	Japan	Retrospective single-centre	32	14.6 ± 1.3	Lenke 1-2	LTV-Based	2
Li ²¹	China	Retrospective cohort	106	14.6 ± 1.7	Lenke 5C	CSVL/LSTV	3.2
Yin ²²	China	Retrospective matched	84	14.9 ± 2.3	Lenke 1A	LSTV-relative	≥2
Qin ²³	China	Retrospective cohort	101	14.9 ± 2.3	Lenke 2A	LSTV-based	2.6
Chen ²⁴	Taiwan	Retrospective cohort	130	14.9 ± 2.9	Lenke 1-4	LSTV-guided	3.2
He ²⁵	China	Retrospective cohort	196	15.1 ± 2.5	Lenke 1A-2A	LSTV-based	2.2
Fujii ²⁶	Japan	Retrospective cohort	69	15 ± 2	Lenke 1B-1C	LTV / NV	4.3
Shu ²⁷	China	Retrospective cohort	85	15.4 ± 2.4	Lenke 5C	Fixed L3	2.7
Yang ²⁸	South Korea	Retrospective cohort	120	15.2 ± 3.3	Lenke 2A	SV / SV+1	4.4
Ketenci ²⁹	Turkey	Retrospective cohort	47	14.6 ± 2.6	Lenke 3C-6C	SV / LTV	2.4
Banno ³⁰	Japan	Retrospective case series	90	15.6 ± 2.6	Lenke 1A-2A	Multi-step SV/LIV rule	≥2
Fujii ³¹	Japan	Retrospective cohort	46	14.0 ± 1.7	Lenke 1B-1C	LIV-LTV distance	4.6
Zhang ³²	China	Retrospective cohort	119	14.6 ± 2.1	Lenke 1-2	EV/NV/SV/LSTV	2.8
Koller ³³	Multicenter	Retrospective multicenter	101	16 ± 4	Lenke 3-6	Surgeon discretion	≥1
Chang ³⁴	South Korea	Retrospective comparative	65	13.4-13.6 yrs	Lenke 1-2	NV / NV-1	11.8
Hua ³⁵	China	Retrospective case series	46	15.4 ± 1.8	Lenke 5C	CSVL/LSTV-guided	2.8
Inami ³⁶	Japan	Retrospective comparative	30*	14.6 ± 2	Lenke 1-2	EV/SV/NV/LTV	4.8
Kim ³⁷	South Korea	Retrospective cohort	57	16.7 ± NR	Lenke 1-6	Supine vs upright LTV	≥2
Okuwaki ³⁸	Japan	Retrospective, Single-center	78	15.3 ± 2.0 (12-20)	Lenke 1-6	LTV / LSTV-based	5

*Inami: posterior fusion group only. LTV, Last Touching Vertebra; SV, Stable Vertebra; NV, Neutral Vertebra; LSTV, Last Substantially Touched Vertebra; CSVL, Central Sacral Vertical Line; EV, End Vertebra

Appendix 2. Distal Adding-On (DOA) Management / Escalation / Revision Across Included Studies

Study	Primary Management	Trigger for Escalation	Revision Indication
Chan ⁶	Observation	Radiographic DAO	—
Li ⁸	Observation	Radiographic DAO	—
Mitchell ⁹	Observation	Radiographic DAO	—
Park ¹¹	Observation	Progressive radiographic DAO (severe case example)	Distal fusion extension for substantial progressive DAO
Li ¹²	Observation ± conservative	Progressive DAO on serial films	—
Andre ¹³	Observation (most) / Mixed	Coronal decompensation / marked imbalance	Distal extension for coronal decompensation
Jamnik ¹⁴	Mixed (mostly observation)	Progressive deformity / trunk shift	Distal fusion extension for progressive deformity/imbalance
Roye ¹⁵	Observation (registry follow-up)	Symptomatic/clinically meaningful decline (subset)	DAO revision (distal extension) in 3 patients
Han ¹⁶	Mixed (mostly observation)	Symptoms or implant complications (not DAO-specific)	Symptoms or implant complications (not DAO-specific)
Guo ¹⁷	NR (risk model study)	NR	NR
Qin ¹⁸	Observation ± brace	Radiographic DAO/progression	—
Yin ¹⁹	Observation ± brace	Radiographic progression (subset braced)	—
Abe ²⁰	Observation	None / NR	—
Li ²¹	Observation for DAO	Radiographic DAO	PJK / hardware issues (no distal extension for DAO)
Yin ²²	Observation	Radiographic DAO	—
Qin ²³	Observation	Radiographic DAO	—
Chen ²⁴	Observation	Radiographic progression/DAO	—
He ²⁵	Observation	Observation	—
Fujii ²⁶	Observation	Radiographic DAO (incl. intraoperative disc risk)	Technique NR (revision for progressive DAO)
Shu ²⁷	Observation	Radiographic DAO	—
Yang ²⁸	Observation	Radiographic DAO	—
Ketenci ²⁹	Observation	Radiographic DAO	—
Banno ³⁰	Observation	Radiographic DAO	—
Fujii ³¹	Observation	Radiographic progression/DAO	Technique NR (revision for progressive DAO)
Zhang ³²	Observation	Radiographic DAO	—
Koller ³³	Observation for adding-on	Radiographic LIV disc angle ≥5°	Implant loosening/infection/rod issues (no adding-on revision)
Chang ³⁴	Observation	Radiographic “unsatisfactory/adding-on”	—
Hua ³⁵	Observation	Radiographic DAO/progression	—
Inami ³⁶	Observation	Radiographic DAO	—
Kim ³⁷	Observation	Radiographic DAO	—
Okuwaki ³⁸	Observation	Radiographic DAO	—

NR, Not Reported; LIV, Lowest Instrumented Vertebra; PJK, Proximal Junctional Kyphosis

Appendix 3. Definitions, Incidence, Natural Course, and Revision of Distal Adding-On (DAO) Across Included Studies

Study	DAO Definition Type	DAO Incidence	Natural Course	DAO Revision
Li ⁸	Wang-type	21.4%	Progressive distal wedging radiographically	No
Mitchell ⁹	Disc-based (registry consensus)	19.8%	Radiographic progression without treatment	No
Park ¹¹	Wang-type	16.6%	Mostly stable; rare progressive cases	Rare (isolated case)
Li ¹²	Wang-type	31.6%	Majority non-progressive; some radiographic worsening	No
Andre ¹³	Wang-type (CSVL translation ± distal disc angulation)	28%	Majority radiographic only; clinically stable in most cases	Yes (≈3%; distal fusion extension for coronal imbalance)
Jamnik ¹⁴	Hybrid (Cobb + LIV tilt)	62.5%	High progression in immature patients	Yes (18.8%; distal extension)
Roye ¹⁵	Multiple (Cho definition clinically relevant)	0%–26%	Long-term functional impact in Cho-positive cases	Yes (≈2%–3%)
Han ¹⁶	Hybrid (translation + disc angle + rotation)	59%	Radiographic progression; some mechanical complications	No
Guo ¹⁷	Hybrid Wang-type	16.4%	Natural history not reported	NR
Qin ¹⁸	Wang-type	57.4%	Radiographic worsening; clinical stability	No
Yin ¹⁹	Wang-type	23.1%	Radiographic only	No
Abe ²⁰	Wang-type	NR	Radiographic distal progression associated with high flexibility and correction; clinically stable	No
Li ²¹	Wang-type	10.4%	Stable; good clinical outcomes	No
Yin ²²	Wang-type	19%–38%	Higher in atypical curves; stable clinically	No
Qin ²³	Wang-type	23.8%	Radiographic only	No
Chen ²⁴	Wang-type	≈8%	Radiographic progression; no clinical deterioration	No
He ²⁵	Wang-type	20.4%	Radiographic distal progression without intervention	No
Fujii ²⁶	Wang-type	18.8%	Predominantly stable with observation	Yes (1 Case)
Shu ²⁷	Hybrid (curve extension + translation)	18.8%	Radiographic progression only	No
Yang ²⁸	Wang-type	NR	Adaptive distal compensation	No
Ketenci ²⁹	Hybrid (disc angle + CSVL)	29.8%	Associated with distal disc degeneration; clinically stable	No
Banno ³⁰	Hybrid (disc angulation + curve extension)	3.3%	Stable; no distal junctional kyphosis	No
Fujii ³¹	Wang-type	24%	Mostly stabilized or improved; rare progression	Yes (1 Case)
Zhang ³²	Wang-type	32.8%	Radiographic progression without clinical decline	No
Koller ³³	Disc-only / hybrid	34%	Radiographic only; clinical improvement overall	No
Chang ³⁴	Hybrid Cobb-disc-end vertebra	NR	Persistent radiographic progression in adding-on group	No
Hua ³⁵	Hybrid (disc angle + LIV+1 translation)	17.4%	Radiographic worsening; clinical outcomes improved overall	No
Inami ³⁶	Wang-type	20% (posterior group)	Stable; anterior fusion prevented DAO	No
Kim ³⁷	Hybrid Cobb-disc-CSVL	3.5%	Mild or compensatory	No
Okuwaki ³⁸	Hybrid (Wang-type or Cho-type; either definition counted)	3.8%	No specific clinical deterioration from DAO described	NR

NR, Not Reported; LIV, Lowest Instrumented Vertebra; CSVL, Central Sacral Vertical Line

21st Century Perspective on the Changing Pattern of Nerve Injuries from Gunshot Wounds in the U.S.

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ABSTRACT

Gunshot wounds (GSWs) with nerve injuries in the 21st century differ significantly from those reported in the 20th century. The vast majority are now low-velocity civilian injuries, in contrast to high-velocity military injuries previously reported. The rate of nerve injury in civilian GSWs is approximately 5%, compared with the 30% reported in military cohorts. However, the most common pattern of nerve injury in the current civilian population is neurotmesis and partial neurotmesis, in contrast to the majority axonotmesis of the military cohorts. In the 20th century, treatment generally consisted of watchful waiting for signs of spontaneous recovery over three months to six months (axonotmesis) with surgical exploration reserved for patients who failed to show signs of improvement. Late treatment typically consisted of nerve grafts or tendon transfers. Most patients with nerve deficits now benefit from acute repair. New repair techniques have been developed that improve outcomes. The new techniques are reviewed in a companion article by Dr. Mercer in this Journal.¹

Keywords: Axonotmesis; Gunshot Wounds; Neurotmesis

INTRODUCTION

Nerve injuries from gunshots have transitioned with the turn of the century, from the high-percentage, high-energy ballistic axonotmesis typical of the 20th century to the lower-percentage, low-energy ballistics neurotmesis or partial neurotmesis more commonly seen in the 21st century. The clinical significance of this transition is that early surgical treatment of the injured nerve is now more frequently indicated with the current pattern of injury.²

HISTORY

Nerve injuries associated with gunshot wounds (GSWs) in the civilian population were historically considered relatively uncommon during the 20th century. During their five-year residency (1980-1985) in Vermont, the author only encountered three GSWs, despite training in the era of every-other-night-call. Much of the 20th-century literature on GSWs in general, and on associated nerve injuries in particular, was derived from military populations. This literature formed the basis of treatment guidelines. Classic publications on the treatment of nerve injuries from GSWs include those by Fischer and Mitchell.^{3,4}

An important factor when evaluating peripheral nerve injuries from gunshots is the percentage of GSWs associated with a nerve deficit. However, several challenges arise when attempting to determine this percentage. It is more difficult to determine both the numerator (presence of nerve deficit) and denominator (total GSWs) than it might

appear. Most reports on the treatment of nerve injuries come from nerve surgeons, who typically do not treat GSWs that lack an associated nerve injury, creating an inherent sampling bias.

GSWs can occur anywhere in the body, but they generally fall into axial (head, neck, chest, abdomen, pelvis) or appendicular (extremities) categories. Peripheral nerve injuries are typically the result of injuries to the extremities, making the key question the percentage of extremity GSWs that result in peripheral nerve deficits. Injuries to the brain or spinal cord are neurologic, but fundamentally different from peripheral nerve injuries and are not surgically repairable. Many patients often sustain multiple GSWs affecting both axial and appendicular body parts, further complicating classification.

Another challenge is that many GSWs are lethal, whereas peripheral nerve injuries are typically treated late. Lethal injuries never present to a nerve clinic and GSWs without nerve injury similarly do not present to a nerve clinic. GSWs without fracture are often not even referred to orthopaedics. As a result, the specialists who see the numerator and denominator populations differ. Additionally, nerve deficits present at the time of injury may not be recognized immediately, and some resolved spontaneously within hours or days. Physicians are primarily interested in peripheral nerve deficits that persist for at least two days after injury, which further influences how the numerator is defined.

20TH CENTURY PERSPECTIVE ON GSWs WITH NERVE INJURIES

In 1942, Seddon, working at Oxford, identified three patterns of nerve injury: neurapraxia, axonotmesis, and neurotmesis.⁵ Neurotmesis represents complete anatomic division with no potential for spontaneous recovery. Axonotmesis is a lesion in continuity with Wallerian degeneration of the axons, with the potential for spontaneous recovery. However, recovery is slow, approximately 1 mm per day or 1 inch per month, often requiring three months to nine months. Neurapraxia is a transient injury with spontaneous early recovery occurring over hours to days.⁵

The terminology chosen by Seddon was “neurapraxia,” derived from the Greek “praxia” meaning “activity.” “Apraxia,” in contrast, means “absence of activity.” This distinction matters because subsequent authors have frequently misspelled the word as “neuropraxia.” If such a word existed, it would imply “normal nerve function or activity,” the opposite of the intended meaning. This unfortunate misspelling is understandable, given that “neuro-” is commonly used to refer to nerves and both neurotmesis and axonotmesis contain the letter “o.” “Otmesis” is derived from ancient Greek for “cut.” The appropriate spelling is neurapraxia, *not* neuropraxia.⁵

The Seddon classification of nerve injuries became the accepted standard of the 20th century and beyond. It plays a very direct role in guiding treatment and predicting outcome. Neurapraxia required no surgical intervention, and early spontaneous recovery (over hours to days) was the typical outcome. Axonotmesis likewise required no surgical intervention, but recovery is delayed, often taking months and sometimes remaining incomplete. When treated nonoperatively, neurotmesis resulted in no recovery. In the latter half of the 20th century, the development of nerve repair and grafting techniques improved outcomes of neurotmesis.

Omer established the typical pattern of nerve injuries resulting from GSWs in 1974. He reported that 30% of non-lethal extremity GSWs were associated with a nerve deficit.⁶ The most common pattern of nerve injury was axonotmesis, accounting for approximately 70% of cases, whereas only about 20% were neurotmesis. The clinical significance of this finding is that the natural history of an axonotmetic injury is spontaneous, though very slow, recovery without the need for surgical intervention. In axonotmesis, the nerve structure remains intact, but the axons within the sheath are disrupted and undergo Wallerian degeneration. The nerve typically regrows spontaneously at a pace of about 1 mm per day, or roughly 1 inch per month. Therefore, recovery of motor and sensory function in the upper extremity typically takes three months to six months, and even longer in the lower extremity. Omer also reported outcomes of nonoperative treatment in 595 patients with nerve injury from extremity GSWs, with 69% demonstrating spontaneous

recovery.⁷ The treatment recommendation was to avoid early nerve surgery and instead observe for signs of spontaneous recovery over three months to six months, with the expectation of spontaneous recovery in the majority of patients. If no signs of recovery were present at three months to six months (~20% of patients), then surgical exploration was advised followed by neurolysis (if in continuity), nerve repair (if approximation was possible), or nerve grafting. If nerve reconstruction was not possible, motor deficits could be treated with tendon transfers. It was not considered worthwhile to operate on 100% of patients to only benefit 20% (neurotmesis). There was also concern that surgical dissection could delay recovery of nerves that were healing spontaneously. This remained the standard treatment for nerve injuries associated with extremity GSWs throughout the 20th century.^{8,9}

There were some indications for operative exploration and treatment of nerve injuries, for example in gunshot-related humerus shaft fractures with radial nerve deficit. If the radial nerve was in the surgical field for debridement, the nerve would be directly exposed and the extent of injury noted. If fixation of the fracture was performed with indirect techniques (external fixation to healing, intramedullary nail, etc), the radial nerve would *not* be independently exposed. If plating of the fracture were performed, it would depend on the surgical approach. If an anterior surgical approach is used for plating, the radial nerve is avoided and therefore not exposed. However, a posterior surgical approach requires identification and protection of the nerve. In those cases, the nerve would be dissected in normal tissue remote from the traumatic wound and then followed through the zone of injury. If the nerve was in continuity, no additional treatment was required. If the nerve was transected, the ends were marked and a second-stage repair or graft was performed.¹⁰⁻¹²

Bullet velocity is an important aspect of the injury pattern seen after GSWs. The kinetic energy dissipated to the tissue is equal to one-half the mass multiplied by the velocity squared ($KE=1/2mv^2$). Because the energy of the bullet is directly related to the square of the velocity, high-velocity military weapons (over 1000m/sec) produce much higher kinetic energy than low-velocity civilian hand guns.¹³ Omer’s cohort of patients with nerve injuries from GSWs consisted of U.S. soldiers injured in Vietnam, most of whom were wounded by high-velocity military weapons. High-velocity weapons create a large zone of soft-tissue injury surrounding the path of the bullet. The nerve may be injured either directly by the bullet or indirectly by the extensive surrounding ballistic zone. Because of the large zone of injury with high-velocity weapons, indirect nerve damage is much more common than direct nerve damage.

There was also a delay between injury and subspecialty (nerve) evaluation in Omer’s military cohort. These patients were injured in Vietnam and then treated,

stabilized, and transported through multiple levels of care before ultimately arriving in the U.S. at Brooke Army Hospital in San Antonio. This process typically took about two weeks. Therefore, many nerve injuries that resolved during the initial two weeks (neurapraxia) were not identified as nerve injuries. In addition, soldiers who died before reaching Brooke Army Hospital were not included in the denominator. With these factors contributing to both the numerator and denominator, Omer reported that 30% of patients with GSWs had a nerve injury. He also identified the most common peripheral nerve injury pattern in patients sustaining extremity GSWs as axonotmesis (70%).⁶

21ST CENTURY PERSPECTIVE

There are now approximately 110,000 GSWs per year in the U.S.^{14,15} Brown reported 284 GSW patients treated by orthopaedic surgeons at a single hospital in New Orleans over one year.¹⁶ The author's experience at The University of New Mexico Hospital (UNMH) (1986 – 2025) is more similar to New Orleans than to Vermont.; UNMH sees approximately one GSW per day (Figure 1).¹⁷ The author's personal experiences, during residency in Vermont and as an attending in New Mexico, come from the only Level I Trauma Centers in their respective (border) states. However, the Vermont experience reflects a small northern-border state with a population of 500,000 in the 1980s. By contrast, New Mexico is a large southern-border state with a population of 2 million in 2025. The dramatic increase from one GSW per year to one GSW per day is primarily attributable to an increased frequency of gunshot injuries.

Multiple authors in the 21st century have noted that their experience did not fully align with Omer's data or the accepted treatment algorithms.¹⁷ In their 2004 review of GSWs, Volgas observed that "much of the previous publication has been from military settings," which differed considerably from the civilian patients they were treating.¹⁸ Pereira, reported civilian experience from Los Angeles in the *Journal of Plastic Surgery*, similarly found that although

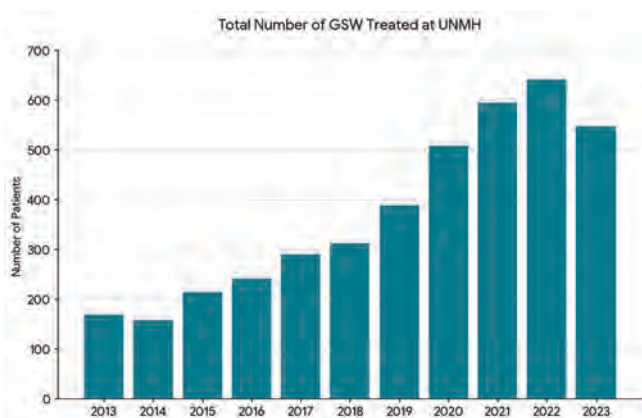


Figure 1. GSWs treated at The University of New Mexico Hospital over the past 12 years.

GSWs are common, "few sustain nerve or tendon injury."¹⁹ Of 1,358 extremity GSWs, only 62 involved peripheral nerve injuries (5%), a rate much lower than the 30% reported by Omer in high-velocity military GSWs.¹⁹ Beidas made a similar observation in 2011, noting that "the incidence of nerve injury in civilian GSWs of extremity is lower than previously reported in military population."²⁰ They reported only 74/1,851 (4%) and stated that "nerve injuries are far less prevalent in civilian GSWs."²⁰ They also reported that the presence of a fracture significantly increased the likelihood of a nerve deficit: 14% in extremity GSWs with fracture versus only 4% in those without fracture.²⁰

Another change evident in 21st century literature is that although the percentage of patients with nerve deficit has decreased, those who do present with a deficit are better treated with early nerve surgery. In 2004, Stepan compared their recent (21st century) to past (20th century) treatment. When treatment was delayed for several months to allow spontaneous recovery, many patients did not recover. When they operated, they found a large percentage of "neuroma in continuity," which required resection and nerve grafting.² They subsequently changed their practice and concluded that "contrary to accepted dogma, 60% of extremity GSWs with nerve injury require (benefit from) acute repair."² When they performed acute surgical exploration, they found that 55% of nerve injuries were neurotmesis or partial neuro-tmesis. They also found that ultrasound was a useful tool for identifying nerve injuries that required, and were amenable to, surgical repair. Outcomes following earlier nerve repair were superior to those achieved with late nerve reconstructions.²

WHY?

The etiology of current (21st century) patients with nerve injuries from GSWs is typically caused by low-velocity civilian hand guns. Low-velocity injuries create only a small zone of soft-tissue injury surrounding the path of the bullet. As a result, nerve injuries are less prevalent, but if they do occur, they are much more likely to result from direct contact with the bullet path rather than from the much smaller zone of concussion. Nerve injuries from the path of the bullet are more likely to be neurotmesis or partial neurotmesis, from which spontaneous recovery is unlikely. Nerve injuries caused by the concussive zone are more likely to be axonotmesis. A recent basic-science investigation in an animal model of high-velocity GSWs demonstrated a high incidence of histologically demonstrated axonotmesis in the soft-tissue concussive zone of injury.²¹ Omer was not wrong!

The pattern of the nerve injury in the current (21st century) cohort is most commonly neurotmesis or partial neurotmesis.² Partial neurotmesis is a new category in which there is no distal sensory or motor function at the time of injury, and the pathological anatomy lies between Seddon's axonotmesis and neurotmesis. Part of the circumference of nerve structure is physically disrupted while part

remains intact. Although length and continuity of the nerve is preserved, the circumferential conduit is partially disrupted. Spontaneous recovery is less predictable in partial neurotmesis than in classic axonotmesis. This pattern helps explain the high incidence of “neuroma in continuity” reported by Stepan.²

It is not that the 20th century principles were incorrect; rather the mechanism of injury has changed, and the resulting injuries follow a different pattern. New diagnostic and therapeutic modalities have been developed, and the optimal treatment algorithm has changed accordingly.

There are a variety of new surgical treatment options for neurotmesis and partial neurotmesis with the potential for improved outcomes including:^{22,23}

- » Conduits and scaffolds
- » Laser welding and photobiological modulation therapy
- » Acellular allografts
- » Supercharging and end-to-side nerve grafting
- » Vascularized nerve grafts
- » Neurotization
- » Interfascicular nerve grafts
- » Neurolac
- » Nerve transfers
- » Exotherapy

These new surgical options are the subject of a companion article submitted to this Journal by Dr. Mercer.¹

The perspective derived from 20th century military cohorts remain applicable in the 21st century when managing high-energy GSWs. Although high-energy bullets are now the exception rather than the rule, they do still occur. In those situations, it may be more appropriate to delay surgical exploration of the nerve unless neurotmesis can be demonstrated clinically (eg ultrasound or other modalities).

CONCLUSION

There has been a significant change in the pattern of peripheral nerve injuries associated with extremity GSWs in the U.S. in the 21st century compared with 20th century literature.

1. GSWs are common in the U.S. in 2025, with an estimated incidence at 110,000 per year.
2. The percentage of extremity gunshot victims who sustain a peripheral nerve injury is approximately 5%, much lower than the 30% reported in the 20th century.
3. Of those few patients with peripheral nerve injury associated with a low-velocity GSWs in the 21st century, the majority (~60%) demonstrate neurotmesis or partial neurotmesis, a newly recognized category. This contrasts with the 70% axonotmesis reported in the 20th century military cohorts.
4. The optimal treatment has also evolved. Given the current pattern of injury, it is often worthwhile to explore the injured nerve early to identify and treat neurotmesis and partial neurotmesis. This is in contrast

to the classic treatment of delaying intervention for three months to six months to observe for signs of spontaneous recovery.

5. There are new diagnostic modalities available, including ultrasound and magnetic resonance imaging, which may identify nerve injuries requiring and amenable to surgical repair.
6. There are new surgical treatment options for neurotmesis and partial neurotmesis.

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Peripheral Nerve Repair and Reconstruction: Current Techniques, Adjuncts, and Emerging Therapies

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ABSTRACT

Peripheral nerve injuries require reconstruction when direct, tension-free repair is not possible. A range of reconstructive strategies are used to restore continuity and promote axonal regeneration, including graft-based reconstruction, nerve transfers, conduit-based repair, supercharged end-to-side augmentation, and emerging regenerative therapies. Autologous interfascicular nerve grafts and vascularized grafts remain established techniques, whereas processed nerve allografts provide a donor-sparing alternative. Nerve transfers are increasingly used for proximal injuries with long regeneration distances, and conduits are an option for gaps shorter than 5 mm. Nerve-wrapping techniques are used to reduce perineural scarring and preserve gliding in complex or revision cases. Emerging adjunctive therapies, including electrical stimulation, nerve fusion approaches, and exosome-based biologics, aim to enhance axonal growth and optimize the regenerative environment. This review summarizes current evidence for these approaches, focusing on indications, outcomes, and limitations of these techniques.

Keywords: Allograft/Autograft; Biologics; Nerve Regeneration; Nerve Transfer; Peripheral Nerve

INTRODUCTION

Peripheral nerve injuries remain a significant cause of long-term functional loss after trauma. When direct, tension-free repair is not possible, a variety of reconstructive strategies are available to restore nerve continuity, including grafting, nerve transfers, conduits, supercharged end-to-side (SETS) augmentation, and regenerative therapies.

GRAFTS

Nerve grafting remains a fundamental strategy for reconstruction of peripheral nerve defects when direct, tension-free repair cannot be achieved. Several graft-based techniques are currently used in clinical practice, including autologous interfascicular grafts, vascularized nerve grafts, processed acellular allografts, and hybrid augmentation strategies such as SETS repair.

Interfascicular autografting remains a core reconstructive strategy when a gap prevents tension-free coaptation.¹ Autologous interfascicular grafting is the original technique for bridging nerve gaps (Figure 1). This technique uses multiple small-diameter cable grafts aligned with fascicular groups to maintain internal nerve organization and direct axonal regeneration.² Fibrin glue can be used to stabilize the multiple fascicles during suture repair; however, it dissolves within one week to two weeks and is not recommended as a

sole fixation method without sutures.³ This reconstruction with an interposed donor nerve allows a tension-free repair and helps avoid connective tissue proliferation, gap formation, and poor fascicular alignment seen when the nerve is repaired under tension.² In one study of radial nerve injuries treated with cable sural nerve autografting, approximately 72% of patients achieved at least M3 function and 44% achieved M4 or better function.⁴ In the same series, timing was strongly associated with outcome: 85% of patients grafted within six months achieved at least M3 recovery, whereas no patient repaired more than 12 months after injury regained useful function.⁴ Outcomes decline with increasing gap length and prolonged denervation time, and the requirement for autologous nerve harvest introduces additional donor-site morbidity.¹

Vascularized nerve grafts were developed to provide immediate perfusion to the transplanted nerve segment through microvascular anastomosis. They may be beneficial in long gaps, scarred wound beds, or failed reconstructions but require greater microvascular technical skill.⁵ In a clinical series evaluating vascularized ulnar nerve grafts for C5 root reconstruction, 9 of 11 patients (82%) recovered at least M3 elbow flexion, and 6 of 11 achieved M4 strength, demonstrating that vascularized grafts can provide motor recovery in selected brachial plexus reconstructions.⁶

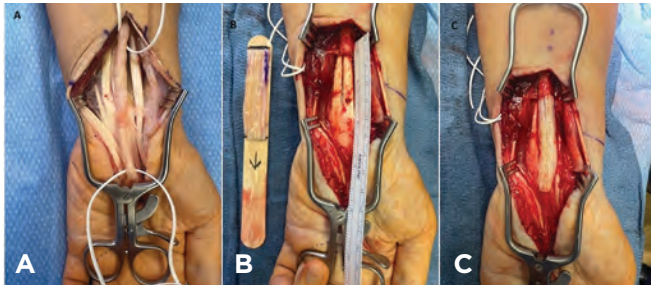


Figure 1. Median nerve reconstruction with sural nerve autograft. A) Median nerve complex injury; B) resection to healthy fascicles; and C) reconstruction with sural nerve autograft. (Courtesy of Nathan Morrell, MD).

