Temple University Journal of Orthopaedic Surgery & Sports Medicine

Joseph J. Thoder, MD

Volume 11 Spring 2016

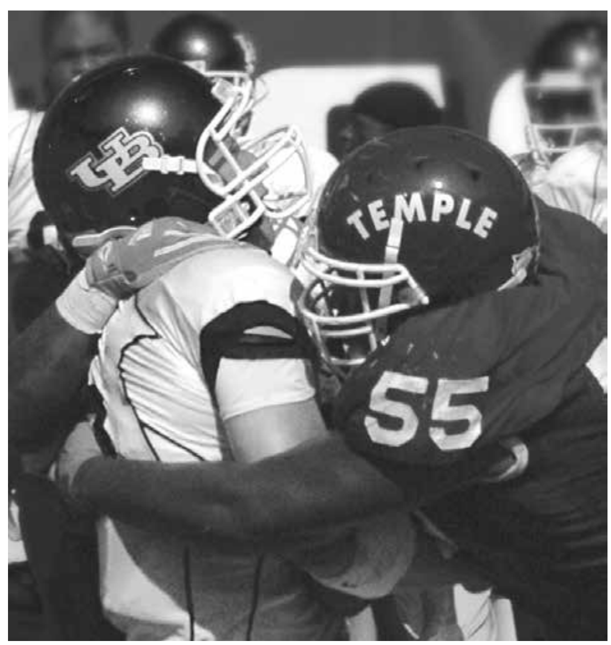
A John Lachman Society Publication

The Temple University Concussion and Athletic Neurotrauma Program

Cerebral concussion, traumatic brain injury, transient spinal cord paralysis and brachial plexus injuries are potentially serious insults to the nervous system that are associated with contact athletic injuries. In accord with the principle that the management and return-to-play decisions should only be made by a qualified professional, Temple University has established its **Concussion and Athletic Neurotrauma Program.**

Temple's experienced, multidisciplinary faculty is well-suited to evaluate and manage athletic-induced neurotrauma, utilizing the latest imaging capabilities, neurocognitive **ImPACT™** testing and clinically established **return-to-play** protocols.

Utilizing the facilities of Temple University Hospital, Temple Orthopaedics & Sports Medicine satellite offices, Temple Medical School faculty and in concert with the Shriners Hospitals for Children in Philadelphia, this program is designed to provide the necessary experience to meet the needs of team and family physicians, athletic trainers, athletic administrators, coaches, parents and, most importantly — the athletes.



Proper tackling technique protects both head and cervical spine.

Research Goals

Current understanding of cerebral concussion and athletic-induced traumatic brain injury is limited to a variety of descriptive classifications and epidemiologic patterns. Lacking is an application of the known underlying pathophysiology to clinical management practice with particular regard to injury prevention. Clearly, much is not known and there are many questions to be answered regarding athletically-induced neurotrauma. The goal of this program is to bring this issue to the same meaningful conclusion that Temple physicians achieved with paralytic spinal cord injuries 35 years ago.

Temple University Hospital

Clinical Program

Athletes sustaining impact injuries and experiencing any of the following signs or symptoms should be evaluated and, if indicated, managed by a physician experienced with athletic injuries to the head, spine and brachial plexus:

Central Nervous System

- Loss of consciousness
- Confusion
- Dazed appearance
- Forgetfulness
- Unsteady movements
- Slow cognition
- Personality changes
- Retrograde/antegrade amnesia
- Headache
- Dizziness
- Nausea or vomiting
- Altered sense of well-being

Spinal Cord

- Four extremity paresthesias (numbness)
- Four extremity weakness
- Four extremity transient paralysis

Brachial Plexus

- "Stinger" lasting more than 20 minutes
- "Stinger" with persistent weakness
- Recurrent "stingers"

The neurotrauma team consists of orthopaedic sports medicine specialists, neurologists, neurosurgeons, neurophysiologists, physiatrists and biostatisticians.

ATHLETES REQUIRING EVALUATION AND/OR MANAGEMENT CAN BE SEEN AT FOUR OF TEMPLE'S CLINICAL SITES:

Temple University Hospital

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Temple Orthopaedics & Sports Medicine

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Letter from the Chairman

It is with great honor and pride that I compose my first chairman's address for inclusion in the *Temple University Journal of Orthopaedics Surgery & Sports Medicine,* Volume 11. Having recently been selected to serve as the fifth Chairman in the history of our department, I would like to take a moment to reflect upon our continued mission and values. Temple Orthopaedics and Sports Medicine has always been and remains committed to providing the highest level of clinical care to the entirety of Philadelphia, regardless of complexity of problem or social situation. Simultaneously, we remain dedicated to our primary educational mission — to train the next generation of promising young orthopaedic surgeons.

While the mission remains constant, we must acknowledge that the environment within which we achieve our goals is ever changing. Economic and social challenges are everywhere in health care and we are certainly not shielded from this at Temple Health. However, I am confident that we will realize the great opportunity that also exists during this time of challenge. In turn, we will see a resurgence of Temple Orthopaedics as a leader, both regionally and nationally, in the years to come. While we will look to the past for guidance, we will redefine, restructure and reinvent the avenues by which we continue to deliver the highest level of clinical care. At the same time, education will remain our focus. We will move to the virtual classroom and simulated surgery to provide our residents and students the volume of experience they require, despite external pressures that put the time of our educators at a premium.

At the time of this writing, the transition is underway. We will see an explosion in total number, diversity and scope of practice of our faculty over the next three years. Collaboration across all of Temple Health, the Lewis Katz School of Medicine and Temple University will continue to grow. Our physician-led teams will continue to approach clinical and research problems with tremendous energy.

Special thanks must be given to Joseph Torg, MD and Saqib Rehman, MD in their role as faculty advisors. Arianna Trionfo, PGY4 has carried on the tradition as Editor-in-Chief and has been the driving force to completion of this work. I would also like to acknowledge the efforts of our research coordinator, Joanne Donnelly, for her tireless efforts with our residents and through coordination of the Temple medical student research program.

The *Temple University Journal of Orthopaedics Surgery & Sports Medicine* represents a picture in time as to the efforts and accomplishments of our faculty, residents and students. In its 11th edition, the journal continues to expand. Please enjoy the efforts of our department.

Eric J. Kropf, MD

Letter from the Editor-in-Chief

The writers, associate editors and I are very proud to bring you the *Temple University Journal of Orthopaedic Surgery & Sports Medicine,* Volume 11. In many ways, this volume builds on and continues the standard of excellence established in previous editions.

The Temple Pearls section highlights several of the cutting-edge surgical techniques taking place at our home and affiliate institutions. Our Distinguished Alumni section highlights how the work of Temple-made surgeons has changed the face of orthopaedics throughout the years. Our Special Events section gives the reader a basic overview of the department's major activities during the past year. In total, the *TUJOSSM* delivers a broad overview of our continuing dedication to clinical and academic excellence.

This year, Temple University has been well represented in several highly-regarded academic journals including the *Journal of Hand Surgery, Orthopaedic Clinics of North America,* and the *Journal of Pediatric Orthopaedics.* In addition, we have had the privilege of presenting our work at several prestigious national meetings including the American Academy of Orthopaedic Surgeons, American Association for Hand Surgery, and the American Orthopaedic Foot and Ankle Society.

In keeping with the adage "To whom much is given, much is expected," we have all benefited from the tutelage and generous contributions of our faculty and alumni — especially Dr. Joseph Thoder, to whom this volume is dedicated. Dr. Thoder's unwavering dedication to patients and residents, his abundant knowledge of orthopaedics (and life in general) as well as his vision for the future of medicine have been both humbling and inspiring. May we all aspire to follow in his footsteps. In the spirit of giving back to all the dedicated surgeon-educators who have trained us, the *TUJOSSM* represents the cumulative efforts of individuals who have given their time and talents to create such valuable work.

I would like to thank my associate editors, Colin Mansfield, Will Smith and Justin Kistler, our faculty advisors, Joe Torg and Saqib Rehman, and our research coordinator, Joanne Donnelly — without whom this publication would not have been possible.

Arianna Trionfo, MD
Editor-in-Chief
Class of 2017

Letter from the Residency Director

Without exaggeration, it continues to be my great privilege to lead a strong residency program that is amongst the most sought after in the country. This past year, we received over 850 applications for our four residency spots, a number that continues to steadily rise each year. The program is fortunate to have faculty members that remain focused on the residents, even as external factors increase pressure to focus more on efficiency than education. After some attrition over the last several years, we anticipate a few additions to the attending staff this year that will no doubt expand the educational experiences of the residents.

While we welcome the new faculty, we part ways with our current senior residents, all of whom are leaving Philadelphia for their fellowships in warmer locales. Three of the four are heading to fellowships in Sports Medicine: Rupam Das is headed to the University of South Florida in Tampa. He would be wise to remember where he spent more of his time when he is on the field as the Bulls play the Temple Owls. Kasey Komperda will be heading to Southern California for his fellowship, as he extends his tour of the US from the Midwest to the East Coast, and on to the West Coast. He will be joined there by Colin Mansfield, who will be returning to the West Coast to complete his training at USC, where he will swallow his pride and cheer along with the Trojan Song Girls when their team plays his University of Washington Huskies. Finally, Mark Solarz resisted the trend towards Sports fellowships this year. He will be going south to Gainesville, FL for a fellowship in Hand Surgery at the University of Florida. Fortunately for Mark, who has a difficult time suppressing his support of the Notre Dame Fighting Irish while on the opposing team's sideline, the Gators will not be hosting Notre Dame this coming season.

I take a great deal of pride in assuring those who read this journal that Temple is able to continue to produce very capable clinicians and surgeons. As you can see in these pages, the Temple program is also turning out doctors who will advance our understanding of Orthopaedic Surgery with their research, and will maintain a national recognition of our strength.

J. Milo Sewards, MD

Message from the John Lachman Society

The John Lachman Society was founded in 2004 to honor Dr. Lachman and propagate his principles of integrity, teaching, and excellent patient care. The Society also provides discretionary funds for the Chairman to promote and support the academic mission of the Department including student and resident research. The mechanism to accomplish these goals is through the Society's support of the John Lachman Orthopedic Research Fund (JLORF), incorporated in Pennsylvania as a non-profit corporation. The Internal Revenue Service has determined that the John Lachman Orthopedic Research Fund is exempt from federal income tax under 501 (C) (3) of the Internal Revenue Code and that contributions to the fund are tax deductible.

Those interested in membership in the John Lachman Society should contact the Chairman of the Membership Committee, Philip Alburger, MD or Milo Sewards, MD, c/o The John Lachman Society, P.O. Box 7283, Wayne, PA 19087.

JOHN LACHMAN SOCIETY MEMBERSHIP — JANUARY 1, 2016

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Anthony Salem, MD
Richard Sandrow, MD
Samuel Santengelo, MD*
Richard Savino, MD
H. William Schaff, MD
Joseph Scornavacchi, MD

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(Continued on next page)

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At the annual meeting of the board of directors of the John Lachman Orthopedic Research Fund, the following officers were re-elected for a one-year term:

President: J. Milo Sewards, MD
First Vice President: Eric Lebby, MD
Second Vice President: Dave Junkin, MD
Treasurer: Albie Weiss, MD
Secretary: Joe Torg, MD

The summer medical school intern program continues to be a most successful program. This past summer, 18 sophomore medical students participated in the program. In addition to a number of the students producing manuscripts suitable for publication in the *Journal,* it has been evident that a major value of this program is that in view of the curriculum changes no longer requiring students to rotate through orthopedics, those students interested have an opportunity to interface with our department. Clearly, this has become a major avenue of acquainting students to the residency program.

In view of the success of the Temple Orthopedic Summer Program, a course will be added to the first year medical student curriculum to teach the students how to conduct a clinical research project based on the model we have developed in our department. The course will cover all aspects of clinical research. Topics that will be covered include: how to develop the research question, literature review including primer on the use of PubMed or OVID or other search engines, use and disclosure of public health information, role of the IRB and responsibilities to protect the data, IRB submission guidelines, and mandatory ethics certification. Clearly, Temple Orthopedics functions as a trendsetter in medical student education!

Once again, the John Lachman Society published and distributed the *Temple University Journal of Orthopaedic Surgery & Sports Medicine,* Volume 10. Eighteen hundred copies of the *Journal* have been distributed as follows: a) active faculty of the Temple University School of Medicine, b) orthopedic surgeons who are alumni of Temple University School of Medicine, c) members of the John Lachman Society, d) department chairman and residency directors of all orthopedic programs throughout the United States, and e) fellowship directors to all orthopedic programs throughout the United States.

Academic support for resident travel to meetings by the John Lachman Orthopedic Research Fund during the period January 1, 2015 through December 31, 2015, involved 11 residents who have attended either formal courses or national meetings.

The John Lachman Society web page can be entered at www.johnlachmansociety.org.

The John Lachman Orthopedic Research Fund is committed to a $2,500 year expenditure for texts and other educational materials for resident teaching.

The John Lachman Society, through the John Lachman Orthopedic Research Fund and working in close cooperation with the Temple-Shriners' Alumni group, continues its mission to support and enhance both the academic program of the department and the orthopedic residency program.

Joe Torg, Secretary

Letter from the Office of Clinical Trials

The Office of Clinical Trials and Research Support has been going strong since 2004 when it was established under the direction of Pekka A. Mooar, MD and Joseph S. Torg, MD and supported by the School of Medicine's Office of Clinical Research Administration, with Ms. Joanne Donnelly as the full-time research and program coordinator.

The program is now in its twelfth year and continues to fulfill the vision of providing the Department of Orthopaedics and Sports Medicine with industry-sponsored clinical trials, resident-initiated research and the eight-week summer research program geared toward those Temple medical students with an interest in orthopaedics. Funding for the program is provided through the federal work-study program and supplemented by the department. The summer research program will host 17 Temple medical students in 2016. The eight-week program involves teaching the students the fundamentals of clinical research via a research topic selected by our orthopaedic surgeons and culminates in generating a finished manuscript. There is an orientation by Dr. Susan Fisher, Department of Clinical Sciences Professor and Chair on the "Nuts and Bolts of Statistics for Clinical Research." Lauri Fennell, Temple Reference and Emerging Technologies Librarian, provides the students with basic and advanced research searching options through PubMed and Ovid and other search engines, as well as RefWorks for managing citations. Chad Pettengill, from the Temple Institutional Review Board, will speak to the students regarding the guidelines pertaining to clinical research. I am looking forward to another exciting and fruitful year with the students.

Current Industry-Sponsored Clinical Trials Drug or Device

Stryker

(INSITE) Intramedullary Nail Versus Sliding Hip Screw Intertrochanteric Evaluation: A Multi-Center Randomized Controlled Trial of Intramedullary Nail Versus Sliding Hip Screw in the Management of Intertrochanteric Fractures of the Hip

Saqib Rehman, MD, Principal Investigator; Bruce Vanett, MD, Sub-Investigator;
Christopher Haydel, MD, Sub-Investigator, Phase IV Device. Closed to enrollment, in data collection phase — 19 subjects enrolled.

Department of Defense

Assessment of Severe Extremity Wound Bioburden at the Time of Definitive Wound Closure or Coverage: Correlation with Subsequent Post-Closure Wound Infection (Bioburden Study)

Saqib Rehman, MD, Principal Investigator; Christopher Haydel, MD, Sub-Investigator.
Prospective cohort observational study. Closed to enrollment, in data collection phase — 4 subjects enrolled.

AESCULAP

A Phase 3, Prospective, Randomized, Partially Blinded Multi-Center Study to Measure the Safety and Efficacy of Novocart® 3D, Compared to Microfracture in the Treatment of Articular Cartilage Defects

J. Milo Sewards, MD, Principal Investigator; Pekka A. Mooar, Sub-Investigator;
Eric Kropf, MD, Sub-Investigator. Open to enrollment — 4 subjects enrolled.

Department of Defense

Local Antibiotic Therapy to Reduce Infection After Operative Treatment of Fractures at High Risk of Infection: A Multi-Center, Randomized, Controlled Trial — VANCO Study

Saqib Rehman, MD, Principal Investigator; Christopher Haydel, MD, Sub-Investigator.
Open to enrollment — 1 subject enrolled.

American Orthopaedic Foot and Ankle Society (AOFAS)

Venous Thromboembolic (VTED) Prophylaxis Following Orthopaedic Foot and Ankle Surgery: A Randomized, Controlled, Comparison Trial

Pending site selection, still undetermined. Joseph Eremus, MD, Principal Investigator.

Joanne M. Donnelly

Dedication

Joseph J. Thoder, MD

Albie Weiss, MD

As the fourth Chairman of the Temple University Hospital Department of Orthopaedics and Sports Medicine, Dr. Joseph J. Thoder continued a remarkable tradition of leadership and commitment to education that has been fostered since the department began.

Dr. Thoder is a life-long resident of Pennsylvania, having received his undergraduate degree from Lehigh University and his medical degree from Temple University. He completed his orthopaedic surgery residency at Temple University Hospital under the guidance of the legendary John Lachman, MD and then he served as a Fellow in Hand Surgery with Dr. James Hunter at the Thomas Jefferson University Hand Rehabilitation Center. After a brief turn in private practice, Dr. Thoder returned to Temple where he has continued to serve for more than 25 years.

Always respected and admired by his residents, Dr. Thoder assumed the role of Orthopaedic Surgery Residency Program Director in 1994 before ascending to department chair in 2000. But respect and admiration alone do not do justice to the love and loyalty he has garnered from both his trainees and colleagues. Dr. Thoder embodies the virtues of dedication and passion, and his commitment to his craft is perhaps best reflected in the personalized care he provides for his patients.

His academic accomplishments are impressive, with voluminous peer-reviewed publications to his credit, a litany of invited lectureships, and recognition nationally on the management of distal radius fractures. But his greatest academic achievement has always been the creative and effective way he teaches his trainees to understand the complexities of upper extremity care. One need only witness his annual lecture on carpal mechanics, in which he uses "volunteer residents" to role play the eight carpal bones as the wrist moves, to comprehend the passion he has for teaching his craft in a way that any resident would be hard pressed to forget.

To define Joe Thoder only in terms of his professional accomplishments would be to sell him short as a human being. Outside of the hospital walls, he is a devoted husband and father of five children, head of his household (affectionately referred to as "The Ponderosa"), and its primary home improvement contractor. His projects are vast and varied — from wainscoting, to deck building, to stone veneering and room framing. The quality of his work is always consistent, in keeping with his reputation as a phenomenal and technically-gifted surgeon.

Joe is the orchestrator of family vacations, knowing that even before each trip is over, everyone will already be looking forward to next year's adventure. As a gifted host and entertainer, he has organized several events, including Stadium Conditions, Monday Night Football parties, Beers of the World parties, an annual NCAA tournament extravaganza, and How to be a Gentleman and Lady party.

In dedicating this year's Journal to a beloved Department Chair, mentor, and friend, the editorial board expresses its gratitude for his exemplary service to our department. We are enriched by his presence and it is our sincere hope that his legacy and spirit will always remain a prominent part of our institution.

Commentary

Introducing the Lewis Katz School of Medicine

Giselle Zayon

On October 13, 2015, Temple University School of Medicine became the Lewis Katz School of Medicine at Temple University — a dedication the University enacted to honor one of its biggest supporters and most enthusiastic advocates.

"Anyone who spent time with Lewis Katz could not help but be swept away by his tremendous curiosity, boundless energy, and his genuine concern for people from all walks of life," said Temple University President Neil Theobald. "It is an honor to commemorate this great philanthropist and Temple trustee at the university he loved."

Patrick O'Connor, Chair of the University Board of Trustees, said, "In countless ways, Lewis touched the lives of thousands in this region, often without them ever being aware that he was behind their good fortune. The Lewis Katz School of Medicine at Temple University will continue that tradition, by improving the health and welfare of men, women, and children for decades to come."

Lewis Katz 1942–2014
Illustration by: Jason Seiler

An alumnus and long-time Temple trustee, Katz grew up in a row house in Camden, NJ. His widowed mother worked two jobs. Young Katz worked, too. He had a paper route and sold pots and pans door-to-door. After he graduated from Camden High School, an anonymous donor's scholarship enabled him to attend Temple University — an act that Katz later credited with launching his own philanthropy, a magnificent record that Partners for Livable Communities called "inspirational work bridging racial and economic divides."

With holdings in banking, professional sports, and media (including *The Philadelphia Inquirer* and *Daily News*) the astute lawyer and businessman made a lot of money and gave a lot away — quietly writing six-figure checks to establish churches, synagogues, and schools. Katz counted the Boys & Girls Clubs of America, the Starlight Children's Foundation, the American Heart Association, and his beloved Temple University among his favorite charities. His $25 million gift to Temple University School of Medicine — the single-largest in its history — turned out to be his last.

In addition to naming its medical school in his honor, Temple University has also established the Lewis Katz Scholarships, full-tuition scholarships for undergraduates who show promise for difference-making through civic and service-leadership.

Two weeks before the tragic accident that took his life, Katz gave an award-winning speech at Temple University's 2014 Commencement. In it, he implored the graduates to make a difference with their lives. "He certainly did that with his own," said Larry Kaiser, MD, FACS, the Katz School Dean and Temple University Health System CEO.

Distinguished Alumni Paper

Stress Fractures of the Tarsal Navicular

A Retrospective Review of Twenty-One Cases

Joseph S. Torg, MD;[1] Helene Pavlov, MD,[2] Leroy H. Cooley, MD,[1] Michael H. Bryant, MD,[1] Steven P. Arnoczky, DVM,[2] John Bergfeld, MD,[3] Letha Y. Hunter, MD[4]

[1]*Sports Medicine Center, University of Pennsylvania, Philadelphia, PA;* [2]*Department of Radiology and Laboratory of Comparative Orthopaedics, The Hospital for Special Surgery, New York, NY;*
[3]*Department of Orthopaedic Surgery, The Cleveland Clinic, Cleveland, OH;*
[4]*Department of Orthopaedic Surgery, University of Washington School of Medicine, Seattle, WA*

Abstract

In a multi-institutional study, we analyzed 21 stress fractures of the tarsal navicular bone in 19 patients with particular reference to the clinical and radiographic characteristics, the results of treatment, and the complications associated with the fracture. In addition, microangiographic studies were done on five fresh human cadaver specimens to determine the vascular patterns peculiar to the tarsal navicular bone.

The fractures occurred predominantly in young male athletes (mean age, 21.8 years). Because routine radiographs failed to show the fracture, or showed it but it was not recognized, the interval between the onset of symptoms and diagnosis ranged from less than one month to 38 months (mean interval, 7.2 months). For 14 of the 21 lesions, radionuclide bone scans were needed to locate the abnormality in the tarsal navicular and for 17, anteroposterior tomograms made with the dorsum of the foot parallel to the tomographic cut were needed to confirm the diagnosis of fracture (in 14) or to evaluate further the stage of healing (in three).

The characteristic fracture was oriented in the sagittal plane and located in the central one-third of the bone, and was either partial or complete. Initially, 19 fractures were treated conservatively and two were treated surgically. Treatment included immobilization in a non-weight-bearing cast for six to eight weeks for 10 fractures; immobilization in a weight-bearing cast for four; limitation of activity with continued weight-bearing for five; open reduction and internal fixation for one acute displaced fracture; and an autogenous bone graft for one non-union. All 10 fractures that were initially treated in non-weight-bearing casts healed without complications. Seven of the nine patients whose fractures were treated by limitation of activity but continued weight-bearing or by immobilization in a weight-bearing cast were unable to resume vigorous activity after that treatment because of pain associated with delayed union, non-union, or recurrence of the fracture.

Reprinted with permission from the *Journal of Bone and Joint Surgery,* Vol. 63-A, No. 5, pp. 700–712, June 1982.

The so-called broken-hock or stress fracture of the tarsal navicular has long been recognized as a common problem occurring in the outside limbs of greyhounds when they race counter-clockwise on a circular track.[1] In humans, however, stress fractures of the tarsal navicular have been observed rarely.[8, 12, 17] In 1970, Towne et al. first described two such fractures in high-school boys and noted that the lesion was a vertical fracture that "may require special roentgenographic views and laminography for detection." One of these fractures was successfully treated by immobilization in a non-weight-bearing plaster cast and the other was treated by an autogenous bone graft, internal fixation, and three months of non-weight-bearing immobilization.

Devas[7] subsequently described two stress fractures of the tarsal navicular bone. These occurred in two women, 60 and 66 years old. Both fractures healed after six weeks of immobilization in a plaster cast. Orava et al. reported on one such lesion in a series of 142 stress fractures, an incidence of 0.7 per cent. More recently, Goergen et al. described the cases of two runners who had a stress fracture of the navicular. Both fractures were vertical, through the central one-third of the bone. One, which was complete and required open reduction and internal fixation, healed in five months, and the other was successfully treated by immobilization in a non-weight-bearing cast for three months.

In this paper, we are reporting on a multicenter study of 21 stress fractures of the tarsal navicular in 19 patients.

Materials and Methods

The 21 stress fractures of the tarsal navicular in this retrospective study occurred in 19 recreational, amateur, and professional athletes who were treated at the University of Pennsylvania, The Cleveland Clinic Foundation, and the University of Washington Sports Medicine Facilities.

The study included a review of all of the data on the stress fractures found in the hospital and clinic records. The recorded data included age, sex, athletic activity and ability, clinical complaints, interval between the onset of symptoms and diagnosis, results of treatment, and complications.

The original radiographs of all 21 feet were examined to determine if the fracture was visible on them and if there were any common radiographic features that characterized the involved feet.

Technetium-99m methylene diphosphonate radionuclide bone scans[14] had been performed on 12 of the 19 patients (with 14 fractures). The patterns of uptake of the isotope were evaluated and correlated with the radiographs.

Tomograms, which had been made for 17 of the tarsal navicular fractures, were reviewed to determine the optimum position of the foot for demonstration of the fracture. The location and extent of the fracture, the amount of displacement of the fragments, and the presence or absence of delayed union or non-union were also recorded. In addition, follow-up radiographs, tomograms, or both were reviewed to determine patterns of healing and complications for all 21 fractures. These radiographic studies were analyzed for signs of resorption, sclerosis, and cystic degeneration along the margins of the fracture.

The final results of the treatment of these fractures could be evaluated in 15 patients with 17 fractures. The other four patients, with four fractures, were still disabled at the time of follow-up, 16 to 42 months after the beginning of treatment, because of non-union or recurrence of the fracture. The average length of follow-up of all 21 fractures was 20.8 months, with a range of four to 42 months.

In an attempt to determine whether the blood supply of the tarsal navicular might have played a role in the development or behavior of the fractures, microangiographic studies were carried out by one of us (S. P. A.) in the Laboratory of Comparative Orthopaedics at The Hospital for Special Surgery. Five fresh ankle specimens from human cadavera were used. The anterior and posterior tibial arteries of each specimen were isolated, cannulated, and perfused with 30 milliliters of India ink. The ankles were then frozen and sections five millimeters thick were cut with a bandsaw in the frontal (three specimens) and transverse planes (two specimens). Each section was fixed in 10 per cent buffered formalin and cleared using a modified Spalteholz technique.[4, 5] The tarsal navicular was then isolated on a final dissection of the cleared specimen.

Clinical Findings

There were 17 male patients, two with bilateral involvement, and two female patients (Table 1). Their average age was 21.8 years (range, 15 to 24 years). All had been participating in physical activity at the time of injury. Eight of the fractures occurred while the patient was playing basketball: three at the professional, one at the collegiate, and four at the high-school level. Six fractures were in runners: one recreational distance runner, two collegiate middle-distance runners, and three high-school middle-distance runners. Four fractures occurred in football players: two professionals and two in high school. There was one fracture in a high-school soccer player. A recreational tennis player and a ballet dancer, both women, also sustained the injury. Nine left and 12 right feet were involved. The time from onset of symptoms to definitive diagnosis ranged from less than one month to 38 months, with a mean of 7.2 months.

All patients gave a history of insidious onset of vague pain on the dorsum of the foot or the medial aspect of the longitudinal arch, or both. The pain was an ill defined soreness or cramping sensation in the foot which was aggravated by activity. The area directly over the tarsal navicular was tender in 17 of the 21 feet, while in the remainder the tenderness was not well localized. Characteristically there was little, if any, swelling of the area and no discoloration or limp. Dorsiflexion of the ankle, motion of the subtalar joint, or both was limited in 10 of the 21 involved limbs. Ten patients had cavus or high-arched feet, four had flexible pes planus, and seven were described as having normal-appearing longitudinal arches.

Radiographs and Bone Scans

Initial routine radiographs, including anteroposterior, lateral, and oblique projections, were available for all 21 feet. Five of the fractures were demonstrated and recognized at the time of the initial evaluation. For four others, the initial radiographs were interpreted as negative, but when they were reviewed later, the fractures were visible. For the remaining 12 fractures, of which 10 were partial and two were complete, the radiographs did not demonstrate the lesion. The nine fractures that were visible on routine radiographs were all complete.

The radionuclide bone scans, available for 14 of the involved feet, all showed increased isotopic uptake in the tarsal navicular.