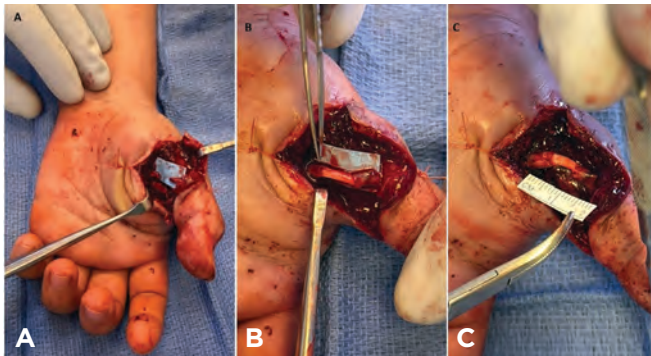


Figure 2. A), B), and C) Digital nerve reconstruction with allograft nerve.

Processed acellular nerve allografts have emerged as an alternative that avoids donor nerve harvest while preserving the extracellular matrix architecture required for axonal guidance. These grafts are derived from cadaveric peripheral nerve tissue that undergoes decellularization, removing immunogenic cellular components while preserving the basal lamina and extracellular matrix structure that guide regenerating axons.⁷ Clinical evidence suggests that these grafts perform well in short sensory nerve defects, particularly digital nerve injuries (Figure 2). A multicenter randomized controlled trial comparing processed nerve allografts with conduit repair for digital nerve gaps of 15 mm to 25 mm demonstrated significantly improved sensory recovery with allografts, including superior static two-point discrimination and higher rates of sensory recovery.⁸ Additional multicenter cohort studies have reported sensory recovery in approximately 80% to 88% of digital nerve repairs reconstructed with processed nerve allografts, with comparable outcomes across a range of sensory nerve gap lengths.⁹ It should be noted that a substantial portion of these high reported success rates is derived from industry-supported multicenter registry data and may reflect potential selection bias. While these outcomes approach those historically reported for autografts in short sensory nerve gaps, systematic reviews indicate that results are less predictable in larger defects and in mixed motor nerves, where evidence remains limited and varied.⁷

SETS augments distal reinnervation, particularly in proximal nerve injuries, in which an expendable donor nerve is

coapted to the side of an injured nerve to enhance axonal regeneration, supplementing the distal nerve with additional motor axons while preserving native proximal regeneration.⁹ In a systematic review, Dunn et al¹⁰ reported recovery of intrinsic hand function in approximately 91.9% of patients, with reinnervation at a mean of 3.7 months and minimal donor-site morbidity. The most widely used SETS transfer is the anterior interosseous nerve to ulnar nerve transfer.¹¹

INTRAOPERATIVE NERVE STIMULATION DURING RECONSTRUCTION

Intraoperative nerve stimulation (IONS) has emerged as an adjunct in complex peripheral nerve reconstruction. Techniques including electromyography and nerve stimulation mapping allow real-time assessment of motor fascicles, particularly in nerve transfer procedures or reoperative fields. This technology continues to evolve, with improvements in the accuracy of nerve stimulation devices facilitating clear isolation of individual fascicles that can be used for transfer to an injured and silent mixed motor nerve. One example is the radial-to-median nerve transfer for high median nerve injuries.¹² IONS is increasingly used in brachial plexus reconstruction and complex extremity trauma to improve fascicular alignment and reduce the risk of misdirectional reinnervation. Evidence remains limited but is increasing in the context of complex reconstructions.^{13,14}

NERVE TRANSFERS

Neurotization and nerve transfers are key strategies in peripheral nerve reconstruction, particularly for proximal injuries in which long regeneration distances and prolonged denervation substantially limit the success of traditional grafting techniques. These techniques restore function by coapting a healthy donor nerve or expendable fascicle directly to the distal motor branch of an injured nerve, bypassing the injury and shortening reinnervation time. Successful transfer depends on donor selection, tension-free coaptation, and cortical adaptation.⁹ Because mixed motor nerves contain both sensory and motor components, this procedure relies heavily on the use of a nerve stimulator to ensure accurate localization of the transfer site within the mixed motor nerve and to identify an appropriate expendable donor. While traditionally emphasized for proximal injuries, distal nerve transfers have gained increasing attention because of their ability to further shorten reinnervation distance and improve functional outcomes. By performing coaptation closer to the motor endplate, distal transfers may allow more rapid and reliable recovery, particularly in delayed presentations, very proximal transections, or when proximal nerve quality is compromised.^{9,15}

An important technical consideration in nerve transfer surgery is the method of coaptation, specifically end-to-end (ETE) versus end-to-side (ETS) techniques. ETE coaptation remains the standard approach when a donor

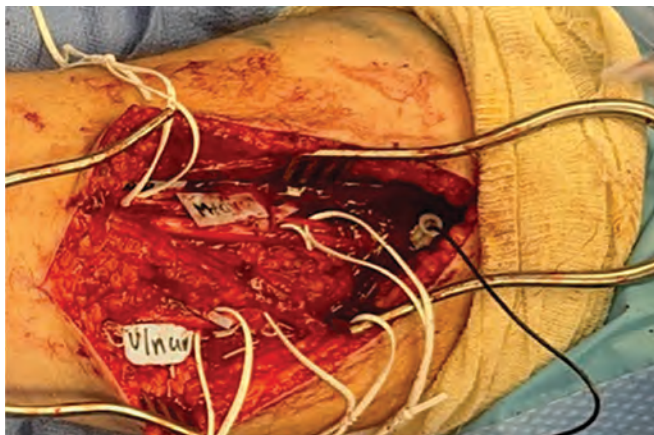


Figure 3. Medial arm dissection. Fascicular nerve transfers from the median and ulnar nerve to the biceps and brachialis, respectively, for musculocutaneous nerve deficit.

nerve or fascicle can be sacrificed, providing direct axonal input to the silent recipient nerve and enabling reinnervation. ETS coaptation allows augmentation of a partially intact nerve without transecting the recipient nerve.⁹

Clinically, nerve transfers are especially effective in partial brachial plexus injuries, in which proximal lesion location and long reinnervation distances often preclude successful outcomes with grafting alone. Restoration of elbow flexion is the most consistently reliable outcome following these procedures. In partial plexus injuries, such as musculocutaneous nerve deficits, a fascicular transfer, which involves transferring fascicles from the ulnar and median nerve to the biceps and brachialis branches of the musculocutaneous nerve, has shown highly reproducible results, with most patients achieving Medical Research Council grade M4 elbow flexion (Figure 3).¹¹ A systematic review and meta-analysis by Vernon Lee et al¹⁶ further supports the effectiveness of nerve transfers, demonstrating high rates of functional recovery and suggesting that intraplexal transfers (within the brachial plexus) generally outperform extraplexal options (outside the brachial plexus) because of shorter regeneration distances and more favorable donor characteristics.

Beyond traumatic peripheral nerve injuries, the role of nerve transfers continues to expand and may be an option for restoring function in central nervous system conditions, particularly incomplete spinal cord injury. In this setting, nerve transfers can restore upper-extremity functions, such as elbow extension, grasp, and pinch, by rerouting intact peripheral nerves above the level of injury to denervated muscles below. Early clinical studies have demonstrated meaningful functional gains in appropriately selected patients, particularly when intervention occurs prior to irreversible motor endplate degeneration.¹⁷ This expanding application highlights the versatility of nerve transfers for functional restoration beyond peripheral nerve discontinuity.

TARGETED MUSCLE REINNERVATION (TMR) AND REGENERATIVE PERIPHERAL NERVE INTERFACES (RPNI)

TMR and RPNI are used in the management of symptomatic neuromas and post-amputation pain.^{18,19} TMR redirects transected peripheral nerves into motor nerve branches of nearby muscles to provide physiologic targets for axonal ingrowth, thereby reducing neuroma formation and neuropathic pain.²⁰ RPNI involves implantation of transected nerve endings into free or vascularized muscle grafts, creating a biologic interface that supports organized reinnervation and reduces disorganized axonal sprouting.

TMR

TMR is a surgical technique designed to reduce neuroma formation and neuropathic pain by redirecting transected peripheral nerves into expendable motor nerve branches of nearby muscles. This provides a physiologic target for regenerating axons, promoting organized reinnervation and limiting aberrant nerve sprouting. Initially developed to improve myoelectric prosthetic control, TMR has demonstrated substantial benefit in reducing both residual limb pain and phantom limb pain.^{20,21} The procedure can be performed at the time of amputation (primary TMR) or in a delayed fashion for established symptomatic neuromas (Figure 4). Increasing evidence suggests that prophylactic use at the time of amputation may decrease the incidence of chronic pain syndromes.²¹

RPNI

RPNI is an alternative technique in which transected nerve endings are implanted into free or vascularized muscle grafts. The graft serves as a biologic scaffold that supports axonal ingrowth and organized reinnervation, reducing disorganized sprouting and ectopic neural activity associated with neuroma formation. Unlike TMR, RPNI does not require identification of a motor nerve recipient, making it especially useful in anatomically constrained areas, distal extremities, or revision settings with limited available

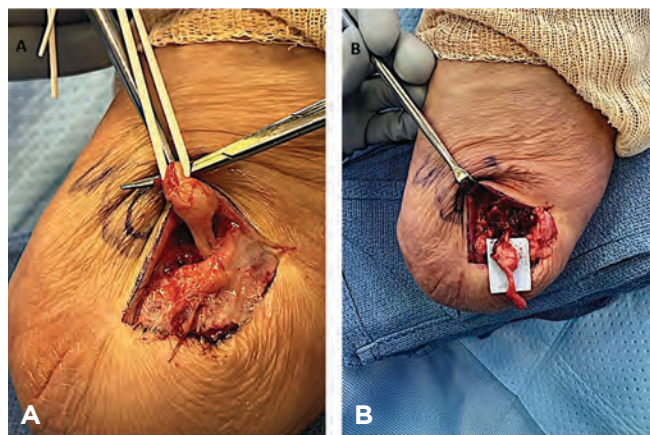


Figure 4. A) Peroneal neuroma; B) after mobilization and prior to neuroma excision in preparation for TMR.

targets.¹⁹ RPNI can be applied both prophylactically and for treatment of established neuromas and has demonstrated effectiveness in reducing residual limb pain, phantom limb pain, and local neuroma symptoms.¹⁸

CLINICAL OUTCOMES AND CONSIDERATIONS

Both TMR and RPNI have shown superior outcomes compared with traditional neuroma management strategies, including traction neurectomy and simple implantation into surrounding tissue.²¹ Patients undergoing these procedures report decreased pain, reduced reliance on analgesics, and improved functional outcomes. Comparative studies suggest that both techniques are effective, with selection often guided by factors such as injury pattern, availability of motor targets, soft-tissue condition, and timing of intervention. While TMR may be favored in proximal injuries with accessible motor branches, RPNI offers greater flexibility in distal or complex cases.²²

CONDUITS AND SCAFFOLDS

Nerve conduits and scaffolds are tubular biomaterials used to bridge small peripheral nerve gaps and guide axonal regeneration across the injury site. These devices create a protected microenvironment that supports axonal regeneration across the defect while avoiding the donor-site morbidity associated with autologous nerve graft harvesting. Conduits are most commonly used in small sensory nerve injuries, particularly digital nerve defects shorter than 5 mm, where the short regeneration distance allows successful axonal bridging within the conduit lumen.²³

In a systematic review of digital nerve reconstruction, approximately 72% of conduit repairs achieved sensory recovery. Rates of recovery were reported to be higher for reconstruction with autografts and allografts.²⁴ Conduits used for small sensory nerve injuries of the hand, mainly digital nerves, has demonstrated sensory outcomes comparable to primary repair in short gaps.²⁵

NERVE CONDUITS AS A DETENSIONING TOOL FOR NERVE COAPTATION SITE

A nerve conduit can be used as an adjunct at the nerve coaptation site to offload the repair and improve fascicular alignment (Figure 5). The technique can be applied to coaptations including primary nerve repair and the multiple coaptations in nerve-gap reconstruction with donor nerve. Conduits may function as external splints at coaptation sites, reducing tension and micromotion, though clinical evidence remains limited.^{26,27} The conduit redistributes mechanical forces across the repair, reducing focal strain and limiting suture-line deformation under physiologic load as tension is transferred to the interface between the conduit and the native nerve.²⁸ Additionally, conduit-assisted nerve repairs have been shown to maintain structural integrity after mechanical stress, preserving a continuous path for



Figure 5. Conduit positioned proximal to the radial sensory nerve coaptation, advanced over the repair to contain the fascicles and offload the coaptation.

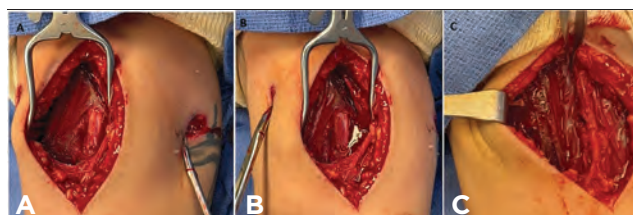


Figure 6. A) Entry and B) exit of the bullet trajectory through the biceps muscle, with significant soft-tissue disruption surrounding intact but contused median nerve. Clinically, there was complete nerve deficit with no sensory or motor function. C) The nerve is wrapped to minimize scarring to surrounding tissues, preserve gliding, and facilitate maximum recovery.

regenerating axons and preventing disruption of the coaptation site.²⁹

NERVE CONDUITS AS BARRIER TO SCARRING IN COMPLEX TRAUMA

In the setting of complex or disrupted wound beds, nerve-wrapping techniques are used to protect repaired or exposed nerves, minimize perineural scarring, and preserve gliding, particularly across mobile regions such as joints. Following neurolysis or repair, the nerve may be enveloped with a barrier to scarring (Figure 6). Available materials include autologous vein, synthetic wraps, and porcine, bovine, or human placental biomaterials, all of which serve to physically separate the nerve from the surrounding traumatized environment. Preclinical work has demonstrated that such nerve-shielding strategies reduce extraneural collagen deposition, attenuate inflammatory response, and decrease perineural adhesion formation in experimental models, thereby improving conditions for axonal regeneration and nerve excursion.^{30,31} These findings support the concept that interposing a protective interface between nerve and surrounding scar-prone tissue can preserve gliding mechanics and potentially enhance recovery in challenging reconstruction and revision settings.³²⁻³⁴

Nerve tape is a relatively new sutureless or hybrid coaptation material available for use in the repair of transected peripheral nerves. The system employs an external microadhesive with a mechanical metal micro-barb scaffold that interfaces with the perineurium when the material is wrapped around the nerve. Clinical data remain limited, and longer-term outcomes are still being defined.³⁵

REGENERATIVE THERAPY

Electrical stimulation

Electrical stimulation (ES) has emerged as a promising adjunct to enhance peripheral nerve regeneration following injury and repair. Brief, low-frequency ES applied intraoperatively (most commonly 20 Hz continuous stimulation for 60 minutes, as used in randomized controlled trials) has been shown to accelerate axonal outgrowth, improve the rate of target reinnervation, and enhance functional recovery.³⁶ Proposed mechanisms include upregulation of neurotrophic factors such as brain-derived neurotrophic factor (BDNF) and its receptor TrkB, as well as increased expression of regeneration-associated genes that promote axonal sprouting. Preclinical studies consistently demonstrate improved axonal regeneration and earlier muscle reinnervation with ES, while early clinical studies in humans undergoing carpal tunnel release and digital nerve repair have reported faster sensory and motor recovery compared with controls. Although alternative stimulation durations and protocols have been explored in experimental settings, the most reproducible clinical evidence supports a standardized 60-minute intraoperative application.³⁶ Despite these encouraging findings, variability in stimulation protocols and limited large-scale clinical data remain barriers to widespread adoption.^{37,38}

Polyethylene Glycol (PEG) Fusion and FK506

Nerve-fusion techniques, including PEG-mediated axonal fusion, represent a novel approach to peripheral nerve repair aimed at restoring immediate axonal continuity rather than relying solely on slow axonal regeneration. PEG fusion works by sealing disrupted axolemmal membranes and facilitating direct reconnection of proximal and distal axons, thereby enabling rapid return of electrophysiologic conduction and potentially accelerating functional recovery. Adjunctive pharmacologic strategies have also been explored to enhance regeneration, including the use of immunomodulatory and neurotrophic agents, such as FK506. FK506 has been shown in preclinical and early clinical studies to promote axonal regeneration independent of its immunosuppressive effects, likely through upregulation of growth-associated proteins and enhancement of Schwann-cell activity. Other investigational adjuncts include growth factors, stem cell-derived products, and extracellular vesicles, which aim to further optimize the regenerative microenvironment.³⁶ While these approaches demonstrate promising experimental results, clinical translation remains limited, and challenges related to reproducibility, safety, and standardization must be addressed before widespread adoption in routine peripheral nerve reconstruction.³⁹⁻⁴⁵

Exosomes

Exosome-based therapies are an emerging regenerative strategy that use exosomes—small extracellular vesicles (~30 nm – 150 nm) released by cells—to promote tissue repair and modulate biologic processes. In the context of peripheral nerve injury, exosome therapies are most commonly derived from mesenchymal stem cells (MSCs), Schwann cells, or other regenerative cell sources. Rather than transplanting whole cells, exosomes deliver the beneficial paracrine signals of these cells without the risks associated with cell-based therapies (eg immune reaction, tumorigenicity). Mechanistically, exosomes have been shown to promote axonal regeneration, enhance Schwann-cell proliferation and migration, reduce inflammation, and support angiogenesis. Although clinical evidence remains limited, early reports suggest potential benefits when exosomes are used in conjunction with surgical nerve repair.

Preclinical studies of exosome-based therapy for nerve regeneration have reported consistent improvements in structural and functional outcomes across peripheral nerve injury models.³⁹ Most studies used rodent sciatic nerve injury models, in which exosome administration resulted in measurable improvements in compound muscle action potentials, sciatic functional index, axonal diameter, and myelination, as well as reduced muscle atrophy compared with untreated controls. Exosomes derived from mesenchymal stem cells and Schwann cells were the most commonly studied sources and were typically delivered either through local injection at the injury site or incorporated into nerve conduits and graft constructs.

REHABILITATION AND NEUROMUSCULAR RE-EDUCATION (NMR) AS OUTCOME DETERMINANTS

Postoperative rehabilitation and neuromuscular re-education are critical determinants of functional recovery following peripheral nerve reconstruction. Targeted motor retraining, sensory re-education, and electromyography-guided biofeedback have been shown to improve cortical plasticity and enhance integration of reinnervated muscles, particularly following nerve transfers and TMR procedures.⁴⁶

COST-EFFECTIVENESS AND RESOURCE AVAILABILITY

Cost-effectiveness and resource availability are important considerations in modern peripheral nerve reconstruction (Table 1). Advanced techniques such as nerve transfers, TMR, and RPNI require specialized microsurgical expertise and institutional resources, which may limit availability in resource-constrained settings. Economic analyses of neuroma-management strategies demonstrate that procedures such as TMR and RPNI may reduce long-term health care costs by decreasing chronic pain burden, opioid utilization, and revision surgery rates; however, upfront procedural costs and required surgical expertise remain barriers to widespread implementation.⁴⁷ In contrast,

Table 1. Modern Cost-Effectiveness and Resource Availability in Modern Peripheral Nerve Reconstruction.

Technique	Primary Indication (Gap/Injury Pattern)	Evidence Level	Donor Morbidity	Relative Cost	Availability	Key Notes
Primary Repair (Direct Coaptation) ¹	Short gaps where tension-free repair is possible (typically minimal or no gap)	High (clinical consensus, cohort data)	None	Low (lowest supply and OR cost) ⁵⁰	Available	Gold standard when feasible; outcomes decline with tension
Autologous Interfascicular Nerve Graft ¹	Moderate nerve gaps when direct repair not possible	High (large clinical series, foundational studies)	Yes (sensory deficit at donor site)	Low- Moderate (lower implant cost vs allograft)	Available	Millesi technique; benchmark reconstruction strategy
Vascularized Nerve Graft ⁵	Large gaps, scarred beds, failed prior grafts, proximal injuries	Moderate (limited comparative clinical series)	Yes	High (long OR time, microsurgery)	Limited (microsurgical expertise required)	Maintains intrinsic blood supply; used in complex reconstructions
Processed Acellular Nerve Allograft (PNA) ⁷	Small-moderate sensory nerve gaps (especially digital nerves)	Moderate-High (Randomized Controlled Trials + registry data)	None	High initially but potentially cost-effective long-term	Available Cost-dependent	~80%-88% sensory recovery in short gaps; limited motor data
Supercharged End-to-Side (SETS) ⁹⁻¹¹	High ulnar nerve injuries; incomplete regeneration risk	Moderate (systematic reviews, cohort studies)	Minimal	Moderate (added OR complexity)	Specialized centers	Augments native regeneration; reduces denervation time
Nerve Transfers (Neurotization) ^{9,11,15}	Proximal injuries with long regeneration distances (brachial plexus, delayed repair)	High (multiple clinical series, meta-analyses)	Variable (depends on donor nerve)	Moderate-High (complex surgery, specialized care)	Specialized centers	Shortens regeneration distance; improves motor recovery
Targeted Muscle Reinnervation (TMR) ^{18,19}	Amputation neuroma pain; post-amputation pain syndromes	High (clinical series + systematic reviews)	Procedure-dependent	High upfront, may reduce long-term pain-related costs	Specialized centers	Redirects transected nerves into motor targets; reduces neuroma formation and neuropathic pain; improves patient-reported outcomes
Regenerative Peripheral Nerve Interface (RPNI) ^{18,19}	Neuroma prevention; post-amputation pain	Moderate-High	Minimal (muscle graft harvest)	Moderate-High, potentially more cost-effective than TMR	Specialized centers	Implantation of nerve into free muscle graft; promotes organized reinnervation and reduces disorganized sprouting
Nerve Conduits / Scaffolds ²⁰⁻³³	Small sensory nerve gaps (≤ 5 mm)	Moderate (heterogeneous comparative studies)	None	Moderate (implant and OR cost; less than allograft) ⁵⁰	Available	Inferior outcomes vs graft/allograft in larger gaps
Nerve Wrapping (Biologic/ Synthetic Barriers) ^{27,28}	Revision surgery, scar-prone beds, mobile zones (joints)	Low-Moderate (preclinical + limited clinical data)	None	Low-Moderate (implant dependent)	Increasing availability	Reduces adhesions, preserves gliding
Electrical Stimulation (Adjunct) ³⁴⁻³⁸	Acute repair augmentation	Moderate (early clinical + strong preclinical data)	None	Low	Increasing availability	Enhances axonal growth and reinnervation speed
Nerve Fusion (PEG-mediated repair) ³⁴⁻⁴⁶	Experimental adjunct for acute transection repair	Low (early experimental/limited clinical translation)	None	High (experimental)	Limited (research settings)	Aims for immediate facilitation of axonal continuity
Exosome-Based Therapies ⁴⁷	Adjunct regenerative enhancement (investigational)	Low (preclinical + case reports)	None	High (investigational)	Experimental	Promotes Schwann-cell activity, axonal growth

autologous grafting and conduit-based repair remain more broadly accessible but may be associated with higher rates of secondary procedures in complex injuries. Technique selection should balance functional outcomes with health care resource utilization.

PEDIATRIC NERVE INJURY CONSIDERATIONS

Pediatric peripheral nerve injuries present unique biological and reconstructive challenges. Children demonstrate enhanced regenerative potential compared with adults; however, injury patterns, smaller nerve caliber, and long-term musculoskeletal growth must be considered in surgical planning.

In a large retrospective series of pediatric nerve repairs, approximately 95% of patients achieved at least partial recovery, with more than half demonstrating complete functional recovery at final follow-up.⁴⁸ Age remains a critical prognostic factor, as outcomes decline with increasing age, with significantly inferior recovery observed in children older than 10 years.³⁹

Despite this regenerative advantage, injury patterns in children are often complex and differ from those in adults, frequently involving high-energy trauma, fractures, or crush mechanisms that may obscure associated nerve injury.⁴⁹ For example, forearm fractures can result in nerve entrapment within fracture callus or scar tissue, with delayed neurologic deficits requiring later surgical exploration.⁴⁸ Pediatric nerve reconstruction can be challenging because donor autograft nerves are small caliber. Allograft nerve-reconstruction techniques may be applied in the pediatric setting with good results.⁴⁸

CONCLUSIONS

Peripheral nerve reconstruction has evolved into an adaptable and increasingly sophisticated field. Autologous nerve grafting remains the historical foundation for bridging nerve gaps, whereas vascularized grafts and processed nerve allografts have expanded options for complex or donor-limited scenarios. Nerve transfers, including SETS techniques, have redefined management of proximal injuries by shortening functional regeneration distance and improving the potential for motor recovery. Conduits and scaffolds offer reliable solutions for select short-gap (< 5-mm), sensory injuries, although outcomes remain less predictable than those achieved with donor-nerve grafting strategies. Adjunctive therapies such as electrical stimulation, and exosome-based approaches reflect an expanding focus on modulating the regenerative environment itself, targeting Schwann-cell activity, axonal sprouting, inflammation, and reinnervation efficiency. Successful outcomes depend on both structural repair and the biologic environment.

Ultimately, no single technique is universally applicable; rather, successful outcomes depend on thoughtful

integration of reconstructive tools with injury-specific factors such as transection level, gap length, timing, and surrounding soft-tissue condition. Ongoing advances in regenerative biology, biomaterials, and neuromodulation are likely to further refine this evolving surgical toolkit and continue improving functional recovery after peripheral nerve injury.

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Infection Rates in Gunshot-Related Hand Fractures Treated Nonoperatively

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ABSTRACT

Background: Firearm-associated injuries in the U.S. represent a major public health crisis, contributing substantially to major levels of morbidity, mortality, and economic stress. Recommendations for the management of gunshot-related hand fractures remain limited, particularly in low-velocity injuries, and current guidance often leaves treatment decisions to the discretion of the operating surgeon.

Methods: A retrospective analysis was performed to identify phalangeal and metacarpal fractures at a Level I trauma center from 2017 to 2023, resulting in 579 patients. Only fractures resulting from firearm injuries were included, resulting in 56 patients. Infection rates were observed in patients treated nonoperatively and those treated operatively.

Results: Of the 56 patients, 38 (68%) were treated operatively, and 18 (32%) were treated nonoperatively. The overall infection rate was 2 of 56 patients (3%). Two of the 38 patients treated operatively developed an infection after surgery (5.26%). Of the two patients who developed an infection, one required a return visit to the operating room. Both patients who developed infections reported current tobacco use, and one also had a history of poorly controlled diabetes. All patients in the study received antibiotics at presentation, most commonly 2 g of cefazolin or ceftriaxone.

Conclusion: Guidelines for the management of low-velocity, gunshot-related hand fractures remain debated, particularly regarding the need for debridement and prophylactic antibiotic administration. This study suggests that low-velocity fractures of the phalanges and metacarpals that do not warrant bony or soft-tissue procedures may be managed without antibiotics and formal irrigation and debridement, without an associated increase in infection risk.

Keywords: Antibiotics; Forelimb; Gunshot Wound; Hand

INTRODUCTION

For years, firearms have been the second leading cause of trauma-related death in the U.S., following motor vehicle accidents (MVAs). More recently, firearm-associated deaths have increased while deaths from MVAs have declined, and by 2014 the number of deaths from MVAs and gunshot injuries had become equivalent.¹ In 2019, gunshot wounds (GSWs) accounted for 20% of deaths among individuals aged 15 to 34 years.² The incidence of non-fatal GSWs has continued to rise, with more than 535,000 occurring between 2014 and 2018.³ These ballistic injuries have become a significant economic burden for the healthcare system, with annual costs approaching \$20 billion.² Some studies suggest that these costs reach upwards of \$48 billion annually when accounting for medical expenses and lost wages.⁴ Despite rising rates of non-fatal GSWs, particularly those involving the extremities, management guidelines for hand injuries remain poorly defined, likely contributing to unnecessary healthcare costs and increased demand on orthopaedic trauma services.⁵ In the absence of standardized guidelines, treatment decisions are left to the

discretion of the managing physician, which may lead to unnecessary operations and avoidable hospital admissions.⁵

Low-velocity bullets are generally defined as traveling at speeds below 2,000 ft/s (610 m/s), while high-velocity bullets travel at or above 2,000 ft/s.^{3,6,7} Some authors further define a medium velocity range between 1,000 ft/s and 2,000 ft/s.⁶ The kinetic energy (KE) of a bullet is directly related to the degree of injury it can produce, where KE is equal to one-half the mass times velocity ($KE = \frac{1}{2} MV^2$).⁶ Wounds secondary to high-velocity weapons have a higher degree of soft-tissue damage than those from low-velocity weapons.⁸

Wartime experience has provided foundational principles for management of high-velocity GSWs; however, the high-velocity rifles used in combat produce injuries that differ substantially from those caused by the low-velocity pistols and small rifles more commonly encountered in civilian settings.^{3,6} In non-combat settings, most handgun-related injuries are classified as low-velocity because these weapons have muzzle velocities below 2000 ft/s.²

In low-velocity injuries, tissue damage is generally confined to the path of the bullet and its fragments, whereas high-velocity injuries may cause destruction of tissues and structures several centimeters from the point of entry.³

Although civilian, low-velocity gunshot injuries are occurring at higher rates, management remains largely based on experience from World War II and the Vietnam War.⁸ In fact, much of the existing literature on ballistic injuries to the wrist and hand focuses on high-velocity, wartime injuries.² Though war has offered us valuable insight into the treatment of higher-energy hand injuries, important differences exist in the management of lower-energy injuries. High-velocity extremity GSWs often necessitate initial debridement followed by temporizing fixation because of extensive soft-tissue damage and fracture instability. In contrast, low-velocity extremity GSWs typically involve less soft-tissue compromise, and several authors advocate treating these injuries similar to non-GSW-related fractures, with an emphasis on minimizing complications while restoring function.³

Large studies and meta-analyses have described infection rates of <2% in GSW-related fractures treated nonoperatively with antibiotics and local wound care, and many additional authors describe similarly low rates of infections in injuries caused by low-velocity firearms.^{3,8} At this institution, no standardized guidelines exist for the management of GSW-related hand fractures. These injuries are most commonly treated according to this institution’s open-fracture protocol, which includes administration of 2 g of ceftriaxone or cefazolin upon arrival. Therefore, the purpose of this study was to review infection rates in nonoperatively managed GSW-related hand fractures to help standardize treatment practices.

METHODS

A retrospective analysis was conducted of 46 metacarpal, 29 proximal phalangeal, 12 middle phalangeal, and 6 distal phalangeal fractures resulting from low-velocity ballistics injuries treated at this institution between 2017 and 2023. Collectively, 93 fractures in 56 patients were included. Using ICD-10 codes, the authors identified 579 patients with metacarpal or phalangeal fractures between 2017 and 2023. From this data, only patients whose fractures were secondary to gunshot wounds were included, resulting in a total of 56 patients. A minimum three-month follow-up duration was required for inclusion. Excluded were any patients lost to follow-up, or those who had not yet reached the three-month follow-up threshold.

Infection rates were compared between patients treated operatively and nonoperatively. Operative management was defined as formal irrigation and debridement (I&D) performed under general anesthesia, with or without fixation and splinting at the time of surgery. Nonoperative management included limited bedside washout and/or local wound care, with or without splinting, performed in the emergency department.

All patients in the study received antibiotics upon admission, most commonly 2 g of ceftriaxone or cefazolin per this institution’s open fracture protocol. In addition to infection rates, risk factors for infection, primarily smoking and diabetes, were evaluated. Demographics and fixation methods (including closed reduction percutaneous pinning [CRPP], intramedullary nailing, dynamic external fixation, amputation, etc) were recorded but had no significant bearing on this study.

Statistical data was analyzed using JMP Pro V 16.2.0 (a product of SAS Inc., Cary, NC). Categorical data was

Table 1. Association of operative versus nonoperative intervention in the development of infection. *Comparison of infection rates between patients managed operatively (formal debridement) and nonoperatively. Fisher’s exact test was used to evaluate the association between treatment approach and infection development, stratified by diabetes status, smoking history, and antibiotic administration.*

Operating Room for Formal Debridement					
	No		Yes		Fisher’s Test (P)
	N	Column %	N	Column %	
Developed Infection					1.0000
No	18	100.00%	36	94.74%	
Yes	0	0.00%	2	5.26%	
Diabetes					1.0000
No	18	100.00%	36	94.74%	
Yes	0	0.00%	2	5.26%	
Smoking					0.7785
No	7	38.89%	17	44.74%	
Yes	11	61.11%	21	55.26%	
Abx Given					--
Yes	18	100.00%	38	100.00%	

Abx, Antibiotics

Table 2. Infection rate in operative versus nonoperative groups with identified risk factors. *Summary of infection outcomes and associated variables among patients treated operatively or nonoperatively, including antibiotic use, requirement for subsequent operative visits, smoking status, and diabetes mellitus.*

	Developed Infection	Received Abx	Required OR Visit Later	Smoker	DM
Operative (38) [67.86%]	2	38	1	21	2
Nonoperative (18) [32.14%]	0	18	0	11	0

Abx, Antibiotics; OR, Operating Room; DM, Diabetes Mellitus

Table 3. Odds ratios for diabetes and smoking in relation to infection development. *Calculated odds ratios with 95% confidence intervals and significance values ($Prob > \chi^2$) evaluating the association between diabetes or smoking status and infection occurrence. Odds Ratio for Diabetes and Smoking.*

Odds Ratio for Diabetes					
Level 1	Level 2	Odds Ratio	Prob > Chisq	Lower 95%	Upper 95%
Yes	No	18	0.0982	0.5852746	553.58633
No	Yes	0.0555556	0.0982	0.0019064	1.7085998
Odds Ratio for Smoking					
Level 1	Level 2	Odds Ratio	Prob > Chisq	Lower 95%	Upper 95%
Yes	No	7766527.4	0.9956	0	--
No	Yes	1.2876e-7	0.9956	0	--

Table 4. Fisher's exact test for diabetes and smoking as predictors of infection. *Distribution of infection occurrence by diabetes and smoking status, with corresponding Fisher's exact test P-values. Diabetes showed a trend toward statistical significance ($P = 0.0708$). Fischer's Test shows diabetes approaching statistical significance.*

	Developed Infection		Fisher's Test (P)
	No (N Row%)	Yes (N Row%)	
Diabetes			0.0708
No	53 (98.15%)	1 (1.85%)	
Yes	1 (50.00%)	1 (50.00%)	
Smoking			0.5013
No	24 (100.00%)	0 (0.00%)	
Yes	30 (93.75%)	2 (6.25%)	

summarized using frequencies and percentages. Associations between categorical data were assessed using Fisher's exact test. Logistic regression was used to determine whether diabetes and/or smoking predicated the development of infection. Model fit was determined using the chi-square test and the area under the receiver operating curve (ROC-AUC). A P -value <0.05 was considered statistically significant (Table 1).

RESULTS

Of the 56 patients included, 38 (68.86%) were treated operatively and 18 (32.14%) were treated nonoperatively. All nonoperative patients underwent bedside washout with betadine and saline, with or without minor

debridement, followed by local wound care and splinting as indicated. A small number of patients who ultimately underwent formal I&D also received an initial bedside washout prior to operative treatment. In total, two (3.5%) patients developed an infection, both of whom were in the operative cohort (2 of 38, 5.26%) (Table 2). Of these two patients, one underwent operative intervention solely for fracture fixation, while the other underwent I&D in addition to fixation. No patients treated nonoperatively developed an infection. Only one of the two patients who developed an infection required a return to the operating room (OR) for hardware removal and debridement. Both patients with infections smoked cigarettes, and one also had poorly controlled diabetes. In the operative group, 21 patients smoked; two of the patients who smoked also

Table 5. Study population demographics. *Distribution of study participants by self-identified race/ethnicity, demonstrating a predominantly African American cohort (82%). Study demographics. 82% (46) of patients in the study were African American, 12% (7) were Caucasian, 2.5% (1) was Hispanic or Latino, and 3.5% (2) identified as Other.*

Study Demographics	
African American	82%
Caucasian	12%
Hispanic/Latino	2.5%
Other	3.5%

Table 6. Operative treatment modalities performed.. *Breakdown of surgical interventions for gunshot-related extremity injuries, including irrigation and debridement (I&D) alone or in combination with closed reduction percutaneous pinning (CRPP), amputation, intramedullary nail (IMN), or external fixation (Ex-Fix).*

Operative Procedures Performed for Gunshot-Related Extremity Injuries	
Operative Treatment	Number of Patients
I&D Alone	7 Patients
I&D + CRPP	24 Patients
I&D + Amputation	5 Patients
I&D + IMN	1 Patient
I&D + Ex-Fix	1 Patient

had diabetes, including the patient who developed an infection. Among the 18 patients treated nonoperatively, 11 smoked, and none had diabetes (Table 3).

The difference in infection rates between the two treatment groups was not statistically significant (Fisher’s exact test, $P = 1.000$) (Table 4). However, it should be noted that detecting such a small difference with a 5% type I error rate and 0.85 power would require a sample size of more than 300 patients. That said, the authors believe that the difference in outcomes between the two groups would likely remain insignificant with a higher power.

A nominal logistic model was developed to evaluate infection occurrence as a function of diabetes and smoking status. The overall model was not statistically significant (chi-squared test, $P = 0.0840$), suggesting that neither factor was significantly associated with infection. Individual testing likewise showed no significant predictive capability for diabetes mellitus ($P = 0.1068$) or smoking ($P = 0.2535$). Although the ROC-AUC of 90% is high, the model was unable to meaningfully differentiate between infection and non-infection, effectively predicting no infection 100% of the time for all patients regardless of underlying conditions. This likely reflects the small sample

size and/or the possibility that relevant predictors of infection were not captured in the study.

There is some indication that diabetes may be associated with infection, as the odds ratio for diabetes was relatively high at 18 (Tables 4 and 5), and Fischer’s exact testing showed that this association approached statistical significance ($P = 0.07$). However, additional data from a larger patient cohort would be required before any such relation can be established. Consistent with the authors’ earlier findings, there remains no evidence of an association between infection and operative (formal surgery) versus nonoperative management.

In the operative group, 7 of the 38 patients (18%) underwent irrigation and debridement alone, including one patient who required flexor tendon repair and one who required extensor repair. Twenty-four patients (63%) underwent I&D with CRPP; among these one required cross-finger flap coverage, two required flexor digitorum superficialis (FDS) repair, and two required central slip repair. Five patients (13%) underwent I&D with amputation, and one patient (3%) underwent I&D with dynamic external fixation (Table 6).

DISCUSSION

Historically, particularly during wartime, infection was a major concern following high-energy firearm-related hand injuries. In modern civilian settings, infection rates after lower-velocity injuries have been reported to be low, although all gunshot injuries do carry some risk of infection.⁸ High-energy weapons are clearly associated with higher infection rates, but intermediate-velocity weapons (such as shotguns) have also been shown to increase infection risk. Given what is known about infection rates in higher-energy injuries, one can infer the conclusion reached by Ordog, namely that infection directly correlates with the degree of tissue damage.⁹ In their report, infection was associated with gross wound contamination, significant tissue devitalization, and multiple GSWs. They further proposed that when a low-velocity handgun injury results in a single entry and exit wound, infection is uncommon.^{8,9}

Despite reportedly low infection rates associated with low-velocity hand injuries, the current literature lacks a definitive consensus on initial management, including indications for surgical debridement as well as antibiotic selection and duration.¹⁰ In high-velocity GSWs, operative debridement and temporizing fixation are often required due to severe soft-tissue devitalization. In low velocity injuries, the soft tissues are less compromised.^{3,4} Jabara et al³ suggest that GSWs with minimal soft-tissue injury, such as those caused by low-velocity weapons, do not require surgical debridement unless they are taken to the OR for another injury. In this study, only two patients who were taken to surgery based on fracture pattern developed an infection; one required a return to the OR, and the other

resolved with a course of antibiotics alone. In a study by Kömürçü examining early definitive fixation for handgun-related metacarpal and phalangeal fractures requiring surgery, the reported infection rate was 10.5%, with a 7% rate of revision surgery.⁷ These findings are somewhat higher but only slightly contrasts with Kiehn, Mitra, and Gutowski who reported an infection rate of approximately 8% with early definitive treatment. These studies evaluated patients whose injuries warranted fixation and/or flap coverage. In this operative group, the infection rate was 5%, whereas the overall infection rate was 3% when nonoperative hand fractures were included. This suggests that when GSW-related hand fractures require operative fixation, there is a higher risk for infection than in injuries managed nonoperatively, likely reflecting the greater amount of energy of the sustained injury.

Because current guidelines for nonfatal GSWs to the hand remain inconsistent, patients whose injuries do not require bony fixation or soft-tissue coverage are often mismanaged, placing a strain on the patient and the healthcare system.⁵ Sathiyakumar et al¹¹ reviewed 58 articles addressing operative practices for gunshot-induced fractures of the extremities, including the lower extremities, and found that even among injuries with nonoperative fracture patterns, recommended management varied widely, ranging from superficial debridement to deep debridement or no debridement at all. Based on the findings in this study, the authors recommend simple bedside irrigation with saline and betadine solution in the emergency department, followed by local wound care and splinting as needed, for low-velocity GSW-related hand fractures in which neither the bony injury nor the soft-tissue injury warrants fixation in the OR.

Regarding antibiotics, existing evidence clearly supports early intravenous (IV) antibiotics for high-energy injuries with open fractures; however, there remains ongoing debate regarding the need for antibiotics and the appropriate duration of therapy in low-energy GSWs.^{4,8} Some studies, such as those by Turker and Capdarest-Arest⁸, have no meaningful difference in infection rates for low-energy gunshot wounds regardless of whether prophylactic antibiotics are administered. While most surgeons agree that low-energy GSWs treated surgically should receive a standard perioperative course of antibiotics, debate persists regarding appropriate regimens for nonoperative injuries.³ In the 1990s, a small study by Geissler et al¹² found that these injuries could be managed without antibiotics and without an increased risk of infection. More recently, a meta-analysis by Jabara et al³ reported similar findings, showing no difference in infection rates in low-velocity, GSW-associated fractures regardless of whether patients received antibiotics. A study by Nguyen et al¹³ concluded that a single dose of IV antibiotics administered in the emergency department saved an average of \$1,436 per patient with simple GSW

injuries in actual facility expenses. A recent survey of Orthopaedic Trauma Association members demonstrated wide variation in treatment practices for GSW-related extremity fractures. Most respondents reported that their group practice consisted of administering a single dose of IV antibiotics, with or without an oral outpatient course. Less experienced providers (<5 years in practice) tended to use more aggressive antibiotic regimens.³ The current practice described here is to administer at least a single dose of IV antibiotics in addition to gentle irrigation in the emergency room, followed by an oral outpatient course for low-velocity, GSW-related hand fractures.

This study suggests that formal irrigation is unnecessary for GSW-related hand fractures that do not require bony fixation or soft-tissue repair, and that gentle bedside irrigation with betadine solution is sufficient without increasing the risk of infection. Limitations of this study include its retrospective nature, limited documentation of wound size and soft-tissue features, and a relatively small sample size. It is well established that uncontrolled diabetes and smoking are risk factors for infection. The single patient with diabetes who developed a significant infection requiring return to the OR had uncontrolled diabetes, which may have contributed to his infection and abscess formation. Odds ratio and Fischer analyses indicate that diabetes has the potential to be associated with, and possibly predictive of, infection, which may prompt surgeons to consider additional precautions in these patients; however, larger-scale studies are needed to confirm these associations. No analyses of this data suggested that smoking was related to infection outcomes, though larger studies are again warranted to validate these findings.

Based on this data, the authors suggest that low-velocity, GSW-related hand fractures whose bony and soft-tissue injury patterns do not require surgical repair can be managed without formal I&D in the OR. Gentle bedside irrigation with betadine solution and saline appears sufficient and does not increase the risk of infection. Larger-scale, prospective studies are needed to confirm these findings and to help establish protocols for managing these injuries, with the goal of minimizing complications and costs for patients while reducing strain on the healthcare system and orthopaedic teams.

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The Effect of Institutional Reputation on Clerkship Grades

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ABSTRACT

Background: Clinical rotation scores have been reported to predict resident performance. However, the reporting of clerkship grades varies widely across institutions. The authors explored the correlation of an institution's reputation and the percentage of students receiving honors.

Methods: During the review of applicants for orthopaedic residency, the percentage of students receiving the highest grade in the surgery and internal medicine clerkships was recorded for each institution. The authors then compared published institutional rankings with the proportion of students awarded honors in these clerkships.

Results: One hundred nineteen institutions were reviewed. There was poor correlation between the institutional rankings by *U.S. News & World Report* and Doximity and the percentage of students receiving top grades in surgery ($r = -0.07$ and -0.07), internal medicine ($r = -0.19$ and -0.19), or overall class standing ($r = -0.01$ and -0.06).

Conclusion: The authors found that the variation in the percentage of students receiving the highest grade in clinical clerkships is not associated with an institution's reputation. They recommend that clerkship score reporting be standardized and that clerkship grades not be used to compare students across institutions.

Keywords: Academic Performance; Clinical Competence; Educational Measurement; Professional Competence; School Admission Criteria

INTRODUCTION

Garrison Keillor described the residents of Lake Wobegon as a place "where all the women are strong, all the men are good looking, and all the children are above average."¹ The tendency to exaggerate the traits of those with whom one associates is known as the *Lake Wobegon effect*. This human bias can influence how individuals evaluate those they have trained. When a program director was asked why all applicants from his institution had received honors in every clinical rotation, were ranked as top rotators, and were listed as guaranteed to match, he stated that the reputation of the medical school allowed the recruitment of only the very best students. This raised the question of the role of medical school reputation in the inflation of clinical grades reported in the Medical Student Performance Evaluation (MSPE).²⁻⁴ The MSPE is intended to provide an objective summary of a student's personal attributes, experience, and academic accomplishments.⁵ To communicate effectively with residency programs, an MSPE should be easy to interpret and consistent across institutions. This was the intent of the MSPE Task Force convened by the American Colleges of Physicians.

A review by Brenner reported that the clerkship grade was an area "ripe for misinterpretation" and created barriers to comparing students across schools because of wide

variation in grading practices.⁵ This report found that variations in the way grades were reported obscured their meaning. Clerkship grades have also been shown to vary by rotation order during the third year, by specialty within the discipline, and by campus within the institution.⁴ These inconsistencies hinder the usefulness of these data for the primary consumers of the MSPE – program directors – as they attempt to select the most qualified learners for their programs.⁵

The recent decision to discontinue reporting United States Medical Licensing Examination Step I scores will increase the importance of other data points in resident selection. Grades in required clerkships have been considered an effective measure of future resident performance, particularly in the affective domain.^{3,6} In orthopaedics, clerkship grades have been shown to predict resident evaluations and board examination performance.⁶ However, recent reports in obstetrics and gynecology have questioned this correlation.⁷ To serve as an effective tool for distinguishing applicant potential, program directors require a valid data set that is generalizable, consistent, and accurate in assessing a student's performance during clinical rotations.

The objective of this study was to determine whether a higher percentage of students receive top scores on

clerkship rotations at more prestigious institutions. Institutional rankings from commonly available reports were used to represent the perceived ability of highly ranked schools to attract higher-performing applicants. This bias may contribute to inflation of an institution's grades on the basis of the presumed superiority of its matriculating students.

METHODS

During the review of applicants for orthopaedic residency in 2021, a single MSPE for each unique institution (119 institutions) represented by an applicant was examined to determine the percentage of students who received the highest grade offered. The authors converted the nomenclature used for the top performance category to "honors," even when a different label was used.⁴ For graphical representations of grade distributions, the total number of all students in all included categories was measured manually. The percentage of students in the top category of internal medicine (if ambulatory/outpatient and inpatient were graded separately, only the inpatient rotation was used), general surgery, overall clerkship rank, and overall class rank was recorded.

The reputation of a medical school has been represented in prior literature by the *U.S. News & World Report* rankings, Doximity rankings, and the Princeton Review: Gourman Report of Graduate Programs.^{6,8,9} The authors retrieved the most current U.S. News and Doximity rankings from their respective websites. The Gourman rankings had not been updated in 20 years and were not considered relevant to the competitiveness of medical school recruitment for this cohort of students. Each medical school received a numerical ranking based on its position in the *U.S. News* research ranking and a separate ranking based on the Doximity ranking.

The correlation between online institutional reputation rankings and the percentage of students receiving honors in medicine, surgery, and overall class ranking was calculated. The number of programs reporting an overall clinical rotation standing was insufficient for analysis. Correlations were performed using Excel version 1808 for Windows (Microsoft Corp, Redmond, WA). For the graphical representation, programs that reported only pass/fail grades were assigned zero students receiving honors; these programs were excluded from the correlation calculations.

RESULTS

One hundred nineteen institutions were reviewed. One hundred institutions reported grade percentages in the surgery and internal medicine clerkships. Sixty-nine institutions reported percentages for class standing. Twenty-three institutions reported overall standing in the clerkship. There was substantial variability in the percentage of students receiving top grades in surgery, with a

mean of 34.0 (14.8); in internal medicine, with a mean of 33.5 (13.2); and in class rank, with a mean of 22.2 (7.3).

There was poor correlation between institutional ranking by *U.S. News & World Report* and the percentage of students who received top grades in surgery ($r = -0.05$), medicine ($r = -0.08$), or overall class standing ($r = -0.01$) (Figures 1 & 2). There was similarly little correlation between institutional ranking by Doximity and the percentage of students who received top grades in surgery ($r = -0.07$), medicine ($r = -0.19$), or overall class standing ($r = -0.06$) (Figures 3 & 4).

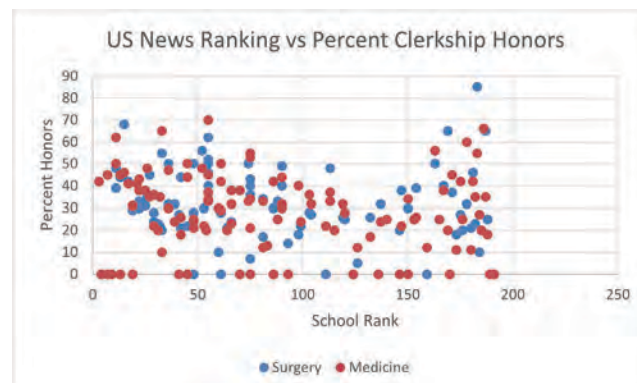


Figure 1. Comparison of *U.S. News & World Report* institutional ranking with the percentage of students receiving honors in clinical clerkships.

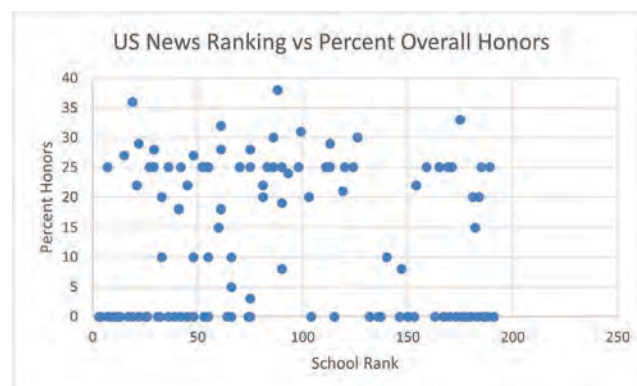


Figure 2. Comparison of *U.S. News & World Report* institutional ranking with the percentage of students receiving the top grade for overall standing.

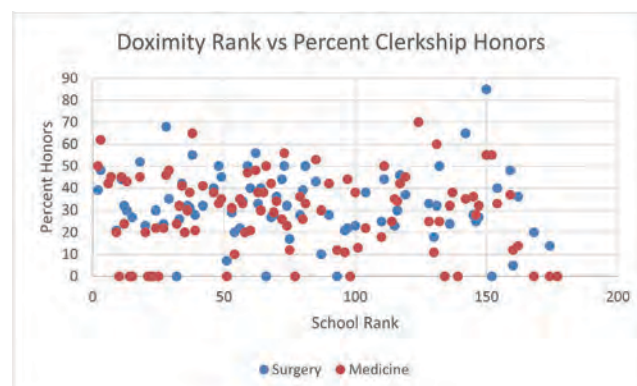


Figure 3. Comparison of Doximity institutional ranking with the percentage of students receiving honors in clinical clerkships.

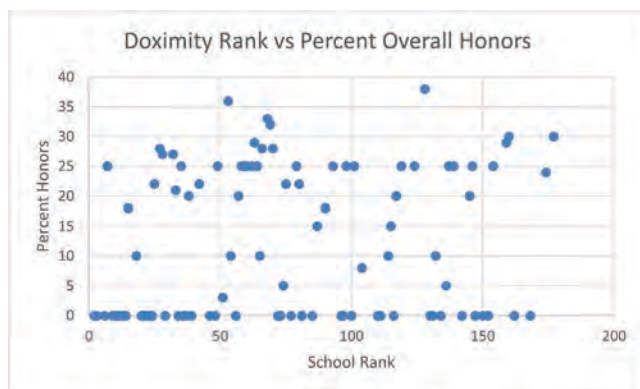


Figure 4. Comparison of Doximity institutional ranking with the percentage of students receiving the top grade for overall standing.

DISCUSSION

In Brenner's assessment of MSPEs, the only consistently included data were clerkship grades, but these were difficult to interpret because of variations in reporting methods and descriptive terminology.^{2,5} The authors noted that a substantial time commitment was required to determine the meaning of reported scores and the percentage of students who received the highest marks. Even terminology that appeared standardized, such as "first quartile," was open to interpretation, with some programs reporting up to 40% of students in the high-performing quartile and others using the "first quartile" to represent the lowest-performing students.

The primary end point of this study was to determine whether variability in clerkship grading across postsecondary programs was associated with institutional reputation. There is support in the residency literature for the idea that high-performing students may self-select into higher-performing institutions.¹⁰⁻¹⁴ This pattern likely extends to medical school recruitment. However, this study did not identify a relationship between the percentage of students who received top scores in clinical rotations and the institution's reputation. The variation observed in clerkship grades, ranging from 5% to 70%, was consistent with previous reports in the literature.⁴ These findings suggest that the ability of an institution to recruit high-performing students does not account for the observed variation in clerkship grading.

Variation in grading also leads to substantial inequity in the selection process. When only the reported honors designation is considered, students at institutions that award honors to only 5% of learners are disadvantaged compared with those at schools where 70% receive honors. This inequity is compounded when institutions use ostensibly standard terminology to mean something different, such as defining a quartile as something other than 25% or using inconsistent descriptors such as "first." Reviewers already face difficulty identifying key metrics in MSPEs because of variation in reporting formats. It is unreasonable to expect them to account for the wide

variation in grading practices between institutions or even between campuses within the same institution.

This study is limited by its sample size. Because the applicant pool was drawn from a single institution, not all medical schools could be represented; however, given the broad variability observed across a wide range of school rankings, it is unlikely that inclusion of additional institutions would have produced a strong correlation. In addition, the methodologies used by *U.S. News & World Report* and Doximity to rank institutions have been criticized.⁸ However, both ranking systems have been documented in the literature to influence applicants.^{9,10,13} The use of these institutional ranking systems is justified because their effect on applicants' choice of medical school is well established. That influence could lead high-ranking schools to inflate their students' grades. This study is further limited by the uncertainty regarding the extent to which institutional ranking affects the choices of the highest-performing students and how faculty incorporate perceptions of institutional prestige into their evaluations.

CONCLUSION

This analysis demonstrated that variation in the percentage of students who receive the highest grade in clinical clerkships is not associated with institutional reputations. The observed variation in honors awarded during clinical rotations cannot be explained by the assumption that institutions recruiting superior students would therefore expect a higher proportion to achieve top marks. To make the process more transparent and to provide high-quality data for programs selecting residency candidates, standardization of clerkship score reporting is recommended. Dividing reported scores into thirds and designating them as top, middle, and lower would align with the mean percentages of honors in surgery (34%) and medicine (33%) observed in this study. Such an approach would still allow top-performing students to be recognized while better supporting the MSPE Task Force's goals of providing meaningful data for resident selection.

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Increased Mortality and Reduced Survival in Nonagenarians with Hip Fractures: Implications for Geriatric Care

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ABSTRACT

Background: Hip fractures in nonagenarians (patients aged ≥ 90 years) are becoming increasingly common as the population ages, yet outcomes in this group remain poorly characterized. This study compared in-hospital mortality and survivorship at three months, six months, and one year after hip fracture surgery in nonagenarians with a younger elderly cohort aged 65 years to 89 years. Secondary outcomes included fracture characteristics, surgical management, and discharge disposition.

Methods: A retrospective chart review was conducted on patients who underwent hip fracture surgery at a single Level I Trauma Center from August 2019 to December 2021. Patients were grouped into nonagenarians and those aged 65 years to 89 years. Demographics, comorbidities, fracture type, surgical management, mortality, and survivorship were collected. Chi-square testing with Bonferroni correction was used for statistical comparisons.

Results: The mean age was 93 years in the nonagenarian cohort and 72 years in the younger cohort. Nonagenarian individuals experienced similar in-hospital mortality rates (6.25% vs 1.10%; Odds Ratio [OR] 6.0; 95% Confidence Interval [CI] 0.65 – 55.0; $P > 0.05$). Survival was significantly lower for nonagenarians at three months (78% vs. 97%; OR 0.10; $P < 0.05$), six months (67% vs. 95%; OR 0.10; $P < 0.05$), and one year (58% vs. 95%; OR 0.08; $P < 0.05$). No significant differences were found in fracture type, surgical approach, discharge location, or one-year readmission rates.

Conclusion: Nonagenarians experience substantially higher mortality and markedly reduced survivorship following hip fracture surgery compared with younger elderly patients. These findings underscore the importance of multidisciplinary perioperative care and comprehensive geriatric assessment to optimize outcomes in this vulnerable population.

Keywords: Hip Fractures; Morbidity; Mortality; Nonagenarians; Survival

INTRODUCTION

Hip fractures are associated with high morbidity and mortality in the elderly population, who often sustain these injuries from a ground-level fall or other low-energy mechanism. The number of hip fractures continues to rise in the growing elderly population, with some projections estimating 500,000 hip fractures per year by 2040.¹ As the population ages, an increasing proportion of patients will belong to a subset consisting of individuals 90 years or older (nonagenarians). Nonagenarians present unique challenges to multidisciplinary teams regarding both intraoperative and postoperative management.

Some studies of nonagenarian hip fractures have recorded one-year mortality rates as high as 38%.² One large retrospective chart review of more than 1,500 patients found no significant difference in one-year mortality when comparing patients younger than 85 years with those aged 85 years and older.³ Another large retrospective review using the Taiwanese national database reported that age was a risk factor for higher mortality and increased need for reoperation; however, that study included only

patients aged 90 years and older and did not compare nonagenarians with a younger cohort.⁴ To date, few studies have investigated in-hospital mortality and survivorship among nonagenarian patients with hip fractures. The primary aim of this study was to determine in-hospital mortality and survivorship at three months, six months, and one year following surgical management in this population. Secondary aims included characterizing fracture type, surgical management, and discharge disposition.