Tomograms were made for 17 of the 21 feet. These tomograms confirmed a delayed union of the navicular in one patient and a non-union in another. In one patient, the fracture had healed with a notched defect in the proximal articular border of the navicular bone. The tomograms that demonstrated the fractures and the notched defect were dorsoplantar, with the dorsal surface of the middle part of the foot parallel to the tomographic cut. The dorsal surface of

Table 1

Case	Sex, Age at Injury	Side of Fracture	Sport and Level of Activity	Time from Onset of Symptoms to Diagnosis (Mos.)	Interpretation of: Routine Radiographs Initial	Interpretation of: Routine Radiographs Review	Interpretation of: Bone Scans	Interpretation of: Tomograms	Type of Fracture	Method of Treatment‡	Result of Treatment‡	Time from Onset to Full Activity (Mos.)	Length of Follow-up (Mos.)	Final Result
1	M, 17	L	Football, high school	3	Neg.	Neg.	Pos.	Pos.	Partial: dorsal prox. articular border	Cast, NWB, 6 wks.	Osteoporosis, medullary cyst; complete healing	6	24	Asympt.
2	M, 17	R	Track, middle-distance, high school	1	Neg.	Neg.	None	Pos.	Partial: dorsal prox. articular border	Cast, NWB, 6 wks.	Complete healing	3	32	Asympt.
3	M, 37	L	Track, recreational	2	Neg.	Neg.	Pos.	Pos.	Partial: prox. articular surface, transverse dorsal fragment	Limitation of activity, WB	Delayed union	—	16	Disabled
4	M, 16	R	Track, middle-distance, high school	5	Neg.	Pos.	Pos.	Pos.	Complete: non-displaced	Cast, NWB, 8 wks.	Complete healing	4	18	Asympt.
5	M, 22	R	Track, middle-distance, college	38	Pos.	Pos.	None	Pos.	Complete: acutely displaced	ORIF, cast, NWB, 6 wks.	Complete healing	6	18	Asympt.
6	M, 27	L	Basketball, professional	2	Neg.	Pos.	Pos.	Pos.	Complete: dorsal transverse fragment	Continued activity, then cast and partial WB	Recur. of fracture, osteoporosis	—	42	Disabled
7	F, 44	R	Tennis, recreational	11	Neg.	Neg.	Pos.	Pos.	Partial: dorsal prox. articular border	Cast, WB, 8 wks.; exploration of sinus tarsi at 42 mos.	Non-union	—	30	Disabled
8*	M, 17	L	Basketball, high school	17	Neg.	Pos.	Pos.	Pos.	Complete: non-union	Medullary curettage, autogenous bone graft, cast, NWB, 6 wks.	Complete healing	7	18	Asympt.
9*	M, 17	R	Basketball, high school	7	Neg.	Neg.	Pos.	Pos.	Partial: dorsal prox. articular border	Limitation of activity, WB	Complete healing	7	18	Asympt.
10†	M, 27	L	Basketball, professional	2	Neg.	Neg.	Pos.	Neg.	Partial: dorsal prox. articular border	Cast, NWB	Complete healing	4	30	Asympt.
11‡	M, 27	R	Basketball, professional	0	Neg.	Neg.	Pos.	Pos.	Partial: dorsal prox. articular border	Limitation of activity, WB	Recur. of fracture	—	24	Disabled
12	M, 21	R	Track, middle-distance, college	12	Neg.	Neg.	Pos.	Pos.	Partial: dorsal prox. articular border	Limitation of activity, WB	Complete healing	4	18	Asympt.
13	M, 17	L	Basketball, high school	3	Pos.	Pos.	None	None	Complete: non-displaced	Cast, NWB, 6 wks.	Complete healing	4	12	Asympt.
14	F, 22	L	Ballet, recreational	14	Pos.	Pos.	None	None	Complete: non-displaced	Unna boot, WB, 4 wks.	Recur. of fracture; NWB, cast, 6 wks.; complete healing	11	12	Asympt.
15	M, 23	R	Football, professional	3	Neg.	Neg.	Pos.	Pos.	Complete: non-displaced	Cast, NWB, 6 wks.	Complete healing	3	30	Asympt.
16	M, 15	L	Basketball, high school	2	Pos.	Pos.	None	None	Complete: non-displaced	Cast, NWB, 6 wks.	Complete healing	4	30	Asympt.
17	M, 20	R	Basketball college,	2	Neg.	Neg.	Pos.	Pos.	Complete: non-displaced	Cast, NWB, 6 wks.	Complete healing	3	12	Asympt.
18	M, 23	R	Football, professional	6	Neg.	Neg.	Pos.	Pos.	Partial: dorsal prox. articular border	Cast, NWB, 6 wks.	Complete healing	3	6	Asympt.
19	M, 15	R	Football, high school	1	Neg.	Pos.	None	None	Complete: dorsal transverse fragment	Cast, WB, 6 wks.	Non-union; autogenous inlay bone graft with internal fixation; complete healing	5	28	Asympt.
20	M, 17	L	Soccer, high school	20	Neg.	Neg.	Pos.	Pos.	Partial: dorsal prox. articular border	Cast, NWB, 6 wks.	Complete healing	4	4	Asympt.
21	M, 17	R	Track, middle-distance, high school	1	Pos.	Pos.	None	Pos.	Complete: non-displaced	Cast, WB, 6 wks.	Delayed union; NWB, cast, 18 wks.; complete healing	8	8	Asympt.

*Left and right feel of same patient. †Left and right feel of same patient. ‡WB = weight-bearing and NWB = non-weight-bearing. ORIF = open reduction and internal fixation.

the navicular can be aligned parallel to the tomographic section to provide a true dorsoplantar view of the navicular by inverting the foot and elevating the medial side of the fore part of the foot. For five feet, tomograms were made with the foot in the described position and in the standard position, with the foot flat on the tabletop. In those five feet, the fracture was evident only on the tomographic cuts that were made with the position of the foot adjusted as described.

All of the fractures were in the sagittal plane and were located in the central third of the bone. Ten of the fractures were partial, involving only the dorsal cortex, and 11 were complete. Of the partial fractures, nine involved the proximal articular border (Fig. 1) and one, the distal articular border (Fig. 2). Eleven of the fractures were complete; 10 were non-displaced (Fig. 3) and one was displaced. A transverse dorsal fracture fragment was associated with one partial fracture of the proximal articular border (Fig. 4) and with two complete fractures (Fig. 5).

Serial radiographs of 15 fractures were available for assessment of the various healing patterns. The margins of the fractures became ill defined after immobilization and there was bone resorption at the fracture site in 11 feet. The resorption produced radiographic widening of the fracture gap, and in four of these feet, an intramedullary "cyst" formed (Fig. 6). The apparent cyst was associated with extreme disuse

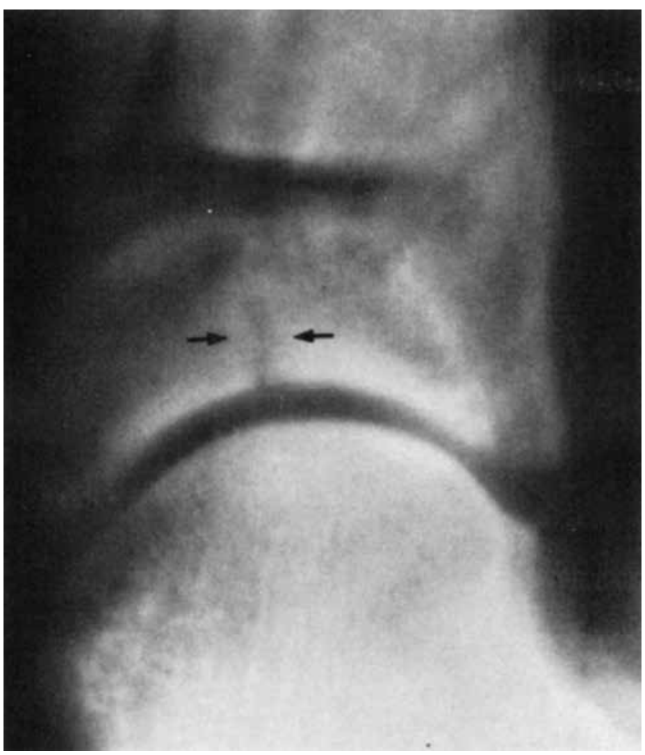


Figure 1. Case 11, a 27-year-old professional basketball player with bilateral partial proximal stress fracture of the navicular. An anteroposterior tomogram of the right foot made one month after the onset of symptoms shows a partial stress fracture involving the proximal articular border of the tarsal navicular, but the distal articular border as seen here and on companion cuts showed no evidence of fracture. Deeper sections also showed that the fracture was limited to the dorsal aspect of the bone.

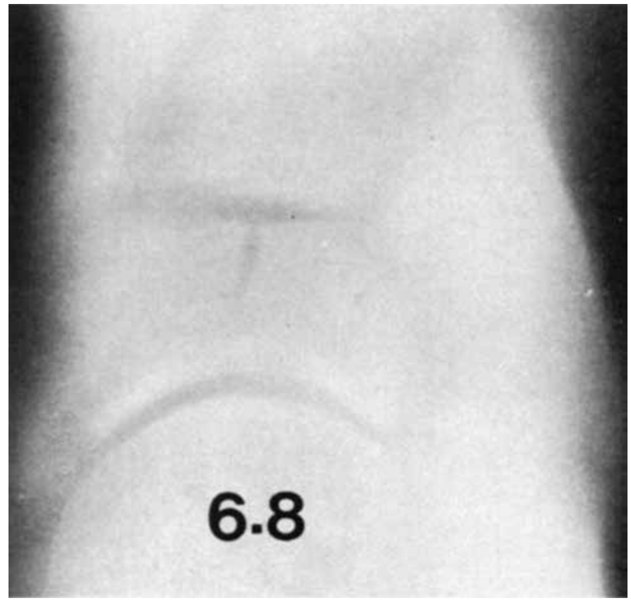


Figure 2. Case 2, a 17-year-old middle-distance runner. Tomograms made one month after the onset of symptoms show a partial stress fracture involving the distal articular border of the tarsal navicular. This tomogram and companion sections revealed that the proximal articular border was intact. A deeper section did not show the fracture, which indicates that it was limited to the dorsal aspect of the bone (see Figs. 11-A and 11-B).

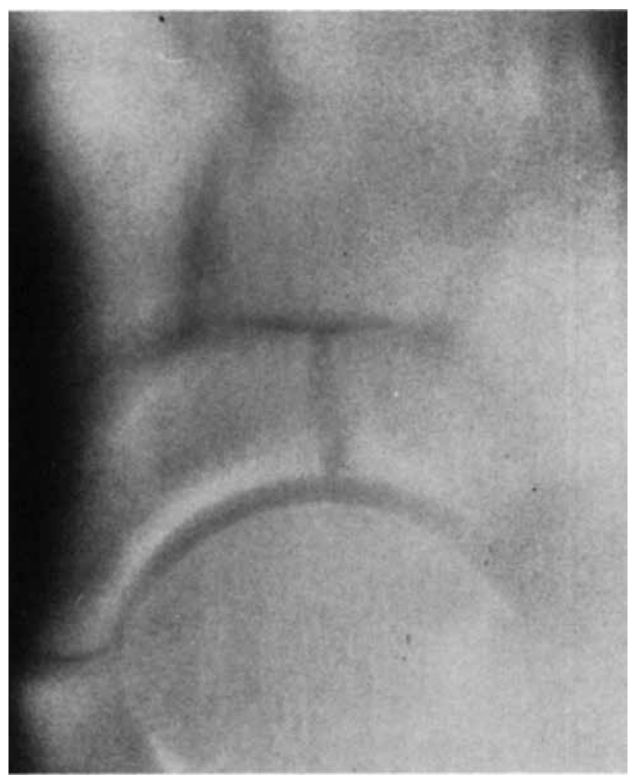


Figure 3. Case 4, a 16-year-old middle-distance runner. A tomogram made five months after the onset of symptoms shows a complete, undisplaced stress fracture of the tarsal navicular. Both the proximal and the distal subchondral cortices were involved, and the defect extended through the entire depth of the bone.

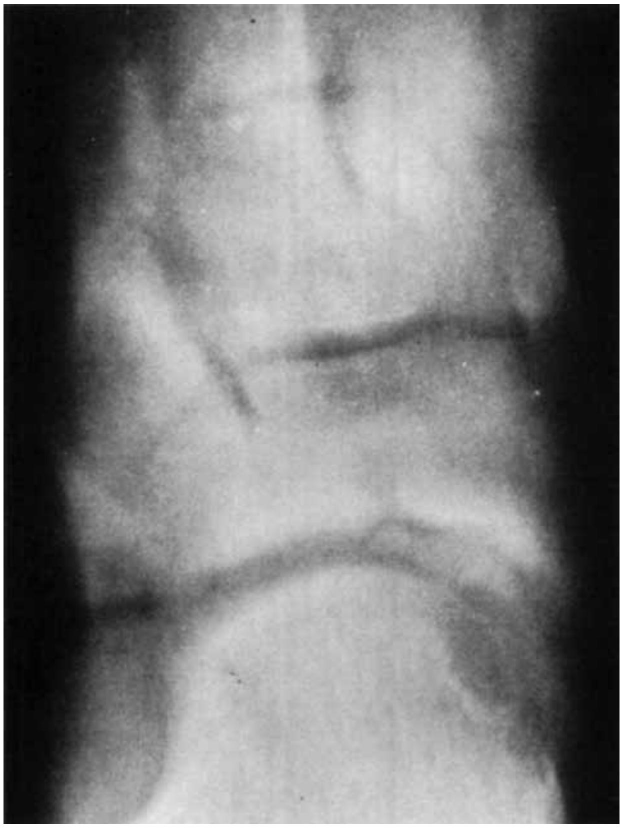


Figure 4. Case 3, a 37-year-old recreational distance runner. The anteroposterior tomogram made two months after the onset of symptoms shows a proximal partial fracture in the sagittal plane and an associated transverse fracture through the proximal articular border. The transverse fragment appears as a radiodensity in the medial aspect of the talonavicular joint.

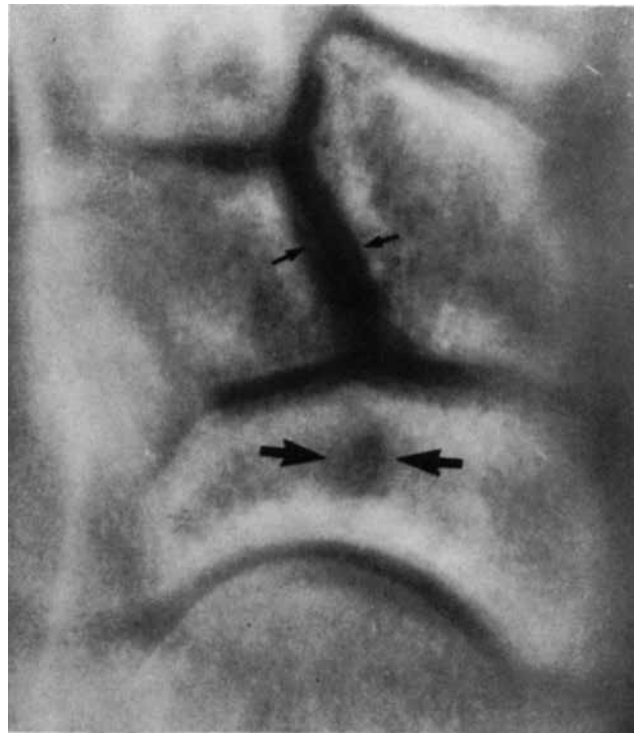


Figure 6. Case 1, a 17-year-old football player. Tomograms made three months after the onset of symptoms showed several changes that are sometimes associated with the normal healing pattern of a stress fracture: an intramedullary cyst, which appeared as a non-marginated radiolucency (large arrows); sclerosis of the proximal articular border of the navicular; and generalized osteoporosis manifested by subcortical resorption (small arrows).

osteoporosis, and in two feet, it was large enough to be identified on a routine lateral radiograph of the foot. With successful treatment, these fractures and cysts resolved, as was evident on subsequent radiographs.

Notching of the proximal dorsal cortex of the navicular was observed in two feet. In one, the notch was within the dense bone of the proximal articular border and represented a healed fracture defect (Fig. 7). In the other, the notch extended as a narrow radiolucent line with sclerotic borders into an intramedullary cyst and was associated with a clinical picture characteristic of a delayed union (Fig. 8).

The bone structure of the feet, as shown by the radiographs, was analyzed by one of us (H. P.), a radiologist, to determine the incidence of radiographic variations such as a short first metatarsal, metatarsus adductus, and the

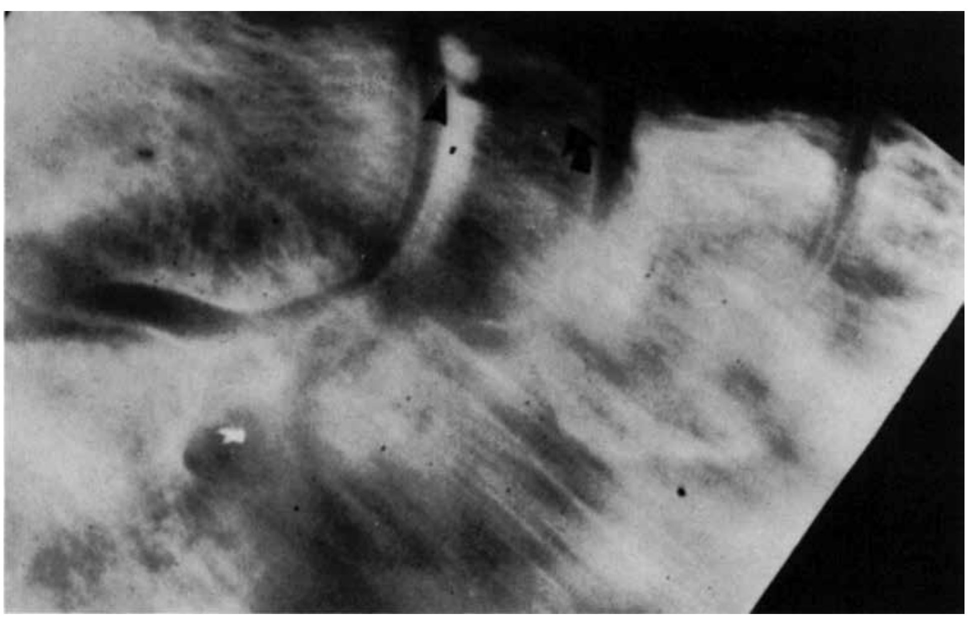


Figure 5. Case 6, a 27-year-old professional basketball player, was disabled because of recurrence of a complete sagittal fracture associated with a large transverse fragment and marked osteoporosis. The lateral tomogram shows the transverse fragment in the proximal articular border (arrowhead) and an intramedullary cyst that had formed at the fracture site (arrow).

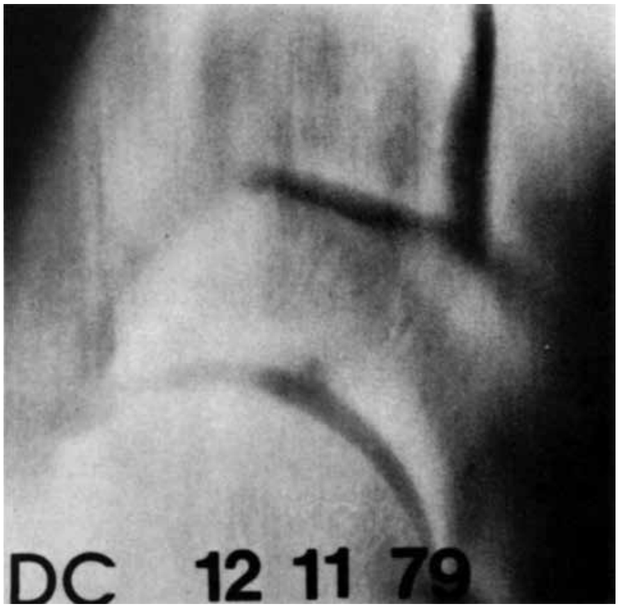


Figure 7. Case 10, a 27-year-old professional basketball player with bilateral stress fracture. The tomogram of the left foot, which had been treated with immobilization in a plaster cast and non-weight-bearing, shows a healed fracture 12 months after the onset of symptoms and a characteristic notching of the proximal articular border at the site of the fracture.

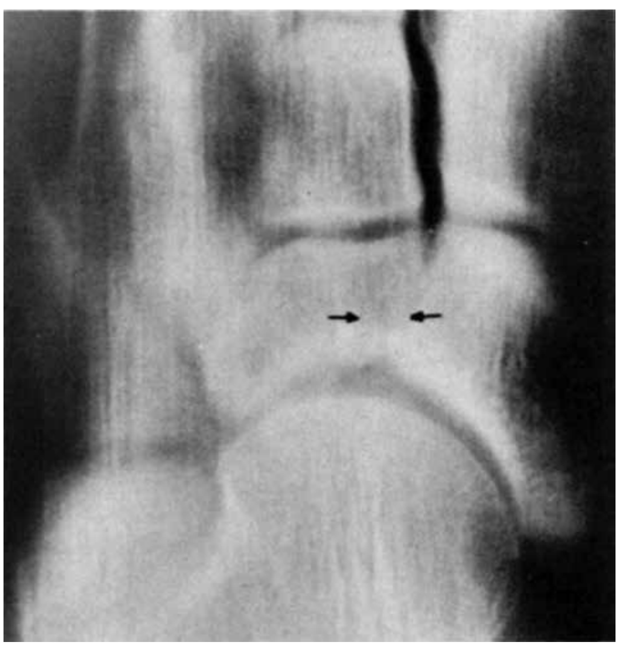


Figure 8. Case 7, a 44-year-old recreational tennis player with a partial fracture in the proximal articular border of the navicular. The patient was treated with immobilization in a below-the-knee weight-bearing cast for eight weeks. At eight weeks, she still had persistent pain. Tomograms showed a notch in the proximal articular border which was in continuity distally with a thin channel and an intramedullary cyst. The notch and channel were completely surrounded by sclerotic bone, indicating a delayed union rather than normal healing with a notched deformity as shown in Fig. 7.

like. This analysis revealed sclerosis of the proximal articular border of the tarsal navicular in 20 feet; a short first metatarsal in 17; metatarsus adductus in 17; hyperostosis or a stress fracture of the second, third, or fourth metatarsal (occurring singly or in combination) in 15; multiple juxta-articular ossicles in 14; and plantarward displacement of the cuneiform with respect to the navicular in 15 feet. In addition, the dorsal aspects of both the talus and the navicular were irregular in 15 feet, including an os supratalare in four, an os supranavicularis in six, talar beaks in four, and hypertrophic proliferative changes in 10 feet (Figs. 9-A and 9-B).

Results of Treatment

In this series, there was no indication that the result of treatment varied according to the type of fracture. On the other hand, it did appear that failure to treat seven of the fractures (Cases 3, 6, 7, 11, 14, 19, and 21) with non-weight-bearing may have contributed to disability because of delayed union, non-union, or recurrent fracture. In contrast to these seven fractures, 10 undisplaced, uncomplicated fractures (five partial and five complete) that were treated by immobilization in a plaster cast and non-weight-bearing for six to eight weeks all healed. These 10 patients returned to full activity after an interval ranging from three to six months (mean, 3.8 months) and remained asymptomatic.

In two patients with a partial fracture who were treated simply by limitation of activity and continued weight-bearing, the fracture healed and both patients returned to full activity, one at four months and the other at seven months. Another patient who was treated similarly had a refracture five months after clinical and radiographic healing. This fracture healed after a non-weight-bearing cast was worn for eight weeks. In a fourth patient, a complete fracture that initially was treated with a weight-bearing cast for two months without healing subsequently went on to clinical and radiographic union after four months of non-weight-bearing.

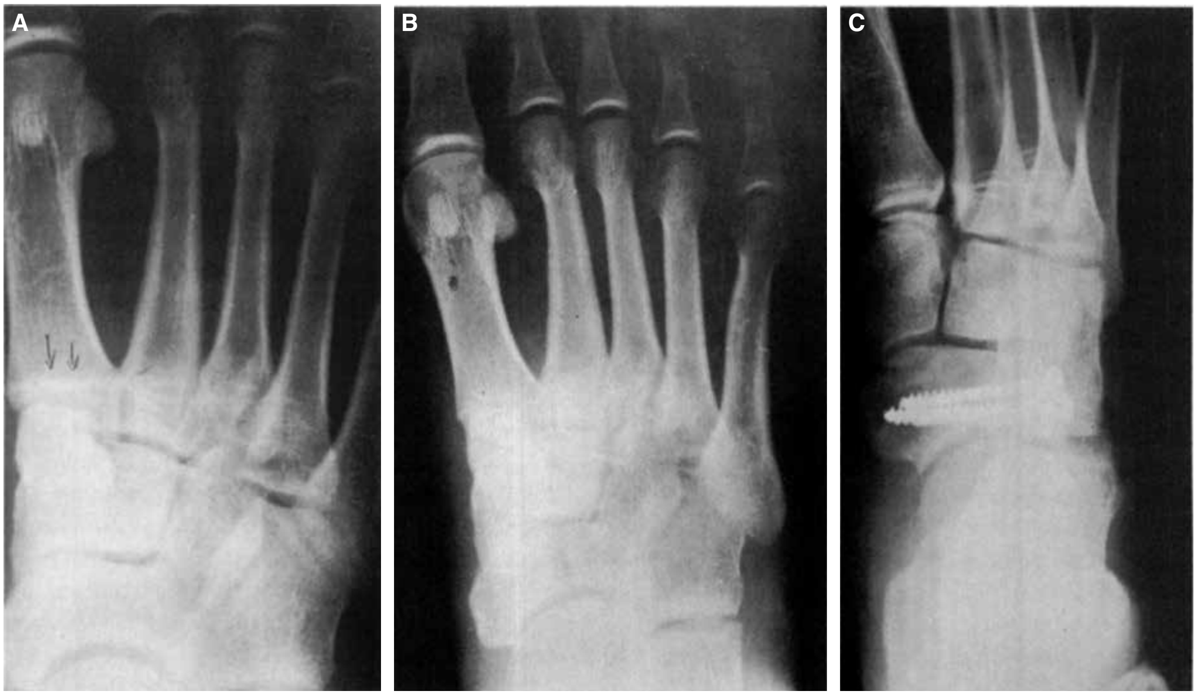
Four patients, two of them professional basketball players, were treated with either weight-bearing casts or limitation of activity and no immobilization. Subsequently, all four were disabled for 16 to 42 months (mean, 28 months): two because of delayed union and two because of a recurrence of the fracture.

The definitive treatment of a navicular fracture in three patients was surgery. One patient with an acutely displaced fracture (Case 5) was treated initially by open reduction and internal fixation with two compression screws (Figs. 10-A, 10-B, and 10-C). Of the other two patients, one (Case 19) had a non-union after treatment with a weight-bearing cast and another (Case 8) had a non-union and aseptic necrosis at the time of diagnosis, 17 months after the onset of symptoms. Both of these patients were treated with autogenous inlay bone grafts, one with and the other without internal fixation (Figs. 11-A and 11-B). Postoperatively, all three patients were immobilized in a non-weight-bearing cast for six to eight weeks. All three had complete healing and returned to full activity at five to seven months.

Figures 9-A and 9-B. Case 2, a 17-year-old middle-distance runner with a partial stress fracture of the distal articular border of the navicular. The patient had radiographic characteristics that we suspect may predispose a foot to this injury or at least be associated with a stress fracture.

Fig. 9-A. Anteroposterior radiograph. There is sclerosis of the proximal articular border of the navicular, a short first metatarsal, hyperostosis or a healing stress fracture of the second metatarsal, and metatarsus adductus of the first through fourth rays .

Figure 9-B. The lateral radiograph shows two accessory ossicles, an os trigonium and os supratalare. The dorsal elevation of the dorsal surfaces of the talus and navicular with respect to the dorsa of the cuneiforms is not evident, as this is not a weight-bearing radiograph.

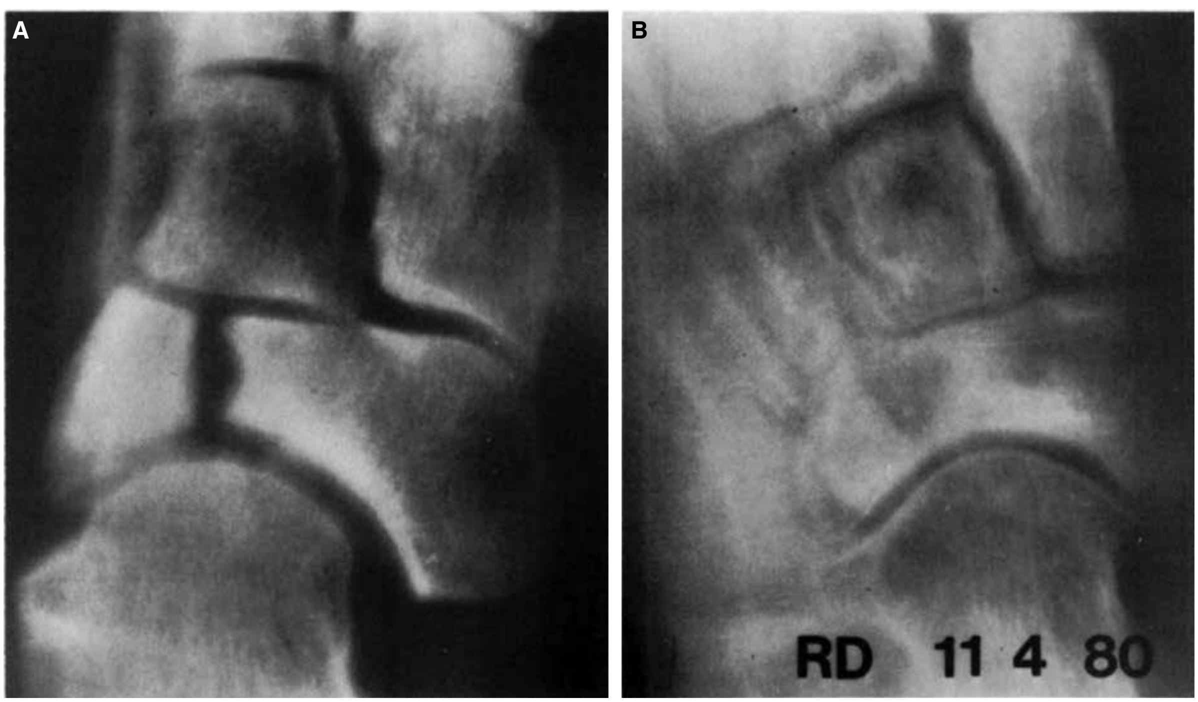


Figures 10-A, 10-B, and 10-C. Case 5, a 22-year-old intercollegiate runner, had pain in the right foot for 38 months .

Fig. 10-A. On a routine anteroposterior radiograph, the tarsal navicular appeared normal. (Arrows were drawn because it was erroneously thought that the cuneiform-first metatarsal joint was abnormal and was responsible for the symptoms.)

Fig. 10-B. One week later, repeat radiographs demonstrated a complete, acutely displaced fracture in the sagittal plane.

Fig. 10-C. The fracture was treated with open reduction and internal fixation using two cancellous-bone screws. Excellent reduction was obtained and maintained, and the fracture went on to complete healing after six weeks of immobilization in a below-the-knee non-weight-bearing cast.



Figures 11-A and 11-B. Case 8, a 17-year-old basketball player with stress fractures of both tarsal naviculars.

Fig. 11-A. A tomogram of the left foot 17 months after the onset of chronic, ill defined pain in the foot shows a complete, displaced fracture of the tarsal navicular as well as sclerosis of the lateral fragment and of the margins of the fracture, findings consistent with non-union and aseptic necrosis of the lateral fragment. The non-union was treated by open reduction, curettage of the medullary sclerotic bone, and insertion of an inlay autogenous iliac-bone graft.

Fig. 11-B. A tomogram made four months after operation shows complete incorporation of the bone graft and healing of the fracture. Although there was some narrowing of the medial part of the talonavicular joint, the patient returned to full activity without symptoms.