METHODS

A retrospective chart review was performed that included all patients undergoing surgery for femoral neck fractures, intertrochanteric femur fractures, and subtrochanteric proximal femur fractures from August 2019 to December 2021, identified using ICD-10 codes at this institution. The nonagenarian cohort consisted of patients who were 90 years or older on the date of surgery. The comparison group included patients older than 65 years but younger than 90 years.

The authors collected the following information for each patient: age, sex, and body mass index (BMI). In-hospital

Table 1. Demographic Characteristics: Age, Sex, and Body Mass Index (BMI).

Variable	Nonagenarians	Younger Adults
Age (mean)	93.17	72.29
Male	14 (24.56%)	38 (42.22%)
Female	43 (75.43%)	52 (57.78%)
BMI (mean)	22.8	24.64

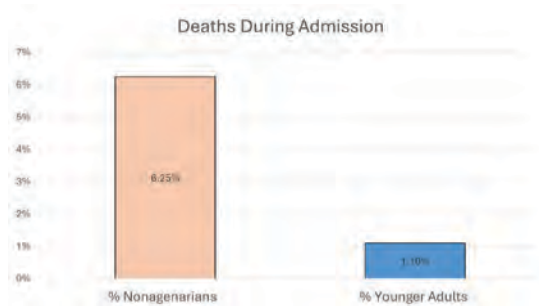


Figure 1. In-hospital mortality among nonagenarians and younger adults. An asterisk represents statistical significance with $P < 0.05$.

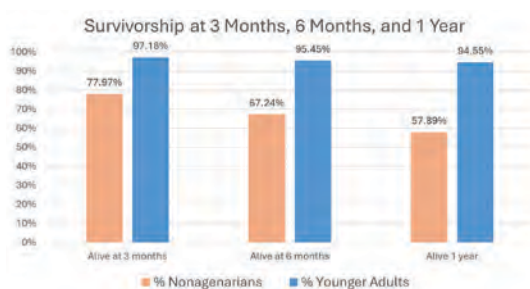


Figure 2. Survivorship at three months, six months, and one year among nonagenarians and younger adults. An asterisk represents statistical significance with $P < 0.05$.

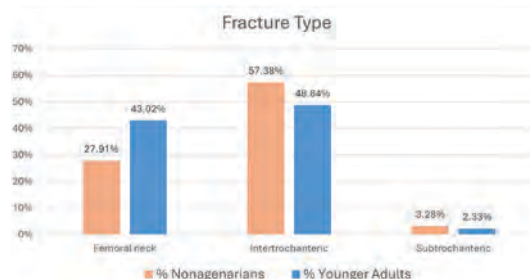


Figure 3. Fracture type among nonagenarians and younger adults.

mortality and survivorship at three months, six months, and one year were recorded. Patients were further compared by peritrochanteric fracture type (femoral neck, intertrochanteric, and subtrochanteric) and by surgical management (hip screw and short plate, short nail, intermediate nail, long nail, hemiarthroplasty, or total hip arthroplasty). Rates of discharge to inpatient rehabilitation, a skilled nursing facility, or home were compared between cohorts. Readmissions within one year were also compared. Descriptive statistics and chi-square testing were used for all categorical variables, with the Bonferroni correction applied.

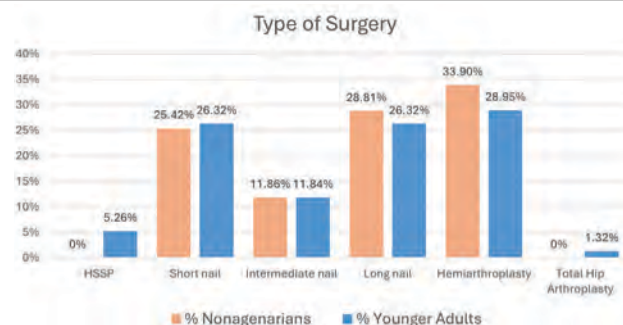


Figure 4. Type of surgery among nonagenarians and younger adults.

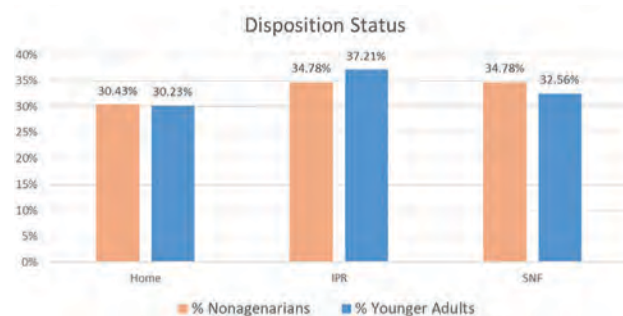


Figure 5. Disposition status among nonagenarians and younger adults.

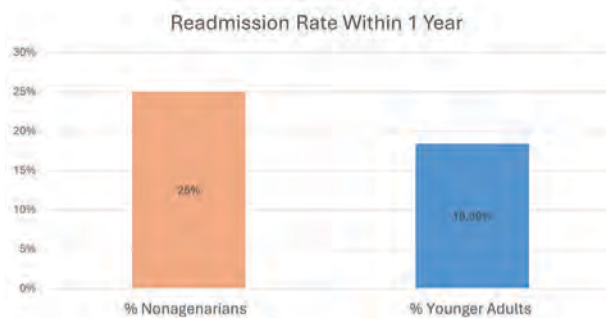


Figure 6. Readmission rate within 1 year among nonagenarians and younger adults.

RESULTS

The mean age of individuals in the nonagenarian cohort was 93 years compared with 72 years in the control population. A total of 153 individuals were included, consisting of 90 in the control group and 63 in the nonagenarian cohort. The BMI was 22.8 in nonagenarians and 24.6 in controls. The nonagenarian cohort was composed of 25% males and 75% females, compared with 42% males and 58% females in the comparison group ($P = 0.02$) (Table 1). Nonagenarian individuals experienced similar rates of in-hospital mortality (6.25% vs 1.10%; OR 6.0; 95% CI 0.65

Table 2. In-Hospital Mortality, Survivorship, Original Fracture Type, Surgery Type, Disposition, and Readmission Rates Within 1 Year.

Variable	Nonagenarians	Younger Adults	P Value
Death During Admission	4 (6.25%)	1 (1.10%)	0.07
Alive at 3 Months	46 (77.97%)	69 (97.18%)	0.00064 *
Alive at 6 Months	39 (67.24%)	63 (95.45%)	4.1E-05 *
Alive 1 Year	33 (57.89%)	52 (94.55%)	< 0.00001 *
Original Fracture Type			
Femoral Neck	24 (27.91%)	37 (43.02%)	0.65556
Intertrochanteric	35 (57.38%)	42 (48.84%)	0.30703
Subtrochanteric	2 (3.28%)	2 (2.33%)	0.72637
Surgery Type			
Hip Screw Side Plate	0 (0%)	4 (5.26%)	0.0734
Short Nail	15 (25.42%)	20 (26.32%)	0.76441
Intermediate Nail	7 (11.86%)	9 (11.84%)	0.97485
Long Nail	17 (28.81%)	20 (26.32%)	0.45077
Hemiarthroplasty	20 (33.90%)	22 (28.95%)	0.53767
Total Hip Arthroplasty	0 (0%)	1 (1.32%)	0.3765
Disposition			
Home	14 (30.43%)	26 (30.23%)	0.98595
Inpatient Rehabilitation	16 (34.78%)	32 (37.21%)	0.84996
Skilled Nursing Facility	16 (34.78%)	28 (32.56%)	0.85542
Readmissions within 1 Year	7 (25%)	16 (18.39%)	0.44698

An asterisk beside the *P* value represents statistical significance.

– 55.0; $P > 0.05$) (Figure 1, Table 2). Of the four nonagenarians who died during admission, the causes of death were cerebral fat embolism and acute hypoxic respiratory failure in two patients, and unknown/multifactorial causes in the remaining two. The single death in the younger cohort was attributed to sepsis. Nonagenarians had significantly lower survival rates at three months (78% vs 97%; OR 0.10; 95% CI 0.0221 – 0.4759; $P < 0.05$) (Figure 2, Table 2), six months (67% vs 95%; OR 0.10; 95% CI 0.0271 – 0.3521; $P < 0.05$) (Figure 2, Table 2), and one year (58% vs 95%; OR 0.08; 95% CI 0.0221 – 0.2845; $P < 0.05$) (Figure 2, Table 2). There were no significant differences between groups in fracture type, hardware used, or discharge disposition (Figures 3–5, Table 2). No differences were observed in one-year readmission rates following surgical management (Figure 6, Table 2).

DISCUSSION

This study demonstrated no significant difference in in-hospital mortality between nonagenarians with hip fractures and their younger counterparts. However, nonagenarians have significantly decreased survivorship at three months, six months, and one year following surgery. These findings are consistent with previous literature describing expected survivorship in this elderly population.^{5,6}

Several factors contribute to worse long-term outcomes in the nonagenarian cohort. Advanced age is inherently associated with increased comorbidities, frailty, and decreased physiologic reserve, all of which can exacerbate the impact of a hip fracture. Research by Panula et al⁷ reported that comorbid conditions such as cardiovascular disease, diabetes, and cognitive impairment significantly worsen prognosis in elderly patients with hip fractures. Haentjens et al⁸ further demonstrated that the risk of mortality after a hip fracture remains elevated for several years, with the most pronounced risk occurring within the first six months.

Although the authors did not find a statistically significant difference in in-hospital mortality, the *P* value of 0.07 suggests a trend toward significance. It is possible that with a larger sample size, a true difference, if present, might have become evident. Numerous studies have reported that nonagenarians experience a significantly higher likelihood of in-hospital mortality.^{9–13} Vochteloo et al⁹ reported a relative risk of in-hospital mortality of 1.98 when comparing nonagenarians with patients aged 65 years to 89 years who sustained a hip fracture ($P < 0.001$). Similarly, Shah et al¹⁰ found that nonagenarians were more likely to die during their hospital stay ($P = 0.001$) and within one year of surgery ($P = 0.001$). Given that the results of this study trended toward significance, it is likely

that a larger sample size would have allowed detection of this difference if one truly existed.

The higher in-hospital mortality observed in many studies among nonagenarians may be attributed to several acute factors. These include perioperative complications such as cardiac events, infections, and thromboembolic incidents, which are more prevalent and severe in older patients. Roche et al¹⁴ reported that medical complications are the leading cause of death in elderly patients with hip fractures during hospitalization. The stress of undergoing surgery, limited social support, and subsequent immobilization can precipitate a cascade of adverse events in frail older adults, complicating their recovery.¹⁵

Post-discharge survivorship was notably decreased in the nonagenarian group. The decline in survival at three months, six months, and one year may be attributable to several factors. Although prior literature suggests that advanced age is associated with worse functional recovery, this study did not demonstrate a higher rate of discharge to rehabilitation or skilled nursing facilities among nonagenarians compared with younger elderly cohorts. Thus, the data do not directly support an increased likelihood of institutionalization in this population. Instead, the primary difference observed was reduced survival at three-month, six-month, and one-year time points among patients older than 90 years. This may reflect the impact of age-related comorbidities and overall frailty rather than differences in immediate postoperative functional recovery. Notably, similar discharge dispositions between groups may suggest that, from an orthopaedic and rehabilitation standpoint, hip fracture surgery does not impose a disproportionately greater barrier to early functional recovery in nonagenarians, although further study with direct functional outcome measures is warranted. Patients in this age group are significantly more likely to experience secondary complications such as pneumonia, urinary tract infection, or pressure ulcers, all of which are significant predictors of mortality.¹⁶⁻¹⁸

These findings emphasize the critical need for comprehensive geriatric assessment and multidisciplinary management of patients with hip fractures older than 90 years. Prestmo et al¹⁹ demonstrates that integrated orthogeriatric care models, which incorporate geriatrician involvement from admission through rehabilitation, can improve outcomes by addressing the complex medical and functional needs of this population. Age-specific postoperative care pathways have been well described in the orthogeriatric literature and may have broader applicability to other patient groups. These include multidisciplinary orthogeriatric co-management models, which have been shown to reduce complications such as delirium through coordinated medical and surgical care; standardized delirium-prevention protocols incorporating daily cognitive screening, minimization of

deliriogenic medications, and sleep optimization; multimodal, opioid-sparing analgesia strategies, including regional nerve blocks; and early-mobilization protocols with initiation of physical therapy on postoperative day one.²⁰⁻²²

Systematized, structured care pathways have been implemented successfully, demonstrating decreased time to surgery as well as reduced readmission and mortality rates.²⁰ Optimizing preoperative medical status, ensuring prompt surgical intervention, and implementing tailored postoperative care plans are essential strategies to mitigate the high mortality and poor survivorship observed in this population. Of note, delirium has been shown to be a significant independent risk factor for mortality in this patient group.²¹

This study has several limitations that should be acknowledged. First, its retrospective design may introduce selection bias, as it relies on existing medical records that may not capture all relevant variables or complications. The study population is derived from a single institution, which may limit the generalizability of the findings to other settings. Variations in postoperative care and rehabilitation protocols, which could influence outcomes, were not accounted for. Additionally, socioeconomic status and support systems, factors known to affect recovery and long-term survival, were not evaluated. The study design, methodology, and analysis also did not incorporate predictive variables that may influence outcomes, nor did the analysis control for individual comorbidities that could have contributed to the results.

Future research should focus on prospective, multicenter studies to validate these findings across diverse populations and healthcare settings. Investigating the impact of comprehensive geriatric care models, including early involvement of geriatricians and tailored postoperative rehabilitation programs, could provide valuable insights into improving outcomes for nonagenarian patients with hip fractures. Further studies should also explore the role of socioeconomic factors, social support systems, and specific comorbidities in influencing recovery and long-term survival. Developing and implementing age-specific surgical and postoperative care protocols may help mitigate the high mortality and poor survivorship observed in this vulnerable population. Time to surgery is also an important and frequently debated factor in outcomes following hip fracture, and it was not evaluated as an independent predictor of mortality in this study. The primary aim of this study was to assess age-related differences in survival; therefore, time to the operating room was not included in the analysis. However, given existing literature suggesting that surgical delay may influence morbidity and mortality, future studies incorporating time to surgery as a covariate would be valuable in further elucidating its impact within this particularly vulnerable nonagenarian population.

CONCLUSION

In conclusion, the significant differences in survival rates between patients older than 90 years and younger individuals with hip fractures underscore the need for targeted interventions. These findings contribute to a growing body of evidence that informs how clinicians structure conversations with patients regarding expectations and postoperative outcomes. Future research should focus on identifying specific risk factors and developing age-specific management protocols to improve outcomes for this vulnerable cohort. By enhancing perioperative care and rehabilitation strategies, it may be possible to reduce mortality and improve quality of life for elderly patients with hip fractures.

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Analysis of Patient Factors That Predict Early Restoration of Neutral Dorsiflexion After Achilles Tendon Rupture

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ABSTRACT

Background: Achilles Tendon Rupture (ATR) is a common musculoskeletal injury with an increasing incidence in the United States. Early functional rehabilitation is a key component of improving patient outcomes, and restoration of range of motion is a common threshold for progression to strengthening. Neutral ankle dorsiflexion represents an important early milestone in ATR recovery. This study aimed to assess which patient factors were associated with achieving this early rehabilitation milestone.

Methods: A retrospective review was performed on 70 patients who sustained ATR and were treated at an academic center. Demographics, baseline characteristics, and common ATR risk factors were collected. The primary outcome was whether patients achieved neutral ankle dorsiflexion at the six-week follow-up visit. Univariate analysis was conducted to assess associations between risk factors, and multivariate analysis was subsequently performed for variables of interest.

Results: There were 70 patients, with a mean age of 41.87 years $\pm$ 13.8 years; 56 were male (80%) and 14 were female (20%). In univariate logistic regression, only operative management demonstrated a statistically significant association with achieving the six-week clinical milestone of neutral dorsiflexion (Odds Ratio [OR]: 5.48, 95% Confidence Interval [CI]: 1.51 – 22.01, $P < 0.01$). This association persisted after controlling for age, sex, and hypertensive status (OR: 5.48, 95% CI: 1.66 – 19.9, $P < 0.01$).

Conclusion: Operative treatment of acute ATR was independently associated with earlier recovery of ankle dorsiflexion. Achievement of early dorsiflexion was largely independent of most baseline patient characteristics. For patients who prioritize early rehabilitation progression, operative management may offer a meaningful short-term advantage.

Keywords: Cohort Studies; Range of Motion; Articular; Rehabilitation; Tendon Injuries

INTRODUCTION

Achilles tendon rupture (ATR) is a common musculoskeletal injury with an estimated incidence of 7 to 40 per 100,000 person-years.¹ Despite advances in treatment and rehabilitation strategies, patients frequently experience prolonged deficits in ankle strength, endurance, and functional performance after injury.^{2,3} These deficits are believed to result from complex and incompletely understood remodeling of the triceps surae muscle complex, which has been shown to undergo substantial changes following ATR.⁴ Functional testing of post-injury remodeled tendons has shown that the remodeling process is insufficient to restore muscle function, which may partly explain the long-term functional deficits observed after ATR regardless of treatment modality.^{5,6} Historically, operative management was favored because of lower rerupture rates; however, modern nonoperative protocols incorporating early functional rehabilitation have demonstrated comparable

long-term outcomes, contributing to ongoing controversy regarding the optimal treatment strategy.

As rehabilitation protocols have continued to evolve, increasing emphasis has been placed on early functional recovery rather than long-term patient-reported outcomes. Early weightbearing and controlled ankle motion have been shown to improve short-term function, patient satisfaction, and return to activity without significantly increasing complication rates.^{7,8} Regardless of treatment preference or immobilization method, progression through rehabilitation is inherently milestone-driven, with advancement dependent on the restoration of foundational range-of-motion and strength parameters achieved in a step-wise manner.⁹

Neutral ankle dorsiflexion represents an important early milestone in ATR recovery.¹⁰ Achieving this threshold permits progression from protective immobilization and passive motion to strengthening, gait normalization,

proprioceptive training, and functional rehabilitation. Failure to restore dorsiflexion in the early postoperative or post-injury period may delay rehabilitation advancement and prolong functional recovery. Although restoration of neutral dorsiflexion may facilitate functional recovery, it is crucial to avoid dorsiflexion beyond the neutral position early after injury. This precaution is essential to prevent tendon elongation, an irreversible complication associated with worse functional outcomes.¹¹ Despite its clinical relevance, limited literature has examined patient- or treatment-related factors associated with early dorsiflexion recovery following ATR.

The purpose of this study was to evaluate factors associated with achieving neutral ankle dorsiflexion at six weeks after acute ATR. The authors hypothesized that patients treated operatively would be more likely to achieve neutral dorsiflexion at six weeks than those treated nonoperatively.

METHODS

Institutional review board approval was obtained before retrospective chart review was performed on patients with the International Classification of Diseases, Tenth Revision (ICD-10) codes for ATR during a 10-year period from January 1, 2015, to January 31, 2024. The diagnosis of ATR was confirmed by chart review and based on clinical examination findings, including altered resting tension relative to the uninjured side, a positive Thompson test, or palpable tendon defect. All patients underwent radiographic evaluation with plain radiographs at initial presentation. Magnetic resonance imaging was not required for diagnosis but was reviewed when previously obtained as part of the clinical record.

All patients aged 18 years to 89 years with confirmed ATR were included in the study. Patients were excluded if ankle range-of-motion assessment at the six-week follow-up visit was not documented; if bilateral ruptures were present; or if radiographs and/or clinical evaluation suggested an alternative diagnosis (eg ankle fracture). Patients were also excluded if the mechanism of injury was high energy (eg motor vehicle collision, trauma); if the injury was not an acute rupture; or if there was a traumatic laceration of the tendon or a rerupture following prior treatment.

All patients in this study were treated by a single orthopaedic surgeon who is board-certified in foot and ankle surgery at an academic medical center. Operative management consisted of primary ATR performed using standard techniques at the discretion of the treating surgeon. Nonoperative management followed a functional rehabilitation protocol involving immobilization in plantar flexion with a gradual progression toward neutral alignment. Post-treatment immobilization and rehabilitation protocols were broadly similar in structure, emphasizing protected motion initially, with advancement contingent on

clinical progress. Details of the rehabilitation protocols for operative and nonoperative patients are summarized below.

Post-treatment rehabilitation followed a standardized protocol emphasizing early protected motion with gradual progression of weightbearing and range of motion. Patients were initially immobilized in plantarflexion and maintained nonweightbearing for the first three weeks. From weeks three to six, they transitioned to a walking boot with heel lifts and partial weightbearing with crutches, during which active ankle range of motion was initiated without passive stretching. At six weeks, heel lifts were removed once neutral dorsiflexion was achieved, and patients progressed to weightbearing as tolerated in the boot and initiated strengthening exercises while avoiding dorsiflexion beyond neutral. At 12 weeks, patients advanced to full weightbearing out of the boot with progressive strengthening and functional activity, with return to higher-impact activities by six months.

Information about each patient's treatment course and demographics were recorded, including factors previously associated with the risk of ATR: age, sex, race, occupation, tobacco use, participation in athletic activities (termed "athlete status"), mechanism of injury, medical comorbidities, and history of Achilles tendinopathy. The primary outcome was achievement of neutral ankle dorsiflexion at the six-week follow-up visit. Neutral dorsiflexion was defined as the ability to achieve a plantigrade ankle position on clinical examination, as documented in the medical record. This outcome was analyzed as a binary variable (achieved vs not achieved).

Statistical Analysis

The threshold for statistical significance was set at $P < 0.05$. Univariate analysis was conducted and reported using descriptive statistics, including means, frequencies, and standard deviations. All categorical variables were analyzed using Fisher's exact test because of low sample sizes. Continuous variables were analyzed using Student t test. Logarithmic regression analysis was performed on individual variables to assess associations with achieving neutral dorsiflexion at six weeks. Variables of interest were then included in multivariate regression analysis to evaluate associations with meeting the six-week dorsiflexion milestone. Statistical analysis was performed using R Statistical Software (version 4.2.2; R Foundation for Statistical Computing) and Excel (Microsoft).

RESULTS

There were 70 patients who met inclusion criteria, with a mean age of 41.87 years $\pm$ 13.8 years; 56 were male (80%) and 14 were female (20%) (Table 1). The mean body mass index (BMI) for the cohort was 31.65 $\pm$ 7.37. Eleven patients (16%) had a BMI between 18 and 25, 24 patients (34%) had a BMI between 25 and 30, and 35 patients (50%) had a BMI greater than 30. Of the 57 patients with recorded insurance status, 14 (25%) had insurance at the

Table 1. Achilles Tendon Rupture Cohort Overview (n = 70).

Variable	Count	n	(%)
Age, Mean ($\pm$ SD)	41.87 $\pm$ 13.76	70	--
Sex (M; F)	56M;14F	70	--
Laterality (L; R)	29L;41R	70	--
BMI Class 1 (18 – 25)	11	70	16%
BMI Class 2 (25 – 30)	24	70	34%
BMI Class 3 (> 30)	35	70	50%
Insurance Status	14	57	25%
Smoker	16	70	23%
Hypertension	20	70	29%
Dyslipidemia	6	70	9%
History of Tendinopathy	4	70	6%
History of Achilles Rupture	5	70	7%
Nonoperative Management	24	70	34%
Operative Management	46	70	66%
6-Week Dorsiflexion	53	70	76%

SD, Standard Deviation; M, Male; F, Female; L, Left; R, Right; BMI, Body Mass Index

Table 2. Achilles Tendon Rupture Operative vs Nonoperative (n = 70).

Variable	Nonoperative (n = 24)	Operative (n = 46)	P Value
Age, Mean ($\pm$ SD)	45.62 $\pm$ 13.65	39.91 $\pm$ 13.55	0.10
Sex (Female) (%)	7 (29.2%)	7 (15.2%)	0.21
BMI Class, n (%)			
BMI Class 1 (18 – 25)	7 (29.2%)	4 (8.7%)	0.04*
BMI Class 2 (25 – 30)	8 (33.3%)	16 (34.8%)	1.00
BMI Class 3 (> 30)	9 (37.5%)	26 (56.5%)	0.21
Smoking History	7 (29.2%)	9 (19.6%)	0.38
Hypertension	8 (33.3%)	12 (26.1%)	0.58
Dyslipidemia	3 (12.5%)	3 (6.5%)	0.41
History of Tendinopathy	1 (4.2%)	3 (6.5%)	1.00
History of Rupture	2 (8.3%)	3 (6.5%)	1.00

SD, Standard Deviation; BMI, Body Mass Index *Statistically significant ($P < 0.05$)

Table 3. Univariate Analysis on Factors Predicting 6-Week Dorsiflexion.

Variable	OR	95% CI	P Value
Age	0.98	(0.94, 1.02)	0.34
Sex (Female)	0.50	(0.12, 2.25)	0.30
BMI Class, n (%)			
BMI Class 1 (18 – 25)	1.53	(0.27, 16.08)	1.00
BMI Class 2 (25 – 30)	0.94	(0.27, 3.64)	1.00
BMI Class 3 (> 30)	0.86	(0.25, 2.94)	1.00
Smoker	0.95	(0.23, 4.75)	1.00
Hypertension	0.47	(0.13, 1.77)	0.22
Dyslipidemia	0.62	(0.08, 7.45)	0.63
History of Tendinopathy	0.96	(0.07, 53.51)	1.00
History of Achilles Rupture	1.30	(0.12, 68.37)	1.00
Operative Management	5.48*	(1.51, 22.01)	< 0.01*

OR, Odds Ratio; CI, Confidence Interval; BMI, Body Mass Index; *Statistically significant ($P < 0.05$)

Table 4. Multivariate Analysis on Factors Predicting 6-Week Dorsiflexion.

Variable	OR	95% CI	P Value
Age, Mean (±SD)	1.01	0.96, 1.06	0.81
Sex			
Male	--	--	--
Female	0.76	0.18, 3.57	0.71
Hypertension			
No	--	--	--
Yes	0.47	0.10, 2.11	0.32
Surgical Management			
No	--	--	--
Yes	5.48*	1.66, 19.9	< 0.01*

OR, Odds Ratio; CI, Confidence Interval; *Statistically significant ($P < 0.05$)

time of presentation. Regarding comorbidities, 16 patients (23%) reported tobacco use, 20 (29%) had hypertension, and 6 (9%) had dyslipidemia. Six patients (6%) had a history of Achilles tendinopathy, and five patients (7%) had a history of ATR.

Of the 70 included patients, 46 (66%) underwent operative treatment and 24 (34%) received nonoperative management. A total of 53 patients (76%) achieved the clinical milestone of neutral dorsiflexion at six weeks following index treatment. Table 2 summarizes the demographic characteristics of the operative and nonoperative groups. There was a statistically significant difference in class 1 BMI, with a greater proportion of patients in the nonoperative group. All other variables were not statistically significant.

Table 3 outlines the univariate analysis evaluating associations between specific patient factors and achievement of the six-week dorsiflexion milestone. Operative treatment was the only variable with a statistically significant association with meeting six-week dorsiflexion (Odds Ratio [OR]: 5.48, 95% Confidence Interval [CI]: 1.51 – 22.01, $P < 0.01$). BMI class, smoking status, history of tendinopathy, and rupture history were not independently associated with achieving neutral dorsiflexion at six weeks.

Multivariate analysis was performed to assess the influence of age, sex, hypertension, and operative management on achieving six-week dorsiflexion (Table 4). When controlling for these factors, operative management remained statistically associated with an increased likelihood of attaining neutral dorsiflexion at six weeks (OR: 5.48, 95% CI: 1.66 – 19.9, $P < 0.01$).

DISCUSSION

The principal finding of this study was that operative management of acute ATR was independently associated with a higher likelihood of achieving neutral ankle dorsiflexion at the six-week follow-up visit. Restoration of neutral dorsiflexion represents a clinically meaningful early

rehabilitation milestone, as it often permits progression from protective immobilization and passive motion to strengthening, gait retraining, and functional rehabilitation.¹⁰ Although long-term outcomes after operative and nonoperative treatment have been shown to be comparable in contemporary literature, these findings suggest that operative treatment may facilitate earlier functional recovery by enabling more timely advancement of rehabilitation.^{5,11,12}

Early functional rehabilitation has become a cornerstone of modern ATR management.⁸ Prospective studies have shown that operative treatment allows for earlier recovery of calf strength and greater patient satisfaction compared with nonoperative treatment.¹² Although structural factors such as soleus muscle atrophy and tendon lengthening have been proposed as mechanisms underlying these differences, few studies have examined the influence of patient-specific factors on progression to functional rehabilitation.¹³ The present findings complement existing literature by identifying the influence of common patient-specific risk factors on a clearly defined functional milestone—early restoration of neutral ankle dorsiflexion. Although this study did not directly assess strength outcomes, earlier achievement of neutral dorsiflexion may allow rehabilitation to transition sooner from range-of-motion focused therapy to strengthening and functional exercises, potentially contributing to the early strength and performance differences reported in surgically treated patients.

Early weightbearing and controlled ankle motion are important components of rehabilitation after ATR, and the ability to progress from protective immobilization to weightbearing can improve short-term functional outcomes and patient satisfaction without increasing rerupture rates.¹³⁻¹⁵ Progression through these rehabilitation protocols remains contingent on achieving foundational range-of-motion thresholds. Neutral dorsiflexion serves as a key transition point and protective threshold at which therapists can safely initiate more aggressive strengthening and functional training.¹⁶ Patients who do not achieve this milestone may experience delayed rehabilitation progression despite adherence to standardized protocols.

The results of this study indicate that early restoration of neutral dorsiflexion was largely independent of most baseline patient characteristics. Variables commonly considered to impair recovery—including age, sex, BMI, smoking status, and cardiovascular comorbidities—were not significantly associated with failure to achieve neutral dorsiflexion at six weeks. This finding suggests that early range-of-motion recovery may be more modifiable by treatment strategy than by baseline patient factors. From a clinical perspective, this is particularly relevant when counseling patients with comorbidities who prioritize early functional recovery, as operative treatment may offer early rehabilitation advantages that are not

inherently limited by patient demographics or medical history. Although these potential benefits do not outweigh the inherent risks of surgery for individuals with significant comorbidities, they may support a more informed discussion of the expected outcomes and aid in shared decision-making regarding operative versus nonoperative management of ATR.

The ongoing debate regarding operative versus nonoperative treatment of ATR has traditionally focused on rerupture rates, complication profiles, and long-term patient-reported outcomes. Although accelerated functional rehabilitation has narrowed differences in these endpoints, early recovery trajectories remain highly relevant to both patients and providers.^{17,18} The present study suggests that early dorsiflexion recovery may represent an underappreciated factor influencing short-term recovery patterns and warrants consideration in shared decision-making.

Several limitations should be acknowledged. Baseline comparison between the operative and nonoperative cohorts demonstrated largely similar demographic and clinical characteristics, with the exception of a higher proportion of patients with normal BMI (18 – 25) in the nonoperative group (Table 2). While this suggests overall comparability between groups, it also reflects potential selection bias in treatment allocation inherent to the retrospective design. The retrospective design introduces the potential for selection bias, and all patients were treated by a single surgeon at a single institution, which may limit generalizability. Ankle range of motion was assessed clinically rather than with standardized goniometric measurements, and adherence to rehabilitation protocols could not be fully quantified. Additionally, although this study focused on a discrete early outcome, downstream strength and functional performance were not directly evaluated.

Despite these limitations, this study highlights the importance of early range-of-motion recovery following ATR and identifies operative management as a factor associated with achieving neutral dorsiflexion at six weeks. Moreover, the relative independence of early dorsiflexion recovery from most baseline patient characteristics suggests that early rehabilitation trajectories may be modifiable and not solely determined by patient comorbidity burden. Future prospective studies should examine whether early restoration of dorsiflexion mediates improvements in strength recovery, functional performance, and time to return to activity, thereby further informing patient-centered treatment decisions.

CONCLUSION

Operative treatment of acute ATR is independently associated with improved early recovery of ankle dorsiflexion, a clinically meaningful milestone that facilitates progression to strengthening and functional rehabilitation.

Notably, achievement of early dorsiflexion was largely independent of most baseline patient characteristics, indicating that early functional recovery is not solely dictated by patient demographics or comorbidities. For patients who prioritize early rehabilitation progression, operative management may therefore offer a tangible short-term advantage, even when long-term outcomes are expected to be similar.

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Insertion of an Internal Joint Stabilizer Through a Posterolateral Approach for the Management of Complex Elbow Instability

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ABSTRACT

Background: Complex elbow fracture-dislocations represent a substantial surgical challenge. Achieving adequate stability while permitting early postoperative motion is essential to prevent stiffness. The internal joint stabilizer (IJS) has emerged as an alternative to hinged external fixation, providing internal dynamic stabilization with improved patient tolerance and reduced risk of soft-tissue complications. Although the IJS is commonly inserted through a lateral approach, injuries involving multiple anatomical structures may necessitate broader exposure.

Purpose: To describe the surgical technique for IJS insertion through a posterolateral approach (PLA) for complex elbow injuries involving multiple anatomical structures.

Methods: The PLA provides extensile exposure to the posterior, lateral, and medial aspects of the elbow through a single incision. The approach uses the interval between the ulna and the anconeus muscle to assess the radiocapitellar and ulnohumeral joints. A structured sequence of reconstruction is followed. Coronoid fixation, radial head management, ligamentous reconstruction, and ulnar nerve decompression are performed before IJS assembly. Fluoroscopic guidance is used to ensure accurate placement of the central axis pin.

Results: The PLA facilitates single-incision management of complex elbow instability. Proper sequencing improves visualization and implant positioning, avoids interference among fixation elements, and supports a concentric ulnohumeral reduction. Once assembled, the IJS maintains stable reduction and permits controlled range of motion.

Conclusion: The PLA for IJS insertion is an effective technique for complex elbow injuries requiring access to multiple anatomical structures through a single incision. It facilitates efficient IJS placement, achieves stable fixation, and promotes early mobilization while minimizing complications associated with external fixation.

Keywords: Early Mobilization; Elbow Fracture; Upper Extremity

INTRODUCTION

Complex fracture-dislocations of the elbow represent some of the most challenging injuries encountered in upper extremity surgery.^{1,2} The elbow is the second most commonly dislocated major joint, and more than one quarter of all elbow dislocations are associated with fracture.³ The fundamental goal of operative treatment is to restore sufficient structural stability to permit early, controlled postoperative mobilization.^{4,5} Failure to initiate motion promptly after fixation markedly increases the risk of permanent joint stiffness, which remains the most frequent and functionally debilitating complication of these injuries.^{6,7}

The internal joint stabilizer ([IJS]; Skeletal Dynamics, Miami, FL) is a subcutaneous, hinged internal fixator designed to maintain concentric ulnohumeral reduction while allowing immediate, guided motion.⁸ The device has been shown to provide satisfactory clinical outcomes with low rates of

recurrent instability across a spectrum of unstable elbow injury patterns, including the terrible triad, Monteggia fracture-dislocation variants, and chronic dislocations.⁸⁻¹⁰ Comparative data suggest that the IJS offers similar functional outcomes to hinged external fixation while reducing soft-tissue complications and improving patient acceptance.¹¹

Although the IJS is most commonly inserted through a direct lateral approach – which is appropriate for most simple dislocations and radial head fracture-dislocations (Figure 1) – certain injury patterns require access to anterior and medial structures that cannot be adequately addressed through a limited lateral window alone.^{9,12} These include injuries with substantial coronoid fractures, medial collateral ligament (MCL) disruption requiring repair, or cases in which ulnar nerve decompression and transposition are indicated. In such circumstances, the posterolateral approach (PLA) provides a single, extensile exposure that

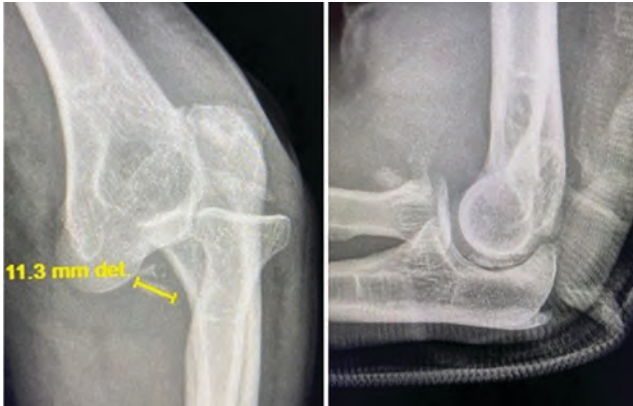


Figure 1. Anteroposterior view showing a complex elbow dislocation. Lateral radiograph after reduction demonstrating an articular fracture fragment.

allows all injured structures to be addressed before IJS implantation.

The purpose of this article was to describe the surgical technique for IJS insertion through the PLA, outline the indications for this approach, and detail the sequential reconstructive steps essential for safe and effective implant placement.

Indications and Contraindications

The PLA for IJS insertion is indicated in complex elbow fracture-dislocations requiring access to multiple anatomical structures that cannot be adequately managed through a standard lateral window. Specific indications include 1) coronoid fractures requiring direct fixation or capsular reattachment, 2) MCL injury necessitating repair, 3) ulnar nerve involvement requiring decompression or transposition, 4) injuries with combined medial and lateral structural disruption, and 5) cases in which broad, single-incision exposure facilitates efficient sequential reconstruction and IJS placement.

Relative contraindications include significant active skin or soft-tissue infection overlying the operative field, prior posterior incisions that may compromise wound healing, and injuries in which instability can be reliably managed through a standard lateral approach.

Surgical Anatomy

The PLA exploits the internervous plane between the anconeus (innervated by the radial nerve) and the subcutaneous border of the ulna. This interval provides access to the radiocapitellar joint, the lateral ulnohumeral articulation, and, when extended proximally by splitting the triceps tendon, the posterior distal humerus.¹³ Medial structures are accessible by elevating the soft-tissue envelope circumferentially around the distal humerus. The posterior interosseous nerve lies approximately 3 cm distal to the radiocapitellar joint when the forearm is in neutral rotation and must be protected during distal dissection.¹⁴ The ulnar nerve traverses the cubital tunnel at the medial epicondyle and requires identification and protection

throughout the procedure, particularly during drilling for the IJS central axis pin.

METHODS

Patient Positioning

The patient is positioned in the lateral decubitus position with support of the pelvis and thorax using a vacuum beanbag or lateral positioning device. An axillary roll is placed to protect the dependent brachial plexus. The arm is positioned in 90° of shoulder abduction and 90° of elbow flexion and supported on a padded Mayo stand, a pneumatic arm holder, or a well-leg holder from an orthopaedic fracture table. Alternatively, the patient may be positioned supine with the arm across the chest supported by a pneumatic arm holder or padded Mayo stand, which may facilitate fluoroscopic imaging.¹⁵

The surgeon stands posterior to the patient. The operative table should be adjusted to allow the surgeon to look directly down onto the elbow, optimizing visualization throughout the procedure. A platform or step stool may be required to achieve the appropriate working height. The fluoroscopy unit is positioned perpendicular to the arm to allow ready acquisition of true lateral projections; anteroposterior (AP) imaging requires lifting the arm and rotating the extremity 90°.

Incision and Approach

A midline posterior incision is made over the proximal forearm, curves laterally around the olecranon, and returns to the midline over the proximal arm. Full-thickness skin flaps are elevated medially and laterally to protect the cutaneous nerves and superficial venous drainage. Deep dissection proceeds through the interval between the lateral border of the ulna and the anconeus muscle. This plane is carried distally to expose the radiocapitellar joint and extended proximally by splitting the triceps tendon longitudinally to the degree required for visualization.

Subperiosteal dissection is performed around the radial neck using a small key elevator. This permits controlled subluxation of the radial head into the sigmoid notch for inspection, open reduction and internal fixation (ORIF), or excision in preparation for radial head arthroplasty. Excision of the radial head, when required, improves access to the lesser sigmoid notch, the coronoid process, and the anterior capsule. If the lateral collateral ligament (LCL) is intact, it may be released to enhance anterior exposure and is repaired at the conclusion of the case. Supination and internal rotation of the forearm further expose anterior structures, including the coronoid process and anterior capsule. Additional medial exposure, when required for MCL repair or ulnar nerve management, is obtained by elevating the medial soft-tissue envelope.

Ulnar Nerve Management

When medial access is required, the ulnar nerve is identified proximal to the medial epicondyle, decompressed through

the cubital tunnel, and protected throughout the procedure (Figure 2). Subcutaneous anterior transposition is performed at the surgeon's discretion based on the presence of pre-operative ulnar nerve symptoms, the degree of retraction required, and the risk of iatrogenic traction injury. The nerve must be identified and protected before drilling for the IJS central axis pin to prevent entry into the cubital tunnel and potential iatrogenic injury.

Sequential Reconstruction

Following adequate exposure, reconstruction proceeds from deep to superficial and from posterior to anterior, addressing the most difficult-to-reach structures first to optimize visualization before implant placement.

Coronoid fracture: If the coronoid fracture is large enough to contribute to instability, internal fixation is performed using posteroanterior screws or a buttress plate. Fractures classified as O'Driscoll type 1 (tip) may be addressed by capsular reattachment using drill holes placed through the anterior ulnar cortex and secured with high-tensile suture; these sutures are passed but not tied until the end of the case.^{16,17} Drill holes for capsular repair must be positioned so they do not interfere with subsequent screw placement for the IJS base plate.

IJS base plate and central axis pin: The IJS trochlear targeting guide is used to position the central axis pin through the center of rotation of the distal humerus. Fluoroscopic guidance in the lateral projection is used to confirm a "bull's-eye" position at the center of the capitellum and lateral epicondyle (Figures 3 & 4). The AP projection confirms that the axis pin transects the trochlea at its midpoint (Figure 5). Two-times magnification is recommended at this step to improve targeting accuracy. Once correct positioning is confirmed, the condyles are drilled and the axis pin is inserted. The medial cortex must not be breached with the guidewire or drill to avoid injury to the ulnar nerve if it has not been transposed (Figure 5). In the grossly unstable elbow, the joint may be temporarily dislocated to facilitate jig application and starting-point identification without fluoroscopy before reduction for definitive pin placement (Figure 6).

Base plate assembly: The coronoid screw is placed through the base plate first, as the adjacent capsular-repair drill holes are in close proximity and their relative positioning is critical. The olecranon tip screw is applied next, followed by the distal shaft screw.

Radial head management: Radial head ORIF or arthroplasty is completed after the base plate is secured. The radial head component should not be inserted before the ulnar base-plate screws are placed, as the arthroplasty stem obstructs the fluoroscopic images required for accurate screw positioning and capsular repair drill-hole placement.

Capsular and ligamentous repair: After reduction of both the radiocapitellar and ulnohumeral joints, the previously

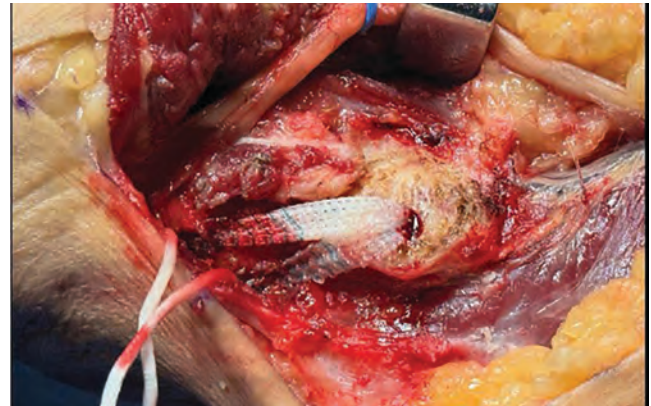


Figure 2. Medial approach to the elbow with anterior transposition of the ulnar nerve. Suture-construct reconstruction of medial collateral ligament



Figure 3. Lateral radiograph showing the internal joint stabilizer trochlear targeting guide in position. Fluoroscopic confirmation on the lateral projection demonstrating the "bull's-eye" appearance at the lateral epicondyle/capitellum.

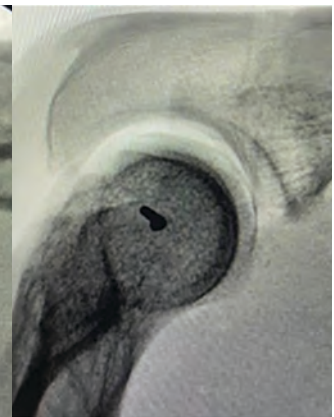


Figure 4. Lateral fluoroscopic image confirming the "bull's-eye" position of the central axis pin at the center of rotation of the distal humerus.

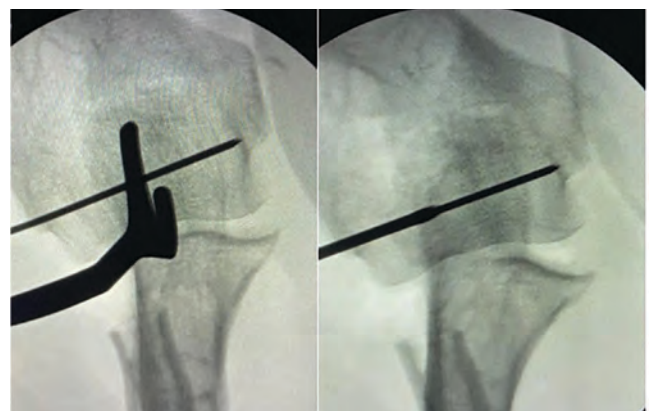


Figure 5. Anteroposterior fluoroscopic image confirming that the axis pin transects the trochlea at its midpoint using the trochlear guide. Symmetric pin position is required to ensure proper hinge-axis alignment.

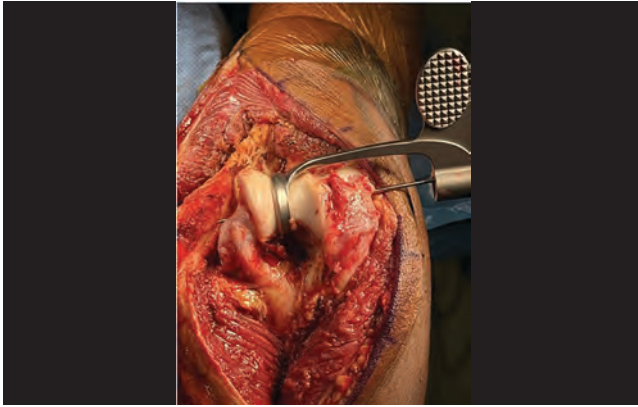


Figure 6. Technique for the grossly unstable elbow. The joint is temporarily dislocated to facilitate application of the targeting jig. Closed reduction is achieved before definitive pin insertion under fluoroscopic control.

placed anterior capsular sutures are tied. The LCL and MCL are repaired using bone-tunnel techniques at the lateral and medial epicondyles, respectively. The integrity of these repairs is confirmed through intraoperative range-of-motion assessment.

IJS Assembly and Final Assessment

With all osseous and soft-tissue repairs complete, the IJS is assembled. The shoulder is positioned at 90° of abduction with the forearm in supination and the elbow at 90° of flexion to facilitate reduction. Axial compression is applied across the olecranon and all hinge components are locked. The elbow is taken through a full arc of motion under live fluoroscopic imaging to confirm concentric reduction, absence of impingement, and smooth mechanical function throughout the range of motion.

Wound Closure

A meticulous layered closure is performed. Given the extensive soft-tissue exposure and the irrigation required for these complex reconstructions, an incisional negative-pressure wound therapy (NPWT) device is routinely applied to reduce wound complications and promote primary healing.

Postoperative Management

Active-assisted range of motion is initiated on the first postoperative day under the supervision of a hand therapist, consistent with the primary therapeutic objective of early mobilization. A splint is used for comfort between exercise sessions during the first two weeks. The IJS is typically removed at a second procedure approximately four months to six months postoperatively, once adequate stability has been confirmed clinically and radiographically.⁸⁻¹⁰

RESULTS

Use of the PLA enabled comprehensive single-incision exposure of the lateral, posterior, and medial elbow,

facilitating sequential reconstruction of all injured structures before IJS assembly. Adherence to a structured deep-to-superficial sequence improved visualization and minimized interference between fixation elements. Placement of the ulnar base plate before radial head arthroplasty allowed unobstructed fluoroscopic assessment, supporting accurate screw positioning and capsular-repair placement.

Precise central axis pin-placement using biplanar fluoroscopy reliably achieved a concentric ulnohumeral reduction. In cases of gross instability, temporary dislocation of the joint facilitated accurate jig application and starting-point identification before definitive pin insertion. Protection of the ulnar nerve during medial dissection and drilling prevented iatrogenic injury, particularly in cases with limited visualization.

Meticulous soft-tissue handling and maintenance of a posterior skin bridge reduced wound complications despite the extensile exposure. Collectively, these technical factors resulted in stable fixation and permitted early, controlled postoperative range of motion.

Pearls and Pitfalls

Sequence matters: Reconstruction must proceed from deep to superficial. Placing the radial head arthroplasty before the base-plate screws obstruct the fluoroscopic images needed for accurate ulnar fixation, representing a critical technical error.

Capsular-repair drill holes: These must be placed before the base plate is definitively secured. Their location in proximity to the coronoid screw requires careful preplanning to avoid interference.

Axis-pin placement: Two-times magnification and unobstructed biplanar fluoroscopy are strongly recommended. The “bull’s-eye” on the lateral view and a midtrochlear position on the AP view are nonnegotiable before drilling.

Grossly unstable elbow: Temporary dislocation to apply the jig is a reliable technique when reduction cannot be maintained. Reduction is then achieved before final pin insertion under fluoroscopy.

Ulnar nerve protection: The medial cortex must not be penetrated with the drill or guidewire unless the ulnar nerve has been transposed and protected. This risk is highest in patients with obesity or those with limited medial visualization.

Soft-tissue handling: The PLA is extensile but not forgiving of rough technique. Gentle retraction, preservation of the posterior skin bridge, and routine incisional NPWT substantially reduce wound complications.

DISCUSSION

The primary challenge in the operative management of complex elbow fracture-dislocations is achieving sufficient stability to permit early motion while addressing all

contributing structural injuries.^{1,4,5} Stiffness remains the dominant long-term complication, and delay in initiating postoperative range of motion substantially worsens functional outcomes.^{6,7} The IJS addresses this dilemma by providing dynamic internal stabilization of the ulnohumeral joint while allowing immediate, controlled motion—an advantage recognized across multiple clinical series.⁸⁻¹¹

The standard lateral approach to IJS insertion is well suited to simple dislocations and radial head fracture-dislocations in which the medial structures do not require direct repair. However, complex injuries—particularly those involving substantial coronoid fractures, MCL disruption, or ulnar nerve pathology—benefit from the extensile access afforded by the PLA.^{9,12} A single posterior incision provides simultaneous access to the lateral, posterior, and medial aspects of the elbow, avoiding the need for multiple incisions and their attendant risks.

The importance of coronoid restoration in complex elbow instability is well established. O'Driscoll's classification of coronoid fractures by anatomical subtype—tip, anteromedial, and basal—guides surgical decision-making regarding fixation strategy.^{16,17} Tip fractures (type 1) in the setting of a terrible triad injury may be managed by anterior capsular reattachment when the fragment is too small for screw fixation.¹⁷ Larger anteromedial and basal fractures require direct buttress plating or posteroanterior screw fixation. The PLA, particularly after radial head excision, provides the exposure necessary to address each of these fracture subtypes.

MCL repair has been a subject of ongoing debate in the terrible triad literature. Current evidence supports a selective approach in which the MCL is repaired only when the elbow demonstrates residual instability after lateral reconstruction.^{5,18} The PLA facilitates this assessment by providing immediate access to medial structures should intraoperative instability testing indicate the need for MCL repair or augmentation.

The strict sequence of reconstruction described in this report is not arbitrary. Placing the radial head arthroplasty before the ulnar base-plate screws introduces fluoroscopic obstruction that compromises accurate coronoid screw placement and capsular-repair-drill-hole positioning. The sequence—coronoid, base plate, arthroplasty, capsular repair, LCL/MCL, and IJS assembly—has been developed through clinical experience to optimize visualization, minimize technical conflicts, and ensure anatomic restoration at each step before advancing to the next.

The present report is a technical description and is subject to the inherent limitations of technique articles, including the absence of prospective outcomes data and quantitative functional measures for this specific approach. Future comparative studies examining functional outcomes, complication rates, and operating time for the PLA versus

the standard lateral approach in matched injury patterns would further define the role of this technique. In conclusion, the PLA for IJS insertion is a versatile and reliable technique for complex elbow instability requiring access to multiple anatomical structures through a single incision. Its principal advantage lies in providing an organized, extensile exposure that enables sequential, anatomic reconstruction of all injured structures before IJS assembly. Strict adherence to the reconstructive sequence described herein is essential to avoid technical conflicts and to achieve a stable, concentrically reduced elbow that tolerates early postoperative motion. When applied with meticulous technique and appropriate indications, this approach simplifies the management of otherwise demanding elbow reconstructions and supports the overarching goal of stable, early functional rehabilitation.

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Popliteus Interposition in Metaphyseal Tibial Fractures: The Radiographic Clues That Cannot Be Missed

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

ABSTRACT

High-energy proximal tibia fractures present significant challenges for orthopaedic surgeons, with well-recognized risks including malreduction and nonunion. Although double plating through two mini-open parallel incisions is an established technique for selected patients, nonunion can still occur. One potential contributing factor is entrapment of the popliteus muscle within the distal spike of the posteromedial plateau fragment. This report uses illustrative cases to demonstrate how to identify, address, and prevent this complication. Strategies for managing delayed cases that progress to nonunion are also discussed.

Keywords: Knee Injury; Orthopedic Surgery; Pseudoarthrosis; Tibial Plateau Fracture

INTRODUCTION

Tibial plateau fractures represent approximately 1% of all adult fractures. The primary goals of treatment are to achieve bone healing, restore alignment, and optimize functional recovery. Nonunion is an uncommon complication, occurring in roughly 4% of cases, and is most often associated with technical factors.^{1,2}

This case report describes popliteus muscle entrapment within the posteromedial tibial fracture fragment, resulting in malreduction and, in some instances, nonunion. The authors present four cases in which the popliteus muscle became interposed between the beak of the posteromedial fragment and the tibial diaphysis, leading to posterior fragment malreduction or failure of union. The objective is to increase surgeon awareness of this potential pitfall when managing these fractures.

CASE REPORT

Case 1

A 35-year-old woman sustained injuries in a motorcycle crash. During surgical treatment of her proximal tibia fracture, indirect reduction of the posterior fragment using manual traction was unsuccessful. A limited posteromedial approach allowed removal of the interposed popliteus muscle and resulted in an anatomic reduction of the fragment (Figure 1).

Case 3

A 31-year-old woman was involved in a motorcycle crash. During surgical management of a Schatzker VI fracture of the right tibial plateau, a small interposition of the distal muscular portion of the popliteus hindered anatomic indirect reduction. To address this, a limited posteromedial approach was performed to remove the interposed muscle, enabling an anatomic reduction (Figure 2).

Case 2

A 37-year-old woman presented to this facility one year after surgical fixation of a Schatzker VI fracture of the right proximal tibia, reporting pain with weightbearing. Computed tomography imaging demonstrated a proximal tibial nonunion associated with soft-tissue interposition. Intraoperatively, the popliteus muscle belly was found to be entrapped within the fracture site. The muscle was released, and a structured autogenous iliac crest bone graft was used to fill the nonunion defect (Figure 3).

Case 4

A 44-year-old woman was involved in a motorcycle crash, resulting in an open Schatzker VI fracture of the left tibial plateau associated with an extensor mechanism rupture. The emergency team performed single-stage management of both injuries. She subsequently developed pain with weightbearing, and hardware removal was performed 13 months after the initial procedure; however, her

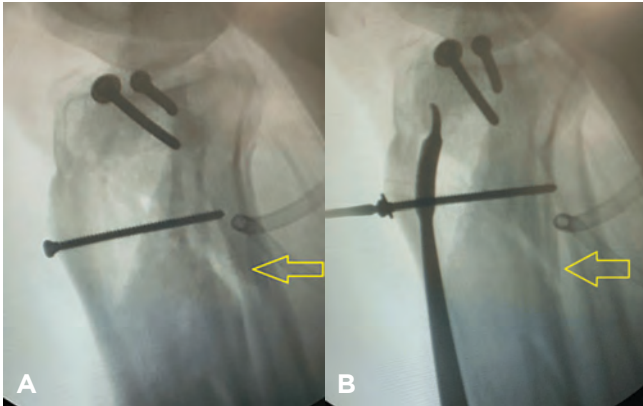


Figure 1. (A) The arrow highlights the posteromedial fragment that remained unreduced due to popliteus muscle entrapment; (B) The yellow arrow indicates the anatomically reduced fragment after removal of the interposed popliteus muscle belly.

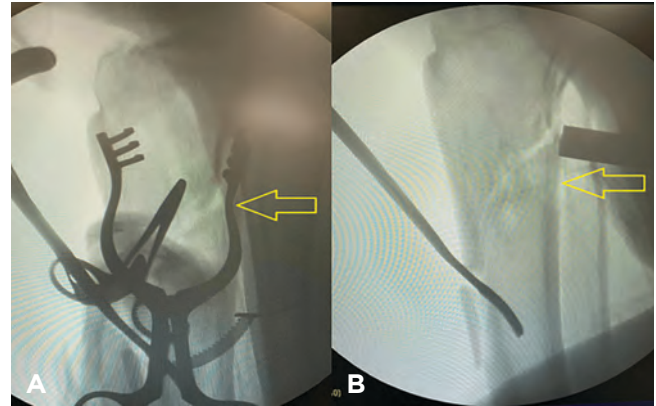


Figure 2. (A) The arrow indicates the radiographic gap caused by popliteus muscle interposition within the fracture. (B) The yellow arrow highlights the reduced fracture after removal of the muscle belly.

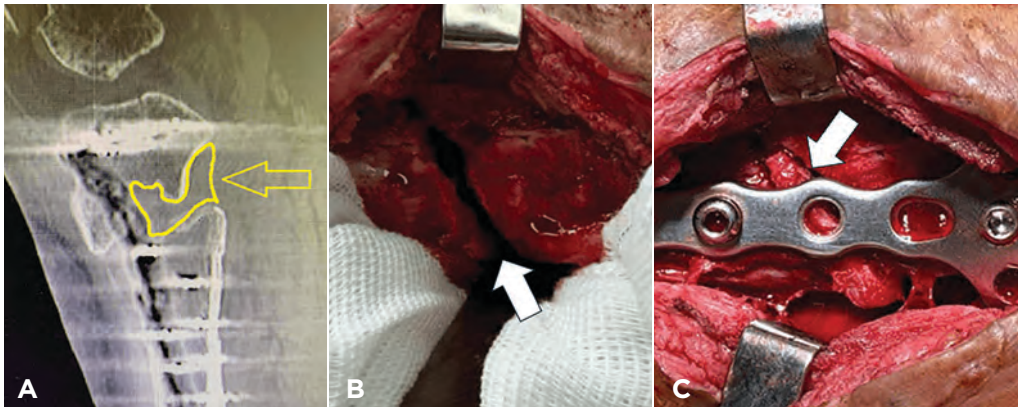


Figure 3. (A) Computed tomography (CT) sagittal view – the yellow line delineates the nonunion area caused by the popliteus muscle interposition; (B) Nonunion gap after removal of the entrapped popliteus muscle; (C) Intraoperative view showing the iliac crest autograft and proximal tibia plate.