Microangiograms of five fresh cadaver feet demonstrated that the tarsal navicular in all specimens was supplied by numerous small vessels that arose from branches of both the anterior and posterior tibial arteries. These vessels entered the navicular throughout its non-articular surfaces and radiated toward the center of the bone.

Since most of the surface area of the tarsal navicular is covered with articular cartilage, only a small so-called waist of cortical bone is available for vessels to enter and leave the bone. The transverse sections showed that the medial and lateral vessels supplied primarily the medial and lateral thirds of the bone, leaving the central one-third relatively avascular (Fig. 12).

Discussion

Stress fractures occur commonly in the weight-bearing bones of military recruits,[2, 9, 15] distance runners,[3, 11] and others who participate in prolonged and vigorous activity.[6] However, the occurrence of this lesion in the tarsal navicular appears to be either rare or infrequently recognized.

The circumstances surrounding the occurrence of the 21 tarsal navicular stress fractures in the 19 patients in this series suggest certain features that may contribute to the development of the lesion. All of the patients were very active physically. Foot abnormalities, including a short first metatarsal and metatarsus adductus, as well as limited dorsiflexion of the ankle or limited subtalar motion, or both, were present in some patients and may have concentrated stresses on the tarsal navicular. The findings of sclerosis of the proximal articular border of the talus, narrowing of the talonavicular joint, talar beaking, accessory ossicles, and malalignment at the dorsal margins of the talonavicular and navicular-cuneiform joints in some patients may indicate the presence of some type of mechanical abnormality in the involved feet.

Microangiographic studies of the blood supply to the tarsal navicular demonstrated relative avascularity of the middle third of the bone. All of these findings suggest the hypothesis that repetitive cyclic loading, associated with some as-yet-unidentified variations in foot structure, may result in fatigue failure through the relatively avascular central portion of the tarsal navicular.

Prompt diagnosis of tarsal navicular stress fractures requires appropriate radiographic studies. Routine standing anteroposterior, lateral, and oblique radiographs of the foot should be made when a tarsal navicular stress fracture is suspected. The tarsal navicular is frequently underpenetrated on these radiographs, and a coned-down anteroposterior radiograph centered on the tarsal navicular may be required for visualization. The continuity of the cortical bone of the navicular, especially on the anteroposterior radiograph, must be carefully examined, because when there is a fracture, the lateral fragment resembles a separate tarsal bone and can easily be overlooked.

If the routine radiographic examination is normal or equivocal, a radionuclide bone scan of both feet should be obtained, using technetium-99m methylene diphosphonate. Localized augmented isotopic uptake is interpreted as abnormal (Fig. 13).

When the radionuclide bone scan indicates a lesion of the tarsal navicular but the routine radiographic examination is normal, tomograms of the tarsal navicular are required. The position of the foot for the tomographic examination is critical and should be established accurately using fluoroscopic guidance. Tomograms must be made with the tarsal navicular in the true anteroposterior position. To do this, the foot should be slightly inverted until the entire medial-lateral width of the tarsal navicular is demonstrated fluoroscopically. Exact positioning for the anteroposterior tomogram is important because the typical stress fracture is in the sagittal plane through the center of the bone and is obscured by even slight obliquity with respect to the x-ray beam (Figs. 14-A and 14-B). Also, the dorsal surface of the tarsal navicular must be parallel to the plane of the tomographic cut because in most cases an incomplete stress fracture is confined to the dorsal aspect of the bone and can be obscured if the tomographic plane is oblique (Figs. 15-A and 15-B). The position of the foot that is necessary in order to place the tarsal navicular in the anatomical anteroposterior plane is illustrated in Figure 16. The 21 tarsal navicular stress fractures in this series could be divided into three separate groups: uncomplicated fractures that went on to complete healing with treatment; those in which there was a complication when they were first seen and in which treatment resulted in successful

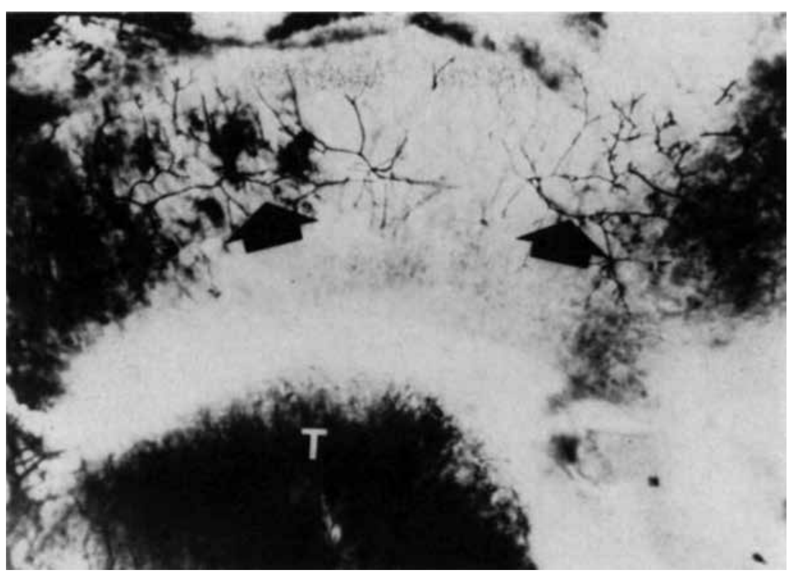


Figure 12. A microangiogram of the right tarsal navicular from a human cadaver, prepared by a modified Spalteholz technique (see text). As seen in this transverse section, medial and lateral vessels (arrows) supply the two ends of the navicular. The central one-third, over the dome of the talus (T), is relatively avascular.

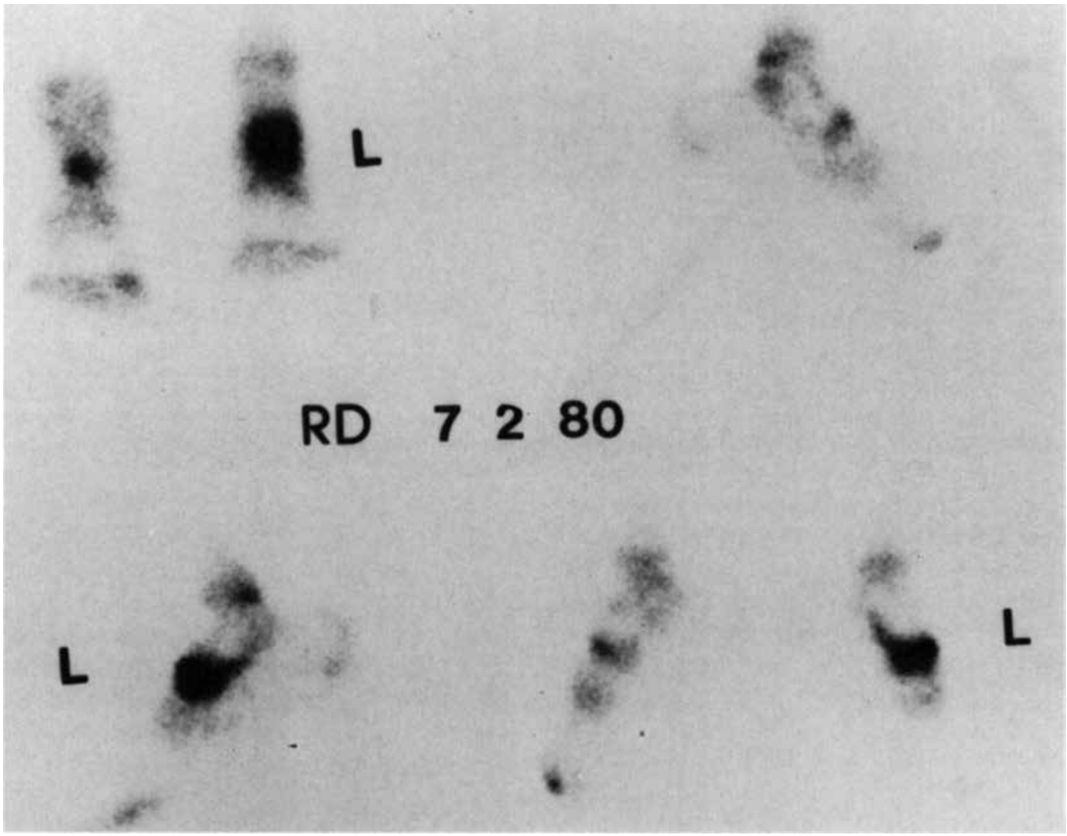


Figure 13. Four views of a radionuclide bone scan, demonstrating a bilateral abnormality. In a clockwise direction starting in the upper left corner, the scans shown are: a frontal view of both feet, a lateral view of the right foot, a medial view of both feet, and a lateral view of the left foot. Increased uptake is seen bilaterally in the region of the navicular but is more intense on the left, indicating that the abnormality on the left is more extensive, more acute, or both.

Figure 14-A. A model of the skeleton of the foot, demonstrating the orientation of the tarsal navicular with the foot positioned for a standard anteroposterior radiograph. Note that in this position the widest transverse axis is oblique to both the x-ray beam and the surface of the cassette. The typical stress fracture of the navicular is in the sagittal plane in the central one-third of the bone and therefore is obliquely oriented with respect to the x-ray beam.

Figure 14-B. The same model of the foot, showing the medial side of the fore part of the foot elevated and the entire foot inverted to make the widest diameter of the tarsal navicular bone perpendicular to the x-ray beam. Most important is that the sagittal plane of the central one-third of the bone lies parallel to the beam and perpendicular to the film; this relationship is necessary to show all partial and some complete stress fractures of the tarsal navicular.

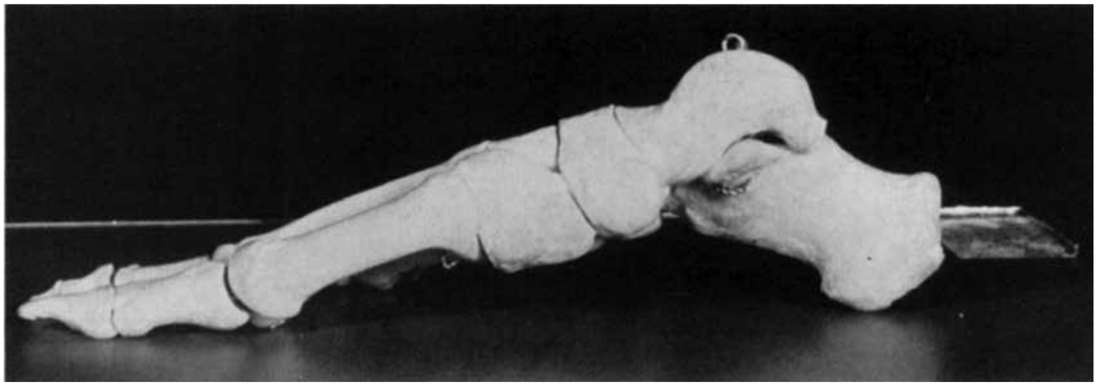


Figure 15-A. Medial side of the model positioned for a standard dorsoplantar radiograph. Note that the longitudinal axis of the tarsal navicular is oriented so that it is oblique to both the x-ray beam and the surface of the film. Partial fractures of the proximal articular border will be obscured in this position.

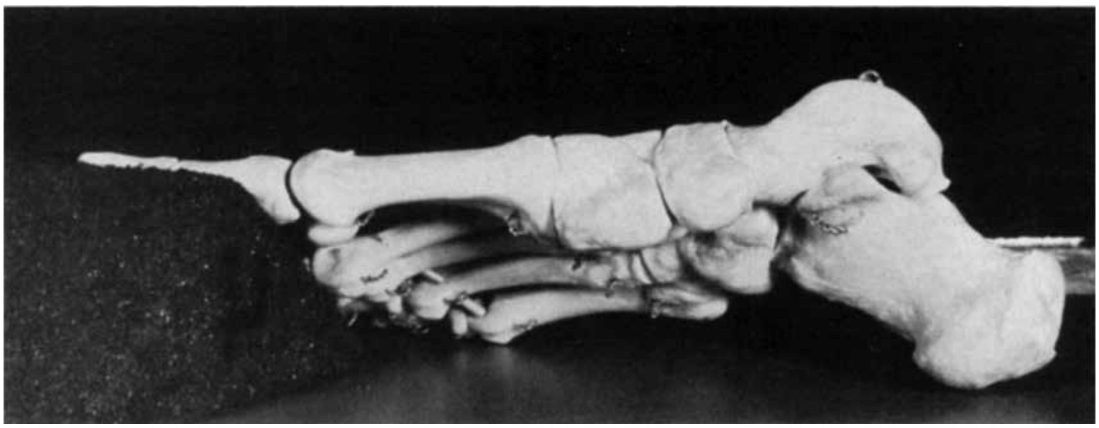


Figure 15-B. Model of the foot positioned with the medial side elevated to make the long axis and the dorsal surface of the navicular perpendicular to the x-ray beam and parallel to the film.

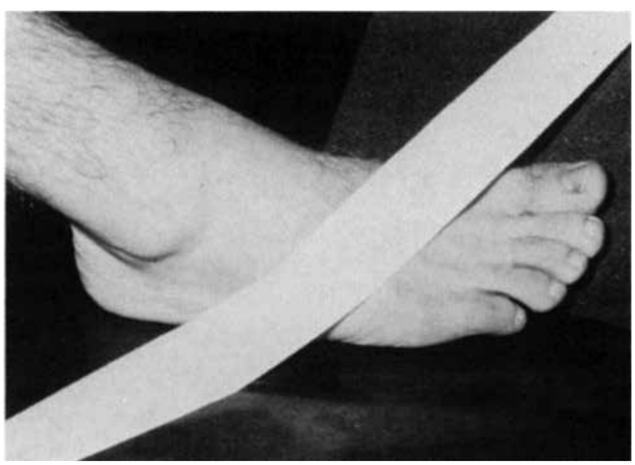


Figure 16. A foot placed on a foam wedge and taped to the cassette in the correct position to make a so-called anatomical anteroposterior radiograph. The medial side of the fore part of the foot is elevated so that the entire foot is inverted. Fluoroscopy should be used to ensure proper positioning of the foot.

healing: and those in which delayed union or non-union developed despite treatment, or in which there was a recurrence of the fracture following treatment.

Of the 12 uncomplicated fractures that went on to successful healing, 10 were treated by immobilization in a plaster cast and non-weight-bearing for six to eight weeks, and two healed with only limitation of activity and continued weight-bearing.

Two complicated fractures, one with acute displacement of the fragments and the other with an established non-union and aseptic necrosis of the lateral fragment, were treated surgically at the outset: the first by open reduction and internal fixation and the second by medullary curettage and autogenous bone-grafting. Both fractures were immobilized in a non-weight-bearing cast for six weeks postoperatively, and both healed.

In seven patients, the result of treatment was either a delayed union, a non-union, or a fracture after healing. All seven had been permitted to continue weight-bearing during the initial treatment. In two of these seven fractures, union was delayed but healing occurred after immobilization in a non-weight-bearing cast for eight weeks in one and 18 weeks in the other. A third fracture, initially treated in a weight-bearing cast for eight weeks, went on to non-union, which was successfully treated by an inlay bone graft and internal fixation followed by immobilization in a non-weight-bearing cast for eight weeks. The other four patients were disabled and unable to participate in their sports activity as a result of the fractures. One patient (Case 6) was a professional basketball player with a complete, non-displaced fracture associated with a dorsal transverse fragment. Initially, he attempted to continue playing on the injured foot, but eventually the fracture was immobilized in a series of partial-weight-bearing casts. The fracture healed, but marked osteoporosis accompanied by pain developed. Subsequent attempts to return to professional basketball resulted in recurrence of the fracture and continued disability 42 months after the initial injury. Of interest in this patient was the fact that surgical exploration of the sinus tarsi at 42 months after injury demonstrated a fibrocartilaginous calcaneal-navicular communication.

The other three fractures that resulted in disability were partial, proximal, undisplaced fractures, one having an associated dorsal transverse fragment. One was treated with a weight-bearing plaster cast and the other two, with limitation of activity and weight-bearing. Of these three patients, the first (Case 11), a professional basketball player who was treated by limitation of activity and continued weight-bearing, had a refracture at 12 months and was still disabled at 24 months; the second, a recreational distance runner (Case 3) who was similarly treated, had delayed union and was still disabled at 16 months; and the third, a recreational tennis player (Case 7) who was treated with a weight-bearing cast, had a non-union and was still disabled at 30 months.

On the basis of this experience, we concluded that both uncomplicated, partial stress fractures and non-displaced, complete stress fractures of the tarsal navicular should be treated by immobilization in a plaster cast with non-weight-bearing for six to eight weeks. Displaced, complete fractures and ununited fractures should be treated with internal fixation or bone-grafting as necessary, followed by immobilization and non-weight-bearing until union has occurred.

Treatment by limitation of activity but continued weight-bearing or immobilization in a weight-bearing plaster cast may not be successful and can result in prolonged morbidity and disability.

Note: The authors wish to thank Dr. Vincent DiStefano, Dr. John R. Hazel, and Dr. Gilbert Wright for their contributions of clinical material to this study.

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Management of Tarsal Navicular Stress Fractures

Conservative Versus Surgical Treatment: A Meta-Analysis

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Abstract

Purpose: This study was conducted to provide a statistical analysis of previously reported tarsal navicular stress fracture studies regarding the outcomes and effectiveness of conservative and surgical management.

Study Design: Systematic review.

Methods: A systematic review of the published literature was conducted utilizing MEDLINE through Ovid, PubMed, ScienceDirect, and EBSCOhost. Reports of studies that provided the type of tarsal navicular stress fracture (i.e., complete or incomplete), type of treatment, result of that treatment, and the time required to return to full activity were selected for analysis. Using a mixed generalized linear model with study as a random effect and treatment as a fixed effect, cases were separated and compared based on three different types of treatment: conservative, weightbearing permitted (WBR); conservative, non-weightbearing (NWB); and surgical treatment. The outcome of the treatment was recorded as either successful or unsuccessful based on radiographic and/or clinical healing of the fracture and time from onset of treatment to return to activity.

Results: There was no statistically significant difference between NWB conservative treatment and surgical treatment regarding outcome ($P = .6441$). However, there is a statistical trend favoring NWB management (96% successful outcomes) over surgery (82% successful outcomes). Weightbearing as a conservative treatment was shown to be significantly less effective than either NWB ($P = .0001$) or surgical treatment ($P < .0003$).

Conclusion: Non-weightbearing conservative management should be considered the standard of care for tarsal navicular stress fractures. The authors could find no advantage for surgical treatment compared with NWB immobilization. However, there is a statistical trend favoring NWB over surgery. Rest or immobilization with weightbearing was inferior to both other treatments analyzed. The authors concluded that conservative NWB management is the standard of care for initial treatment of both partial and complete stress fractures of the tarsal navicular.

Keywords: tarsal navicular stress fractures; outcomes; management guidelines; treatment

The purpose of this article is to provide a systemic review and meta-analysis of previously reported tarsal navicular stress fracture (TNSF) studies regarding the outcome effectiveness of conservative and surgical management by evaluating three parameters: (1) the success rate and time of return to activity of incomplete compared with complete TNSFs that were managed with non-weightbearing (NWB) cast immobilization or surgery; (2) the success rates for management of TNSFs utilizing NWB cast immobilization for six weeks, NWB cast immobilization for less than six weeks, weightbearing cast and/or rest, and surgical management consisting of open reduction and internal fixation (ORIF) and/or bone grafting; and (3) differences regarding return to activity between conservative management consisting of NWB cast immobilization for six weeks or less, weightbearing cast and/or rest, and surgical management.

The stress fracture of the tarsal navicular was first described in humans in a 1970 case study by Towne et al.[31] Early studies showed that it was a rare injury, accounting for only 0.7% to 2.4% of all stress fractures. As awareness of the injury has increased, so have the reported number of cases, with tarsal navicular stress fractures currently representing up to 14% of stress fractures in some series.[3, 5, 17, 19]

In 1982, a retrospective study of 21 cases demonstrated that both uncomplicated, partial stress fractures and non-displaced, complete stress fractures of the tarsal navicular heal with conservative treatment.[30] Conservative treatment consisted of NWB cast immobilization for six to eight weeks, followed by gradual weightbearing in a boot for two to six weeks until pain-free. The effectiveness of this treatment has been reaffirmed by several subsequently published studies.[15, 18] It appears, however, that current management of this injury more frequently utilizes surgical intervention both as a first-line treatment or following failed treatment with weightbearing conservative management because of pressure on both the athlete and the physician to have the athlete more quickly return to competition.[6, 7, 11] In 2000,

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Saxena et al.[28] suggested that surgical intervention will decrease the amount of time for an athlete to return to preinjury activity level. The most recently reported data by Saxena and Fullem[27] in 2006 contradict this, demonstrating that there is no significant difference between surgical and conservative management. In 1992, Khan et al.[18] reported that NWB cast treatment compares favorably with surgical treatment after failed weightbearing treatment. A meta-analysis of previously reported outcomes of conservative and surgical management of TNSF studies may clarify the issue.

Materials and Methods

A systematic review of the published literature on TNSF was conducted. We searched MEDLINE through Ovid, PubMed, ScienceDirect, and the EBSCOhost Reseach Database. The following search terms were entered and modified according to the requirement of each database: ‘‘tarsal navicular’’ and ‘‘stress fracture’’ or injury; and ‘‘treatment’’ or ‘‘surgery’’ or ‘‘management.’’ There were no restrictions on date of publication, publication status, or language. The search generated 31 articles, with 23 reports, of which 12 were case reports, four were case series, and seven were comparative cohort studies (see online Appendix for this article at http://ajs.sagepub.com/supplemental/). Ten of the articles were limited to descriptive reviews of the fracture.

The data are presented as three subsets depending on parameter documentation. Subset I included studies that reported fracture types as partial or complete, treatment variables, successful/unsuccessful outcomes, and time to return to activity. Subset II included all reports that documented the fracture without defining if it was partial or complete but defined treatment variables, successful/unsuccessful outcomes, and time to return to activity. Subset III included reports limited to documentation of the fracture and successful/unsuccessful outcomes without including time to return to activity.

The reports that provided the type of stress fracture, type of treatment, result of that treatment, and the amount of time required to return to full activity were selected for analysis. The type of stress fractures reported were classified as either ‘‘incomplete’’ or ‘‘complete’’ based on the radiographic and/or imaging information provided. The outcome of the treatment was considered ‘‘unsuccessful’’ if the patient continued to have pain following the end of treatment, was unable to return to his or her previous activity level, or experienced a recurrence of the fracture. A ‘‘successful’’ outcome was one in which the patient was pain-free, able to return to previous activity level, and did not have recurrence of the fracture.

The cases were separated into four groups based on the type of treatment: (1) conservative, weightbearing permitted; (2) conservative, NWB for six weeks; (3) conservative, NWB for less than six weeks; and (4) surgical treatment. The cases were classified based on whether the treatment modality was the initial treatment, or secondary treatment after a failed initial therapy. The majority of cases with failed initial therapy involved weightbearing; therefore, our analysis primarily compares NWB conservative treatment with surgical intervention. The outcome was recorded as either successful or unsuccessful based on the stated criteria. Sources of variation within and among the groups examined included type of fracture, time elapsed until onset of treatment; type of treatment, age, and gender. Statistical analysis was performed using a mixed generalized linear model with study analyzed as a random effect (assumes heterogeneity among studies) and treatment, fracture type, age, and sex as fixed effects. The SAS v9.1 statistical software (SAS Institute, Cary, North Carolina) was used for all analyses. Analysis of variance and the Fisher exact test were calculated for comparisons using a two-tailed significance level of $P \leq .05$.

Results

Three hundred thirteen TNSFs were identified in 23 reports in the peer review literature and are included in this analysis.

Subset I

In subset I, 17 reports with fractures that met the inclusion criteria were analyzed. As described, the cases were separated into three groups, and the mixed generalized linear model was used to examine random effect. It was determined that of the variations examined, only the type of treatment was statistically significant regarding a successful outcome ($P = .0002$). The data indicate the propensity of TNSFs to respond to treatment was independent of fracture type (i.e., partial vs complete). Fifty incomplete fractures and 12 complete fractures were treated conservatively, compared with 13 incomplete fractures and 12 complete fractures treated surgically. The fracture type, partial or complete, was not statistically significant when comparing NWB conservative and surgical treatment with regard to a successful outcome ($P = .994$) (Table 1).

Analysis of subset I data further determined the outcomes (fracture healing) were not statistically different comparing fracture type ($P = .9943$), time of onset of treatment ($P = .7008$), age of patient ($P = .3323$), or sex of patient ($P = .1255$) (Table 1).

Table 1. Meta-Regression Results of Fracture Type, Onset of Treatment, Type of Treatment, Age, and Sex on Outcome (Successful/Unsuccessful)

Effect	*F* Value	*P*
Fracture type		.9943
Onset of treatment		.7008
Type of treatment		.0002
Age		.3323
Sex		.1255

Subset II

As described, subset II included those reports that documented fracture treatment variables, successful/unsuccessful outcomes, and time to return to activity without defining if the fracture was partial or complete.

Analysis of Combined Subsets I and II Reports on Treatment Modalities and Time to Return to Activity

Having demonstrated that the type of fracture was not a statistically significant variable regarding success of outcome, a more comprehensive data analysis was performed incorporating other published studies that provided statistical summaries of fracture healing and time to return to activity outcomes. Data analysis included outcome success and return to activity for 251 TNSFs reported in the literature between 1970 and 2005. Seventy (96%) of the 73 fractures initially treated with NWB cast immobilization for six weeks had a successful outcome with return to activity on average 4.9 months. Seventeen (77%) of the 22 fractures treated with NWB cast immobilization for less than six weeks had a successful outcome with return to activity in an average of 3.7 months. Only 43 (47%) of the 92 patients initially treated with weightbearing rest and/or cast immobilization experienced a successful outcome, with return to activity on average 5.7 months. Fifty-four (82%) of 66 fractures initially treated surgically had a successful outcome with return to activity in an average of 5.2 months (Tables 2 and 3).

Comparing the modes of treatment, there is no statistically significant difference between NWB conservative treatment and surgery ($P = .6441$). However, there is a statistical trend favoring NWB management (96% successful outcomes) over surgery (82% successful outcomes). There is a statistically significant difference between conservative treatment with weightbearing permitted and NWB conservative ($P = .0001$) and surgical treatment ($P = .0003$) (Table 4).

Table 4. Differences of Treatment (Least Square Means)*

Treatment 1	Treatment 2	*P*
NWB	SURG	.6441
NWB	WBR	<.0001
SURG	WBR	.0003

*NWB, non-weightbearing; WBR, conservative, weightbearing permitted; SURG, surgery.

Analysis of Secondary Treatment

We further analyzed and compared the effectiveness of NWB treatment with surgical intervention as secondary treatment modalities following failed weightbearing management. The same sources of variation were examined as for the cases of initial treatment. Although of limited value because of the small numbers, there was no statistically significant difference between the treatment methods ($P = .5783$) (Table 5).

Table 2. Summary of Subset I and Subset II Reports and Success of Various Initial Treatment Modalities*

	Authors/Year/No. of TNSFs								Totals
Treatment	Torg et al.[30]/ 1982/21	Fitch et al.[11]/ 1989/34	Khan et al.[18]/ 1992/86	Bojanic and Pecina[4]/ 1997/18	Saxena et al.[28]/ 2000/22	Saxena and Fullem[27]/ 2006/19	Burne et al.[6]/ 2005/20	Others**/ 31	251
NWB/cast, 6 wk	10/10		19/22	18/18		6/6	2/2	15/15	70/73 (96%)
NWB/cast, <6 wk			9/13				4/5	4/4	17/22 (77%)
WBR	2/9	13/18	9/34		8/13		8/13	3/5	43/92 (47%)
Surgery†	2/2	12/16	12/20		9/9	13/13		6/6	54/66 (82%)

*TNSF, tarsal navicular stress fracture; NWB, non-weightbearing; WBR, conservative, weightbearing permitted.
**Others include Ostlie and Simons[23] (2001), Alfred et al.[1] (1992), Murray et al.[22] (2005), Goergen et al.[12] (1981), Ariyoshi et al.[2] (1998), Miller and Poulos[21] (1985), Gordon and Solar[13] (1985), Ting et al.[29] (1988), Towne et al.[31] (1970), Dennis and Lombardi[10] (1988), Roper et al.[26] (1986), and Hunter[16] (1981).
†Surgery includes open reduction and internal fixation, bone grafting, and ossicle excision.

Table 3. Summary of Subset I and Subset II Reports on Average Time to Return to Activity in Months*

	Authors/Year/No. of TNSFs								Totals
Treatment	Torg et al.[30]/ 1982/21	Fitch et al.[11]/ 1989/34	Khan et al.[18]/ 1992/86	Bojanic and Pecina[4]/ 1997/18	Saxena et al.[28]/ 2000/22	Saxena and Fullem[27]/ 2006/19	Burne et al.[6]/ 2005/20	Others**/ 31	251
NWB/cast, 6 wk	3.9		5.6	6		4		5.7	4.9
NWB/cast, <6 wk			3.7					4.2	3.7
WBR	5.5	10	5.8		4.3			3	5.7
Surgery†	6	8	5.4		3.1	3.7		4.9	5.2

*TNSF, tarsal navicular stress fracture; NWB, non-weightbearing; WBR, conservative, weightbearing permitted.
**Others include Ostlie and Simons[23] (2001), Alfred et al.[1] (1992), Murray et al.[22] (2005), Goergen et al.[12] (1981), Ariyoshi et al.[2] (1998), Miller and Poulos[21] (1985), Gordon and Solar[13] (1985), Ting et al.[29] (1988), Towne et al.[31] (1970), Dennis and Lombardi[10] (1988), Roper et al.[26] (1986), and Hunter[16] (1981).
†Surgery includes open reduction and internal fixation, bone grafting, and ossicle excision.

Table 5. Results of Secondary Treatment Following Failure of Initial Weightbearing Permitted/Cast Management*

Treatment	Variable	N	Mean	Standard Deviation	Minimum	Maximum
NWB	Age, y	3	17.6	4.04	14	22
	Onset of treatment, mo	3	6	7.0	1	14
	Weeks in cast/boot	3	4.6	1.2	4	6
	Time to full activity return, mo	3	7.6	3.5	4	11
SURG	Age, y	18	23.5	8.0	15	45
	Onset of treatment, mo	18	4.27	6.1	0	24
	Weeks in cast/boot	17	16.8	13.4	2	44
	Time to full activity return, mo	17	6.82	1.8	3	8

*NWB, non-weightbearing; SURG, surgery.

Subset III

Potter et al.[24] reported 32 fractures in 26 subjects in a series in which time to return to activity was not included. Treatment outcomes were not statistically significant for pain (P = .984) or function (P = .170) between NWB cast immobilization and surgical fixation. Also, Hulkko et al.[15] reported nine fractures that did not meet subset I and II inclusion criteria.