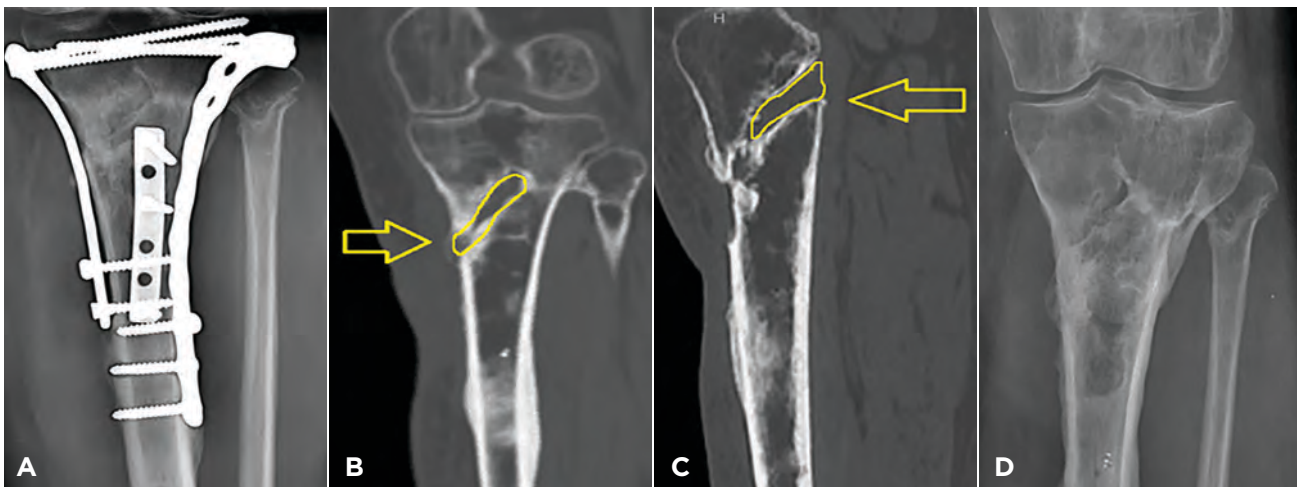


Figure 4. (A) Thirteen-month postoperative radiograph indicating misdiagnosed fracture healing; (B) Coronal CT image illustrating entrapment of the popliteus muscle belly (highlighted in yellow); (C) Sagittal CT image showing the nonunion region delineated by the popliteus muscle (yellow area); (D) Follow-up radiograph six months after iliac crest grafting with press-fit fixation, no hardware was required.

symptoms persisted. Surgical revision revealed interposition of the muscular portion of the popliteus, resulting in nonunion. Revision surgery involved removal of the interposed tissue and placement of a structured iliac crest autograft, which achieved a stable press-fit fixation without the need for additional hardware and resulted in fracture union with resolution of symptoms (Figure 4).

DISCUSSION

The popliteus muscle tendon originates in the lateral femoral condyle, passes beneath the lateral collateral ligament, and attaches to the fibular head via the popliteofibular ligament. Its muscular portion crosses medially across the posterior wall of the tibia and inserts above the soleus line.

Restoration of limb alignment and articular congruity are key goals in the treatment of tibial plateau fractures, as malalignment of the mechanical axis increases compartmental loading and predisposes patients to post-traumatic osteoarthritis. Sagittal plane alignment and precise apposition of bone fragments are also critical to promote union.³ During indirect reduction of proximal tibia fractures, surgeons must recognize the potential challenge posed by Schatzker VI injuries—specifically, when the fracture line traverses the posteromedial region and the popliteus muscle becomes entrapped between fragments. If unrecognized, the entrapment may lead to nonunion, necessitate additional surgical procedures, and increase healthcare costs. Radiographic clues include a fracture line extending to the posterior cortex of the proximal tibia and a radiographic gap on the lateral view during traction. In cases of nonunion, soft-tissue interposition may also be visible within the fracture gap.

Multiple strategies have been described for the surgical management of high-energy proximal tibia fractures. Debate persists regarding whether these complex fractures are best treated with fragment-specific open reduction using multiple approaches or with indirect reduction and minimally invasive fixation.⁴ The authors describe entrapment of the popliteus muscle belly within the posteromedial fragment as a potential cause of malreduction or nonunion among those patients.

A small posteromedial approach, which can be performed with the patient in the supine position and the hip externally rotated, allows removal of the entrapped tissue and facilitates anatomic reduction.⁵ The inferomedial branch of the saphenous nerve and the great saphenous vein are the primary structures at risk and should be clearly identified and protected under direct visualization. The pes anserinus tendons are retracted anteriorly, and the medial gastrocnemius is retracted posteriorly. Within this interval, the soleus and popliteus muscles are identified and released from the fracture site.

Interposition of the popliteus muscle belly may contribute to nonunion in Schatzker VI tibial plateau fractures. Recognition of radiographic indicators of this complication can prompt surgeons to consider an additional posteromedial approach to adequately address the issue and reduce the risk of further complications.

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Exploring the Interaction Between Cranial Nerves V and VII in Chronic Eyelid Myokymia: A Case Report

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Conflict of Interest The authors report no conflicts of interest.

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

ABSTRACT

Eyelid myokymia involves involuntary contractions of the orbicularis oculi muscle and is commonly associated with stress, fatigue, and craniocervical factors. Emerging evidence suggests that altered trigeminocervical interactions and craniomandibular muscle tension may contribute to symptom persistence; however, the condition remains underrecognized in physical therapy. This report describes a 65-year-old woman with chronic benign eyelid myokymia and cervical pain who completed 12 physical therapy sessions that included suboccipital functional dry needling, temporomandibular soft-tissue mobilization (STM), and cervical stabilization exercises. A reduction in eyelid myokymia was first observed at the fifth visit, coinciding with the initiation of temporomandibular STM. These findings suggest that addressing temporomandibular soft-tissue dysfunction may influence eyelid myokymia through modulation of trigeminal-facial nerve interactions, supporting the need for further investigation into neuro-musculoskeletal treatment approaches.

Keywords: Cranial Nerve V; Cranial Nerve VII; Dry Needling; Myokymia; Physical Therapy; TMJ

INTRODUCTION

Eyelid myokymia is a benign condition characterized by involuntary, rapid, and intermittent contractions of the orbicularis oculi muscle, commonly referred to as eyelid twitching.¹ Common triggers include stress, fatigue, caffeine or alcohol consumption, and sleep deprivation.² Its frequent occurrence in high-stress populations has led to the colloquial term “medical students’ disease,” as individuals in training often experience high stress levels.³ Although the condition is generally transient, persistent or recurrent cases may cause distress and functional distractions. The literature on benign eyelid myokymia within physical therapy (PT) is limited; therefore, exploring potential neuroanatomical relationships may help explain symptom patterns and therapeutic responses.⁴ Because treatment of eyelid myokymia in PT is also uncommon, establishing consistent symptom patterns and therapeutic responses remains challenging.⁵

The trigeminocervical nucleus receives afferent input from the trigeminal nerve (cranial nerve [CN] V) and the upper cervical spinal levels (C1–C3), creating a functional connection between the CN V and the upper cervical spine.⁶ This neural convergence provides a pathway

through which cervical and cranial dysfunction may influence cranial nerve excitability and sensorimotor control. The suboccipital musculature, innervated by the dorsal ramus of C1, contributes to proprioceptive input within this network. This also provides a neuroanatomical basis for cervicogenic headaches originating in the suboccipital region, which are often a result of increased muscular tension of the suboccipital musculature.⁷ These neuroanatomical connections between cranial and cervical pathways help explain overlapping symptoms.

The orbicularis oculi muscle, responsible for eyelid closure, is innervated by the facial nerve (CN VII).⁸ CN V and CN VII are linked through shared-blink reflex circuitry, with CN V providing afferent sensory input and CN VII mediating efferent motor output.^{9–11} The temporomandibular joint (TMJ) and associated musculature (masseter, temporalis, and pterygoids) are innervated by branches of CN V and contribute substantially to trigeminal proprioceptive input.^{10,11} Abnormal TMJ mechanics or increased masticatory muscle tension may enhance afferent signaling and promote central sensitization within the trigeminal pathway, thereby influencing facial motor output.¹² Given the shared reflex circuitry and superficial branch connections between CN V and CN VII, disturbances in trigeminal

or upper cervical input could theoretically alter facial motor output and contribute to eyelid myokymia.

Despite these potential interconnections, eyelid myokymia remains underrecognized. Exploring the relationship among cervical mobility, trigeminal input, and facial nerve activity may offer new insight into conservative management approaches. This report aims to generate hypotheses regarding CN V and CN VII neural interactions within the context of PT rehabilitation.

CASE REPORT

A 65-year-old woman presented to PT with a two-week history of acute, sharp, intermittent left-sided neck and shoulder pain, primarily in the upper trapezius (UT) region, with concurrent left eyelid myokymia ongoing for approximately nine months. The myokymia was intermittent, more frequent during periods of high stress, and not associated with visual disturbances. The patient denied alcohol intake or fatigue and reported only minimal caffeine intake (1 cup of coffee daily). Neurologic and ophthalmologic evaluations were unremarkable, and dental evaluation noted primarily left-sided teeth bruxism.

Objective examination revealed decreased strength in bilateral shoulders and reduced deep neck flexor endurance testing. Shoulder and cervical range of motion were within normal limits and symmetrical. Mild cervical and thoracic joint hypermobility was noted. Palpation demonstrated left-sided tenderness over the sternocleidomastoid (SCM), scalenus, UT, cervical erector spinae, and suboccipital musculature. The Neck Disability Index (NDI) score was 18/50 at initial evaluation, indicating mild functional limitation.

Treatment

The patient attended 12 PT sessions over 12 weeks, initially focused on alleviating cervical symptoms and exploring potential factors contributing to the myokymia. Early treatment emphasized symptom modulation, including functional dry needling (FDN) of the UT, SCM, and suboccipital musculature, combined with electrical stimulation (Figure 1). Adjunctive interventions included therapeutic exercise targeting cervical, scapulothoracic, and rotator cuff stability.

By the fifth visit, the patient reported significant improvement in cervical and shoulder symptoms; however, the myokymia remained unaffected. Given the anatomical and neuromuscular connections between the TMJ and facial musculature, TMJ STM was initiated, targeting the lateral pterygoid, masseter, and temporalis muscles. Following the introduction of TMJ-focused intervention, the patient reported an immediate decrease in eyelid myokymia, and this technique was incorporated at each subsequent visit until discharge. Refer to Appendix 1 for a full list of treatments provided during each visit.

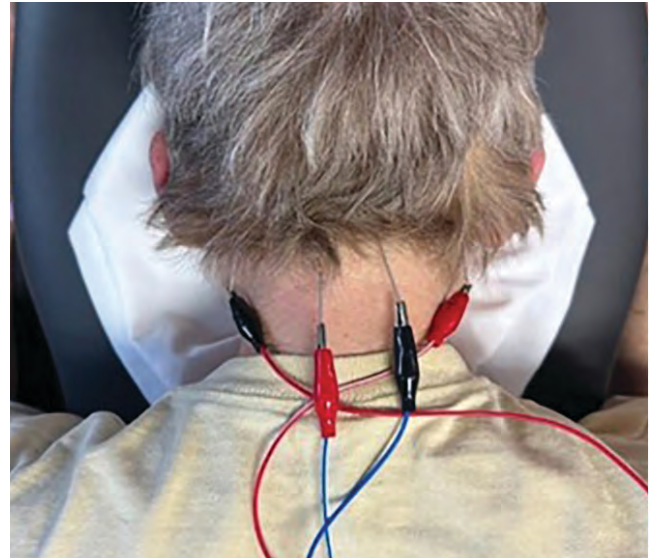


Figure 1. Suboccipital FDN technique combined with electrical stimulation.

Outcome & Follow-Up

At discharge, the patient demonstrated significant subjective and objective improvement. Deep neck flexor endurance increased from 20 seconds at the initial evaluation to 30 seconds at discharge, consistent with normative values for adult women.¹³ The NDI score improved from 18/50 to 0/50, representing a clinically and statistically significant change.¹⁴

Eyelid myokymia symptoms decreased progressively after TMJ STM was introduced. The patient reported a 50% reduction in eyelid twitching both in intensity and frequency compared with baseline. She noticed this improvement particularly during early morning and late evening hours, when symptoms had previously been most pronounced. The patient also noted reduced jaw clenching and decreased bruxism.

No adverse events were reported, and she maintained a regular home exercise program (HEP). At one-month follow-up, the patient reported continued reduction of myokymia and no cervical symptoms.

DISCUSSION

This case describes the improvement of chronic eyelid myokymia symptoms following a combined intervention of FDN, and TMJ STM with adjunct cervicothoracic and scapular stability exercises. The patient reported the greatest reduction in eyelid twitching after STM and was directed to the TMJ region, suggesting that addressing masticatory muscle tension may have contributed to improved neuromuscular control of the orbicularis oculi. The patient denied any changes in caffeine or alcohol consumption, stress, or fatigue/sleep schedule throughout the course of treatment, making it unlikely that these factors contributed significantly to her symptom improvement. A plausible explanation involves modulation of the

trigemino-cervical and trigeminal-facial pathways. CN V mediates blink-reflex afferents, whereas CN VII provides efferent output to the orbicularis oculi. Shared central integration within the brainstem may allow peripheral changes in trigeminal input, such as reduced mechanical tension or altered proprioceptive feedback, to influence facial motor output. Although speculative, this concept aligns with evidence linking trigeminal irritation and suboccipital muscle hypertonicity to increased cranial nerve excitability and altered sensorimotor processing.¹⁵

An alternative explanation is that symptom reduction resulted from decreased muscle tension, which is a recognized contributor to eyelid myokymia.^{3,4} The addition of TMJ-focused manual therapy may have provided sensory input that enhanced relaxation, improved local circulation, or modified central pain and motor control mechanisms. Regardless of the precise mechanism, the temporal relationship between treatment and symptom change supports the potential clinical relevance of addressing cervical and TMJ dysfunction in similar presentations.

This single case cannot establish causality, and symptom improvement may reflect spontaneous resolution or nonspecific therapeutic effects. Interpretation of the findings is further limited by the absence of validated outcome measures for eyelid myokymia, with symptom changes based primarily on subjective patient report rather than objective assessment. Although this represents a methodological limitation, patient-reported outcomes are a core component of PT practice, and in this case the patient reported a high level of satisfaction with both the intervention and the outcomes. Future research would benefit from developing and validating objective measures to quantify eyelid myokymia symptoms, such as surface electromyography or standardized symptom diaries, to enhance data objectivity. Until such tools exist, clinicians must rely on patient-reported outcomes in the absence of established objective measures. Despite these limitations, this case offers an early clinical observation that supports further investigation of the trigeminal-facial connection within neuromusculoskeletal rehabilitation.

Learning Points

- Eyelid myokymia may have a neuromusculoskeletal component, particularly related to temporomandibular and cervical spine.
- TMJ STM may reduce trigeminal nerve tension and indirectly modulate facial nerve excitability.
- PT assessment of the cervical and craniofacial region may provide additional insight when medical and neurological evaluations are unremarkable in patients with myokymia.
- Potential benefits of a PT approach in managing atypical neuromuscular presentations such as eyelid myokymia, emphasizes the importance of timely referral to PT when such presentations occur.

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Appendix 1. Treatment intervention details and therapeutic exercise (progressed per patient tolerance).

Visit	Manual Therapy / TMJ & Cervical STM	Functional Dry Needling (FDN)	Therapeutic Exercise / HEP (Adjunctive)	Other Interventions
	--	Needle Sizes & Placement Standardized Needle Sizes & Target Muscles: <ul style="list-style-type: none"> • Upper trapezius: 0.3 × 40 mm • Sternocleidomastoid (SCM): 0.3 × 30 mm • Suboccipitals – rectus capitis posterior minor and obliquus capitis superior: 0.3 × 30 mm • Medial & lateral pterygoid: 0.3 × 30 mm • Masseter: 0.3 × 30 mm 	--	--
1	--	--	Initial HEP Prescription: <ul style="list-style-type: none"> • Supine chin tuck • Serratus anterior activation at wall • Low trapezius setting at wall • Standing shoulder horizontal abduction with resistance 	Cervical manual distraction, OA / AA MET
2	STM / TPR bilateral UT	Threading Technique: UT (bilateral)	Warm-up: <ul style="list-style-type: none"> • NuStep × 10 min Exercise: <ul style="list-style-type: none"> • Semi-plank scapular stabilization • HEP review 	Cervical manual distraction, OA / AA MET
3	STM / TPR bilateral UT, L SCM, bilateral suboccipitals (4 needles), orbicularis oculi	Threading Technique: UT (bilateral) + L SCM Direct Technique (with e-stim): Bilateral suboccipitals (4 needles)	Warm-up: <ul style="list-style-type: none"> • NuStep × 10 min Exercise: <ul style="list-style-type: none"> • Standing shoulder press • Semi-plank stabilization • Prone mid / lower trapezius activation 	Cervical manual distraction, OA / AA MET
4	STM / TPR bilateral UT, L SCM, bilateral suboccipitals (4 needles), orbicularis oculi	Direct Technique (with e-stim): Bilateral suboccipitals (4 needles)	Warm-up: <ul style="list-style-type: none"> • UE ergometer: 5 minutes in forward direction, 5 minutes in backward direction Exercise: <ul style="list-style-type: none"> • Standing shoulder press • Body Blade stabilization • Circular stabilization drills 	Cervical manual distraction, OA / AA MET
5	STM / TPR bilateral UT, L SCM, bilateral suboccipitals (4 needles), orbicularis oculi Intraoral STM / TPR: medial and lateral pterygoid and masseter	Threading Technique: UT (bilateral) + L SCM Direct Technique (with e-stim): Bilateral suboccipitals (4 needles)	Warm-up: <ul style="list-style-type: none"> • UE ergometer: 5 minutes in forward direction, 5 minutes in backward direction 	Cervical manual distraction, OA / AA MET
6-12	STM / TPR bilateral UT, L SCM, bilateral suboccipitals (4 needles), orbicularis oculi Intraoral STM / T PR: medial and lateral pterygoid and masseter	Threading Technique: <ul style="list-style-type: none"> • Visit 6: UT (bilateral) + L SCM • Visit 7: UT (bilateral) • Visit 8: UT (bilateral) • Visit 10: UT (bilateral) • Visit 11: UT (bilateral) • Visit 12: UT (L) + L SCM Direct Technique (with e-stim): Bilateral suboccipitals (4 needles)	Warm-up: <ul style="list-style-type: none"> • UE ergometer: 5 minutes in forward direction, 5 minutes in backward direction Exercise & HEP Progression: <ul style="list-style-type: none"> • Supine chin tuck • Low trapezius setting • Serratus anterior activation • Resisted shoulder exercises • Chin tuck with biofeedback • Prone I's • Quadruped alternating UE lift • Standing Y lift 	Cervical manual distraction, OA / AA MET

Massive Upper Extremity Neurofibroma Treated with Limb-Sparing Debulking: A Case Report

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Conflict of Interest The authors report no conflicts of interest.

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

ABSTRACT

Surgical management of neurofibromas in Neurofibromatosis type 1 (Von Recklinghausen's disease), can be challenging because tumor size, location, hypervascularity, and tissue friability pose the risk for significant intraoperative and postoperative blood loss. Despite these risks, surgery is often necessary because of functional losses or cosmetic concerns. The authors present a 31-year-old woman with a massive neurofibroma on her right distal forearm, wrist, and hand, who ultimately underwent surgical resection because of functional impairment of her hand. She required postoperative hospitalization and blood transfusion for management of acute blood loss anemia. Because of concerns regarding blood loss and surgical morbidity, the patient underwent staged debulking of the mass. This case is notable for the sheer size of the mass and underscores the importance of preparing for extensive intraoperative blood loss prior to the surgical management of neurofibromas.

Keywords: Forearm; Hemostasis; Neurofibroma; Wrist

INTRODUCTION

Neurofibromatosis type 1 (NF1) is an autosomal-dominant disease that affects approximately 1 in 3000 individuals.^{1,2} NF1 results from the loss of the tumor suppressor neurofibromin, leading to disordered neuronal cell growth along peripheral nerves.¹⁻³ Symptoms include café au lait macules, benign neurofibromas, and iris hamartomas.¹ Another feature is vascular lesions of medium and large arteries, which can result in aneurysms, stenosis, and arteriovenous malformations.⁴ Resection of neurofibromas for functional compromise or cosmetic concerns can result in significant perioperative bleeding because of the hypervascularity and tissue friability within the neurofibroma.^{2,3} This blood loss often necessitates transfusion, longer hospitalization, delayed wound healing, or additional surgical procedures.^{2,3,5} Although nonsurgical management options such as radiation, chemotherapy, and gene therapy exist, surgical debridement remains the most effective treatment for massive neurofibromas, despite the high risk of complications.⁵

The authors present a 31-year-old woman who underwent surgical debulking of a massive neurofibroma on the upper right extremity. This case is notable for the size of the mass and underscores the importance of surgical planning of intraoperative blood loss.

CASE REPORT

A 31-year-old woman with NF1 presented with a massive neurofibroma enveloping the right dorsal hand and wrist.

Present since birth, the mass had been debulked 23 years earlier but continued to grow. She reported forearm and hand pain, numbness in each digit, and difficulty using the hand for activities of daily living. On examination, a 36cm x 20cm x 10cm multilobulated mass encompassed the dorsum of the hand, wrist, and distal forearm (Figure 1). Her resting wrist position was flexed because of the mass effect. Active wrist extension was limited to neutral, with no limit to digital flexion or extension. There was no neurovascular compromise to the hand. Magnetic resonance imaging (MRI) of the mass confirmed a large plexiform neurofibroma involving the dorsal right distal forearm, wrist, and hand with destruction of the carpus (Figure 2). The patient desired surgical treatment. Because of the size of the mass, the surgical team discussed that complete mass excision would require amputation; however, the patient wished to pursue debulking. An intralesional, multi-staged debulking of the tumor was initiated.

Stage One: Dorsal Forearm/Wrist

Under tourniquet, a large ellipse was excised from the dorsal aspect of the hand and wrist and the extensor tendons were identified proximal to the mass and protected. Electrocautery dissection was used within the mass, and large feeding vessels were ligated with suture. The mass was excised from the extensor tendons and the wrist joint capsule; however, it was noted that the mass extended into the radiocarpal joint, abutting the cartilage and distorting the carpal bones. Extensive excision of the mass

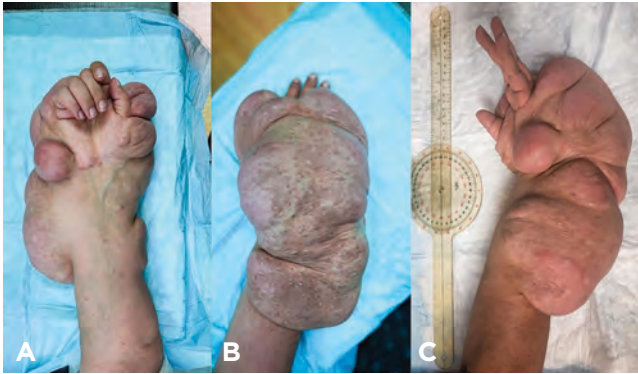


Figure 1. (A) Preoperative volar, (B) dorsal, and (C) lateral photographs of the extensive neurofibroma.

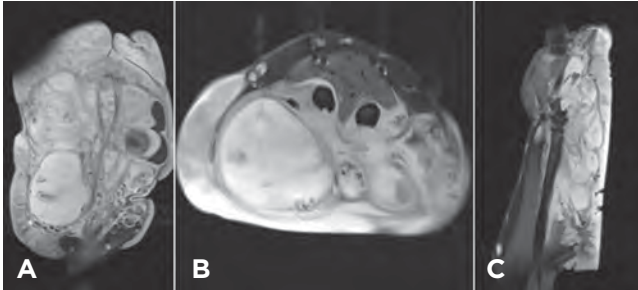


Figure 2. (A) Coronal, (B) axial, and (C) sagittal MRI slices of the neurofibroma, with measurements of 18cm x 24.5cm, 17cm x 10cm, and 26cm x 7cm, respectively.



Figure 3. (A) Volar, (B) dorsal, and (C) lateral photographs of the hand post-first stage forearm debulking.

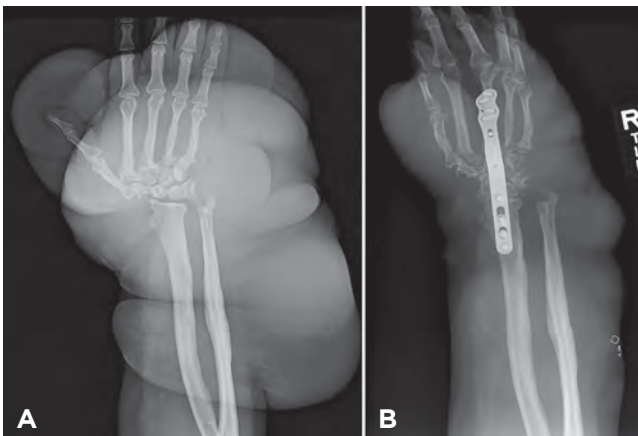


Figure 4. (A) Preoperative and postoperative anteroposterior or wrist radiographs showing carpal instability secondary to tumor burden and (B) subsequent wrist fusion.

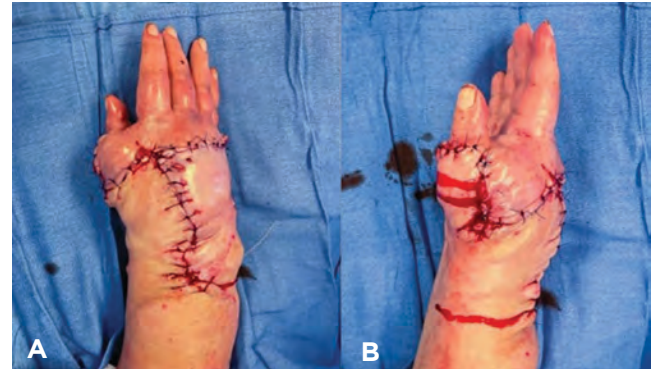


Figure 5. (A) Intraoperative dorsal and (B) lateral photographs after the second, hand debulking, stage.

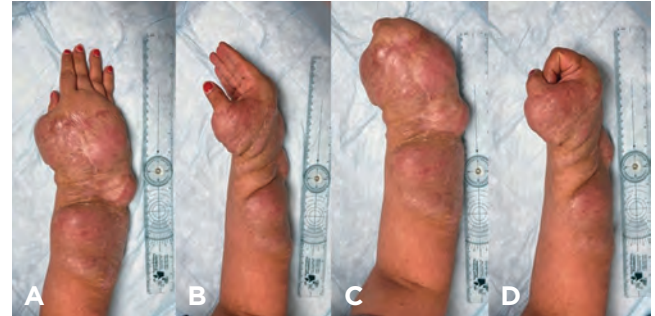


Figure 6. (A) Resting dorsal, (B) resting lateral, (C) full flexion dorsal, and (D) full flexion lateral photographs at final follow-up.

within the wrist joint was deferred at this stage. The second through sixth dorsal compartments, the superficial branch of the radial nerve, and the dorsal cutaneous branch of the ulnar nerve were all identified and protected. Deep, layered closure was deferred because of tissue friability, and closure over a 15-French drain was performed using staples.

Upon tourniquet deflation, significant, non-pulsatile bleeding was encountered, and manual pressure was applied, with hemostasis ultimately achieved using electrocautery. Approximately 1 L of blood was lost, and the patient was hospitalized for hypotension and acute blood loss anemia, with a hemoglobin low of 5.8 g/dL. Two units of packed red blood cells were transfused, and her hemoglobin improved to 8.8 g/dL. She was discharged on postoperative day (POD) four, and her drain was removed on POD 12.

Wound drainage persisted, and a 10-cm x 5-cm necrotic dorsal wound developed, for which the patient returned to the operating room (OR) two weeks later for excisional debridement and revision closure. Intraoperative cultures grew *Morganella morganii*, a gram-negative rod, and she was treated with oral antibiotics per infectious disease recommendations. Negative-pressure wound therapy continued for two weeks, and her skin ultimately healed well (Figure 3).

Stage Two: Dorsal Hand

Three months after the index procedure, the second-stage

debulking was performed. Wrist arthrodesis was also recommended because of the carpal instability secondary to removal of intracarpal tumor volume, lack of active extension due to chronic extensor soft-tissue tensioning from dorsal mass effect, and deformity caused by the tumor (Figure 4). Tranexamic acid was administered, and the surgery was performed under tourniquet. Flaps were designed for cosmesis while preserving the first web space. Tumor was excised from the dorsal aspect of the carpal and metacarpal bones, revealing erosion of the carpometacarpal, midcarpal, and radiocarpal joints with gross instability. Radiocarpal, midcarpal, and third carpometacarpal arthrodesis were performed and reinforced with a dorsal spanning plate (Acumed, Hillsboro, OR). The tourniquet was then deflated, excess skin excised, and incisions closed with interrupted suture, followed by application of an incisional wound vacuum and a volar resting splint (Figure 5). Approximately 1 L of blood was lost again, and two units transfused.