Discussion

There is strong evidence supporting the effectiveness of proper conservative management for both partial and non-displaced, complete stress fractures of the tarsal navicular. Case series or reports from Ostlie and Simons,[23] Alfred et al.,[1] Murray et al.,[22] Towne et al.,[31] Goergen et al.,[12] Ariyoshi et al.,[2] Miller and Poulos,[21] and Ting et al.[29] all reported a 100% success rate when NWB management of at least six weeks was utilized. The data also strongly reaffirm that weightbearing rest or limited activity as a conservative treatment often leads to an unsuccessful outcome, including delayed union or nonunion, refracture, fracture progression, or recurrence of symptoms.[6, 10, 11, 14, 18, 30, 31]

In a multi-institutional study published in 1982, Torg et al.[30] analyzed 21 stress fractures of the tarsal navicular bone in 19 patients with particular reference to the clinical and radiographic characteristics, the results of treatment, and the complications associated with the fracture. In addition, microangiographic studies were done on five fresh human cadaveric specimens to determine the vascular patterns peculiar to the tarsal navicular bone. The fractures occurred predominantly in young male athletes (mean age, 21.8 years). Because routine radiographs failed to show the fracture, or showed it but it was not recognized, the interval between the onset of symptoms and diagnosis ranged from less than one month to 38 months (mean interval, 7.2 months). For 14 of the 21 lesions, radionuclide bone scans were needed to locate the abnormality in the tarsal navicular and for 17, AP tomograms were made with the dorsum of the foot parallel to confirm the diagnosis of fracture or to evaluate further the stage of healing. The characteristic fracture was oriented in the sagittal plane and located in the central one-third of the bone, and was either partial or complete. Initially, 19 fractures were treated conservatively and two were treated surgically. Treatment included immobilization in an NWB cast for six to eight weeks for 10 fractures, immobilization in a weightbearing cast for four, limitation of activity with continued weightbearing for five, open reduction and internal fixation for one acute displaced fracture, and an autogenous bone graft for one nonunion. All 10 fractures that were initially treated in NWB casts healed without complications. Seven of the nine patients whose fractures were treated by limitation of activity but continued weightbearing or by immobilization in a weightbearing cast were unable to resume vigorous activity after that treatment because of pain associated with delayed union, nonunion, or recurrence of the fracture.

In 1989, Fitch et al.[11] reported on the management of 37 stress fractures of the tarsal navicular. Thirteen of the 18 fractures treated with either plaster immobilization or rest with continued weightbearing received a satisfactory result with resumption of activities at an average of 10 months. They reported successful outcomes with 12 of the 16 fractures treated surgically with an average return to activities of eight months. After reviewing the results of Torg et al., the authors stated that they now treat recent fractures with eight to 10 weeks of NWB in a cast. However, Fitch et al. still considered autogenous bone graft as the treatment of choice for complete fracture and those who develop a medullary cyst.

In 1992, Khan et al.[18] reported on the outcomes of conservative and surgical management of 86 navicular stress fractures of athletes. Nineteen (86%) of 22 patients who had initial NWB cast immobilization returned to sports activities at an average of 5.6 months as compared with only 12 (30%) of the 40 patients who initially had continued weightbearing with limited activity with an average return to activity time of 9.3 months. They also reported a successful outcome for five (83%) of the six patients who initially underwent surgical treatment, with average return to activities of 3.8 months. It should be noted that two of these patients simply had small ossicles removed, with no reported fracture. As a secondary treatment following failed weightbearing conservative management, nine (90%) of the 10 patients treated with NWB cast immobilization healed in comparison to 13 (61%) of the 21 patients who underwent surgery. These results led the authors to conclude that NWB cast immobilization is the treatment of choice for TNSFs, and that this treatment also compares favorably with surgical treatment in patients who present after failed weightbearing treatment.

Bojanic and Pecina[4] reported on 18 TNSFs treated with an NWB short-leg cast for six to eight weeks, all of whom returned to resumption of full athletic activities at an average of six months.

Saxena et al.[27, 28] reported two series, one consisting of 22 navicular stress fractures, nine of which underwent ORIF with average return to activity of 3.1 months (range, 1.5–5 months). Thirteen patients were treated conservatively with a weightbearing regimen and eight of the 13 fractures had favorable outcomes with a return to activity of 4.3 months (range, 2–13 months). Five of the 13 had an unsatisfactory outcome and surgery was recommended for both incomplete and complete fractures as well as those with cystic changes and sclerosis.

In 2006, Saxena and Fullem[27] presented a second series of 19 fractures in athletes. Six were treated successfully in an NWB plaster cast with an average return to activities at four months and 13 were treated by ORIF with an average return to activity in 4.1 months. Combining the findings of these two series, 23 had surgery and 18 were treated nonoperatively. The difference in return to activity between the treatment groups was not statistically significant, and the authors concluded that TNSFs take four months to heal with nonoperative or operative treatment.

In 2005, Burne et al.[6] reported on 20 TNSFs and observed that "the published recommendation of [a] minimum of six weeks [of] non-weight-bearing cast treatment does not appear to be translated into clinical management; few patients seem to receive this treatment today." Burne et al. found that the clinical outcome of alternative therapies were inferior to that which is reported for cast immobilization. They also stated that "there is limited evidence to support surgical intervention as a first line of management" and suggested that the large variance in different surgical approaches "may reflect a lack of consistently satisfactory outcomes." They also noted that TNSFs prevented almost half of the participants in their study from returning to sports at their previous level.

In 2004, Lee and Anderson[20] published a case report in which they observed that "because most injuries occur in the dedicated athlete, prolonged conservative treatment options may be unsatisfactory." They reported a case of a 28-year-old professional football player, who spent two weeks in an NWB cast, in whom surgical intervention was undertaken because of his high demand and his "desire to return to professional level as soon as possible." Also noted to justify the surgical intervention, they misrepresented the data of Khan et al., stating that the average return to activity was 3.8 months, when actually it was 5.4 months, the same as the 5.6-month return to activity for NWB cast immobilization for six weeks.

Worthy of note was Ronald Quirk's Presidential Guest Lecture to the American Orthopaedic Foot and Ankle Society in 1998,[25] when he stated that "all patients no matter how long their history are to be placed for six weeks on crutches and a below knee non-weight-bearing cast. This has been successful even in several patients who previously failed surgery." He also pointed out that postoperative complications include nonunion, recurrence of a fracture, and progression of partial fracture to complete fracture.

The recent literature suggests that patients are undergoing surgery or are receiving weightbearing conservative management as a first-line treatment option with the expectation that they will return to their activity more quickly.[6, 27, 28] Although surgical treatment seems increasingly common, it remains largely underreported in the literature. It is our contention that many patients are undergoing unnecessary surgical management for these injuries.

Conclusion

There is no statistically significant difference between NWB conservative management and surgical fixation regarding successful outcome (P = .6441) or time to return to activity. We could not show any advantage for surgical treatment over NWB immobilization. However, there is a statistical trend favoring NWB management over surgery. We conclude that conservative NWB management is the standard of care for initial treatment of both partial and complete stress fractures of the tarsal navicular.

Recommendations for the Future

It is interesting to note that there are case reports suggesting that NWB therapy without cast immobilization was equally effective as NWB therapy with cast immobilization.[10, 31] A future study should involve a comparison of NWB therapy with and without cast immobilization. If equally effective, we believe that patient comfort would be improved if treatment did not require the patient to undergo cast immobilization during the course of NWB treatment.

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Anterior Vertebral Body Tethering: Overview and Technique

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Introduction

The current standard of care for skeletally immature patients with idiopathic scoliosis (IS) with moderate curves (between 20 and 45°) is a thoracolumbosacral orthosis (TLSO).[1] The recently published BrAIST trial demonstrated the effectiveness of bracing in preventing curves from reaching a surgical threshold of 50°.[2] However, the study only looked at bracing for children with curves <40°, and thus no conclusion could be drawn regarding greater magnitude curves. In addition, several prior reports have raised questions about the efficacy of bracing.[3–5] Psychosocial and practical issues may also add to the problems surrounding bracing. Many patients may develop body image concerns while wearing a brace, and brace wear is often required for up to 23 hours a day.[6] Both of these issues are of great concern to patients and their parents and increase the incidence of noncompliance in this population. Additionally, researchers have recently shown that for female patients with AIS, the stress associated with brace wear may be higher than the stress associated with their actual spinal deformity.[7] Thus, bracing is often a poor choice for patients with already limited options.

Many curves, especially in young patients, may ultimately progress and result in traditional surgical intervention with a spinal fusion. Charles et al.[3] reported a 75% fusion rate for patients whose curves were between 21–30° at onset of puberty and a 100% fusion rate in patients with juvenile scoliosis whose curves were >30° at the onset of puberty. However, many problems with spinal fusion also exist, including inhibition of growth over the length of the construct, the development of adjacent level disc degeneration, decreased range of motion, and decreased spinal mobility.[8] Because of the great difficulties with bracing and spinal fusion, surgeons have vigorously searched for alternative surgical approaches which will halt curve progression and modulate growth of the spine.

Extensive preclinical data have been published on vertebral body tethering (VBT) including animal studies as well as biomechanical reports.[8–13] Newton et al. have demonstrated the ability of a unilateral tether to induce deformity in a bovine model with radiographic evidence of disc wedging and rotation, while retaining spine flexibility.[8, 10] Braun et al. have demonstrated similar results in a goat model.[14]

At this time, several case reports and clinical papers have been published or presented at international meetings outlining the safety and efficacy of anterior vertebral body tethering in humans.[15, 16] Briefly, Samdani et al. reported on the 12- and 24-month results of anterior VBT in skeletally immature patients. In their two-year investigation, 11 skeletally immature patients (mean Risser 0.6, Sander 3.4) underwent tethering. Preoperative thoracic Cobb angle averaged 44° which corrected to 20° on first erect radiographs, with progressive improvement at two years (Cobb angle = 13.5°, % correction = 70%; $P < 0.00002$). Similarly, the preoperative lumbar curve of 25° demonstrated progressive and spontaneous correction (first erect = 14.9°, 2 yr = 7.2°, % correction = 71%; $P < 0.0002$). And despite the presumed disadvantages of tethering in treating the axial deformity, thoracic rotation as measured by a scoliometer went from a mean of 12.4° preoperatively to 6.9° at the most recent measurement ($P < 0.01$). No major complications were observed. As anticipated, two patients returned to the operating room at two years postoperatively for loosening of the tether to prevent overcorrection (Figure 1A–H).

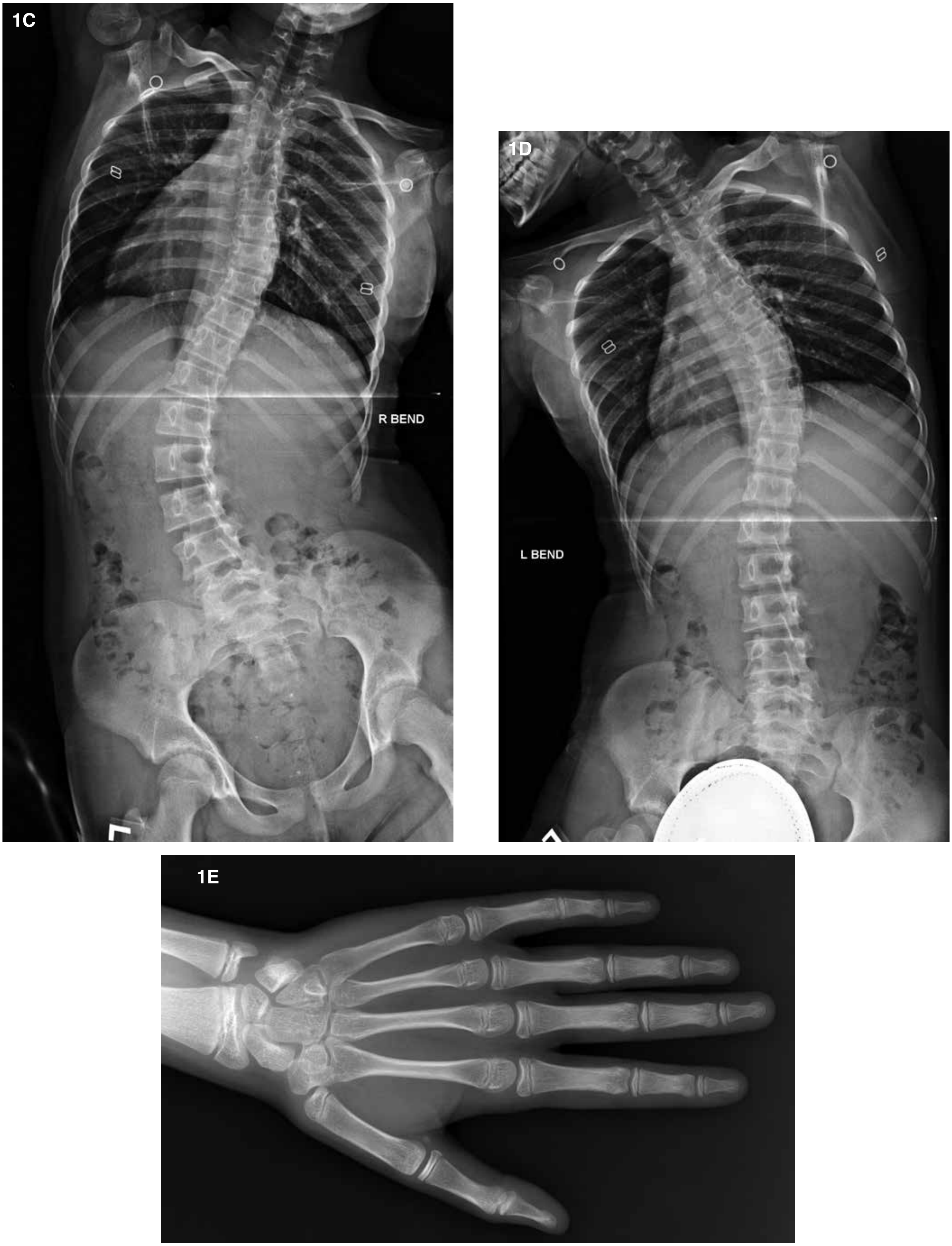
Additionally, Samdani et al. recently presented data on their first 25 patients who have undergone thoracic VBT who have now reached skeletal maturity. Presented at the 2015 annual meeting of the Scoliosis Research Society, Samdani et al. (Samdani AF et al.: Anterior Vertebral Body Tethering for Immature Idiopathic Scoliosis: Results of Patients Reaching Skeletal Maturity. 50th SRS annual meeting, Minneapolis, MN, September 28–October 3, 2015) investigated the effect of VBT on 25 consecutive patients; all were skeletally immature at instrumentation, and only thoracic curves were instrumented. The preoperative thoracic Cobb angle averaged 41° and corrected to 20° on first erect radiograph ($p < 0.05$). This curve displayed progressive improvement to skeletal maturity measuring 14° (percent correction = 66.1%, $p < 0.05$). Similarly, the preoperative lumbar curve of 28° demonstrated progressive correction (first erect = 18°, most recent = 12°, $p < 0.05$). Axial rotation improved 12° preoperatively to 6° at the most recent measurement ($p < 0.05$). The sagittal measurements remained

Figures 1A-H. Preoperative PA **(A)** and lateral **(B)** radiographs of a 12-year-old female who presented with a 50° right sided thoracic curve and a 46° lumbar compensatory curve, Lenke 1C. Thoracic kyphosis (T5–T12) measured 25°. Her thoracic curve measured 22° on lateral bending **(C)** and her lumbar curve measured 17° **(D).** Preoperatively, the patient was skeletally immature, Risser 0 and Sanders 3 **(E).** Due to the magnitude and of the patient's lumbar curve and her Lenke C modifier, a decision was made to tether both curves. Postoperatively, the patient's thoracic curve measured 30° at six weeks and her lumbar curve measured 19° **(F),** the thoracic curve measured 19° at 12 months and the lumbar measured 12° **(G).** At 18-month follow-up, her thoracic curve measured 20° and her lumbar curve measured 19° **(H).** The patient's thoracic kyphosis, lumbar lordosis and overall sagittal alignment were maintained throughout the follow-up period. The patient remains a Risser 2 and as such, we expect some continued modulation of her curves.

stable (thoracic kyphosis: pre-op = 24°, first erect = 21°, most recent = 24°; lumbar lordosis: pre-op = 50°, first erect = 45°, most recent = 52°) and no major complications were observed. While longer term follow-up is still needed to assess implant wear and durability over time, as well as other potential late complications, these data help us to understand the impact of VBT on patients at the end of skeletal growth. These results suggest that VBT can be utilized effectively and safely in this patient population (Figure 2A–G).

Evolving Indications

Candidates for VBT include skeletally immature patients with thoracic, thoracolumbar, and/or lumbar scoliosis curves (generally Risser 0-2, Sanders digital score ≤4). Tethering should be avoided in patients on the extreme ends of maturity or immaturity. Older, more mature patients will fail to achieve growth modulation, and extremely young immature patients will likely experience overcorrection. Currently, VBT is indicated in thoracic coronal curves measuring from


1C
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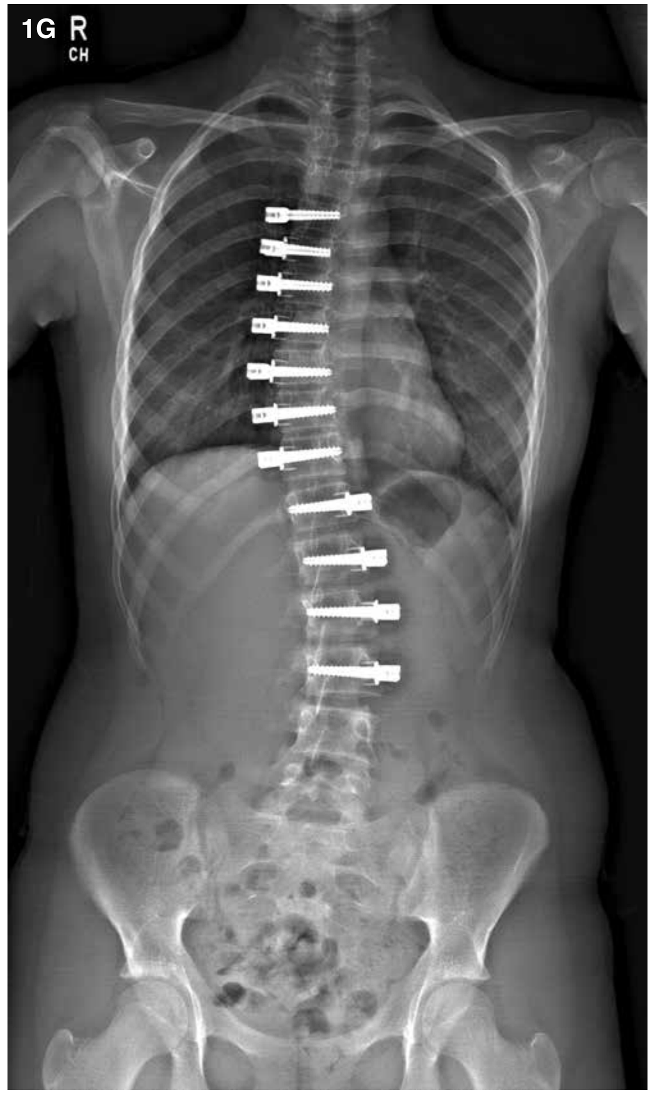


30–70° and lumbar curves measuring 30–60°, although flexibility is most important and curves should ideally bend to < 30°. Due to the potential hyperkyphosing effect of anterior instrumentation, >40° of kyphosis in the thoracic spine is a relative contraindication. In addition, the patient should be counselled that approximately 50% of axial correction can be expected and thus large rib prominences (>20°) are also a relative contraindication.

Surgical Technique

Patient Positioning and Surgical Setup

The patient is placed on the operating table in the lateral decubitus position with the curve side up (Figure 3). The table is not flexed and a small axillary roll is placed beneath the patient. Single-lung ventilation is used. After positioning the patient, biplanar fluoroscopy is used to determine the exact location for the intercoastal portals before the patient is prepped and draped (Figure 4).

Surgical Exposure

In the thoracic spine, three separate 5-mm incisions in length are made in the anterior axillary line through which the camera is inserted. Three 15-mm working portals, through which the screws and tether are placed are made in the posterior and/or mid axillary lines. Depending on the levels being instrumented, the working portals are placed in the intercostal spaces that will optimize instrumentation. Through the working ports, the parietal pleura overlying the spine is reflected anteriorly beginning 1 to 2 mm anterior to the rib heads and carried around toward the opposite side using a harmonic scalpel (Figure 5). This exposure allows

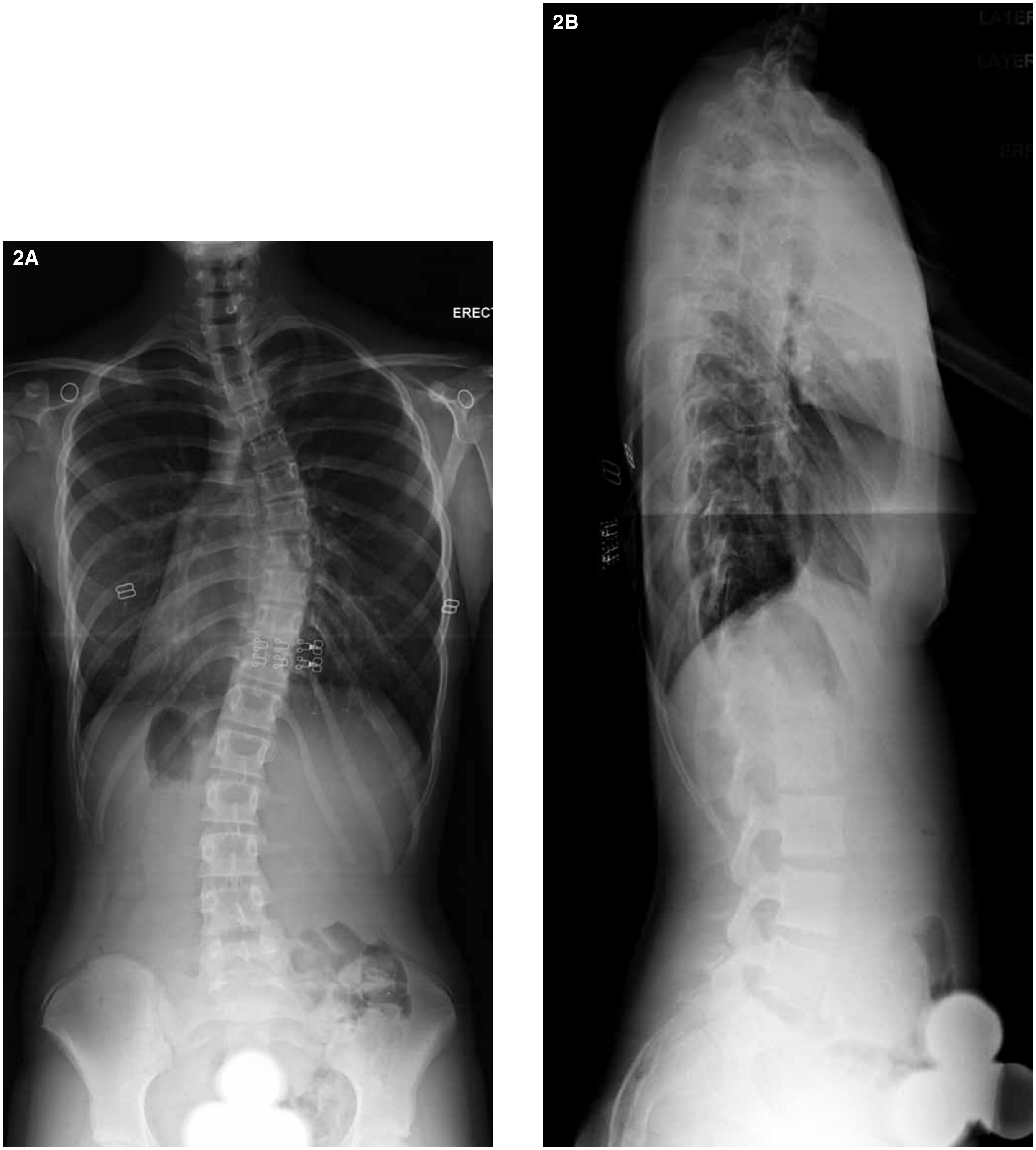
for definitive access to the segmental arteries and veins, which are also divided using the harmonic scalpel. Proper vertebral levels are checked and confirmed using C-arm fluoroscopy in both the anteroposterior (AP) and lateral positions. In rare cases, a small muscle-sparing thoracotomy incision centered on the mid-axillary line is made at the appropriate interspace (typically between intercostal spaces 8–9) with thoracoscopic guidance. This is particularly useful in situations when single-lung ventilation is ineffective.

Screw Placement

At this point, a 15-mm working port is placed in the posterior axillary line overlying the most cephalad ICS that correspond to vertebral bodies that will receive the screws. After a meticulous pleural dissection and exposure of the vertebral bodies (Figures 5 and 6), a three-prong staple is placed onto the most cephelad vertebral body just anterior to the rib head (Figure 7). Its proper position is able to be well visualized with the thoracoscope. The proper position of the staple is checked and confirmed using C-arm fluoroscopy on AP and lateral views. Care is taken to remain just anterior to the rib head to ensure that the staple is not in the foramen. The staple is then malleted into place in the vertebral body, and proper position is checked and confirmed using C-arm fluoroscopy in the AP view. At this time, the screw hole is then tapped using a 5.2-mm tap with guidance by C-arm fluoroscopy. It is advanced from the convexity of the curve toward the concavity across the anterolateral aspect of the vertebral body. When a thoracotomy is performed, the surgeon's hand can be placed onto the opposite side of the spine to assess when the tap has breached the contralateral cortex to achieve bicortical fixation. When a thoracoscopic-only approach is utilized, proper positioning and cortical purchase is checked and confirmed in a stepwise fashion using C-arm fluoroscopy. The length is then measured and the tap removed. In addition, if reconstructed axial images are available, i.e., from an intraoperative computed tomography (CT) scanner or fluoroscopy machine, these are utilized to ensure appropriate screw length. Next, an appropriate-size Dynesys screw (Zimmer, Inc., Warsaw, IN) is advanced by hand (Figure 8). Screw width varies from 5.2 to 6.4 mm and length is typically 25 to 45 mm. Bicortical purchase is confirmed. Again, if a thoracotomy is performed, the surgeon is able to palpate the screw on the contralateral side to confirm bicortical fixation; however, we do not routinely perform thoracotomy at this point in our experience. Proper position is again checked and confirmed using C-arm fluoroscopy. The surgery proceeds in a similar fashion placing screws in the anterior aspect of the vertebral bodies along the length of the proposed construct. When a thoracotomy is performed, the most distal screws can be placed via the thoracotomy incision. After all of the screws have been placed, proper position of each of them is checked again and confirmed using C-arm fluoroscopy on AP and lateral views.

Placement of the Tether

The surgeon then delivers the tether into the chest through the thoracotomy or the most caudad 15-mm port and advances it into the tulip of the most cranial screw (Figure 9). The T-handle pusher is then placed through the most cranial 15-mm port onto the corresponding screw, and the set screw is placed, locking in the tether. The tether is then laid into the tulips of all the set screws. Tension is then placed onto the subsequent caudal screw (at the second vertebral body) as well as another impactor device onto the third body. Careful reduction translation force is placed onto the spine at both of these levels as the tether is tightened. Then the set screw is tightened at the second body. This is performed in similar fashion as the procedure progresses caudally. Three pushers are placed over top of the apical screws when tensioning. A corrective downward and anterior-directed translational force is performed as the tether is tensioned in the tulip of the screw to achieve correction and derotation. This is performed at the third and fourth vertebral body of the construct. Slight compression and distraction may be performed as well. The surgery progresses in similar fashion



Figures 2A–G. Preoperative PA **(A)** and lateral **(B)** radiographs of a 14-year-old female who presented with a 38° right sided thoracic curve and a 24° lumbar compensatory curve, Lenke 1A. Thoracic kyphosis (T5–T12) measured 12°. Her thoracic curve measured 17° on lateral bending **(C).** Preoperatively, the patient was skeletally immature, Risser 2 and Sanders 6 **(D).** Postoperatively, the patient's thoracic curve measured 12° at six weeks **(E),** 7° at 12 months **(F)** and 5° at 24-month follow-up **(G).** The patient's thoracic kyphosis and overall sagittal alignment were maintained throughout the follow-up period. The patient is currently a Risser 4.


2C
AP
SUPINE


2E
ERECT


2D

distally, attaching the tether at caudal levels, tensioning with the aforementioned corrective maneuvers at each level. Global C-arm images are obtained after each screw is engaged into the tether to confirm that there is continued correction of the curvature and also that there is no evidence of pullout or cutout of the screws.

At this point, the residual portions of the tether at the top and bottom of the construct are excised using a scalpel under direct visualization. We will often leave approximately 2.5 cm of tether at both ends to permit adjustments if needed (Figure 10). A chest tube is then placed through one of the small (5 mm) port sites if a thoracotomy incision has been made (Figure 11). Re-expansion of the lung is done under direct visualization.

Wound Closure

If there is a thoracotomy incision, the wound is closed first with a 1 Vicryl paracostal stitch to reapproximate the ICS. The latissimus dorsi and serratus anterior muscles, having been spared, can be repaired using only a 2-0 Vicryl stitch to secure their adjacent fascial edges. Any muscle divided for insertion of the 15 mm ports is also reapproximated with 2-0 Vicryl. The subcutaneous tissues of all wounds are closed with 3-0 Vicryl and the skin edges sutured with 5-0 monocryl subcuticular stitches. The chest tube and local anesthetic catheters are secured with 2-0 Ethibond sutures. Sterile Steri-Strips, 4×4s, and Tegaderm are placed over top of the patient's wounds

Conclusions

A recently presented abstract by Pahys et al. reports our center's overall experience and complications with the first 100 consecutive patients treated with VBT (Pahys et al.: The First 100 Consecutive Anterior Vertebral Body Tethering Procedures for Immature AIS at a Single Institution: Outcomes and Complications in the Early Postoperative Period, 22nd International Meeting on Advanced Spine Techniques, Kuala Lumpur, Malaysia, July 8–11, 2015). Mean operative time and estimated blood loss (EBL) have decreased significantly with increasing surgeon experience; surgical time averaged under 200 minutes and EBL was approximately

Figure 3. Positioning of the patient in the lateral decubitus position with the curve side up.

150 cc for our last 25 patients who underwent this procedure ($p < 0.05$). Only four patients required a blood transfusion (4%). There were no major complications or early implant failures. Intraoperatively, two patients were converted to an open approach after inability to tolerate single lung ventilation, and one patient had transient partial decrease in neuromonitoring that resolved prior to closure. Minor postoperative complications included one patient with prolonged atelectasis requiring bronchoscopy, five patients complained of transient thigh pain/numbness, and one patient has unresolved intercostal neuralgia.

To date, the patients in our cohort have achieved stability or continued correction in their curves and have avoided spinal fusion. They have also subjectively retained spinal mobility. Some literature suggests that the anterior thoracoscopic approach may impact pulmonary function.[17, 18] However, several authors report minimal to no decline in pulmonary function following anterior spine surgery, with thoracoscopic approaches having the least effect.[19, 20]

The potential for overcorrection of course requires attention. Continual skeletal growth along with the mechanical forces of the tether can begin to create a scoliotic curve in the opposite direction. A fundamental consideration is how much "residual curve" to leave behind in an initial tethering procedure. This decision hinges chiefly on how much growth the child has remaining. In patients with significant growth remaining (open triradiate cartilage, Risser 0, etc.), it may be necessary to wait for some continued growth prior to surgery, or leave more residual curve at the index procedure. As well, the use of genetic markers of curve progression may prove to be of added value here. Longer term follow-up is categorically important in order to characterize the temporal relationships between dynamic tethering, skeletal growth, and final correction. Although the concept of VBT is encouraging, clinical experience is still relatively limited, and continued comprehensive research studies need to be conducted to analyze its usefulness as a primary treatment option in this patient population.

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Figure 4. C-arm fluoroscopy is used to determine the exact location for the intercoastal portals.

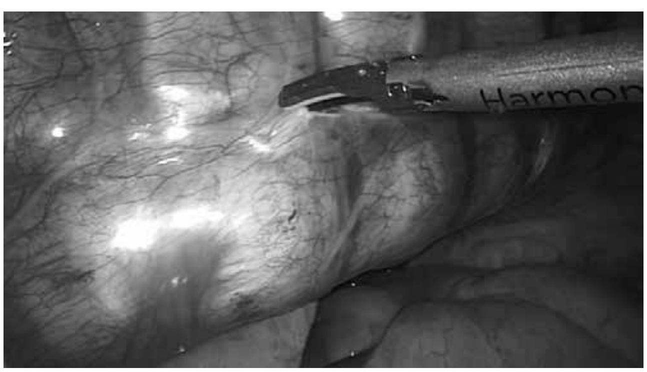

Figure 5. The parietal pleura overlying the spine is incised and reflected anteriorly.

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Figure 6. Exposure of the vertebral bodies.

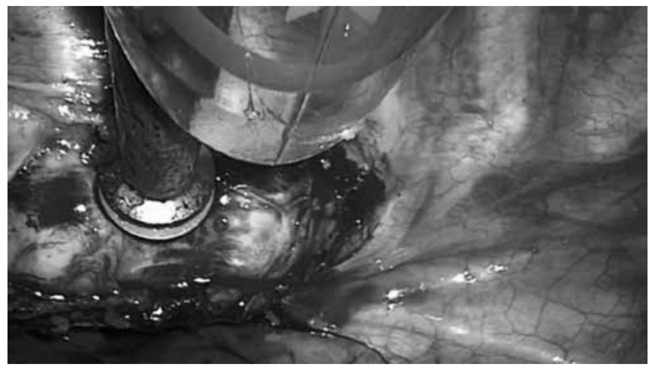

Figure 7. Placement of the three-prong staple onto the vertebral body just anterior to the rib head.

Figure 8. Placement of a 5.2 to 6.4 mm diameter Dyneses screw (typically 25 to 45 mm long) horizontally across the vertebral body; care is taken to remain anterior to the rib head.

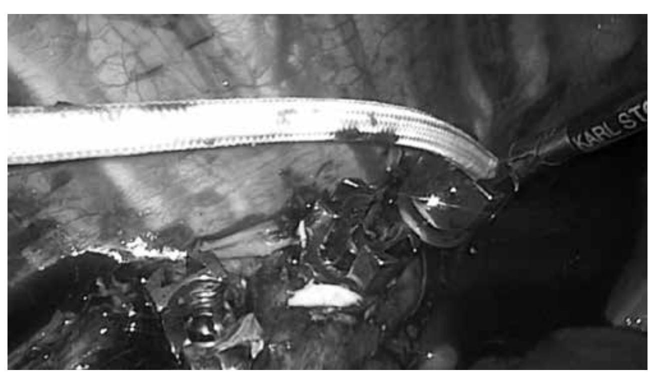

Figure 9. Placement of the tether into the most cephalad pedicle screw tulip.

Figure 10. View of residual tether at caudal segment.

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Figure 11. Wound closure and placement of chest tube.

Practical Radiographic Assessment of Non-Arthritic Hip Pain: How to Identify Femoroacetabular Impingement (FAI) and "At Risk Hips"

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Introduction

Young, healthy active patients (15 to 50 years old) will often present to the outpatient orthopaedic office with hip and groin pain in the setting of athletic overuse or seemingly minor trauma. In order to make a proper diagnosis and determine the best course of treatment, obtaining appropriate radiographs is a crucial first step in the management of these patients.[1] Femoroacetabular impingement and labral pathology remains a challenging diagnosis. In 2009, Clohisy et al. prospectively evaluated 51 patients and showed that the average duration of undiagnosed symptoms was 3.1 years and patients had seen an average of 4.2 providers prior to making the final diagnosis.[2] Improved awareness of causes of athletic hip pain and efficient and systematic approach to the diagnosis can have tremendous impact on the lives of our patients. Despite tremendous advances in computed tomography and magnetic resonance imaging, the importance of obtaining and properly interpreting adequate plain radiographs cannot be overemphasized. Our standardized series of radiographs includes: 1) a true supine antero-posterior (AP), 2) Frog-leg lateral, 3) a 60º Dunn modified lateral and 4) a false profile lateral. We prefer the supine pelvis as it more consistently corrects for issues with pelvic tilt. However, in cases where more advanced arthritic changes are a concern, we will obtain a weight-bearing pelvic radiograph as well. This series of radiographs allows for evaluation of the entire pelvis, involved proximal femur and even some degree of side-to-side comparison. Parvizi et al. and Nepple et al. have both shown that radiographic appearance of the hip and certain patterns of x-ray apparent FAI alone are predictive of intra-articular pathology.[1, 3] In fact, if radiographic evaluation of the hip is relatively normal, the presence of labral pathology is rarely seen. In this paper, we seek to: 1) describe the necessary steps to obtaining standardized hip radiographs and 2) describe a systematic approach to radiographic interpretation to allow for the accurate diagnosis and formulation of the most effective treatment plan in a timely non-invasive manner.

Antero-Posterior (AP) Pelvis View

The AP pelvis radiograph is obtained through a combination of proper patient and beam positioning. The patient is positioned supine with their legs held in internal rotation to neutralize the impact of femoral antetorsion.[4] The central beam should be focused at a distance of 1.2 m from the patient and pointed at the midpoint between the superior border of the symphysis and a virtual line transecting both anterior-superior iliac spines.[4] To verify neutral rotation and pelvic tilt, the radiograph that is obtained should be closely evaluated. The tip of the coccyx and the central sacral line should be centrally aligned. The distance between the pubic symphysis and the sacro-coccygeal junction should be at a consistent height above the pubic symphysis: 2–3 cm in males, and 2–6 cm in females (Figure 1).[4] One must be able to obtain and interpret the AP pelvis in a reproducible manner. In poorly obtained radiographs, positional differences in pelvic rotation or tilt may be misinterpreted as differences in acetabular coverage or version.

Commonly, we see patients who present for surgical consultation never having had an AP pelvic view. Screening AP and lateral of the involved hip are interpreted as "normal" and the patient is referred for MRI, which may also be inconclusive or read as "possible labral tear." Patients with athletic hip pain (particularly females) will generally fall into two broad categories: 1) acetabular overcoverage (FAI) or 2) acetabular undercoverage (dysplasia or borderline dysplasia). Accurate diagnosis of acetabular coverage and version requires appropriate pelvic radiographs.

Acetabular Depth

The supine AP pelvis is the best view for assessment of acetabular depth and coverage of the femoral head. Increased acetabular depth or over coverage of the femoral head is characteristic of pincer type FAI.[4] In this setting, the acetabular rim will contact the femoral head/neck junction in positions of high hip flexion and internal rotation. Repetitive cycles lead to repetitive trauma to the labrum causing degenerative acetabular labral changes and labral tears as the cartilage labrum junction is violated. This is believed to be the genesis of pain for most patients with hip impingement (Figure 2B). Acetabular depth can be evaluated in several ways. The ilioischial line is the key landmark to determining acetabular depth. In a normal hip, the acetabular fossa lies completely lateral to the ilioischial line.[4] In the setting of

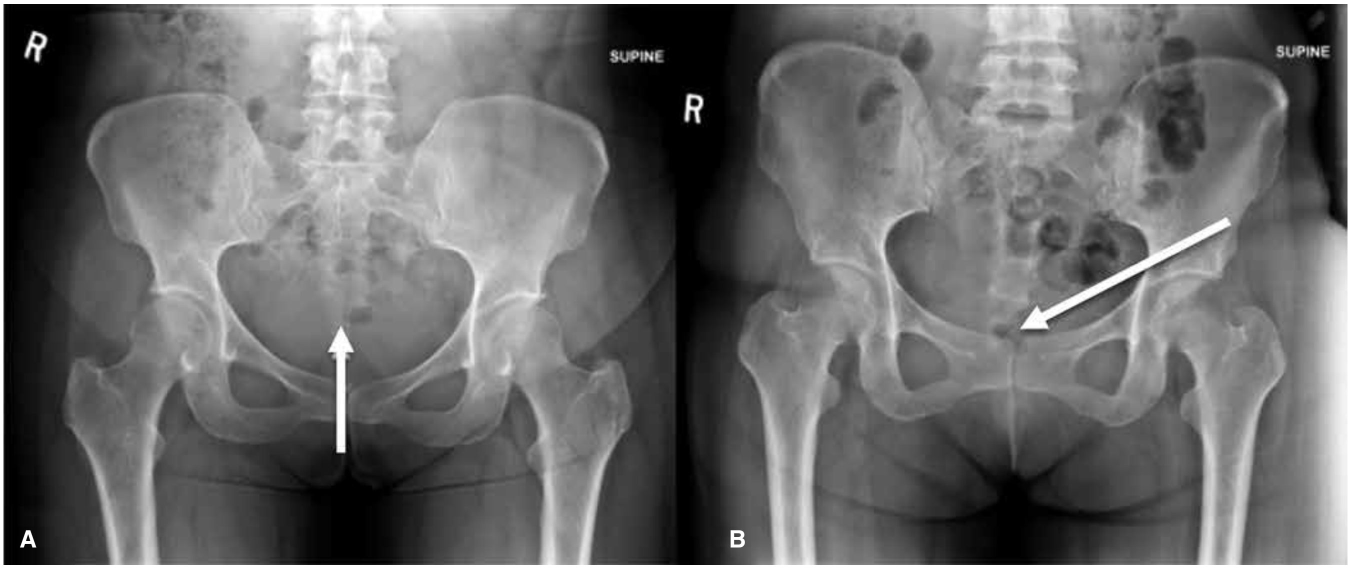

Figure 1A-B. (A) Appropriate supine AP pelvis radiograph of 43-year-old female as the tip of the coccyx and the central sacral line should be centrally aligned with the distance between the pubic symphysis and sacro-coccygeal junction at about 2–6 cm. **(B)** Poorly obtained supine AP pelvis radiograph of 44-year-old female as there is a misalignment between the coccyx and central sacral line and very little distance between the pubic symphysis and sacro-coccygeal junction as they appear to cross each other.

profunda, the acetabula fossa will abut the ilioischial line while in protrusion states, both the acetabular fossa and the femoral head lie medial to the ilioischial line (Figure 2A-B).

Acetabular Coverage

While the acetabular depth of the pelvis can be determined through simple radiograph examination, the acetabular coverage must be determined more accurately through a combination of physical measurements and radiograph examination. The lateral coverage of the acetabulum is determined through the measurement of the Lateral Center Edge Angle (LCEA) (Figure 3A). This angle is formed by a vertical line, a line through the center of the head and the lateral acetabular edge from the supine AP pelvis radiograph. The measurement of this angle typically falls between 25 and 39 degrees, where below this range signals under coverage and over this range signals over coverage.[4] Similarly, the anterior-posterior coverage of the acetabulum is determined through the measurement of the Anterior Center Edge Angle (ACEA), which is formed by a vertical line, a

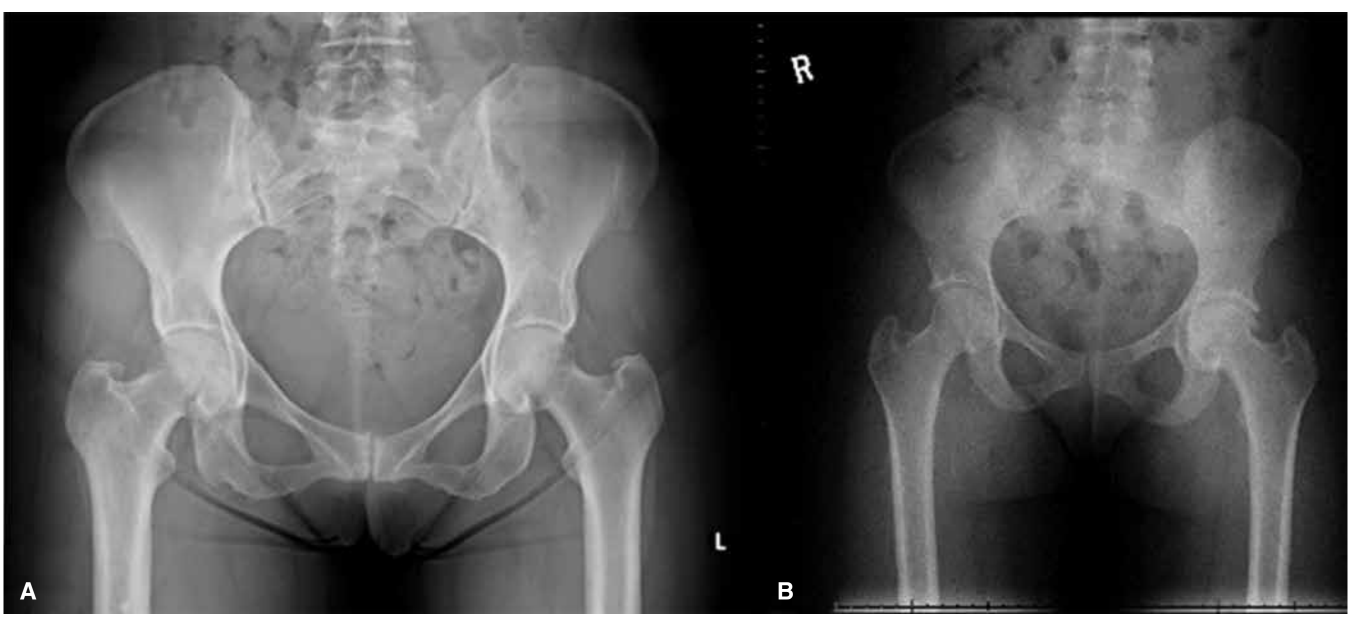

Figure 2A-B. (A) Supine AP pelvis radiograph of a 54-year-old female revealing protusio as both the acetabular fossa and the femoral head lie medial to the ilioischial line. **(B)** Supine AP pelvis radiograph of a 34-year-old female revealing profunda of the right hip joint and pincer type FAI as the acetabula fossa abuts the ilioischial line, causing overcoverage of the femoral head and FAI from pincer type morphology.

line through the center of the head and the anterior acetabular edge from the supine AP pelvis radiograph. Measurements greater than 25 degrees are considered normal while between 20 and 25 degrees is borderline and less 20 degrees indicating significant anterior under coverage or dysplasia (Figure 3B).[4] An anterior CEA greater than 35 degrees is indicative of anterior over coverage or pincer impingement.

These radiographs must be carefully evaluated as Sekiya et al. have found radiographs to show a false-positive cross over sign when the beam is centered over the entire pelvis instead of the midpoint as described previously.

Femoral Head and Neck

The supine AP pelvis view also allows for evaluation of the bony morphology of the anterolateral aspect of the head and neck junction of the proximal femur, which can be correlated to cam morphology and FAI if present (Figure 4A). Abnormal anterolateral morphology of the head and neck junction of the proximal femur causes the femoral head to be non-spherical and increases its overall radius, causing increases shear forces as the head and neck flex into the acetabulum. Repetitive cycles may lead to tearing of the labrum or chondral delamination. The anterior sphericity or non-sphericity of the femoral head is based on the measurement of the alpha angle or the offset between the femoral neck and the head. This is measured with a line from the axis of the femoral neck that runs through the center of the femoral head and connects with where the sphericity or asphericity of the femoral head begins.[4] A normal head and neck offset is measured between 45 and 50 degrees while alpha angles greater than this range are considered an indicator for an abnormal offset and femoral head sphericity.[4] This is evident in patients with FAI from cam morphology as their alpha angles are measured at about 70 degrees or greater (Figure 4B).[1] In addition, the measurement of the femoral neck can also be used to determine risk of FAI as the neck-shaft angle or the angle between the femoral neck axis and the femoral shaft axis will also represent the degree of flexion and internal rotation that can occur at the femoroacetabular junction.[4] Note that the alpha angle cannot fully predict a patient's gross motion as there are a multitude of other factors (femoral and acetabular version, lumbar tilt and motion and soft tissue laxity or contracture).

Neck-Shaft Angle

Normal measurements of this angle fall between 125 to 135 degrees with angles greater than 130 indicating increased varus, which can increase the risk of anterior hip impingement as the bony morphology of the neck and head are limiting the hip's ability to internally rotate and creating a more acute angle between the femoral head and neck (Figure 5).

However, the measurement of the alpha angle and the neck shaft angles are not the absolute indicator of abnormal femoral neck and head offset or asphericity as the non-spherical anterior aspect of the femoral head and neck may not appear on the AP pelvis view, causing the radiograph to appear normal (Figure 6A).[1, 4] Therefore, the limitations of the supine AP pelvis view must be supplemented with lateral radiographs of the pelvis to ensure that all aspects of the hip joint have been evaluated before making a diagnosis on the bony morphology of a patient (Figure 6B).

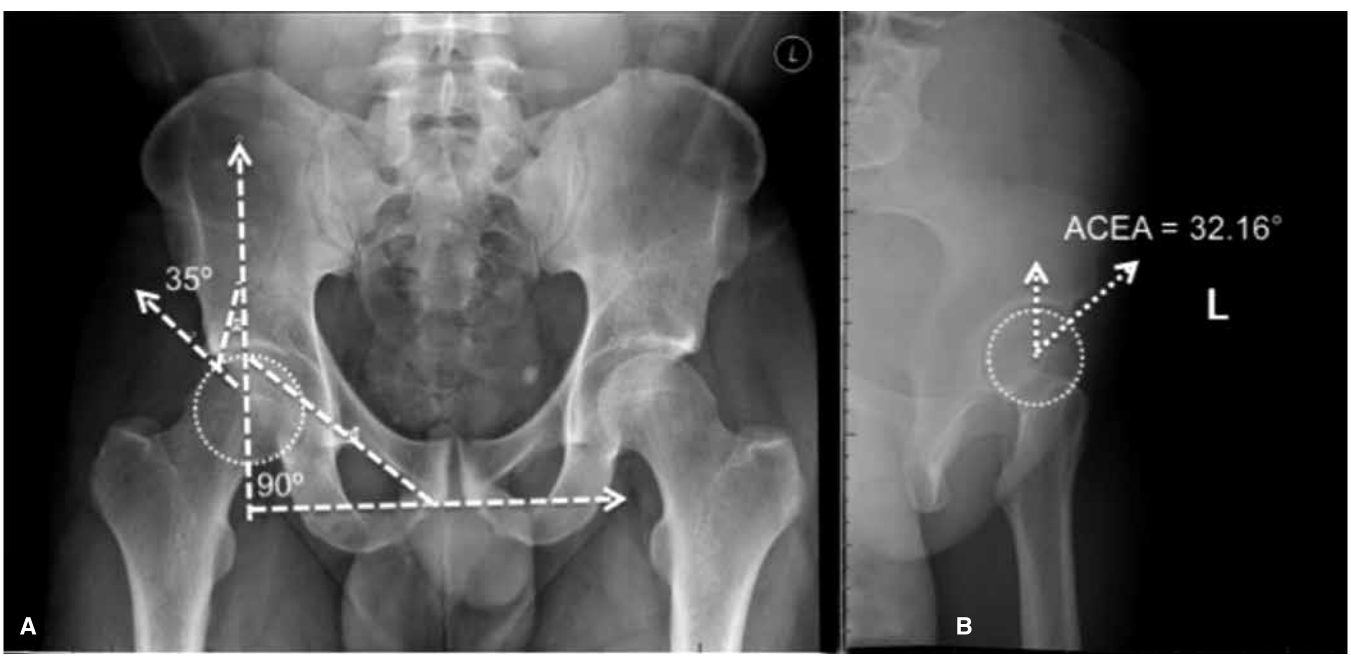

Figure 3A-B. (A) Supine AP pelvis radiograph of 41-year-old male patient with LCEA measurement of 35 degrees in her right hip, indicating normal acetabular coverage. **(B)** ACEA measurement of 32.16 degrees in 28-year-old female patient with ACEA indicating normal acetabular coverage.

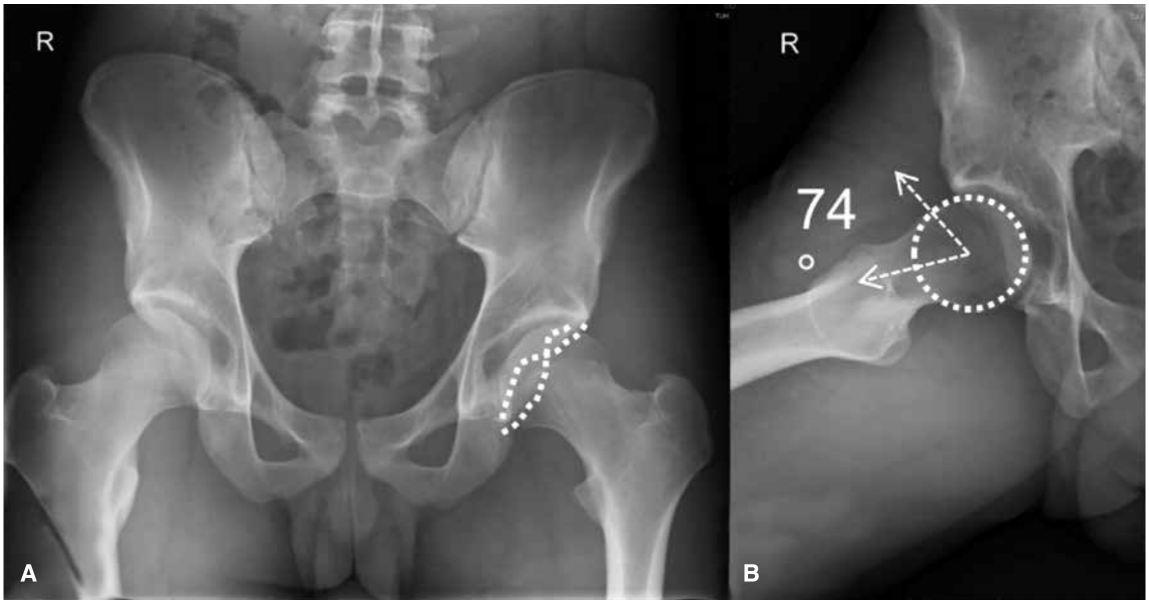

Figure 4A-B. (A) Supine AP pelvis radiograph of a 19-year-old male patient with cranial crossover, apparent cam morphology, and an alpha angle measured at 74 degrees, demonstrating that the alpha angle can be used as an indication of FAI. **(B)** Lateral Dunn radiographs confirming cam morphology and asphericity of the femoral head.

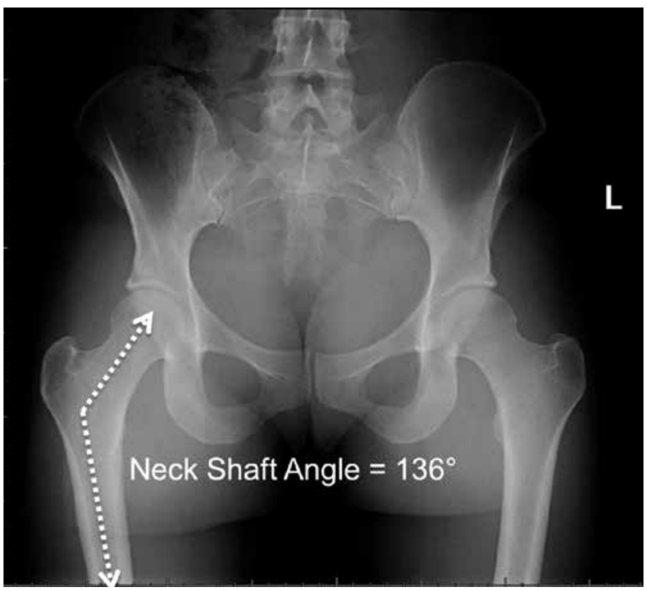

Figure 5. Supine AP pelvis radiograph of 28-year-old female patient with a neck shaft angle of 136 degrees, indicating anterior FAI impingement as the bony morphology of the neck and head are limiting the hip's ability to internally rotate.

Lateral Views

The specific lateral radiographs required to truly evaluate the anterior aspect of the proximal femoral head and neck are the Frog-leg and Dunn lateral views. For the Frog-leg lateral view, the patient should have both hips positioned in flexion and maximal abduction and external rotation for the view to be obtained and as Nepple et al. point out, the Frog lateral view allows for the antero-inferior aspect of the femoral neck and head to be visible, which is often missed or not seen in the supine AP pelvis view (Figure 7A-B, Figure 9A-B).[3] The Dunn lateral view is obtained by positioning the patient's hip in 60 degrees of flexion, maximal abduction, and neutral rotation and this view shows the antero-superior portion of the femoral neck and head and an estimate of the femoral version (Figure 8A-B).[1]

Discussion/Conclusion

Properly obtaining and interpreting pelvis radiographs is an efficient and inexpensive clinical step that allows orthopaedic surgeons to quickly narrow the sources of hip pathology and pain. This imaging combined with pain and range of motion tests provides a guide as to the type of treatment that will effectively manage the symptoms in a patient's hip. However, there are limitations as to the amount of clinical information that radiographs provide on a patient's condition. The presence of FAI and abnormal bony morphology can be determined from radiographs along with the mechanism of how the acetabular labrum is being damaged, but the quality and the actual damage to the labrum itself cannot be determined. Those aspects are accomplished through a magnetic resonance arthrogram (MRA) or diagnostic arthroscopy. Furthermore, radiographs are also limited in that they do not reveal any three-dimensional joint incongruences within the acetabulum that may be occurring as Sekiya et al. describe.[4] As a result, to truly gain an understanding of all the three-dimensional aspects of the pelvis, a computed tomography scan with three-dimensional reconstruction should be acquired. All three forms of imaging may be needed in order to complete a full work-up and make a complete evaluation and diagnosis of a patient's pelvis. Despite these limitations, radiographs and their interpretation are critical to the clinical diagnosis and management of young

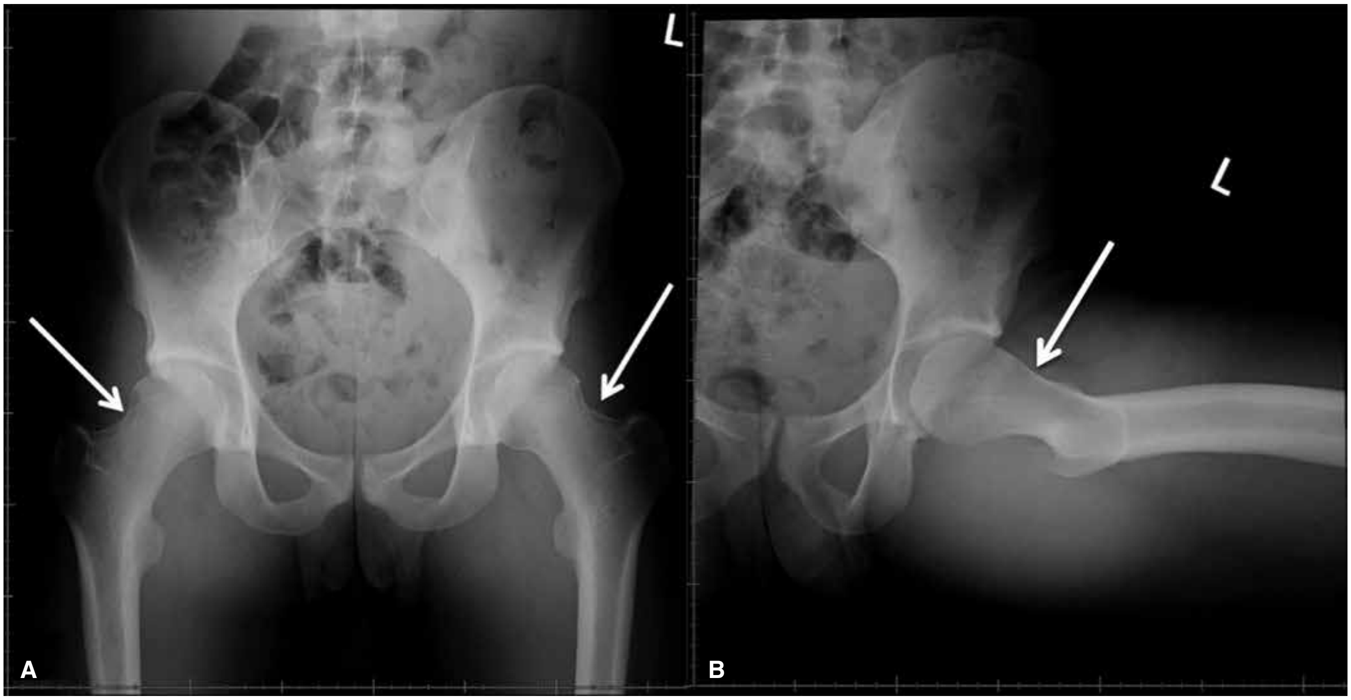

Figure 6A-B. (A) Supine AP pelvis radiograph of 19-year-old male patient that appear to reveal no FAI or abnormal morphology of either femoral head and neck. **(B)** Lateral Dunn radiograph of the same 19-year-old male patient revealing anterosuperior cam morphology and FAI of the left hip.