Negative-pressure wound therapy was discontinued after one week, with eventual healing of her incisions. At final follow-up, one year after her last surgery, the patient expressed cosmetic satisfaction (Figure 6).

DISCUSSION

As neurofibromas grow over time, they often lead to significant functional and cosmetic problems, creating the need for surgical intervention. Because of their complex vascularity, neurofibromas carry a high risk of intraoperative blood loss and postoperative hemorrhage during debulking, which can result in blood transfusions, prolonged recovery, and extended hospitalization.^{2,3,5} Effective management of intraoperative and postoperative blood loss is essential to improving patient outcomes.^{2,3,5}

A preoperative discussion should include anesthesiology to determine how expected and unexpected blood loss will be managed. From a surgical planning perspective, the number of incisions and resections should be minimized.^{5,6} Hemostasis, while challenging, is paramount. Ligating feeding vessels and performing coil embolization prior to surgical resection can help mitigate blood loss.^{3,5-7} However, embolization carries a risk of skin necrosis, and the precise feeding vessel cannot always be identified.² Additionally, bleeding can be minimized by placing deeply penetrating sutures below the level of the neurofibroma. The Tsukisui device and LigaSure are examples of hemostatic instruments used intraoperatively to reduce blood loss through deep suture ligation and bipolar cautery, respectively.^{2,3,8} Furthermore, tranexamic acid (TXA) should be considered, as its use has been associated with lower rates of blood transfusion and reoperation, shorter length of stays and operative times, and higher postoperative hemoglobin levels, without increasing adverse vascular events or mortality rates.⁹

Large neurofibromas pose significant challenges in excision, and the risk of substantial blood loss must not be underestimated. Complete resection is often limited due by extensive tumor burden, complex vascularity, and tumor regrowth.^{6,7,10} Studies suggest that these patients frequently undergo multiple debulking operations, resulting in a progressively less functional and more deformed limb due to osseous and joint destruction.^{7,8,11,12} Multiple debulking procedures can also lead to worsening pain and neurovascular impairment.^{7,8,13} Additionally, the postoperative wound surface may be extensive with a high risk of infection, pain, and skin necrosis.^{7,10,14}

In situations of worsening deformity and loss of function, amputation can improve quality of life and functionality of the limb when combined with rehabilitation and a prosthesis.^{8,11-14} In cases with a very high risk of significant blood loss and wound complications, amputation may be chosen over staged debulking to minimize complications.¹⁰ Additional indications for amputation include significant bony erosion, articular involvement, significant limb dysfunction and intractable pain. Literature describing amputation for massive neurofibromas with these symptoms reports overall positive outcomes, including improvements in pain and function, suggesting that amputation is a viable consideration in appropriately selected patients, although studies directly comparing outcomes in these patients remain limited.^{8,12} With amputation, Targeted Muscle Reinnervation (TMR) or Regenerative Peripheral Nerve Interface (RPNI) should be incorporated to reduce neuromas and phantom pain.¹⁵

In this case, the authors presented a massive neurofibroma and highlighted how tumor complexity and burden pose significant challenges during debulking surgery. While amputation is an option for massive neurofibromas, staged debulking with meticulous hemostasis and preoperative communication with the anesthesia team about the risk for significant blood loss can yield good outcomes while minimizing the risks of intraoperative blood loss.

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Median Nerve Intraneural Hematoma as an Intraoperative Finding During Carpal Tunnel Release: A Case Report

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Conflict of Interest The authors report no conflicts of interest.

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

ABSTRACT

Carpal tunnel syndrome (CTS) is the most common compressive neuropathy and typically progresses slowly. Intraoperatively, flexor tenosynovitis, nerve edema, or hourglass deformity may be observed. In rare cases, acute compression symptoms occur due to mass effect on the nerve. Intraneural hematoma of the median nerve is uncommon and has been reported primarily in acute CTS cases associated with trauma. This report describes an 87-year-old patient with a history of mild CTS who underwent carpal tunnel release due to worsening symptoms. After the initial incision, a thickened flexor retinaculum, an hourglass deformity of the median nerve, and an intraneural hematoma were identified. The hematoma was incised and drained without evidence of new hematoma formation. Postoperatively, the patient experienced rapid improvement of symptoms. This case highlights an unusual intraoperative finding in CTS and broadens the differential considerations for median nerve pathology encountered during routine carpal tunnel release.

Keywords: Carpal Tunnel Syndrome; Epineurium; Hematoma; Median Nerve; Nerve Compression Syndromes

INTRODUCTION

Carpal tunnel syndrome (CTS) is the most common neuropathy, with a prevalence of approximately 5% and an incidence of one to two cases per 1,000 people per year. It typically presents progressively and is bilateral in up to 70% of patients. Risk factors for developing CTS include female sex, pregnancy, obesity, repetitive manual labor or vibratory tools, diabetes, hypothyroidism, and gout. Most cases of CTS progress slowly, and in moderate to severe cases, surgical release results in complete or near complete resolution of symptoms. Intraoperative findings may include flexor synovitis, hourglass deformity, and nerve edema. Less commonly, acute compression symptoms occur and are often caused by trauma, infection, inflammation, anatomical variants, coagulopathy, masses, or iatrogenic causes. Management of acute symptoms requires urgent surgical intervention because of the risk of irreversible damage.¹

This report describes an elderly patient with chronic mild CTS whose symptoms progressed to the point of requiring surgical release, during which an unusual intraoperative finding of an epineural hematoma was identified.

CASE REPORT

An 87-year-old, left-handed woman presented with a history of more than 10 years of mild hand paresthesias, initially nocturnal and later occurring during the day, in the median nerve distribution of both hands. Upon presentation, she reported progressive loss of pinch strength, predominantly in the left hand. She had been taking 75 mg of pregabalin nightly, along with acetaminophen and tramadol, but discontinued these medications because she did not tolerate them. Her past medical history was notable for an elevated body mass index, with no other reported comorbidities. Electromyography and nerve conduction studies demonstrated severe left and moderate right carpal tunnel entrapment neuropathy. Physical examination revealed persistent dysesthesias in the left median nerve distribution with a positive Tinel, mild bilateral thenar atrophy, more severe on the left, and opposition strength of 4/5 bilaterally. Symptoms were markedly more severe on the left side. The diagnosis was explained to the patient, and four weeks later she underwent surgical release of the left carpal tunnel.

The anesthesia team administered a peripheral nerve block. After the skin incision was made, venous bleeding



Figure 1. After incising the thickened flexor retinaculum, an hourglass deformity and intraneural hematoma of the median nerve were identified.



Figure 2. Upon incising the perineurial layer, the hematoma spontaneously evacuated.



Figure 3. The portion of the nerve outside the retinaculum appeared normal.



Figure 4. Healing progressed as expected, and finger mobility, including opposition, returned appropriately.

was encountered; the limb was elevated, and an elastic tourniquet was placed on the forearm. Upon incising the thickened flexor retinaculum, an hourglass deformity of the median nerve and an intraneural hematoma were identified. The neural elements appeared compressed in an hourglass formation, while the overall nerve was enlarged due to the hematoma (Figure 1).

The incision was extended proximally and distally, and the hematoma was observed to span the length and width of the flexor retinaculum but did not protrude proximal or distal to it. No bleeding or hematoma was present in any other tissue or compartment, and no persistent median artery was identified. The hematoma was drained by incising the epineurium, with adequate drainage achieved (Figure 2). After decompression, the region within the hematoma zone appeared injected, whereas the nerve outside this region appeared normal (Figure 3). No new hematoma formation was observed after tourniquet release, and the skin was closed.

The patient was discharged with prescriptions for acetaminophen 1 g every eight hours and pregabalin 75

mg nightly. Two days after surgery, she denied pain and reported significant improvement in her paresthesias. She stated that she had not taken the prescribed medications because she remained pain-free. Follow-up evaluations at one and two weeks demonstrated continued absence of pain and progressive resolution of numbness in the median nerve distribution. The stitches were removed two weeks later. Four weeks later, she had completely healed and demonstrated full finger mobility, including opposition (Figure 4).

DISCUSSION

An extensive review of the literature identified four cases of acute CTS reported secondary to spontaneous median nerve hematoma and two cases associated with routine ingestion of low doses of Aspirin (ASA).

In 1946, Hayden reported a case of median nerve neuropathy in the carpal tunnel caused by spontaneous intraneural hemorrhage.² In 2008, Elrasheid Kheirleiseid et al³ described, in a letter to the editor, a 61-year-old man with acute CTS whose only relevant history was open reduction and internal fixation of an ipsilateral radius fracture 12 weeks earlier. He was found to have a subepineurial hematoma and experienced complete recovery following surgical release.

In 2009, Kokkinakis et al⁴ reported the case of a 71-year-old man with spontaneous onset of a palmar mass proximal to the flexion crease, with no history of CTS or trauma, who was taking low-dose ASA. He presented with edema and hyperesthesia in the median nerve distribution. Blood tests and wrist x-ray were normal. Ultrasound demonstrated a well-circumscribed lesion within the median nerve that displaced its fibers. They confirmed decompression, and after confirming the presence of an intraneural hematoma, it was evacuated, and neurolysis was carried out proximal and distal to the lesion. During the first two weeks, the patient demonstrated substantial improvement in pain, after which a complex regional pain

syndrome developed. He subsequently received multiple treatments, and at 12 months the pain had subsided, although stiffness of the wrist and fingers persisted.

Balakrishnan et al⁵ reported in 2008 a case involving a subperineural hematoma in a 51-year-old man who developed pain, tingling and paresthesias in the distribution of the right median nerve after spending two hours at the gym. The patient was taking ASA 81 mg daily and vitamin E. He underwent urgent surgical release of the carpal tunnel, during which an epineural hematoma was identified. He experienced complete resolution of symptoms within six weeks.

Two reports were identified describing spontaneous hematomas of the sural nerve without identifiable triggering factors. The first involved a 36-year-old woman with a two-month history of a painful mass on the posterior aspect of her right knee and a positive Tinel sign directly over the sural nerve. Blood tests were normal. Contrast-enhanced magnetic resonance imaging (MRI) demonstrated a 1.6-cm longitudinal mass along the sural nerve, with differential diagnoses including a tumor or a nerve subepineural hematoma. The patient underwent surgical decompression, during which an intraneural hematoma was identified and drained, resulting in eventual symptom resolution.⁶

The second case involved a 60-year-old woman with knee osteoarthritis who presented with a mass on the posterior aspect of her right leg accompanied by neurological symptoms. Ultrasound imaging indicated an organized thrombus versus a tumor adjacent to the saphenous and sural nerves. She underwent surgery, during which an intraneural hematoma of the sural nerve was identified.⁷

All the above cases involved an acute or subacute presentation of an intraneural hematoma characterized by localized discomfort, a palpable mass, and neurological symptoms. Although intraneural hematoma of the median nerve is most commonly described in cases of acute CTS associated with trauma, anticoagulation, or coagulopathy, the present case demonstrates that it may also occur in patients with long-standing compressive neuropathy without an identifiable precipitating factor. The patient described in this case had chronic mild symptoms of CTS with acute worsening that necessitated carpal tunnel release. She had no history of blood dyscrasia and was not taking medications known to interfere with the coagulation cascade. This finding carries several implications for clinical practice.

The finding of an intraneural hematoma in a case of chronic CTS is an unusual finding that surgeons should be aware of and prepared to manage. Clinicians should maintain a heightened index of suspicion for an intraneural hematoma in patients whose symptoms deviate from the typical gradual progression of CTS. Sudden or rapidly worsening paresthesias, disproportionate pain, or abrupt loss of function in a patient with previously stable symptoms may suggest an acute compressive event within the nerve itself.

Recognition of this condition can influence intraoperative decision-making. During routine carpal tunnel release, surgeons typically expect findings such as synovitis, nerve flattening, or hourglass deformity. However, identification of nerve enlargement or discoloration should prompt careful inspection of the epineurium. When an intraneural hematoma is encountered, decompression through a controlled epineural incision and evacuation of the hematoma may be necessary to relieve intraneural pressures. Awareness of this entity may guide surgeons toward appropriate decompression of the affected segment rather than limiting the procedure to a simple release.

Postoperative management and prognosis are most favorable when prompt decompression is achieved. As with other causes of acute CTS, timely surgical intervention can lead to rapid symptom improvement through relief of intraneural pressure. In the present case, the patient experienced immediate resolution of pain and rapid improvement of paresthesias, with no recurrence of hematoma. Postoperative care does not appear to differ substantially from standard carpal tunnel release protocols when the hematoma is adequately evacuated and no ongoing bleeding source is identified. However, surgeons should remain attentive to potential contributing factors such as anticoagulant use, vascular anomalies, or underlying bleeding disorders when present.

This case expands the differential diagnosis for intraoperative median nerve abnormalities encountered during carpal tunnel release. Although rare, intraneural hematoma should be considered when unexpected nerve enlargement with discoloration is observed. Recognition and appropriate management may facilitate decompression of the neural elements and contribute to favorable functional outcomes.

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Proximal Iliotibial Band Rupture in a 74-year-old High-Level, Female Athlete: A Case Report

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Conflict of Interest The authors report no conflicts of interest.

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

ABSTRACT

A 74-year-old female endurance athlete presented with progressive pain over the left proximal and lateral hip distal to the iliac crest. Symptoms developed over three weeks, impairing weightbearing. Magnetic resonance imaging demonstrated a high-grade tear of the proximal iliotibial band at its iliac crest insertion. The patient was treated nonoperatively and returned to high-level, asymptomatic competition three months after symptom onset. This case offers a nonoperative approach to the rare presentation of a proximal iliotibial band rupture.

Keywords: Athletic Injuries; Fascia Lata; Iliotibial Band; Rupture

INTRODUCTION

Proximal iliotibial band (ITB) rupture is a rare orthopaedic injury, typically considered a progression of iliotibial band syndrome (ITBS), with most reported cases involving the distal ITB. The authors present a proximal ITB rupture in a 74-year-old woman who competes in high-level endurance athletics.

The ITB originates at the iliac crest, courses distally along the lateral thigh, and inserts onto Gerdy's tubercle of the proximal tibia.¹ It consists of converging fibers from the gluteus maximus (GM) and the tensor fasciae latae (TFL). The primary function of the TFL is hip abduction, with additional contributors to internal rotation, flexion, and knee stabilization.² The function of the ITB itself depends on the position of the knee, but aids in both flexion and extension.³

ITBS is prevalent among runners, cyclists, and military personnel.⁴ However, most cases involve the distal ITB over the lateral femoral epicondyle, resulting in knee pain.⁵ Only six previously published cases describe the diagnosis and treatment of individuals with proximal ITB pathologies (Table 1).^{6–11} This case demonstrates successful nonoperative management of a proximal ITB rupture in an active older adult.

CASE REPORT

A 74-year-old woman presented to this orthopaedic clinic with left hip pain. Her history included lumbar radiculitis, right knee arthritis, and minor sports-related injuries. She was an avid runner and swimmer who frequently competed in long-distance events. She had finished a race three weeks earlier and recalled experiencing low back and hip

pain. At presentation, she noted that the hip pain had worsened substantially, impairing weight-bearing. Walking, running, and sleeping on her left side exacerbated the pain, whereas swimming and bicycling did not. The pain was localized to the proximal and lateral hip distal to the iliac crest. A four-view x-ray of the hip demonstrated no fractures, dislocations, or significant degenerative changes (Figure 1).

Magnetic resonance imaging (MRI) was ordered to rule out stress fractures and evaluate soft tissues. Nine days later, physical examination demonstrated tenderness over the proximal ITB and posterior TFL, as well as pain with Stinchfield examination. Specific provocative maneuvers, such as Ober's and Noble's tests, were not documented in the medical record. She demonstrated full hip range of motion, pain-free single-leg stance, and a normal neurovascular examination. MRI revealed a high-grade partial tear of the proximal ITB at its insertion on the iliac crest (Figure 2). After shared decision-making, a nonoperative treatment plan was initiated, including nonsteroidal anti-inflammatory drugs (NSAIDs), non-weight-bearing exercises, stretches targeting the TFL and ITB, deep-tissue massage, hip abduction strengthening, and side-plank exercises. The patient was advised to perform these activities as tolerated and to use NSAIDs as needed. She planned to compete in another race within the coming weeks and was cleared to participate if she remained asymptomatic during loading activities.

The patient was seen six weeks after her initial visit and two weeks after her race. She reported significant pain relief with minimal modifications to her routine. Given her improved clinical symptoms, she was advised to continue activities as tolerated, and no follow-up MRI was obtained.

Table 1. Summary of Proximal Iliotibial (IT) Band Injuries – Case Reports

Author & Year	Age & Sex	Activity Level	Potential Risk Factors	Diagnosis	Treatment/Outcome
Posadzy-Dziedzic ⁶	58F	Long-Distance Walking	Female, older age, overuse	Proximal IT band enthesopathy (MRI)	Local corticosteroid injection and kinesiotherapy; outcome not reported.
Falótico ¹⁰	34F	Recreational 10k Runner	Female, biomechanical overload, possibly misdiagnosed early	Proximal IT band syndrome (enthesitis)	Failed NSAIDs. Treated with systemic hormonal anti-inflammatories and targeted physical therapy (ITB stretching, pelvic/core strengthening). Gradual return to running in three months.
Patel ⁹	54F	Recreational Gym User	Female. Chronic prednisone use, cyclosporine immunosuppression, stretching injury	Proximal IT band rupture at TFL/ITB junction	Initial physical therapy and rest were ineffective, steroid injection (worsened symptoms), revised physical therapy. Improved pain from 8/10 to 4/10. Walking and jogging pain-free, timeline unspecified.
Decker ⁸	38F	Recreational Runner (15 Miles/Week)	Female. History of lumbar back pain, swayback posture	Proximal IT band enthesopathy	Rest, NSAIDs, cryotherapy, movement-based physical therapy, soft-tissue manipulation, local anesthetic injection. Returned to running without pain in four months.
Vaughan & Anderson ¹¹	Unspecified	Unspecified	Unspecified	Combined Proximal IT band and TFL tear	Suture anchor repair. Deemed safe and technically manageable, the anatomic footprint of the proximal ITB and TFL was restored.
Takahashi ⁷	51M	Recreational Soccer Player	Prior anterior cruciate ligament and meniscus surgeries, repetitive sports trauma	Complete proximal IT band rupture	Conservative: NSAIDs (nimesulide), rest. Declined physical therapy. Returned to sports without pain after five months.

TFL, Tensor Fasciae Latae; NSAIDs, Nonsteroidal Anti-Inflammatory Drugs; F, Female; M, Male

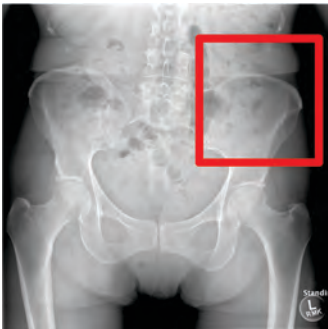


Figure 1. Four-view x-rays of the pelvis demonstrating normal bony anatomy without fractures, dislocations, or other osseous abnormalities.

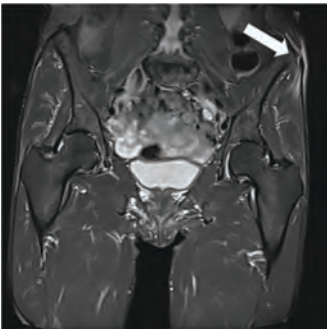


Figure 2. Coronal T2-weighted MRI of the pelvis demonstrating hyperintense signal (white) along the left proximal ITB, consistent with inflammation.

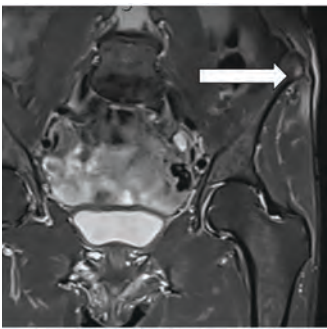


Figure 3. Coronal T2-weighted MRI demonstrating an adjacent slice anterior to the left ITB injury.

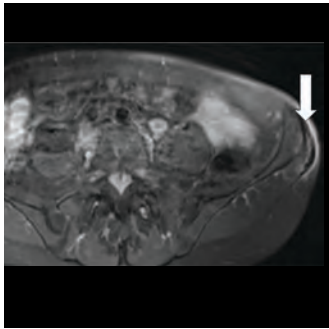


Figure 4. Axial T2-weighted MRI demonstrating the left proximal ITB injury.

at three months after symptom onset. At a 10-month telephone follow-up, the patient denied hip pain during exercise, although she continued to require spinal steroid injections for management of her radiculitis.

DISCUSSION

Proximal ITBS is rarely described in the literature. Sher et al¹² first reported this injury in 2011 in a case series of seven women with MRI evidence of strain at the iliac tubercle entheses of the ITB. Subsequent reports demonstrate a strong female predominance, with only one documented case involving a man.⁷

Women may be at higher risk for proximal ITB pathologies due to a greater hip-width-to-femoral-length ratio,^{9,12} They also exhibit greater peak hip adduction and internal rotation during gait, which may increase tension on the hip abductors and ITB. Additionally, women are also more frequently affected by trochanteric bursitis and gluteus tendinopathies, likely related to pelvic anatomical differences.¹²

Risk factors for proximal ITB injuries are not well defined. However, runners, bicyclists, football players, and weightlifters are known to be at increased risk for distal ITBS.^{12,13} These acute and repetitive microtraumas may also contribute to proximal pathologies (Table 1). Additional proposed risk factors include obesity and chronic corticosteroid use, both of which may compromise the structural integrity of the ITB and surrounding musculature.⁸

The ITB may compensate for muscular imbalances and pelvic abductor weakness.⁸ The patient in this case had chronic L3-L5 radiculitis for several years. In such cases, the superior gluteal nerve may be impinged, potentially weakening the pelvic abductors. This may increase compensatory strain on the ITB, although there is no evidence supporting this association. Notably, lower lumbar back pain was considered a potential contributing factor in the case described by Decker.⁸ Furthermore, this patient's knee pain may have altered her gait mechanics, thereby increasing ITB strain.

Proximal ITB tear should be considered in athletes with pain near the greater trochanter, iliac crest, or anterior superior iliac spine. Physical examination typically demonstrates pain over the iliac tubercle exacerbated by Ober's maneuver.¹⁰ The injury may also present with edema and an audible click near the lateral hip. MRI and ultrasound can provide detailed assessment of the surrounding tissues and are essential for establishing a precise diagnosis.⁸ Increased T2 signal, expansion, or edema at the iliac entheses suggests proximal ITB injury.¹² Other differentials that should be considered include avulsion of the anterior superior iliac spine, sartorius tear, bone or soft-tissue neoplasm, and lateral femoral cutaneous nerve neuropathy.⁶

Treatment may be operative or nonoperative. Surgical intervention should be reserved for cases refractory to

conservative treatment. Suture anchors may be used to reattach the ITB at its proximal insertion on the iliac crest.¹¹ Previous case reports, as well as the present case, suggest that nonoperative treatment is sufficient for most patients (Table 1). A combination of rest, targeted physical therapy, and activity modification may relieve the majority of symptoms.⁹ Strengthening exercises should be followed by light stretching and dynamic motion. Additional interventions include NSAIDs, cryotherapy, local anesthetics, and instrument-assisted soft-tissue manipulation.⁸

This case is unique in that full recovery was achieved despite the patient's age of 74. She did not receive formal physical therapy but reported diligent adherence to stretching and strengthening exercises. Her rapid recovery is likely attributable to her high baseline fitness level and overall health. Proximal ITB pathologies should be considered in patients presenting with lateral hip pain, particularly in female athletes. MRI is recommended in patients with similar presentations to avoid common misdiagnoses. With physical therapy or consistent engagement in a targeted exercise regimen, prognosis is favorable. Limitations of this case include the absence of standardized functional outcome measures to objectively assess recovery.

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Arthroscopic Treatment of Extensive Synovial Chondromatosis of the Knee: A Case Report

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Conflict of Interest The authors report no conflicts of interest.

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

ABSTRACT

Synovial chondromatosis (SC) is a rare, benign monoarticular disorder characterized by intra-articular cartilaginous loose bodies resulting from synovial metaplasia, most commonly affecting the knee. The authors present the case of a 44-year-old man with progressive, debilitating left knee pain, mechanical symptoms, and functional limitations unresponsive to conservative treatment. Radiographs were unremarkable, but magnetic resonance imaging (MRI) demonstrated multifocal noncalcified intra-articular bodies consistent with SC. The patient underwent arthroscopic debridement of the knee with limited synovectomy. Intraoperative findings included innumerable intra-articular cartilaginous loose bodies throughout the knee, synovial proliferation, and grade II chondromalacia. At three months postoperatively, the patient had regained full range of motion, returned to regular physical activity, and reported no recurrence. This case highlights the importance of early MRI evaluation in noncalcified SC and supports arthroscopic debridement without aggressive synovectomy as a safe and effective treatment option for diffuse intra-articular disease.

Keywords: Arthroscopy; Knee Joint; Synovectomy; Synovial Chondromatosis

INTRODUCTION

Synovial chondromatosis (SC) is a rare, benign monoarticular disorder characterized by the synovial formation of multiple intra-articular cartilaginous nodules within the joints.¹⁻⁴ This condition represents a proliferative metaplastic transformation of synovial cells and can affect any synovial joint, with the knee being the most frequently involved site; other commonly reported joints include the hip, elbow, wrist, ankle, and shoulder.²⁻⁶ SC is estimated to affect fewer than 1 in 100,000 individuals, although incidence may vary by population and diagnostic access.³

In the early stages of the disease, cartilaginous nodules develop as outgrowths from the synovial lining.⁶ These nodules may remain adherent to the synovium or detach and become free-floating, forming intra-articular “loose bodies.”^{2,3,5} Milgram classified SC into three distinct phases: stage I, active synovial proliferation without loose bodies; stage II, a transitional phase with ongoing proliferation and early loose body formation; and stage III, quiescent synovium with multiple detached loose bodies, often calcified.^{2,5,7} Patients may report joint swelling, dull or progressive pain, stiffness, crepitus, and limited range of motion.⁴⁻⁶ A classic manifestation is joint locking due to mobile cartilaginous nodules within the joint space.^{5,6} Diagnosis typically involves a detailed clinical history and physical examination supported by imaging modalities

such as plain radiographs, computed tomography, and magnetic resonance imaging (MRI).⁵

While SC is generally benign, there have been rare reports of malignant transformation into chondrosarcoma, particularly in long-standing or recurrent cases.⁴⁻⁶ Early diagnosis and timely surgical management are considered essential to prevent irreversible joint damage.^{1,4} The current standard of care for symptomatic SC includes removal of intra-articular loose bodies, with consideration for synovectomy to excise disease synovium in advanced cases.^{8,9} This approach has been shown to reduce symptom recurrence and limit progressive articular cartilage degeneration.^{1,10} However, in cases of widespread synovial involvement or large-volume loose body burden, surgical planning may be more complex, and the choice between a gentle vs aggressive synovectomy technique remains a topic of ongoing clinical discussion.^{2,11-13}

CASE REPORT

A 44-year-old man with no significant past medical or surgical history presented to clinic with a four-month history of progressive left knee pain. He described the pain as continuous, dull in quality, and rated it 7 out of 10 in severity. The pain was exacerbated by prolonged sitting and associated with functional impairments, including difficulty squatting, kneeling, pivoting, lifting, and partici-

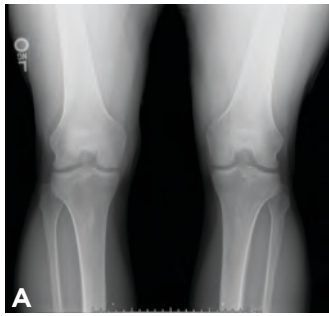


Figure 1. (A) Anteroposterior view of bilateral knees demonstrating normal alignment with no fracture or dislocation; (B) Lateral view of left knee demonstrating normal alignment with no fracture or dislocation.

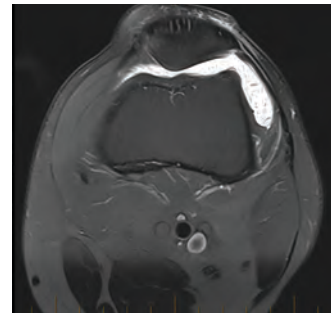


Figure 2. T2-weighted axial MRI revealing mild-sized joint effusion with numerous foci.

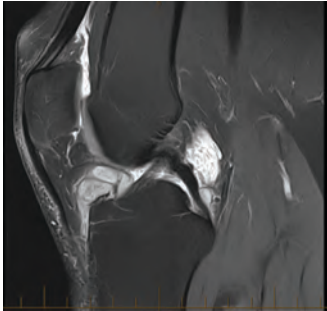


Figure 3. T2-weighted sagittal MRI revealing numerous signal foci with two ganglion cysts and a small Baker cyst.

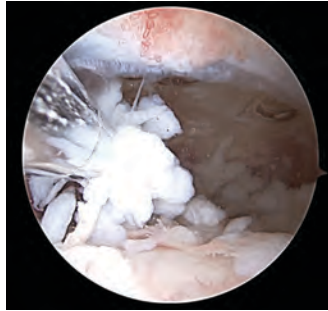


Figure 4. Intraoperative arthroscopic image of supra-patellar pouch revealing extensive synovial chondromatosis with large cartilage body.