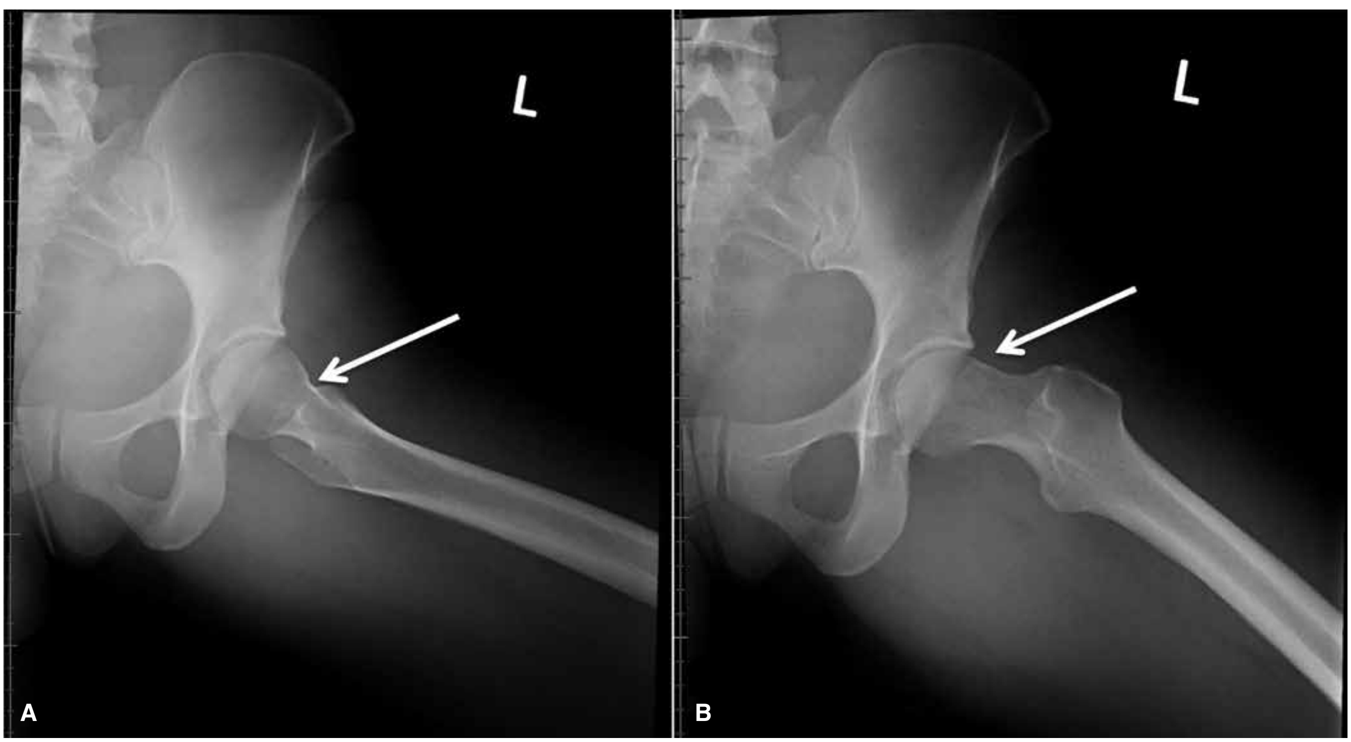

Figure 7A-B. (A) Left Frog-leg lateral view radiograph of a 28-year-old female patient. **(B)** Left Dunn elongated lateral view radiograph of the same 28-year-old patient. These views allow for the anteroinferior and anterosuperior aspects of the femoral neck and head to be evaluated.

healthy active patients who present with hip pathology and pain. Properly obtained and interpreted plain radiographs are a key first step to defining the treatment course. It is extremely rare for patients with normal radiographs to demonstrate significant cartilage or labral pathology at a young age. Conversely, patients with clear evidence of FAI on plain radiographs will have recurrent and often progressive symptoms that respond poorly to non-surgical management.

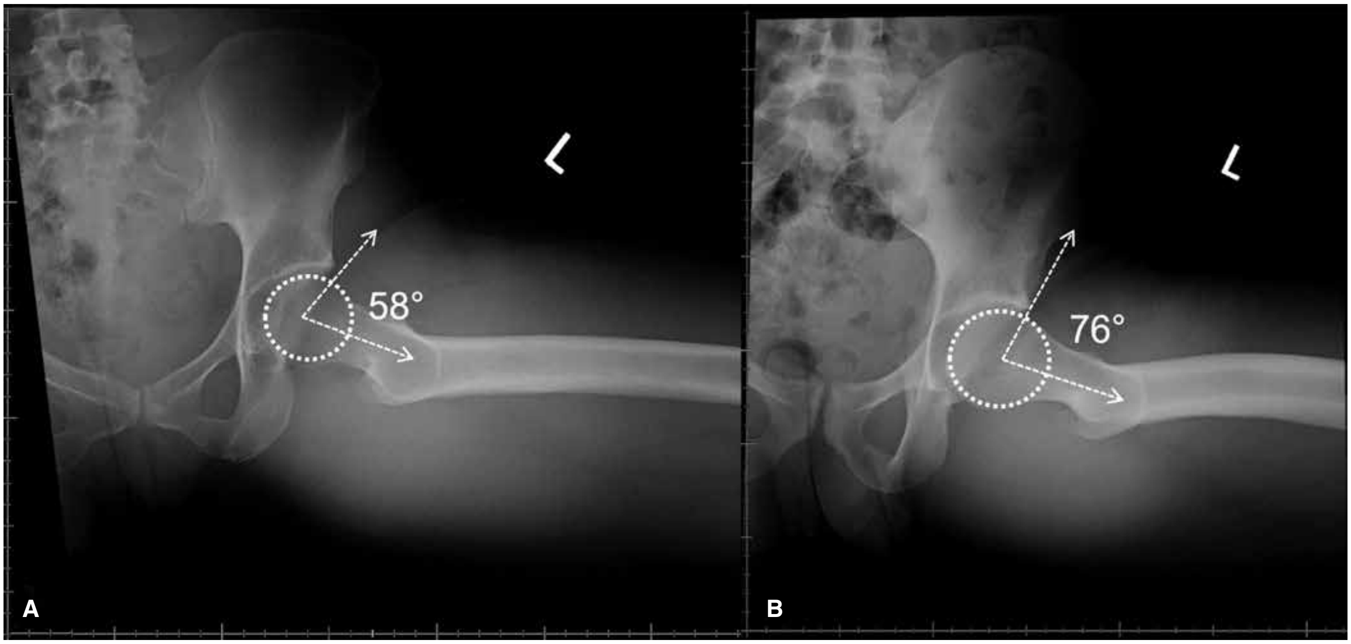

Figure 8A-B. (A) Left Dunn lateral view radiographs of 31-year-old female with alpha angle measured at 58 degrees. **(B)** Left Dunn lateral view radiographs of 19-year-old male with alpha angle measured at 76 degrees, revealing asphericity of femoral head and neck and cam type morphology.

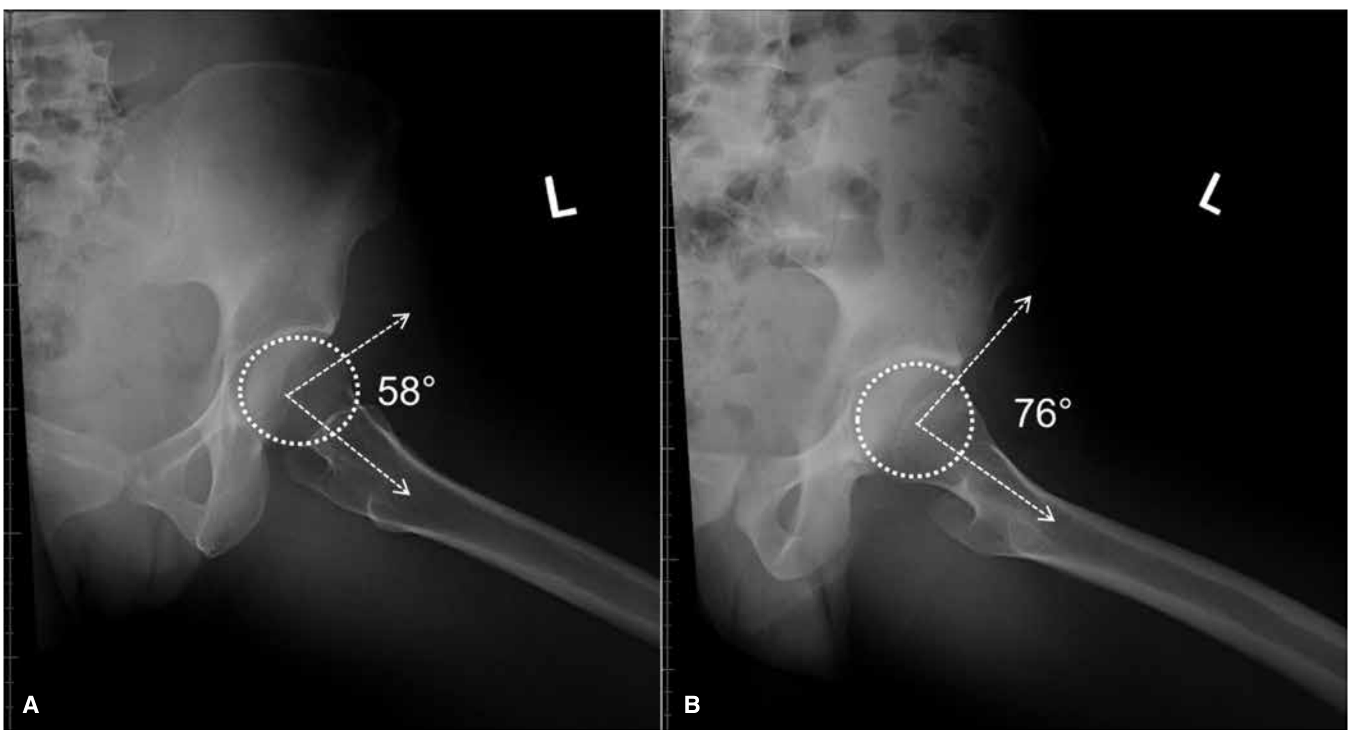

Figure 9A-B. Left Frog-leg lateral view radiographs of 31-year-old female with alpha angle measured at 58 degrees. **(B)** Left Frog-leg lateral view radiographs of 19-year-old male with alpha angle measured at 76 degrees, revealing asphericity of femoral head and neck and cam type morphology.

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Original Research

Insurance Status Plays a Role in Treatment Delays and Rates of Irreparable Meniscal Injury Following Acute Anterior Cruciate Ligament Rupture

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Abstract

Purpose: To determine if patients who are uninsured or covered by Medicaid would experience delays at different stages of care compared to their privately insured counterparts following acute anterior cruciate ligament rupture, and whether this would ultimately lead to higher rates of meniscal and chondral pathology at the time of surgery.

Methods: Demographic and clinical data was compiled for all ACL reconstructions performed by a single surgeon at an urban academic medical center during a consecutive 52-month period. After excluding those with work-related injuries and those who delayed treatment for personal reasons, 68 patients were sorted by insurance status into privately insured (35) and underinsured/Medicaid (33) groups. Intervals at various stages of treatment from the time of injury to ACL reconstruction and findings at the time of arthroscopy were recorded for all patients.

Results: The underinsured patient population experienced statistically significant delays at every time interval tested with the exception of the time from the initial appointment with the treating surgeon to surgery. The average duration from injury to ACL reconstruction was significantly longer for the underinsured group when compared to those privately insured (U: 116.7 days, I: 572.4 days; $p = 0.001$). While the rates of arthroscopically-confirmed chondral and meniscal injuries were not statistically different between groups ($p = 0.99$), there was a significantly increased rate of irreparable meniscal tears in the underinsured group (I: 23.8% v. U: 61.9%, $p = 0.02$) that required partial meniscectomy.

Conclusions: Following acute ACL rupture, privately insured patients have shorter durations to see providers, complete diagnostic tests, and receive treatment. Delays to ACL reconstruction in the underinsured group did not correlate to a higher incidence of chondral injury, but did correlate with a higher rate of irreparable meniscal tears requiring partial meniscectomy.

Level of Evidence: III

Key Terms: access to care, anterior cruciate ligament, medical insurance, meniscal tear

Introduction

Equitable access to medical care continues to be a social challenge in the United States. In 2013, the United States Census Bureau estimated that 42 million people had no medical insurance and over 54 million people were covered by Medicaid.[1] Several studies have demonstrated the detrimental effect of Medicaid coverage or uninsured status on the ability to receive timely medical care in both adults and children.[2–6] Insurance status disparities exist between racial groups as well, as non-Hispanic whites had a 9.8% uninsured rate while that of blacks and Hispanics was 15.9% and 24.3%, respectively.[1] Limited access can affect the outcome of care with delays in diagnosis or treatment leading to greater morbidity in some cases.

Anterior cruciate ligament (ACL) rupture is one of the most common knee injuries requiring surgical treatment and a topic of much research. ACL deficient knees demonstrate altered kinematics[7, 8] and rely more heavily on the posterior horn of the medial meniscus to prevent anterior translation of the tibia.[9] Increased contact forces on the medial meniscus can lead to a higher rate of degenerative tears in chronically ACL deficient knees. Arthroscopic reconstruction of the ACL aims to restore the normal function of the ligament, specifically prevention of anterior translation and rotational instability of the tibia in relation to the femur. While the overall number of ACL reconstructions has been increasing in general,[10] there exists a disparity amongst those being treated surgically and non-operatively. The odds of having this procedure are most increased in younger, white patients, those of higher socioeconomic status, and those covered by private medical insurance.[11]

Patients with a variety of backgrounds and varying levels of medical insurance are treated at our urban academic medical center. In this study, patients with an acute ACL tear were evaluated for their access to medical care and several outcome measures were collected. We hypothesized that the underinsured population would have longer delays to treatment following acute ACL injury and would have more intra-articular pathology including meniscus tears and chondral injuries.

Materials and Methods

Institutional review board approval was obtained to retrospectively collect patient data. A chart review was performed to identify all ACL reconstructions performed by the senior author at a single urban academic hospital during a consecutive 52-month period from October 2009 through January 2014. To be considered for inclusion, patients had to initiate outpatient treatment at our urban university-based orthopaedic sports medicine clinic and complete a minimum follow-up of six months. ACL injury was diagnosed clinically by a sports medicine fellowship-trained orthopaedic surgeon and confirmed in each case with magnetic resonance imaging (MRI). We excluded all revision ACL reconstructions, multi-ligamentous knee injuries, worker's compensation cases and those patients who initiated care at suburban satellite locations.

Seventy patients were identified who met all inclusion criteria. After initial chart review, two patients were excluded as they had elected to delay treatment for personal reasons. Patients were divided into two groups: insured (private carrier) and underinsured (uninsured or Medicaid). Demographic data was collected for age at the time of surgery and sex. Multiple variables were collected for each patient, including: the date of injury, the date of initial evaluation at any physician's office visit, the date when evaluated by the senior author, the date an MRI was ordered, the date an MRI was completed, the date of surgery, the number of postoperative appointments attended, presence of meniscal and chondral injuries confirmed at the time of arthroscopy, and presence of a repairable meniscal tears. Reparability of a meniscus tear was determined by the senior author at the time of arthroscopy. Time of injury was set as time zero, and the number of days elapsed between variables was calculated.

Statistical Analysis

The patients were divided by insurance carrier into: (1) insured and (2) underinsured groups. Continuous variables for elapsed time were compared using the t-test (age) and Wilcoxon rank sum test (time intervals). Categorical variables were compared using Fisher's exact and Chi-squared tests. Significance was defined as $p < 0.05$. All statistical analyses were conducted using SAS® 9.4.

Funding

There were no external sources of funding for this study.

Results

The final cohorts included 35 privately insured (I) and 33 underinsured (U) patients. Demographic results are summarized in Table 1. There was no statistical difference in sex between the two groups (male: 40 [58.8%], female: 28 [41.2%]; p = 0.486). Insured patients were significantly younger on average at the time of surgery than their underinsured counterparts at 24.1 ± 9.3 years in the insured group and 31.2 ± 10.0 years in the underinsured group (p = 0.003). The underinsured patient population experienced multiple statistically significant delays during treatment (Table 2). These included the time from injury to the initial office visit of any physician (I: average 36.3 days, range 0–315 days; U: average 263.4 days, range 0–2015 days; p = 0.027), time between seeing the initial physician and the treating surgeon (I: average 27.1 days, range 0–322 days; U: average 93.9 days, range 0–554 days; p = 0.015), time between ordering and completion of an MRI (I: average 7.4 days, range 0-81 days; U: average 17.1 days, range 0–90 days; p = 0.042), and time between injury and surgery (I: average 116.7 days, range 17–580 days; U: average 572.4 days, range 47–2775 days; p = 0.001). The interval between the first appointment with the treating surgeon and ACL reconstruction was not significantly different (I: 48.6 days; U: 46.0; p = 0.847).

The number of postoperative office visits, while similar, was significantly different (I: 5.1 visits; U: 3.8; p = 0.024). The total number of patients with chondral injury and meniscal tears confirmed during arthroscopy was not statistically

Table 1. Demographic Data

	Insured	Underinsured	p-value
Age (years)	24.1 ± 9.3	31.2 ± 10.0	0.003*
Sex	46.4% female 55.0% male	53.6% female 45.0% male	0.486

Age is provided in average years ± standard deviation. Sex is provided as percentage of males and females.

*Denotes a significant finding, set as p < 0.05.

Table 2. Time Intervals from ACL Rupture to Reconstruction

Time Interval	Private	Underinsured	p-value
Injury to initial outpatient visit, any physician (days)	36.3 ± 77.0	263.4 ± 500.9	0.027*
Initial physician visit to treating surgeon (days)	27.1 ± 57.5	93.9 ± 139.9	0.015*
MRI order to completion (days)	7.4 ± 14.1	17.1 ± 21.7	0.042*
Injury to MRI (days)	37.3 ± 75.5	414.2 ± 678.7	0.003*
Injury to Surgery (days)	116.7 ± 120.4	572.4 ± 692.9	0.001*
Treating surgeon to surgery (days)	48.6 ± 56.2	46.0 ± 55.4	0.847

Values are given as the mean ± standard deviation.
*Denotes a significant finding, set as p < 0.05.

different ($p = 0.99$ and 0.758, respectively), but there was a significantly increased rate of irreparable meniscal tears in the underinsured group (I: 23.8% v. U: 61.9%, $p = 0.02$) that required partial meniscectomy (Table 3).

Table 3. Associated Injuries Determined During Arthroscopy

	Private	Underinsured	p-value
Chondral injury	14.3%	15.2%	0.999
Meniscal injury	60%	63.6%	0.76
Meniscus repairable	61.9%	23.8%	0.03*

Values are given as overall percentages of findings present.
*Denotes a significant finding, set as $p < 0.05$.

Discussion

As hypothesized, the underinsured group experienced significant delays in almost all time periods from acute ACL injury to arthroscopic reconstruction. From the time of injury, the underinsured group required over seven times longer to have their initial outpatient evaluation by a physician, over 10 times longer to have their diagnosis confirmed by MRI, and almost five times longer to have reconstructive surgery when compared to the privately insured group. Our findings are similar to the results of Baraga and colleagues who demonstrated significant delays in diagnosis of acute ACL rupture for those uninsured or those with Medicaid insurance.[2] Their study found that the total time to diagnosis was four times longer and over eight times longer for Medicaid and uninsured patients, respectively, when compared to those privately insured. Our study expanded on these findings by measuring intervals until the time of reconstructive surgery. While the time from ACL injury to reconstruction was significantly delayed in the underinsured group, the time from the first outpatient appointment with the treating surgeon to reconstruction was essentially the same. In our series, the most significant delays occurred in the interval from injury to diagnosis, while the timeframe from diagnosis to surgical reconstruction was relatively constant across groups. We acknowledge that this may be unique to our health system and the senior surgeon's individual practice but importantly, we believe this finding demonstrates that the willingness and effort to undergo appropriate treatment is the same between groups once the diagnosis has been made.

Our second hypothesis, that the underinsured group would have higher rates of chondral and meniscal pathology, was not supported by our data as neither meniscal or chondral pathology was significantly different between the privately insured and underinsured groups. This result is in contrast to the study by Church and Keating that evaluated arthroscopic meniscal findings for those who underwent ACL reconstruction within and after 12 months of injury. They found meniscal tears in 71.2% of knees in the delayed group compared to 41.7% in those who underwent surgery within a year of injury.[12] Their study suggests that delays in reconstruction after acute ACL injury are associated with the incidence of new meniscal pathology. While our overall incidence did not differ between the privately insured and underinsured groups, we found that the rate of irreparable meniscus tears was greater in the underinsured group. Due to a significantly increased interval from injury to surgery in this group, we speculate that the abnormal kinematics seen in ACL deficient knees over time led to progression of tears such that previously repairable tears required partial meniscectomy. In a study by Brophy and colleagues, the articular cartilage of 725 knees undergoing revision ACL reconstruction was evaluated for pathology and cohorts were defined by previous meniscal surgery at the time of initial ACL reconstruction.[13] They found that knees that underwent partial meniscectomy at the time of initial ACL reconstruction were more likely to have chondrosis in the same compartment at the time of revision when compared to those that either underwent meniscal repair or had no meniscal pathology. They found no difference in chondrosis between the meniscal repair group and those that did not undergo meniscal surgery.

Prior studies have also identified partial meniscectomy at the time of ACL reconstruction as an independent risk factor for the development of degenerative osteoarthritis.[14–17] Even in knees with uninjured native ACLs, literature has demonstrated the relationship between partial meniscectomy and progression of osteoarthritic changes on radiographs[18–20] and MRI.[21] This is likely due to an increase in contact stress observed in the tibiofemoral compartment as a result of lost hoop tension in the knee after partial meniscectomy.[22] Taking these findings into account, we believe that the progression of meniscal tears seen after the delay in care by the underinsured group will ultimately lead to more rapid progression of degenerative osteoarthritis and lesser patient reported outcome scores.

Our study has several weaknesses worthy of discussion. Due to the retrospective nature of our data collection, the dates of injury and dates of physician appointments at outside institutions were dependent on patient recollection. While radiographic data and documentation from our hospital and outside institutions were used to corroborate dates, these were not available in every case. This introduced an element of recall bias, particularly in patients whose injury was remote from their presentation to our clinic.

An additional weakness of our study is that it compiles data from a single surgeon at a single urban setting in the Northeast. While our data was similar to the findings of Baraga and colleagues in their urban South Florida setting,[2] extrapolation to all settings throughout the United States cannot be made without further multicenter studies that include multiple regions and settings.

A third weakness of the current study is that the underinsured group was statistically older on average when compared to the privately insured group. While increased age has been identified as a risk factor for the presence of associated meniscal tears and chondral lesions with ACL injury,[23] the average age of our insured and underinsured groups was clinically similar at 24.1 and 31.2 years, respectively. In addition, the presence of an associated meniscal tear was similar for both groups despite the difference in average age. The main difference between groups was the quality of the meniscal tear, as the underinsured group that experienced delays had more degenerative and complex tears requiring partial meniscectomy.

Future studies should be directed towards determining the causes of delay so energy and resources can be directed towards eliminating these barriers to care. While it would be difficult to eliminate voluntary delays for personal reasons, we should aim to reduce systemic factors such as inability to obtain a timely appointment or difficulty finding a surgeon that accepts a particular insurance that would delay appropriate patient care.

Conclusion

When compared to those privately insured, the underinsured population experienced multiple statistically significant delays in care for an acute ACL rupture from the time of injury through the day of surgery. The overall incidence of associated meniscal tears and chondral injuries was similar between groups but there was a significantly higher rate of irreparable meniscal tears in the underinsured population.

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Original Research

Broach Handle Design and Point of Impact Changes Force Distribution in the Femur During Total Hip Arthroplasty

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Abstract

Purpose: Total hip arthroplasty (THA) is being performed through a minimal incision with increasing popularity. Several authors have reported an increased rate of intraoperative fracture during femoral canal preparation with this method. In order to safely perform "less invasive" THA, manufacturers have developed various new broach handle designs. However, the dynamic effects of these handles on the proximal femur have not been widely investigated. This study evaluates three-dimensional broaching forces brought about by specialized curved implantation handles designed to be used during THA via the direct anterior approach. We compare these forces to those from conventional handles as a possible explanation for the increased intraoperative fracture rates that have been reported for these procedures.

Methods: We created a mathematical model using four different broach handles (H1–H4) with varying curves and offsets. These handle designs represent specialized options available for surgeons during minimally invasive arthroplasty. All handles were attached to a broach and digitized using a high-resolution optical system. A virtual model was constructed to include surrounding deformable trabecular and cortical bone. Material constants consistent with the current literature were assigned to Young's moduli and bone densities. Then a finite element analysis was performed. We evaluated the off-plane reaction forces (OPRF) and reaction moments (RM) in three-dimensional planes around the broach while varying the location at which a hammering force was applied. Ratios were obtained at three axial cross-sections along the length of the broach: proximally, in the center, and distally. Moments were measured with respect to the center of the broach. Stress distributions were computed throughout the entire cortical shell.

Results: Stress measurements varied dramatically with different handle designs. In general, effective stress in the proximal femur increases as broach handle offset increases. In one scenario, impacting the double-offset broach handle generated 9.3 times more stress in the proximal femur than when the same force was applied to the straight broach handle. As broach handle offset increased, the percentage of vertically directed force (down the medullary canal) decreased. Thus, more force was directed outward toward cortical bone. Also, the hammer impact location on the broach handle surface resulted in significantly different force ratios that change with handle design. Furthermore, variable impact locations on the double offset broach handle produced vertical to horizontal force ratios between –71% and 37%, thus suggesting that an impact location in which off-plane force distribution is the least hazardous (0%) may exist.

Conclusion: Broach handle design is a critical determinant of resultant forces transmitted to the bone during THA. Curved handles (H3 and H4) generally cause more out of plane forces than straighter handles (H1 and H2), especially in the proximal femur. Unanticipated out of plane forces may play a role in the increased rate of fractures seen during "minimally invasive" procedures. When surgeons use different broach handles in order to accommodate the anatomic constraints, even small changes in design can potentially lead to poor outcomes. There may be optimal locations of impact that vary with broach handle design, and suboptimal impact locations can magnify force displacement which contributes to intraoperative fracture. Manufacturers and surgeons should be aware of this before choosing their preferred equipment.

Introduction

Modern total hip arthroplasty (THA) is one of the most successful and reliable operations in medicine. While THA is safe and effective at treating arthritis and other degenerative conditions of the hip, surgeons are persistently improving current techniques and technology. Recently, there has been an increase in popularity of small-incision techniques, termed "minimally invasive" or "less invasive" approaches to THA.[1, 2] Of these, much attention has been placed on the direct anterior approach (DAA). Proponents claim that this approach is associated with less muscle damage and pain as well as more rapid recovery.[3–5] With the rise in popularity of the DAA, several authors have proposed a concordant increase in the rate of intraoperative complications, with trochanteric fracture, femoral canal perforation, and calcar fracture reported in as many as 2–5% of cases, especially early in the surgeons learning curve for this procedure.[6, 7] Biomechanical studies suggest that intraoperative fractures are most likely to occur in the proximal femur during femoral canal preparation.[8–10]

Implant manufacturers have designed specialized broach handles both to facilitate femoral canal preparation via the DAA and decrease complications associated with limited exposure.[11] However, the dynamic effects of these handles on the proximal femur have not been widely investigated and analysis of an "optimal" broach design does not exist. The aim of our study was to analyze the three-dimensional broaching forces brought about by specialized curved implantation handles designed for the DAA. We compared these forces to those from conventional handles as a possible explanation for the increased intraoperative fracture rates that have been reported for these procedures. Furthermore, we sought to determine if there is an optimal design which decreases undesirable force transmission to the proximal femur.

Material and Methods

We created a mathematical model using four different broach handles (Figure 1). These handle designs represent specialized options currently available to surgeons during minimally invasive arthroplasty. Broach handle 1 (H1) was relatively straight. Broach handles 2 and 3 (H2 and H3, respectively) had increased curvature in a single plane. Broach handle 4 (H4) was a double-offset design.

All handles were attached to a broach in the vertical position and digitized using a high resolution optical system (Romer Arm RA-7330 SI, 0.05 mm resolution). The vertical axis was defined as the "Z-axis" with the cranial direction represented by positive values and caudal direction represented by negative values. Horizontal orthogonal planes were defined as the "X-axis" and "Y-axis." In this paper, these X and Y planes are referred to as "off-axis" since they are perpendicular to the direction of broaching down the femoral intramedullary canal. Based on the scanned point clouds, a virtual model was constructed using Rhinoceros software (Robert McNeel & Associates). The handles and broach were modeled as rigid materials so they would not significantly deform during broaching, as in real practice. Surrounding deformable trabecular and cortical bony shells were then added. Material constants consistent with the current literature were assigned to Young's moduli and bone densities.[12–14]

Then a finite element analysis was performed. We evaluated the resultant reaction forces and reaction moments (RM) in three-dimensional planes around the broach while varying the location at which a hammering force was applied (to account for variability in a surgeon's aim) (Figure 2). In addition to a central (C) point, additional impact points for each handle surface were labeled as follows: Lateral Anterior (LA), Lateral Posterior (LP), Medial Anterior (MA), and Medial Posterior (MP). For H2 through H4, a lateral center (LC) point was chosen to align directly lateral to the center impact point. Moments were measured with respect to the center of the broach. The applied force was a 133 kN point load. This force is equivalent to a 500 g hammer hitting the surface at 4 m/s.

Measurements were obtained at three axial cross-sections along the length of the broach: distal (section 1), central (section 2), and proximal (section 3) (Figure 3).

The following mechanical values were computed: Von Mises stress (MPa) and strain (%) throughout the entire cortical shell, percentage of the resultant (total) force concentrated vertically down the femoral canal at three different sections, percentage of resultant (total) force concentrated horizontally (off-axis) at three different sections, ratio of total moment to total force (N m/kN), and ratio of resultant rotational displacement to resultant vertical displacement (deg/mm).

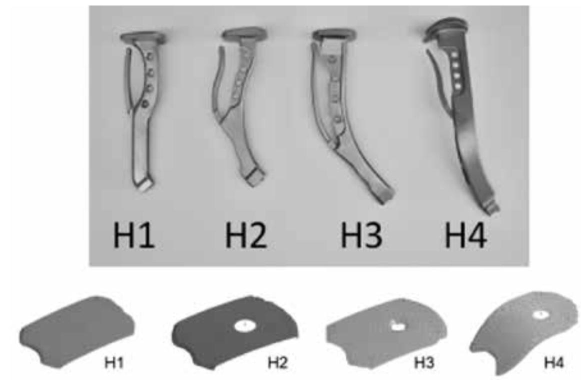


Figure 1

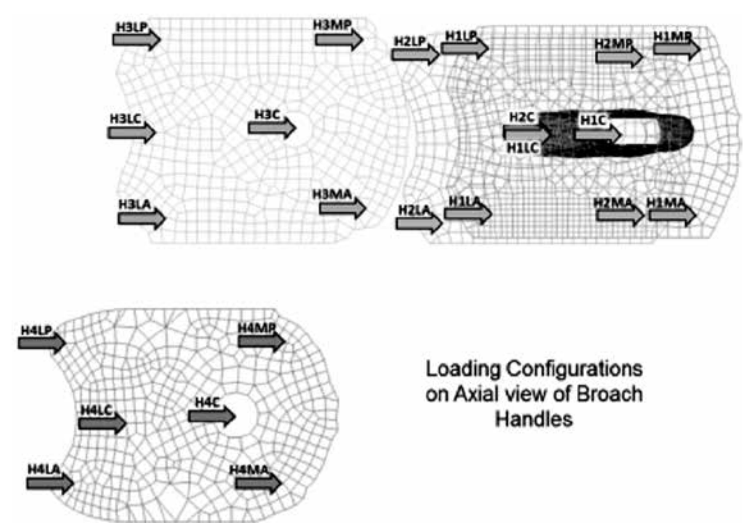


Figure 2

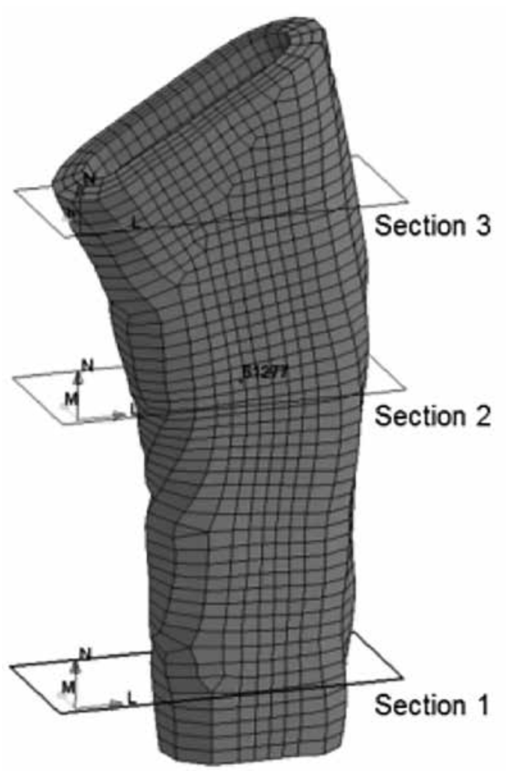


Figure 3

The ratio of force in the Z-axis to the resultant forces in all planes was computed to describe the percentage of total force that is ultimately applied down the femoral canal, as opposed to forces directed outward toward the femoral cortex (Figure 6). Ideally, this number should be –1.0 to indicate a 100% downward force. As broach handle offset increased from H1 to H4, the percentage of vertically directed force (down the medullary canal) decreased. The remaining forces in the X and Y planes may be responsible for intraoperative fracture. Larger offset handles lost 20–60% of their total force (and up to 86.9% when hit inefficiently such as H4-LC), which was then deflected in the off-axis direction. Thus, as handle offset increased more resultant force was directed outward toward cortical bone.

Our data also indicate that varying the hammering location on the broach handle surface resulted in significantly different force ratios that change with handle design (Figure 6). Moreover, variable impact locations on the double offset broach handle produced vertical to horizontal force ratios between –71% and 37%, thus suggesting that an impact location in which off-axis force distribution is the most hazardous (0%) may exist.

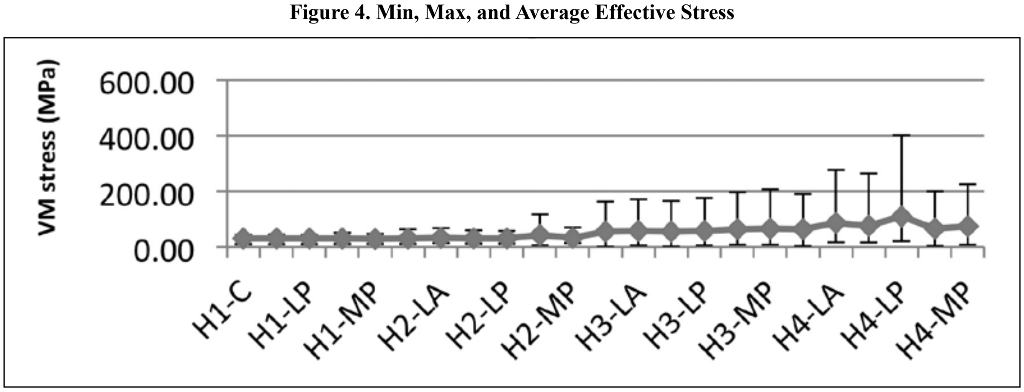
Since the highest regions of stress are in the proximal femur, we then analyzed the percentage of horizontal (off-axis) reaction forces for the proximal femur in isolation (Figure 7). The off-axis reaction forces in this region are most likely to contribute to intraoperative femur fracture. These forces were notably highest when the double-offset broach handle was impacted along its lateral surface.

We also computed the ratio of resultant moment to total force in each section (N m/kN) (Figure 8). This value describes how much moment is generated per unit force. As the moment increases, the stress distribution in bone becomes non-uniform with some regions in tension and other regions in compression. As a result, the chance of failure in tension (which usually has a lower threshold than compression) is increased. Ideally, this value should be

Results and Interpretation

Von Mises (or effective) stress (MPa) and strain (%) throughout the femoral bone were computed to help determine the likely location of bone failure (Figure 4). Stress measurements varied dramatically with different handle designs. In general, effective stress increased as broach handle offset increased. Additionally, maximum effective stress was always concentrated in the medial and/or lateral proximal femur, as in Figure 5. In one scenario, impacting the double-offset broach handle generated 9.3 times more maximum stress in the proximal femur than when the same force was applied to the straight broach handle.

Figure 4. Min, Max, and Average Effective Stress



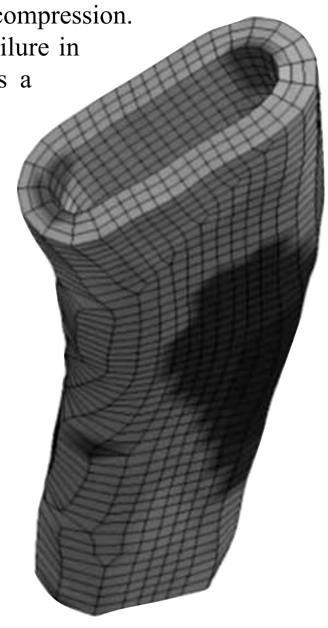


Figure 5

Figure 6. Percentage of Resultant Force in Vertical Axis

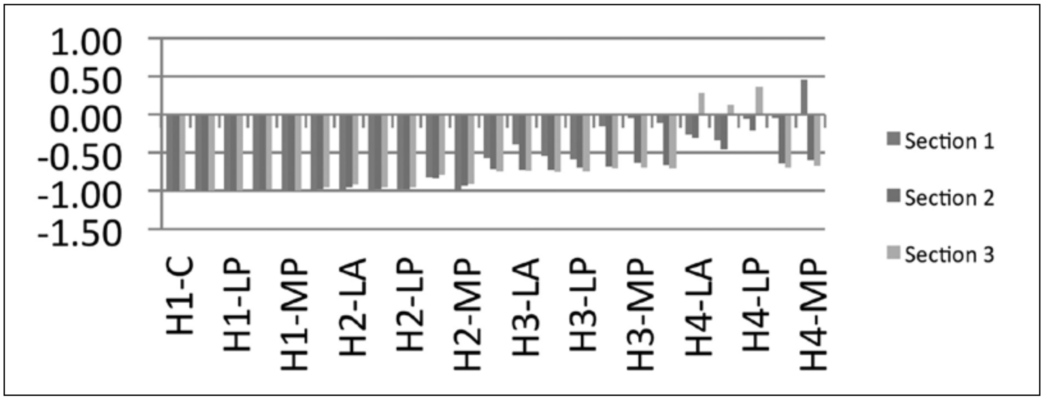


Figure 7. Percentage Off-Axis Reaction Forces (Proximal Femur)

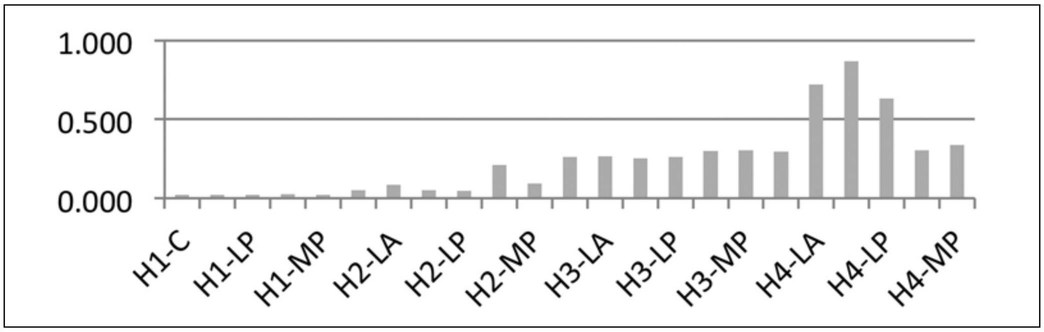
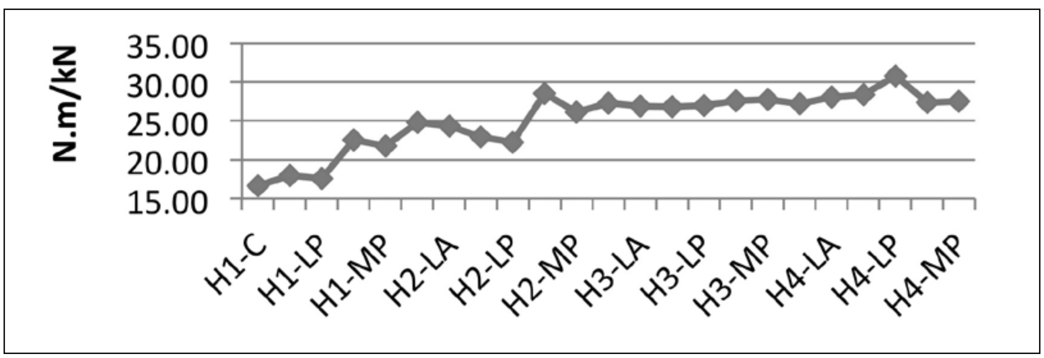


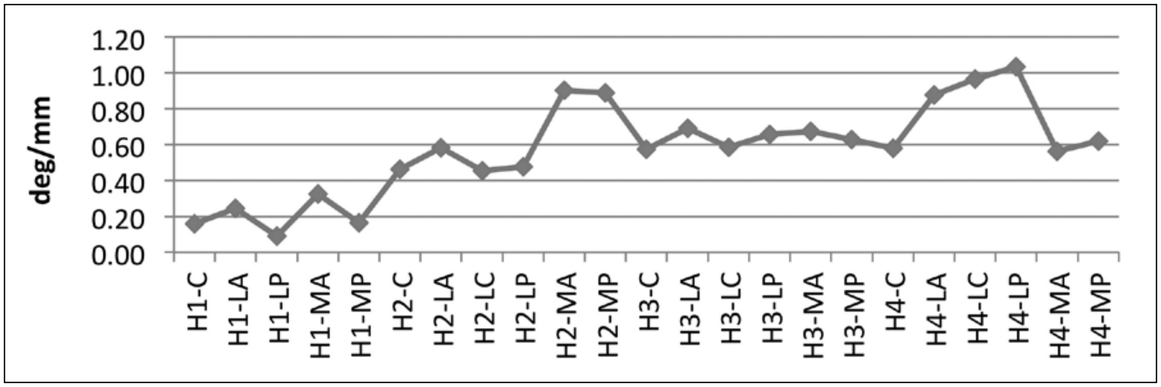
Figure 8. Ratio of Moment versus Resultant Force (Proximal Femur)



zero. Our results indicate that in the proximal femur this ratio also increased with enhanced broach handle offset.

Finally, we computed the ratio of resultant rotational displacement to resultant linear displacement (deg/mm) (Figure 9). This value describes how much the broach rotates per unit of vertical displacement. For example, if a broach barely rotates during vertical impaction, this ratio will be ideal and close to zero. As this ratio increases, the rotational component produced during each impact increases despite minimal advancement toward seating of the broach. As a result, certain regions press harder into bone and the risk of localized failure is increased. As broach handle offset increases, this undesirable ratio of rotation versus vertical displacement becomes more concerning. It is important to note, however, that there are optimal surface impact locations on each broach handle that make this ratio equivalent between different offset broach handles (i.e., H2-LA, all H3 impacts, H4-C, H4-MA, and H4-MP). Moreover, certain locations (such as the medial impact points on H2 and lateral impact points on H4) produce less desirable ratios of rotation per unit of vertical displacement. We believe this is due in part to the force vector having a more linear relationship with the center of gravity of the broach, and in part due to the variable shape at the broach handle surface.

Figure 9. Ratio of Rotation Versus Vertical Displacement



Discussion

Minimally invasive hip replacement surgery has gained popularity based on potential for better outcomes and faster recovery. In order to facilitate the ability for surgeons to perform these procedures, manufactures have developed a number of specialized instruments. In 2006, Nogler et al. described a double offset broach handle specifically designed for use during minimally invasive THA via a direct anterior approach.[11] This modified broach handle minimizes the required femoral elevation, restricts the need for posterior capsular release, facilitates femoral preparation in obese or muscular patients, and decreases risk of soft-tissue damage. Our data indicate that curved and double-offset broach handles enhance off-axis forces in the proximal femur during femoral canal preparation and may consequently increase the risk of intraoperative fracture. Furthermore, impacting a broach handle at suboptimal locations can magnify the displacement of forces that contribute to intraoperative fracture. By contrast, impacting a broach handle surface in certain regions can minimize undesirable off-axis forces and these optimal impact locations vary with broach handle design.

Several authors have echoed our concerns that misdirected forces during femoral canal preparation can lead to intraoperative fracture. Optimal preparation of the femoral canal is necessary in order to obtain a stable, painless, and functional component. Broaching of the femoral canal is a preferred preparation technique.[15] By combining sound frequency analysis with finite element analysis *in vivo,* Sakai et al. postulated that imperceptible microfractures occur during femoral canal preparation prior to noticeable intraoperative fracture.[16] This finding highlights the significance of minimizing energy transmission in undesirable directions during femoral canal preparation. Berend & Lombardi Jr. analyzed 457 THAs performed using either toothed versus low-profile calcar mills.[8] They stated that intraoperative fractures in their series specifically resulted from inappropriate force distributions associated with equipment rather than alternatively suggested factors such as surgeon learning curves. In a series of 395 cementless THAs, fractures only occurred during rasping or insertion of the stemmed component.[9] Authors therefore concluded that intraoperative fractures are caused by abnormal mechanical stresses during femoral canal preparation. Molli et al. compared short and standard-length stems among a series of 658 THAs inserted via a less invasive approach.[10] In their series, short femoral components were associated with a decreased risk of intraoperative fracture. Eighty percent of their fractures occurred in the proximal femur. The authors believed their increased fracture rate among standard stems was due to more aggressive femoral canal preparation. This further supports our hypothesis that increased irregular forces at the proximal femur are hazardous and increase the risk of intraoperative fracture.

Few dependable modalities are routinely available in today's operating theatre to help avoid intraoperative fracture. Surgeons rely on visual, audible, and tactile feedback while balancing the risk of fracture with the risk of poor component fit. Researchers have attempted to apply spectral analysis in order to identify when broaching is complete according to sound frequency.[16, 17] In these studies, the transformation from a high to low pitch is associated with the most appropriately-sized broach. However, these methods are not routinely employed in contemporary operating rooms and the authors of these studies requested that surgeons interpret their results with caution. Surgeons should be made aware of any information that helps avoid dangerous force distributions.

To our knowledge, only one other study in the literature analyzes the effect of broach handle design on resultant broaching force. Putzer et al. constructed a dynamic model and compared force transmission within single versus double-offset broach handles.[18] Their experimental construct consisted of a broach (fixed to a vertical axis by two screws) that impacted a force transducer at the broach tip. Only vertical linear forces, proximally and distally, were measured. They concluded that single-offset broach handles have the highest force peak in the direction of the broach tip and transmit 18–36% more force to the distal broach than double-offset broach handles. These values are consistent with our findings. However, they did not determine where in the broach those "lost" forces (i.e., off-axis forces) dissipated. No finite element analysis was performed. They requested that future studies consider the effect of different impact directions at the broach handle surface. They also did not impact broach handle surfaces at different locations. We addressed all of these unknown elements in our study.

Our study has several limitations. First, while we used constant variables consistent with recent literature, this is still a mathematical model subject to the scientific limitations of theory versus reality. Our goal is not to provide threshold values for different broach handles, but instead to bring to light important characteristics of modern instrumentation design. Second, we decided to give the broach perfect contact with surrounding bone in order to compute global force distributions. In reality, contact points between the broach and bone are concentrated at the proximal edges of the broach in the region of maximum stress. This more realistic addition of proximal forces would amplify our conclusions. Third, some studies incorporate muscular deforming forces into their model. For example, Sakai et al. performed a finite element analysis of femoral stems and included a deforming force at the greater trochanter of 1400N.[19] We chose to analyze broaching forces specifically imparted by different handles in isolation. Doing so allows the surgeon to apply our results across a broad array of surgical approaches. Lastly, all of our hammering force vectors were applied perpendicular to the broach handle surface impact location due to the generally curved head on most surgical mallets. Theoretically, when a curved mallet head impacts a broach handle surface, a portion of that total impact will be transferred as a linear force vector perpendicular to the corresponding tangent line along the mallet head.

We believe our study is important for several reasons. It adds to the growing body of literature that attempts to elucidate mechanism of intraoperative fracture and develop methods to avoid poor outcomes while using limited incision techniques. To our knowledge, this is the only study in the current literature that analyzes forces and stress distributions throughout the entire broach. This is the only study that acknowledges the effects when broach handles are impacted at variable surface locations. Our study also provides critical additions to the only prior study in the literature that compares straight versus curved and double-offset broach handles. Further related studies should attempt to recreate our model using physical specimens.

Conclusion

It is clear that broach handle design is a critical determinant of the resultant forces transmitted to the broach (and ultimately to the bone) during THA. Unexpected forces out of plane likely play a role in the increased rate of fractures seen during "minimally invasive" procedures. Impacting a broach handle at suboptimal surface locations can also cause largely inefficient and dangerous off-axis forces directed toward the proximal femoral cortex. This risk is generally increased as broach handle offset increases. When surgeons use different broach handles in order to accommodate the anatomic constraints of minimally invasive surgery, even small changes in design can significantly increase the three-dimensional force distribution and may potentially lead to poor outcomes.

Our data also proves that there is an optimal location of impact that varies with broach handle design. Finite element analysis provides a useful tool for analyzing broach handle design. As implant and instrumentation designs change over time (such as increased offset and double-offset broach handles), it is important that manufacturers and surgeons to be aware of these analyses before choosing their preferred equipment.

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CT Radiation Dosing of Articular Fractures Can Be Substantially Lowered While Still Providing Sufficient Information for the Operative Surgeon

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Introduction

The introduction of computed tomography (CT) in 1972 radically improved the evaluation of fractures and presented a unique tool to aid in the classification, treatment protocol and preoperative planning of complex fracture patterns. Distal tibia fractures offer a unique challenge in regards to their evaluation and treatment plans and represent 1–10% of all lower extremity fractures.[1] With ever-increasing ease of CT scan machinery and technology, the additive effect to the cumulative radiation exposure of the general population can be significant.[1] The National Council on Radiation Protection and Measurements reported approximately 70 million CT scans were performed in the United States in 2007, an amount which continues to increase annually. Concurrently, the expected average radiation exposure in the US was found to have increased almost six-fold from the early 1980s to 2006 — CT scans being the largest contributor.[20, 21] These findings have subsequently led to an increasing awareness of the need to use the lowest level of radiation dosing that is capable of providing appropriate diagnostic information, also known as the ALARA principle (As Low As Reasonably Achievable).

Various radiation protection quantities are currently used for achieving safe dosing with CT scans. These include the effective dose, absorbed dose, and CT dose index, all with specific calculation parameters.[8] Many factors contribute to the amount of radiation an individual will experience beyond the number of scans, including the tube current and scanning time in milliamp-seconds (mAs), the size of the patient, the tube voltage in kilovolt peaks (kVp) and the specific design of the scanner,[16] with a higher dose generally seen in multidetector CT scanners.

To date, there is no established safe dose of ionizing radiation below which there would be no increased risk of cell damage and subsequent risk of cancer. Specific ranges of radiation, which have shown a significant association with increased cancer risk, have been partially elucidated. Much has been learned by studying patient cohorts following the devastating effects after atomic bombs were detonated in Hiroshima and Nagasaki Japan in 1945, one of the longest running bi-national studies following survivors exposed to the nuclear explosions. Using the distance from ground zero, radiation doses were estimated, and it was found those exposed to a range of 5–150 mSv and greater had a significant increase in risk of cancer. Support for this has been found in a recent multinational retrospective cohort of 400,000 workers in the nuclear industry who were exposed to an average cumulative dose of 20–50 mSv. In this study group, a significant albeit small excessive risk for the development of cancer was demonstrated.[14, 15] The risk is even greater to pediatric populations, due to the age at which they are being exposed and ensuing time for cancer evolution, greater sensitivity of rapidly dividing cells to radiation, as well as their smaller body habitus which can incur greater radiation exposure to sensitive organs.[16] Table 1 demonstrates the mean exposure found by Biswas et al. in common CT scans specific to orthopedics. To reduce exposure in modern day imaging techniques, the ALARA principle was founded in order to minimize the overall insult to the population among both pediatric and adult populations with emphasis on protocols to decrease scan exposures as CT imaging becomes more prevalent.[8–10]

To our knowledge, no study has evaluated the effect of using decreased radiation doses on image quality in lower extremity trauma and the clinical efficacy in subsequent treatment plans. CT scans are increasingly used for assessment and preoperative planning of articular fractures of the extremities. The goal of this study is to determine if the radiation dosing of our standard CT protocol can be signifi-

Table 1. Estimated Mean Effective Dose

Exam	Target	Estimated Mean Effective Dose (mGy)
Dental X-ray	Brain	0.005
PA CXR	Lung	0.01
Lateral XR	Lung	0.15
Pelvis CT	Bladder/axial skeleton	4.85
Spine C/T/L	Brain/thyroid/lung/GI	4.36/17.99/19.15
Shoulder/elbow	Lung/cardiac	0.14–2.0
Hip/knee/ankle	Axial skeleton	0.07–3.0

cantly decreased while still resulting in satisfactory image quality in which a confident diagnosis and treatment plan can be formulated for an intra-articular fracture. It is our hope that a new dosing protocol with decreased radiation exposure can be found which will still have the ability to satisfy appropriate image detail in the treatment of complex fractures using the distal tibia as a model.

Materials and Methods

Six adult cadaveric specimens with 11 legs were selected in order to have an appropriate breadth of fracture gap and step-off variation as well as to provide for adequate data points. Through-knee amputations were performed and 11 AO type C fractures were successfully produced forming anterolateral (Chaput), posterolateral (Volkmann) and medial fracture fragments with a combination of oscillating saw and osteotome as seen in Figure 1. Six legs following fracture creation were then displaced in the axial plane to create gaps of 0, 1, 2, 3, 4, and 5 mm each at the articular surface, held with radiolucent plastic shims each 1 mm in thickness and measurements confirmed with a metal engraved precision ruler. Care was taken not to create fracture separation of the fragments proximally in order to maintain relative stability in the coronal plane. These were then sutured circumferentially to maintain position and the soft tissues were closed in layers. Five legs, using the same protocol, were then utilized to form displacement step-offs of the anterolateral fragment in the coronal plane of 1, 2, 3, 4, and 5 mm each. This was again measured as above and held in place using wooden dowels in three planes, placed by predrilling with a K-wire of appropriate diameter and seated with a mallet. Again soft tissues were closed in layers. These were then placed in a short leg splint and tightly wrapped with four-inch elastic bandages for structural support and transportation.

Radiation Dosing Protocol

All 11 specimens were imaged in a CT scanner (Siemens Somotome Sensation 16). The specimens were each imaged three separate times at different dosing protocols as determined by an attending radiologist. The identity of each specimen was blinded and the name of the specimen recorded to our institution's PACS system (Philips iSite Enterprise v3.6.114) was randomized.

The resulting scans were read by three experienced orthopedic surgery attendings with expertise in this specific fracture as well as two mid-level orthopedic residents. Using questionnaire format, readers were asked to measure the largest displacement at the articular surface on axial views as well as the largest step-off in the coronal plane using the systems digital measuring tools. They were then asked to rank their confidence level on a scale of 1–10 based on the image quality to 1) identify a fracture pattern and 2) formulate a treatment plan considering adequate plain films. An illustrative example of imaging is seen in Figure 2 in order of standard high-dose radiation to low-dose imaging.

A Siemens Somatome 16 multidetector CT scanner was utilized in our institution. Legs were scanned in the supine AP position using a holder and packing material for stabilization purposes. Images were acquired in the axial plane, slice thickness of 0.75 mm reconstructed to 2 mm in bone and soft tissue windows. The field of view was constant at 18.5 cm, and the scan length was constant with a pitch of one. Sagittal, coronal and 3D volume rendered (3D VRT) reconstructed images were obtained. No contrast was used. Dose length product (DLP) was recorded, which is commonly used as an estimate of relative radiation dosages. The DLP can further be converted to Effective Dose (in millisieverts) using a conversion factor as demonstrated by Huda et al.[17]

We utilized three different dose protocols, keeping the kVp constant at 120 while using a variable mAs at 110, 60 and 45, correlating to DLPs of 192, 110, and 82 respectively (Table 2). The mAs of 110 was obtained using the Siemens Care Dose scanning technique, which automatically adapts the radiation dose to the size and shape of the patient by varying the current on the basis of the topogram (scout) image, and comparing the actual patient with a "standard"

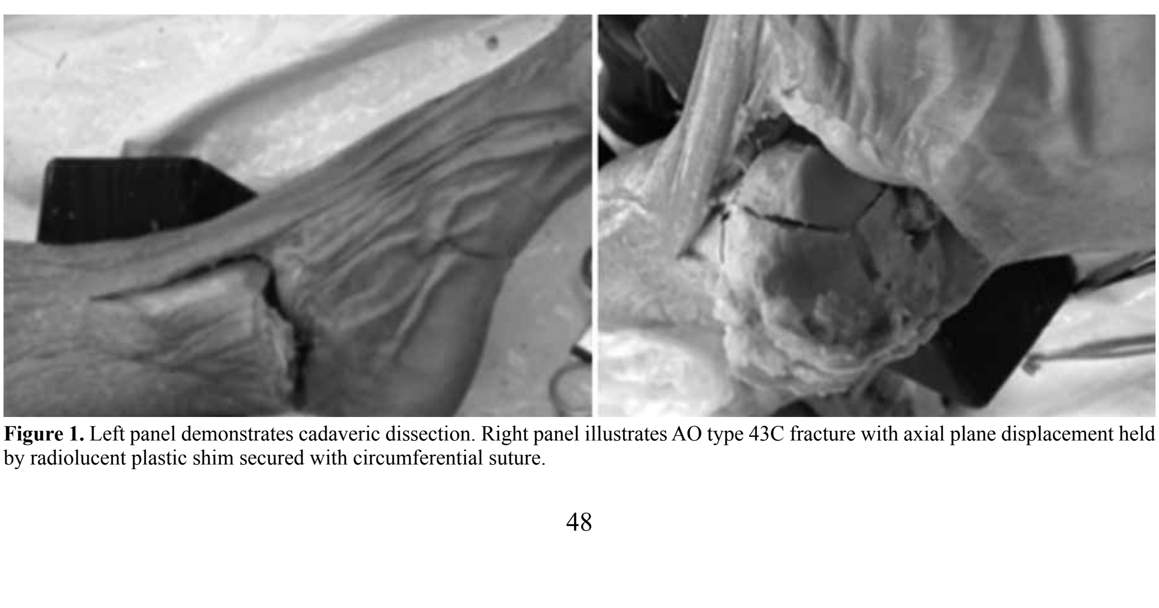

Figure 1. Left panel demonstrates cadaveric dissection. Right panel illustrates AO type 43C fracture with axial plane displacement held by radiolucent plastic shim secured with circumferential suture.

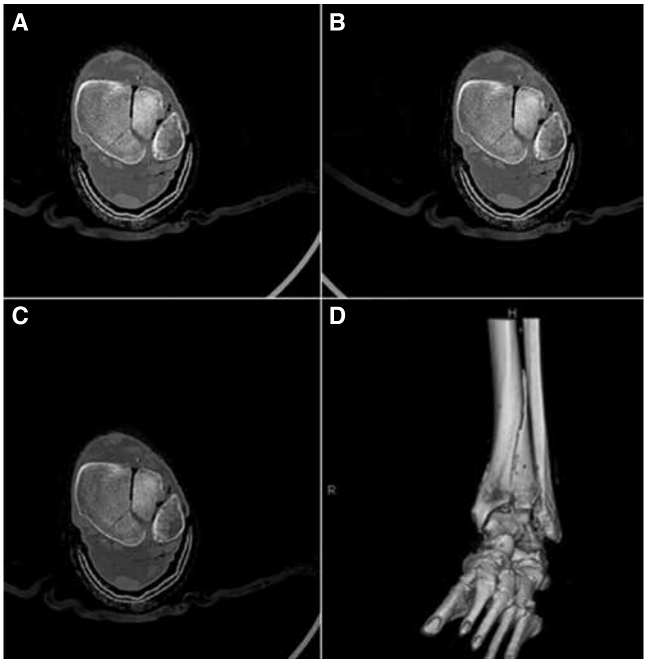

Figure 2. Panels **A–C** represent axial CT cuts at 120 KvP through a distal tibia utilizing progressively lower doses of radiation (110, 60 and 45 mAs, respectively). Panel **D** represents a 3D volume rendered (3dVRT) reconstruction, also available to reviewers.