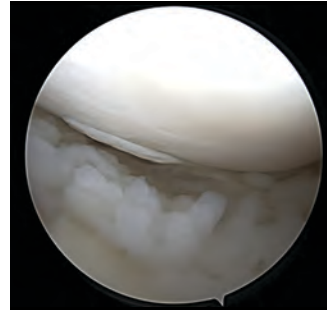


Figure 5. Intraoperative arthroscopic image prior to debridement.

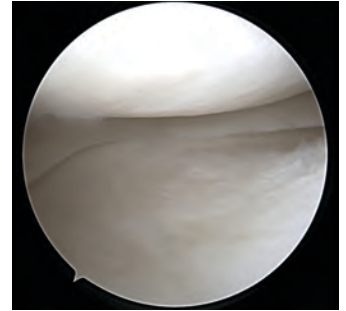


Figure 6. Intraoperative arthroscopic image following debridement.

pating in sports or other strenuous physical activities. He denied any history of recent trauma or injury and reported no use of tobacco, alcohol, or illicit substances.

Physical examination revealed tenderness along the medial and lateral joint lines of the left knee. Strength testing showed full power (5/5), with an intact straight leg raise and preserved range of motion. Sensation to light touch was intact, and the left lower extremity was warm and well-perfused with normal capillary refill. Plain radiographs demonstrated normal bony alignment without evidence of fracture, joint space narrowing, osteophyte formation, or subchondral sclerosis (Figure 1). MRI revealed a mild joint effusion and multiple foci of intermediate to high T2 signal intensity within the joint space, consistent with synovial chondromatosis (Figure 2). Additional findings included two ganglion cysts, one in the posterior medial compartment (4.6 cm x 1.9 cm) and another anterior to the anterior cruciate ligament footprint (2.5 cm x 1.9 cm), as well as subchondral marrow edema involving the anterior medial femoral condyle without an overt fracture line (Figure 3). A small Baker cyst and mild patellar tendinosis were also present.

Due to persistent symptoms despite conservative management with physical therapy and nonsteroidal anti-inflammatory drugs, the patient elected to undergo arthroscopic

intervention. Intraoperatively, extensive synovial chondromatosis was identified involving the patellofemoral, medial, lateral, and posteromedial compartments, as well as the medial and lateral gutters and the intercondylar notch (Figures 4 & 5). Gentle synovectomy and loose body debridement were performed with a shaver, and soft-tissue pockets containing additional loose bodies were decompressed (Figure 6). Grade II chondromalacia was noted on the patella, trochlea, medial femoral condyle, and medial tibial plateau.

The patient showed progressive improvement at follow-up visits at two weeks, six weeks, and three months postoperatively. By three months, he had resumed full weight-bearing without assistive devices, regained full knee range of motion, and returned to regular physical activity with minimal restrictions. Patient-Reported Outcome Measures demonstrated substantial recovery: Knee Injury and Osteoarthritis Score, Joint Replacement improved from 47.49 to 105.00, Patient-Reported Outcome Measurement Information System -10 (PROMIS-10) Physical and Mental scores rose by 7.0 and 3.2 points respectively, Single Assessment Numeric Evaluation increased from 54 to 92, and Visual Analog Scale pain scores declined from 70 to 5. PROMIS pain ratings improved from “moderate” to “mild,” and functional limitations resolved. The Pain

Catastrophizing Scale remained low throughout, reflecting excellent surgical outcome, restored function, and high patient satisfaction.

DISCUSSION

This case underscores the diagnostic and therapeutic challenges posed by SC, particularly when symptoms are insidious and early imaging fails to demonstrate calcified loose bodies.^{9,14,15} Mechanical symptoms such as joint locking, stiffness, and activity-related discomfort, often develop gradually and may be misattributed to more common pathologies such as meniscal tears or early osteoarthritis, thereby delaying definitive diagnosis.^{1,15,16}

While plain radiographs may detect calcified loose bodies in later stages, MRI is far more sensitive in identifying noncalcified nodules, marrow edema, and early synovial proliferation.^{1,4,5,7,15} These findings are especially valuable in the intermediate phases of disease and are instrumental in distinguishing SC from other intra-articular conditions and in planning surgical intervention.^{2,15}

A central consideration in managing SC is whether to perform aggressive synovectomy alongside loose body removal. While isolated loose body excision can lead to symptom relief in select cases, recurrence is significantly more likely if the underlying metaplastic synovium remains untreated.^{1,12} Ogilvie-Harris and Saleh reported a 60% recurrence rate with loose body removal alone compared with 0% when combined with arthroscopic synovectomy.¹⁴ A 2025 systematic review echoed these findings, with recurrence occurring predominantly in patients who did not undergo synovectomy.² These data reinforce the view that addressing the disease at its origin is essential for positive outcomes.

The choice between gentle versus aggressive synovectomy remains subject to surgical judgment and disease burden.¹³ Total synovectomy may offer the most definitive disease eradication but carries higher morbidity, particularly when performed via an open approach.^{8,10} With advancements in arthroscopic techniques, including improved access to posteromedial compartments, gentle or partial synovectomy targeting visibly diseased synovium has emerged as a preferred strategy in many cases, offering a favorable balance between efficacy and morbidity.^{1,5,8,13}

The authors' decision to proceed arthroscopically was guided by the absence of extra-articular disease and the feasibility of accessing all involved compartments. Because the intra-articular findings were pathognomonic, no histologic samples were obtained. The patient's outcome, characterized by restored range of motion and absence of recurrence at three months, supports the effectiveness of limited synovectomy in multicompartmental SC. Nonetheless, recurrence remains a known concern, with studies citing rates of 11% to 30%.⁸

Long-term follow-up is necessary, not only to monitor for recurrence but also because of the rare risk of malignant transformation to chondrosarcoma in longstanding or recurrent disease.^{7,15,17} This case reaffirms the effectiveness of limited synovectomy in providing both symptom relief and durable disease control.^{8,11,12}

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Prosthetic Knee Joint Infection Caused by *Gemella morbillorum*

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

ABSTRACT

Gemella morbillorum is a gram-positive coccus found in the gastrointestinal tract, and is an uncommon cause of human infections, including prosthetic joint infections (PJI). Reported risk factors include immunosuppression, recent gastrointestinal procedures, and poor dental hygiene. This report describes a case of knee PJI caused by *G. morbillorum*, likely due to hematogenous seeding following a colonoscopy three months earlier. The patient is a 70-year-old man with well-controlled diabetes mellitus who had undergone total knee arthroplasty three years prior. He presented with three weeks of left knee swelling. Synovial fluid culture revealed *G. morbillorum*. The patient was treated with debridement, antibiotics, and implant retention (DAIR), followed by prolonged antibiotic therapy. Arthrocentesis remains the gold standard for diagnosis, and the timing of diagnosis significantly affects prognosis. DAIR is a viable surgical option, and antibiotic options include cephalosporins, penicillin, and vancomycin.

Keywords: Arthritis; *Gemella*; Knee Joint; Prostheses; Implants

INTRODUCTION

Prosthetic joint infections (PJI) are among the most serious complications of arthroplasty.¹ Typical symptoms include joint pain, erythema, edema, and swelling. Accurate symptom assessment and timely arthrocentesis are essential to determinate the optimal management approach.² Effective treatment also requires an interdisciplinary team – most commonly involving orthopaedic surgery and infectious disease specialists – to coordinate surgical intervention and antimicrobial therapy.³ Although most PJIs are caused by organisms originating from the skin, hematogenous seeding is well documented, underscoring the importance of a thorough clinical evaluation.²

Gemella morbillorum is a gram-positive coccus and facultative anaerobe found in the gastrointestinal tract, oropharynx and female genital tract.^{4,5} It is a rare cause of severe human infections, such as endocarditis, bacteremia, meningitis, and, infrequently, PJIs.⁶ Recently identified risk factors for *G. morbillorum* PJI include immunosuppression, gastrointestinal carcinomas, hepatorenal diseases, bacterial translocation, and dental procedures.⁷

There have been prior reports of *G. morbillorum* bone and joint infections. This appears to be the first published case of knee PJI caused by *G. morbillorum* in an immunocompetent male, with possible hematogenous seeding following a colonoscopy, managed with debridement, antibiotics, and implant retention (DAIR) and suppressive antibiotic therapy.

CASE REPORT

A 70-year-old man with well-controlled diabetes mellitus presented to the orthopaedic clinic with a two-week history of left knee swelling, pain, and night sweats. He had undergone a left total knee arthroplasty three years earlier without complications. He denied fever, chills, or other associated symptoms. He reported no recent skin injury, drug use, insect bites, pet exposure, or procedures other than a colonoscopy with polypectomy three months earlier. He lived in a rural area approximately three hours from the nearest city and had no recent travel.

On examination, the patient was afebrile with normal vital signs. He was able to bear weight and had a good range of motion in the left knee. A mild effusion was noted. Bedside ultrasound showed a mild-to-moderate clear effusion without evidence of tendinopathy or crystal arthropathy. Laboratory testing revealed a normal white blood cell count and erythrocyte sedimentation rate, with an elevated C-reactive protein (159 mg/L). He was advised to use a short course of nonsteroidal anti-inflammatory drugs, ice, and a knee sleeve, with follow-up in two weeks. Arthrocentesis was deferred because of the mild presentation.

At follow-up two weeks later, symptoms persisted, and inflammatory markers remained elevated. Knee radiographs showed an intact arthroplasty without complications (Figure 1). Arthrocentesis was performed, yielding cloudy fluid with 8,000 white blood cells, 97%



Figure 1. Left knee x-ray demonstrating arthroplasty without complication and diffuse subcutaneous edema.

polymorphonuclear cells, and gram-positive cocci in pairs, later identified as *G. morbillorum* (Table 1). The patient was admitted for further management.

The patient underwent a left knee open DAIR. Empiric antibiotic therapy with vancomycin and ceftriaxone was initiated, as recommended for late-onset PJIs. On day five, synovial fluid cultures grew *G. morbillorum*. Infectious disease specialists narrowed antibiotic therapy to ceftriaxone based on susceptibilities. Blood cultures were negative, although they were obtained after antibiotics were started, which significantly reduces culture yield. Transthoracic echocardiogram (TTE) showed no vegetations. After two weeks, the patient was discharged to a skilled nursing facility to complete a one-month course of intravenous ceftriaxone, followed by long-term amoxicillin. No additional surgical intervention was required. He regained full knee function and remained asymptomatic eight months later, with normalization of inflammatory markers. He continues daily amoxicillin therapy, with plans for lifelong treatment (Figure 2; next page).

DISCUSSION

PJI caused by *G. morbillorum* is rare. Presentation may be subtle, and isolation of this organism from synovial fluid should be considered clinically significant. The authors

Table 1. *Gemella morbillorum* susceptibilities

Antibiotic	MIC* (mcg/mL)	Susceptibility
Ceftriaxone	<= 0.250	Susceptible
Clindamycin	<= 0.120	Susceptible
Erythromycin	<= 0.120	Susceptible
Levofloxacin	<= 1	Susceptible
Meropenem	<= 0.250	Susceptible
Penicillin	<= 0.060	Susceptible
Vancomycin	0.500	Susceptible

*MIC, Minimal Inhibitory Concentration

reviewed three other reported cases of *G. morbillorum* PJI, as detailed in Table 2.⁸⁻¹⁰

In this case, the patient was immunocompetent, and the most likely predisposing factor was a colonoscopy three months before symptom onset. Because *G. morbillorum* can colonize the gastrointestinal tract, hematogenous dissemination was suspected. Blood cultures and a TTE were negative for evidence of endocarditis or bacteremia; however, the blood cultures were obtained two days after antibiotic therapy had begun, which is known to substantially reduce culture yield.

Based on the chronicity of the prosthesis, the three-week duration of symptoms, the absence of a sinus tract, and stable implant fixation, the orthopaedic team proceeded with DAIR. Hematogenous seeding is suspected when symptoms present acutely (less than four weeks), accompanied by a positive synovial culture and a plausible source of bacteremia, such as the recent colonoscopy in this patient.¹¹

Unfortunately, blood cultures were collected after the initiation of empiric antibiotics with vancomycin and ceftriaxone, limiting the ability to confirm hematogenous seeding. *G. morbillorum* susceptibilities are not routinely performed and must be specifically requested. This

Table 2. Comparison Between Three Cases Reported in the Literature

Study	Predispose Factor	Surgery	Antibiotic treatment/ Duration of treatment	Outcome
Pardo-Pol et al ⁸	Prosthetic hip joint 11 years earlier. Alcohol cirrhosis. Psoriasis on Risankizumab	Debridement, antibiotics, irrigation and implant retention (DAIR) and repeat DAIR, day 10	Cefotaxime and amoxicillin/ three months	Favorable
Medina-Gens et al ⁹	Prosthetic hip joint 10 years earlier. Odontogenic infection two months to three months prior	Two-stage arthroplasty revision	Initially cloxacillin and gentamicin Switched cloxacillin to cefotaxime On day 15, switched cefotaxime to penicillin G and stop gentamicin / 4 weeks	Favorable
von Essen ¹⁰	Prosthetic elbow joint infection complicated with two periarticular fistulae. Rheumatoid Arthritis	Two-stage arthroplasty revision	Not mentioned	Not mentioned

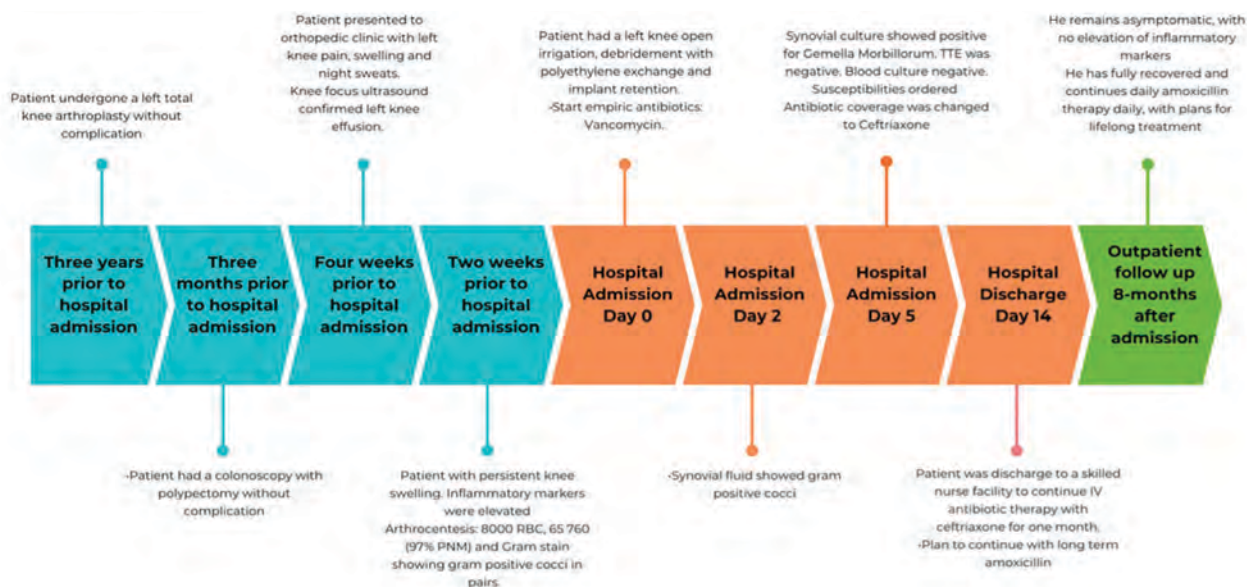


Figure 2. Timeline of patient's presentation.

organism is capable of biofilm formation, which complicates decisions regarding the duration of therapy. Given these challenges, lifelong amoxicillin suppression was recommended.

In the authors' review of the three reported cases, two patients—one with a hip PJI and one with an elbow PJI—underwent a two-stage revision, while another patient with a hip PJI was treated with DAIR. Antibiotic therapy was not described in the first case, but the other two patients received combinations of cephalosporins and penicillin. Reported outcomes were favorable in two of the three cases.

This case contributes to the limited literature on *G. morbillorum* PJI. Given the rarity of this pathogen, documenting clinical presentations and management strategies is essential. Key considerations include obtaining blood cultures when hematogenous PJI is suspected, performing prompt arthrocentesis, conducting echocardiographic evaluation, and using susceptibility-guided antibiotic therapy.

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Arthroscopic Management of a Loose Body in the Pisotriquetral Joint: 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 written consent.

ABSTRACT

The pisotriquetral joint is the smallest of the four joints comprising the wrist and is a source of ulnar-sided wrist pain. This condyloid joint connects the pisiform to the triquetrum and is supported by several surrounding ligaments. A variety of pathologies may affect the pisotriquetral joint, including the presence of loose bodies. Because of its small size and the inherent difficulty of visualization, the pisotriquetral joint is often overlooked as an independent joint. Techniques for arthroscopic visualization and loose-body removal have previously been described using the 6R and 4-5 portals. In the following case report, the authors describe successful visualization and loose-body removal through the 6R and 3-4 portals.

The authors present a case of ulnar-sided wrist pain secondary to an intra-articular loose body within the pisotriquetral joint. The patient's symptoms were unresponsive to nonoperative management, including splinting, therapy, and injections. He underwent wrist arthroscopy with pisotriquetral loose-body removal and debridement. Postoperatively, he experienced substantial improvement in pain.

Keywords: Arthroscopy; Cartilage; Wrist

INTRODUCTION

Ulnar-sided wrist pain is a common manifestation of various wrist pathologies and can significantly interfere with daily activities. In some cases, the source of ulnar-sided wrist pain remains unclear and does not respond to non-surgical interventions. One often overlooked cause is the presence of a loose body within the pisotriquetral joint. Because this joint is difficult to visualize with standard imaging, identifying and surgically debriding the loose body requires a targeted and specialized approach. Limited surgical approaches and visualization techniques for the pisotriquetral joint have been described in the literature. Visualization may be achieved through the 6R, 6U, 3-4, or 4-5 portals, as well as through dedicated pisotriquetral portals.^{1,2} The authors describe an approach for debridement of a loose body within the pisotriquetral joint using the 3-4 and 6R portals. Following debridement, the patient reported complete resolution of symptoms.

CASE REPORT

A 48-year-old right hand dominant man presented with several months of left ulnar-sided wrist pain without clear antecedent trauma. His pain was localized to the ulnar aspect of the left wrist and was associated with difficulty gripping and twisting, despite no inciting injury. Symptoms were initially noted during weightlifting. Although

stretching and yoga provided temporary relief, his pain progressively worsened over time.

On physical examination, the patient demonstrated foveal tenderness and pain with resisted gripping in the supinated position. The left wrist had full range of motion without swelling or skin changes. No crepitus or clicking with wrist circumduction was appreciable. There was no distal ulna instability with shucking in any position of forearm rotation. The patient's extremity was neurovascularly intact. Left wrist radiographs and magnetic resonance imaging (MRI) without contrast revealed an intra-articular loose body within the pisotriquetral joint, as well as possible triangular fibrocartilaginous complex (TFCC) tearing (Figures 1-3).

The patient was initially treated with over-the-counter non-steroidal anti-inflammatory drugs (NSAIDs) and activity modification, with minimal relief. His pain was initially attributed to a partial TFCC injury, and he subsequently underwent corticosteroid injection (CSI) at the level of the TFCC. This provided temporary relief lasting approximately one month before the pain returned to pre-injection levels. Given the recurrence of pain, the decision was made to proceed with wrist arthroscopy to further evaluate the TFCC and the pisotriquetral joint.

Radiocarpal arthroscopy was performed using a Spyder arm arthroscopy setup with approximately 10 pounds of



Figure 1. Sagittal T2 MRI of the left wrist with demonstration of loose body within the pisotriquetral joint (red arrow) with surrounding inflammation.



Figure 2. Coronal T2 MRI of the left wrist with demonstration of loose body in the pisotriquetral joint (red arrow) with surrounding inflammation.

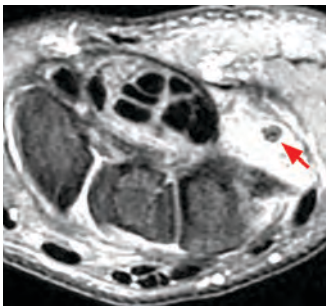


Figure 3. Axial T2 MRI of the left wrist with demonstration of loose body in the pisotriquetral joint (red arrow) with surrounding effusion and inflammation.

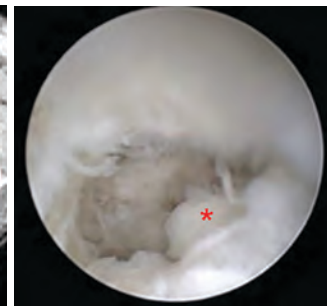


Figure 4. Arthroscopic image of the pisotriquetral joint prior to debridement with the loose body seen in the bottom right aspect of the image indicated by *. The arthroscope is in the 3-4 portal.



Figure 5. Arthroscopic image of the loose body in the pisotriquetral joint as it is removed using an arthroscopic grasper indicated by *. The arthroscope is in the 3-4 portal; the grasper is the 6R portal.

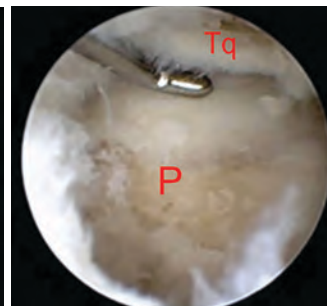


Figure 6. The pisotriquetral joint space after removal of the loose body and debridement. The arthroscope is in the 3-4 portal; the probe is the 6R portal. The probe is positioned between the Triquetrum (Tq) and Pisiform (P).

traction across the wrist. The 3-4 and 6R portals were established. Diagnostic arthroscopy was performed first, followed by debridement of the dorsal aspect of the TFCC, redundant tissue at the base of the ulnolunate ligament, a small flap tear of the membranous portion of the scapholunate ligament, and fraying of the membranous portion of the lunotriquetral ligament. Each of the debrided ligaments was stable upon completion of debridement.

The authors then proceeded with pisotriquetral arthroscopy. Visualization of the pisotriquetral joint may be obtained from the 6R, 6U, 3-4, or 4-5 portals, as well as from dedicated pisotriquetral portals.^{1,2} The 3-4 portal, which has already been established, was initially used to visualize the pisotriquetral joint. The pisotriquetral orifice was assessed and found to be imperforate.^{1,2} A shaver introduced from the 6R portal was used to open the orifice and inspect the pisotriquetral joint (Figure 4). Visualization may be enhanced by flexing the wrist, increasing insufflation pressure, applying direct pressure to the pisiform from the volar or ulnar side, or viewing from additional portals.^{1,2}

A small loose body measuring approximately 3mm – 4mm was identified intra-articularly. It was retrieved using an arthroscopic grasper introduced through the 6R portal (Figure 5). Mild arthritic changes were noted at the proximal aspect of the pisiform articular surface. A small arthroscopic bur was then used to remove osteophytes along the joint rim. A probe was subsequently placed between the pisiform and triquetrum, and the articular surfaces appeared otherwise well maintained (Figure 6).

At follow-up evaluation two months postoperatively, the patient reported markedly improved pain compared with his preoperative status, though he continued to experience mild soreness with push-ups. His incisions were fully healed, and he remained neurovascularly intact. At that time, the patient elected to follow up on an as-needed basis.

DISCUSSION

The pisotriquetral joint is the smallest of the distinct synovial articulations of the wrist.³ Although a distinct entity, it is frequently connected to the radiocarpal joint through a fenestration.⁴ The pisotriquetral joint is a condyloid joint with a loose capsule and does not contribute significantly to wrist joint stability. The flexor carpi ulnaris (FCU) tendon inserts onto the volar aspect of the pisiform; during wrist flexion, the FCU pulls the pisiform proximally and palmarly, widening the pisotriquetral joint space.³ With wrist extension, the pisotriquetral joint tightens.

Pain to the ulnar region of the wrist has numerous potential etiologies. Although uncommon, a loose body in the pisotriquetral joint space should be considered in patients presenting with ulnar-sided wrist pain.^{1,2} When nonoperative measures such as splinting, therapy, and

injections fail, wrist arthroscopy is an appropriate consideration. Indications for pisotriquetral joint arthroscopy include diagnostic examination, debridement of ganglia and synovitis, removal of loose bodies, treatment of pisotriquetral arthritis through total or hemi-pisiformectomy, management of pisiform trauma and post-traumatic sequelae, and reduction of pisotriquetral joint dislocation. The presence of a loose body may result from osteochondral injury or synovial metaplasia following a traumatic event. In cases where a loose body is present, arthroscopic diagnosis and treatment represent an appropriate treatment option.^{1,2}

During wrist arthroscopy, the radiocarpal joint is visualized, and as previously described, is often connected to the pisotriquetral joint through a capsular fenestration.^{1,2} Four types of connections between the pisotriquetral and radiocarpal joints have been described.¹ In a type I connection (approximately 25% patients), there is a thick synovial membrane covering the joint making it impossible to visualize. The patient in this case had a type I connection. For type II connections (approximately 20% of patients), there is a similar, but thinner, synovial membrane with a visible silhouette of the pisiform bone but not the joint itself. In type III connections (<10% of patients), a fenestrated synovial membrane covers the pisotriquetral joint, but the opening is too small to permit passage of an arthroscope. Type IV connections, which comprise the largest proportion (approximately 50% of patients), have either no synovial membrane or a large fenestration through which the arthroscope can easily enter the pisotriquetral joint for visualization.¹

Literature regarding the prevalence and treatment of pisotriquetral joint loose bodies is limited, but available reports support improvement or complete resolution of symptoms following arthroscopic debridement with

loose-body removal.^{1,2} This is consistent with the present case, in which debridement and loose-body removal resulted in substantial pain improvement.

Although pisotriquetral loose bodies are an uncommon cause of ulnar-sided wrist pain, the variable anatomy of the connections between the radiocarpal and pisotriquetral joints can make their identification challenging. This case report supports the consideration of pisotriquetral loose bodies in patients with ulnar-sided wrist pain that is refractory to nonoperative management. Additionally, the connection between the radiocarpal and pisotriquetral joints should be evaluated during wrist arthroscopy, particularly when the etiology of the ulnar-sided wrist pain remains unclear.

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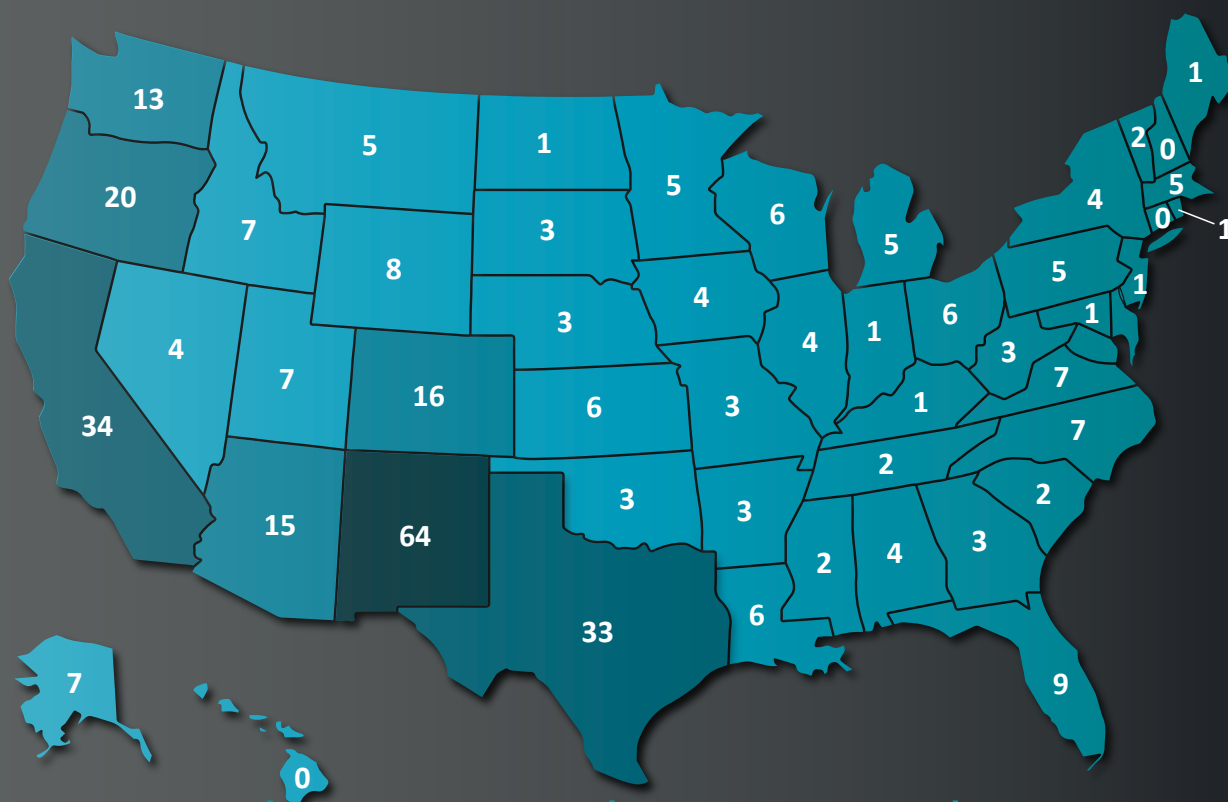
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