Table 2. Difference Between Measured and True Gap and Step-Off by Reader

	Mean Difference		Mean Difference	
Reader	Gap	Std Dev	Step-Off	Std Dev
All Readers (n = 90)	0.74 p < .0001	1.0153	0.11 p = .5	1.3606
Attendings (n = 54)	0.73 p < .0001	1.0727	–0.07 p = .76	1.469
Residents (n = 36)	0.75 p < .0001	0.9373	0.37 p = .094	1.1592

patient. It also adjusts for the different angles during tube rotation. The Care Dose technique is designed to reduce radiation dose. Although we have used 110 mAs as an average, the Care Dose tube current in the ankle was between 107 and 112 mAs, the small range reflecting the only minor variations in size at the ankle. The mAs of 60 and 45 were manually set.

Statistics

An *a priori* power determination was utilized setting p = 80%, which found that at least 60 data points between four observers would need to be obtained. Intra-observer and inter-observer weighted reliability kappa scores were used to evaluate the resulting data as well as student's paired t-test. Data are presented as mean and standard deviation unless stated otherwise. P values of <0.05 were considered statistically significant. Statistical analyses were performed using SAS v9.4 (Cary, NC).

Results

Eleven legs were utilized, and data points collected were used for paired t-tests and kappa evaluation. Measurements were made as described previously utilizing our institutions PACS digital measuring tool. There was significant variability in the measured gap to true gap as a whole (mean = 0.74 p < .0001); however, attendings' measurements were not significantly more accurate (0.73 p < .0001) compared to residents (0.75 p < .0001). The best measurements were made with evaluating step-off, as no significant difference was found for all readers, including evaluating the attendings and residents separately (0.11 p = .5, –0.07 p = .76, 0.37 p = .094 respectively). There was significant variability in the mean confidence levels when taking all of the scans together for both pattern identification and treatment.

Agreement among attendings and residents was poor to moderate in reference to fracture pattern and treatment. There was poor agreement in confidence of fracture pattern, though fair versus agreement in treatment (k = .14 p < .001, k = 0.31, p < .0001). Analysis by separating images into high-standard, midlevel and low radiation doses revealed a significant difference in measurements of the mean gap at all dosing levels; however, the difference remained consistent from high dosing to low (mean = 0.70 p = .001, 0.77 p < .0005, 0.74 p < .0002, respectively). Analysis was further performed to evaluate high-standard dosed image measurements to the lowest-dosed gap, pattern and treatment measurements, which showed no significant difference (mean SD 0.011 ± .6876, p = .95, 0.2414 ± 1.2721, p = .32, .3103 ± 1.0725, p = .13, respectively). No significant difference was found comparing current high-standard and mid-level dosing as well. Furthermore, no significant difference was found in measuring step-off across high-standard, medium and low radiation doses (0.21 ± 1.3507 p = .46, 0.28 ± 1.5948 p = 0.39, –0.16 ± 1.106 p = 0.48 respectively).

Table 3. Difference Between Measured and True Fracture Pattern and Treatment by Reader

	Fracture Pattern Mean Difference		Fracture Treatment Mean Difference	
Reader	(1–10)	Std Dev	(1–10)	Std Dev
Residents (n = 30)	–1.1667 p < .0001	0.6477	–2.1 p < .0001	0.9229
Att vs Res (n = 89)	2.0899 p < .0001	2.4478	1.3371 p < .0001	1.8583

Table 4. Difference Between Measured and True Gap and Step-Off by Dose Using Attending Reads

	Mean Difference		Mean Difference	
Dose Amount	Gap	Std Dev	Step-Off	Std Dev
High (Standard) (n = 30)	0.7 p < .001	1.0554	.2083 p = .46	1.3507
Medium (n = 30)	0.77 p < .0005	1.0726	.2800 p = .39	1.5948
Low (n = 30)	0.74 p < .0002	0.9471	–0.1600 p = .48	1.106

Discussion

Pilon fractures are an example of a high-energy injury with complex intra-articular patterns that require detailed pre-operative treatment plans. An important aspect of this includes advanced imaging with optimal CT scans. Treatment recommendations are in part based on the amount of fracture displacement at the articular surface; displacement of 2 mm or less can be acceptable whereas greater than 2 mm may require reduction to acceptable parameters.[1, 2, 11] Image quality is both a function of exposure and the reconstruction software displaying this information. In this study, we created AO 43C-type patterns using a common Y-shaped morphology as was well-elucidated by Cole et al.[13] In keeping with the ALARA principle, we created three separate scanning protocols to determine if treatment plans could be confidently created while significantly decreasing the radiation dosing. To our knowledge, there are no studies that have been undertaken to demonstrate an optimum level of minimal radiation dosing that will result in appropriate imaging in complex extremity fractures.

In this study, the imaging was evaluated by three experienced orthopedic surgeons as well as two mid-level residents. Unexpectedly, initial analysis of the results did not show that those with attending-level experience were significantly more accurate in measuring the gap distance in the axial plane; however, all groups did well in measuring step-off distances. There was also a relatively fair agreement between measurements, especially in gap measurements, and poor agreement amongst the confidence levels of both fracture identification and treatment when taking all images together. This is consistent with several previous imaging studies of complex distal tibia fractures which have shown only moderate agreement when using the well-known classification systems of Ruedi-Allgower as well as the AO/OTA system.[18] As data has shown these classification systems to not result in excellent agreement, they were not utilized in this study and instead the reader was asked only if they felt confident identifying a fracture pattern based on their own preference. Surprisingly, even without using these classification systems, agreement still remained only fair when including all scans. While some disagreement may be created due to the classification systems themselves, poor confidence level agreement may likely be due to the statistical nature of the kappa value in reference to using a continuous scale of numbers as was used in this study. Concurrently, while treatment confidence may be increased using appropriate imaging, some graders may leave room for intraoperative findings and grade their confidence levels accordingly as this was not specifically addressed in the questionnaire sheets.

While there was a significant difference between the measured gap and true gap at the articular surface, this difference as a whole was relatively small. Most importantly in this study, the analysis comparing the standard, higher dose radiation to lower dose radiation images did not show a significant difference. Step-off across all doses were consistent and did not show a significant difference. When evaluating attendings and residents as a group, there were not significant differences in measuring gaps in the axial plane and this remained consistent in high, medium and low dose groups.

To eliminate any confounding by less experienced readers, we did analyze the attendings separately across the high to low radiation dosed images. Specifically, we looked at the measurements of gap in the axial plane as initial data showed this to have the most variability and potential difference. We also included confidence levels in both identifying fracture patterns as well as treatment plans. Here again, no significant difference was found between the higher dosed images and the lowest dosed images, in either the measurements, fracture identification or treatment plans.

Weaknesses of this current study include the use of fracture patterns without impaction or severe comminution, the presence of which may potentially change the ability to read and measure differences across the low radiation dosed images. Furthermore, it was assumed that the fracture displacements initially created were maintained and did not move during transport to our institutions CT scanner. It is possible some displacement may have occurred; however, we feel confident this would minimally impact our findings.

The three attendings involved in this study are well versed and experienced in this fracture pattern, and include two separate institutions. The results of this study show no significant difference when evaluating high-standard (110 mAs) and low dosed (45 mAs) CT scans using less than one-half the amount of exposure (DLP of 192 vs 82), being read by experienced readers utilizing mid-level residents and attendings. This suggests that in complex extremity fractures, a new CT protocol may potentially be utilized that can significantly reduce radiation exposure. Our initial data shows promise that we may retain satisfactory imaging to both identify a fracture pattern and formulate a treatment plan, while also reducing the collective radiation burden to the skin and bone marrow. Although the skin has less radiosensitivity compared to the gonads, stomach and colon,[19] the extremities are frequently scanned, often multiple times, in the pre- and post-operative workup of trauma patients. The cumulative dose to the skin can therefore be significant. In addition, bone marrow has a similar radiosensitivity to the stomach and colon, and is given the highest weighting by the ICRP. This is particularly important in children, who have a higher degree of hematopoetically active red marrow. Previous studies have shown aberrant bone pathology especially associated with therapeutic doses of radiation to treat various oncologic conditions.[23] High dose radiation has quantifiably shown adverse effects on fracture healing in animal models. Inyang et al. demonstrated a quantifiable decrease in bone volume fraction, trabecular thickness, trabecular number and bone surface-bone volume ratio on a fracture model exposed to 36-Gy radiation dose delivered in 10 fractions over 10 days.[24] The concern for pathologic fracture and non-union in irradiated bone has also spurned many forays into further protective modalities, including current research focusing on potential pharmacological treatments.[22] Although high-dose radiation has been elucidated to carry many deleterious effects, there continues to be a paucity of quantifiable data to show the lowest safe-dose to protect against potential chondral and osseous damage and the effects in fracture healing. As such, the ALARA principle dictates that the lowest possible dose be used to produce diagnostic information in any study.

Conclusion

The results of this study show no significant difference when evaluating current standard (110 mAs) and low-dosed (45 mAs) CT scans using less than one-half the amount of exposure, being read by experienced readers. This suggests that in complex extremity fractures, a new CT protocol may potentially be utilized that can significantly reduce radiation exposure. Our initial data shows promise that we may retain satisfactory imaging to both identify a fracture pattern and formulate a treatment plan while also to reducing the collective radiation burden to the population. Future goals will be to include a greater number of experienced readers to test this application in separate complex extremity fracture types in both adults and children.

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Original Research

How Does Physician Attire Influence Patient Perceptions in the Urban Outpatient Orthopedic Surgery Setting?

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Abstract

Background: Physician attire has hygienic and professional implications, and significantly contributes to the patient-physician relationship. The purpose of this study is to investigate how surgeon attire impacts patient perceptions of trust and confidence in an urban orthopedic outpatient setting.

Methods: Eighty-five patients completed a three-part questionnaire. In the first section, participants viewed eight images: four of a male surgeon and four of a female surgeon wearing a white coat over formal attire, scrubs, business attire, and casual attire and rated each on a 5-level Likert scale. Participants were asked how confident, trustworthy, safe, caring, and smart the surgeon appeared; how well the surgery would go; and how willing they would be to discuss personal information with the pictured surgeon. The participant ranked all images from most to least confident in the second part and the last section obtained demographic information.

Results: The male surgeon wearing a white coat elicited higher ratings in confidence, intelligence, surgical skill, trust and safety when compared to both business and casual attire. For the female surgeon, white coat and scrubs were performed equally; however, the white coat was preferred to business attire in five of seven categories. Casual clothing was widely disliked in all categories for both male and female surgeons. When attire was compared for confidence on a scale, white coat ranked higher than business and casual attire but not scrubs.

Conclusions: In this study, patient preferences varied based on the gender of the pictured surgeon in the survey. Overall, however, the white coat elicits the highest levels of confidence, intelligence, trust, and safety. Furthermore, patients are more willing to discuss personal information and believe that their surgery will go better if the surgeon wears a white coat or scrubs. Given the increasing awareness and concern for physician-spread hospital infection, this study lends support to scrub attire over business or casual attire if physicians move away from the white coat.

Level of Evidence: Level II

Introduction

The influence of physician attire on patient perceptions has been analyzed since Hippocrates, who believed that doctors should be "clean in person, [and] well-dressed."[1–3] For both professional and hygienic reasons, the debate has persisted regarding the most appropriate clothing and how this may affect the patient-physician relationship. Numerous studies have confirmed the strong influence of physician attire on communication, patient education, confidence, trust, respect, adherence to medical treatments, and ultimately the quality of care patients receive.[1, 4–7] Furthermore, attire is one of the few changeable factors proven to have a significant influence on the patient's first impression.[4, 8]

The white coat has been standard physician attire since the late 19th century and was historically preferred over scrubs, formal, and casual dress in various outpatient settings.[1, 6, 8–10] Recently, the United Kingdom Department of Health banned any garment or accessory below the elbow in the setting of clinical care.[11, 12] This mandate was predicated on a series of studies which implicated clothing, particularly the white coat, as a vector which may promote the spread of nosocomial infections.[2, 10–12] Furthermore, these changes served to inform the public of the potential dangers associated with garments and accessories that may make contact with consecutive patients. Thus, their perception of physician professionalism is now balanced against the threat of attire as a potential fomite such as neckties, watches, and long sleeves.

Patient preference for physician attire is further influenced by patient age, cultural and societal standards in that particular region.[6, 7, 11, 13] In the pediatric and psychiatric setting, for example, patients view the white coat as a symbol of authority, which in-turn acts as a barrier in developing a strong patient-physician relationship.[14, 15] Age may also influence preference, with older patients tending to prefer a more formally dressed doctor.[7, 11, 13]

Previous studies across various institutions have claimed virtually every conceivable attire as being preferred, which taken cumulatively serves to explicate the overarching principle that each specialty and patient setting needs individual consideration. With that in mind, there is still scant research regarding the influence of physician attire in an orthopaedic outpatient setting, particularly with regard to urban populations.[16] The purpose of this study is to understand how surgeon attire impacts patient perceptions of trust and confidence in an urban orthopedic outpatient setting. We hypothesize that these patients will prefer physicians in a white coat or scrubs over formal or casual attire.

Materials and Methods

In this prospective, cross-sectional study, a three-part computer-based questionnaire was completed by consecutive patients waiting to be evaluated at an urban outpatient orthopaedic office. Patients were included if they were over 18 years and agreed to be surveyed. Patients who were under 18, answered the survey with values outside the possible range (e.g., 13), or did not respond to more than half of the questions were excluded.

The first survey component randomly presented images of a male or female surgeon, each dressed in four outfits: a white coat over business attire, scrubs, business attire, and casual attire (Figure 1). All jewelry/watches, facial expression and background remained constant.

For each image, the participant was asked to rate, on a 5-point Likert scale, qualities of the surgeon including confidence, intelligence, trustworthiness, safety, and compassion. A scale from one to five was chosen as previous research has failed to demonstrate superiority with more expansive scales.[17] The following questions were asked:

How confident are you in this surgeon?

How smart is this surgeon?

How well do you think the surgery will go if this was your surgeon?

How willing are you to discuss confidential information with this surgeon?

How trustworthy is this surgeon?

How safe is this surgeon?

How caring is this surgeon?

The second part showed all four images of the male and female surgeon lined up next to each other in a single page and asked the participant to rank the images from highest to lowest level of confidence in the surgeon's abilities. The final section procured demographic information such as age, sex, race, education level, employment status and whether or not they had private insurance, no insurance, or Medicare.

Survey responses for the 5-point Likert scale were aggregated to a derived 3-level response. The original responses "not very" and "not at all" were combined and reclassified as "negative," the original responses "very" and "somewhat" were combined and reclassified as "positive," and "neutral" responses remained as such.

Statistical Analysis

The sample size for this study was adequate to achieve a power of 0.80 in avoiding a type II error. All four attires were compared using a Friedman test for statistical significance. Then, pair-wise comparisons were conducted with a Bonferroni correction for multiple comparisons and adjusted p-values were reported. The Wilcoxon rank-sum test was used to determine any difference in ranking attributed to respondent gender and the Kruskal-Wallis tested responses according to age range and ethnicity.

The second component of the survey consisted of comparative rankings for which the Friedman test was used. All reported p-values are two-sided. Data were analyzed using SAS® 9.3 for Windows. The study was adequately powered to detect a significant difference with 95% confidence.

Results

Responses were collected from a total of 85 patients in the orthopaedic surgery outpatient setting at an urban university hospital. Demographic data for participants are summarized in Table 1. The majority of patients included were age 35 to 54, female, African Americans who had private insurance and identified themselves as being unemployed due to their disability.

The responses for male and female surgeons stratified by type of attire and 3-level response comparisons for confidence, intelligence, surgical skill, caring, safety, trustworthiness and ability to discuss important issues are displayed in Table 2. For male surgeons, a white coat was preferred across all categories when compared with business and casual attire ($p < 0.05$). No difference, however, was found between white coat and scrubs with respect to both patient confidence in the surgeon and the ability to discuss important issues. For scrubs versus business attire, no significant difference was identified in any category, and all other outfits were preferred to casual dress (Figure 2).

For female surgeons, white coat was not preferred to scrubs in any category, although it was rated higher than business attire in all categories except for doctor intelligence and caring. While scrubs evoked greater confidence when compared with business attire, no other differences were observed. Finally, as with male surgeons, casual attire was not preferred in any aspect of patient care (Figure 3).

The aforementioned responses were further compared with respect to baseline demographic information including age, sex, and ethnicity. While no difference was found for age and gender, a significant difference did exist with regard to confidence in female surgeons based on ethnicity ($p < 0.05$). For all other categories, however, responses did not significantly vary when compared by respondent ethnicity, and therefore no trends were identified.

In the second component of the survey, respondents ranked the surgeons one through four with regard to confidence. Table 3 demonstrates the results for male rankings and analysis of significance is represented in Table 4. For male surgeons, respondents ranked the white coat significantly higher than business and casual attire; however, no difference was found when compared with scrubs. Further-

Figure 1. Male and female attire photos. Figure 1 demonstrates male **(A)** and female **(B)** surgeon photos arranged here as white coat, scrubs, business and casual attire from left to right.

more, scrubs outranked casual but not business attire, which was also significantly preferred to casual attire in direct comparison (Figure 4). The same observations (Figure 5), in terms of significance, were observed when female surgeons were ranked and direct values and their statistical comparisons are shown in Table 5 and Table 6, respectively.

Discussion

The results of this study demonstrate that orthopaedic surgery patients in an urban outpatient setting generally prefer male surgeons with a white coat and female surgeons with either a white coat or scrubs. In terms of patient confidence in their physician, no difference was observed between scrubs and the white coat over business attire. Respondents' predilection for the white coat is consistent with previous literature which denotes it as symbolic for a clean, competent and professional surgeon.[1, 10, 13] While pediatric and psychiatric patients may accept, or even prefer casual dress, it was widely disliked in the orthopaedic surgery setting.

Recent regulations in the United Kingdom have effectively prohibited white coats along with watches, ties, or long sleeves due to the potential, yet unproven, risk of infection transmission.[2, 11, 12] These changes came on the heels of concerning reports of rising hospital acquired infections, and data which suggest as many as one in 20 patients will contract a nosocomial infection.[12, 18] Regardless of how physicians perceive the legitimacy of the work which substantiates these regulations, several studies have demonstrated

Table 1. Demographic Data

Age Range		
18 to 34	31	36.5
35 to 54	37	43.5
55 or older	14	16.5
Missing	3	3.5
Gender		
Female	44	51.8
Male	38	44.7
Prefer not to respond	1	1.2
Missing	2	2.4
Ethnicity		
American Indian, Alaskan Native, Asian, or Pacific Islander	4	4.7
Black or African American	34	40.0
Hispanic or Latino	20	23.5
White/Caucasian	22	25.9
Missing	5	5.9
Education		
Less than high school degree	4	4.7
High school degree or equivalent (e.g., GED)	31	36.5
Some college but no degree	22	25.9
Associate degree	8	9.4
Bachelor degree	8	9.4
Graduate degree	6	7.1
Prefer not to respond	4	4.7
Missing	2	2.4
Employment Status		
Employed, working full-time	26	30.6
Employed, working part-time	7	8.2
Not employed, looking for work	15	17.6
Disabled, not able to work	23	27.1
Retired	5	5.9
Prefer not to respond	7	8.2
Missing	2	2.4
Insurance		
Medicaid	8	9.4
Medicare	19	22.4
Private insurance	32	37.6
Private insurance and Medicare	4	4.7
I do not have insurance	6	7.1
Prefer not to respond	14	16.5
Missing	2	2.4

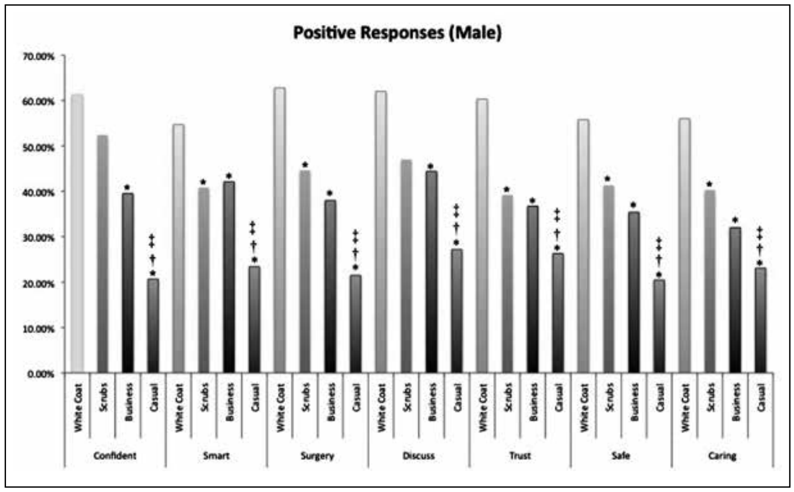

Figure 2 demonstrates positive responses from patients stratified by the question asked: how confident are you in this surgeon (confident), how smart do you think the surgeon is (smart), how well do you think the surgery will go (surgery), how willing would you be to discuss important information with this surgeon (discuss), how trustworthy do you find the surgeon (trust), how safe do you feel with this surgeon (safe) and finally how caring do you find this surgeon (caring).
*$p < 0.05$ for comparisons with white coat
†$p < 0.05$ for comparisons with scrubs
‡$p < 0.05$ for comparisons with business attire

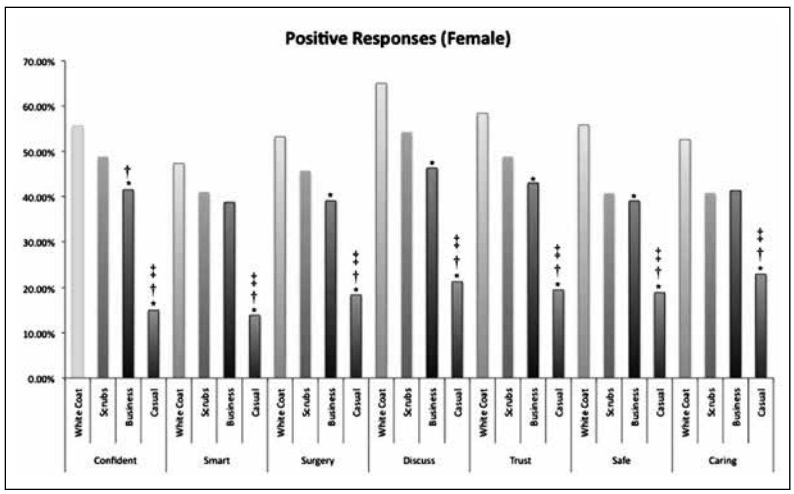

Figure 3 demonstrates patient preferences for female surgeon attire. This was stratified by each of the seven questions and significance is demonstrated.
*$p < 0.05$ for comparisons with white coat
†$p < 0.05$ for comparisons with scrubs
‡$p < 0.05$ for comparisons with business attire

Table 2. P-values for Respondent Comparisons by Category for Male and Female Surgeons

		Confident	Smart	Surgery	Discuss	Trust	Safe	Caring
Male	White Coat vs Scrubs	0.2972	0.0281	0.0035	0.0858	0.0006	0.0281	0.0452
Male	White Coat vs Business	0.0006	0.0273	0.0005	0.0234	0.0003	0.0021	0.0064
Male	White Coat vs Casual	<.0001	<.0001	<.0001	0.0002	<.0001	<.0001	<.0001
Male	Scrubs vs Business	0.0631	1	0.4418	1	1	0.8017	1
Male	Scrubs vs Casual	<.0001	0.0015	<.0001	0.0002	0.0281	0.0002	0.0009
Male	Business vs Casual	<.0001	0.0009	0.0003	0.0015	0.0489	0.0002	0.0064
Female	White Coat vs Scrubs	1	0.9931	1	0.2089	0.4996	0.0753	0.4996
Female	White Coat vs Business	0.0281	0.2972	0.0559	0.0102	0.0437	0.0097	0.1255
Female	White Coat vs Casual	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Female	Scrubs vs Business	0.0423	0.9691	0.0983	0.3634	1	1	1
Female	Scrubs vs Casual	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.0002
Female	Business vs Casual	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001

Table 3. Summary of Photo Ratings for Male Surgeon Attire

Attire	N	Mean	Median	Std Dev	Std Error	Mini-mum	Maxi-mum
White Coat (Male Surgeon)	71	1.86	1.00	1.23	0.15	1.00	4.00
Scrubs (Male Surgeon)	71	2.03	2.00	1.08	0.13	1.00	4.00
Business (Male Surgeon)	69	2.36	2.00	1.12	0.14	1.00	4.00
Casual (Male Surgeon)	69	2.87	3.00	1.28	0.15	1.00	4.00

Table 3 represents patient preferences for the second component of the survey where respondents ordered attire based on surgeon confidence with one being most confident and four as least confident.

Table 4. Summary of P-values for Photo Ratings for Male Surgeon Attire

Comparison	p-Value
All Four Photographs	<.0001
White Coat (Male Surgeon) versus Scrubs (Male Surgeon)	1.0000
White Coat (Male Surgeon) versus Business (Male Surgeon)	0.0055
White Coat (Male Surgeon) versus Casual (Male Surgeon)	0.0002
Scrubs (Male Surgeon) versus Business (Male Surgeon)	0.4611
Scrubs (Male Surgeon) versus Casual (Male Surgeon)	0.0038
Business (Male Surgeon) versus Casual (Male Surgeon)	0.0032

Table 4 demonstrates p-values for the second component of the survey. For male surgeons, white coat was not ranked significantly higher than scrubs in terms of confidence. It did outrank all other attires however.

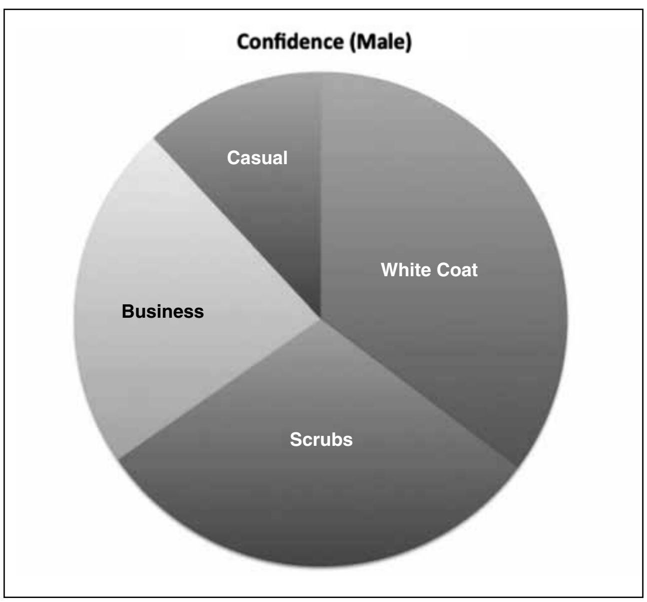

Figure 4 represents the results of the second component of the survey where respondents ranked preference for each attire in terms of confidence. This pie chart demonstrates respondent preferences which where largely in favor of white coat and scrubs.

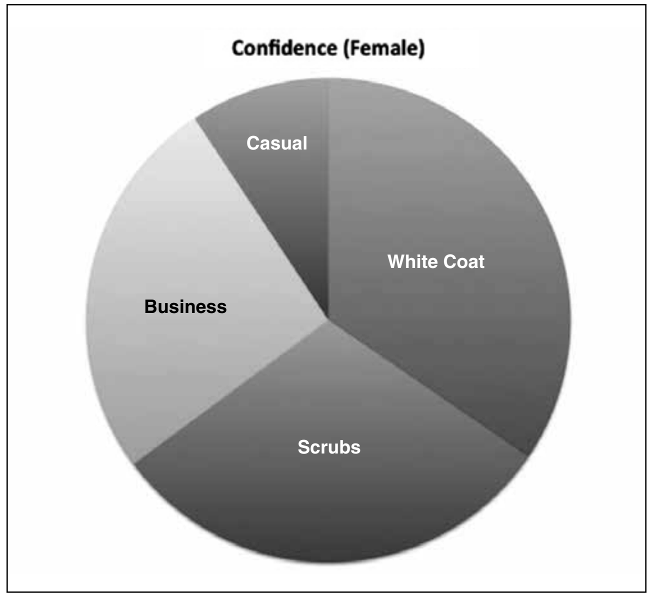

Figure 5 represents the results of the second component of the survey where respondents ranked preference for each attire in terms of confidence. This pie chart demonstrates respondent preferences which where largely in favor of white coat and scrubs.

Table 5. Summary of Photo Ratings for Female Surgeon Attire

Attire	N	Mean	Median	Std Dev	Std Error	Mini-mum	Maxi-mum
White Coat (Female Surgeon)	70	1.94	1.00	1.24	0.15	1.00	4.00
Scrubs (Female Surgeon)	71	2.08	2.00	1.11	0.13	1.00	4.00
Business (Female Surgeon)	69	2.36	3.00	1.06	0.13	1.00	4.00
Casual (Female Surgeon)	70	2.90	4.00	1.32	0.16	1.00	4.00

Table 5 represents patient preferences for female surgeon attire in terms of confidence. Patients ranked one as most confident to four as least confident.

Table 6. Summary of P-values for Photo Ratings for Female Surgeon Attire

Comparison	p-Value
All Four Photographs	<.0001
White Coat (Female Surgeon) versus Scrubs (Female Surgeon)	1.0000
White Coat (Female Surgeon) versus Business (Female Surgeon)	0.0277
White Coat (Female Surgeon) versus Casual (Female Surgeon)	0.0011
Scrubs (Female Surgeon) versus Business (Female Surgeon)	0.8422
Scrubs (Female Surgeon) versus Casual (Female Surgeon)	0.0024
Business (Female Surgeon) versus Casual (Female Surgeon)	0.0162

Table 6 summarizes p-values for respondent preference for female surgeon confidence based on attire. White coat was not significantly preferred to scrubs but was preferred to all other attires.

that patient awareness of the "bare below the elbows" policy may actually influence their preferences for physician attire.[2, 5, 11, 19] As respondents are given information on the potential role of physician clothing as a bacterial vector, they change their preferences away from white coats and long sleeved clothing.

More recent investigations indicate a growing preference for scrubs and "smart casual" attire, which are not only perceived as hygienic in conforming with the bare below the elbows regulations, but further serve to identify the treating physician.[16, 20] In fact, several authors postulate that while variations may exist from specialty to specialty, the unifying factor in clothing preferences is simply a uniform or outfit which conforms with the patients preconceived image of a doctor.[2, 21] Therefore, it is not surprising that both the white coat and scrubs were nearly equally well received in our study, as both outfits are seen in hospitals, television shows, and movies as attire which identifies the treating physician.

Finally, patient age has been implicated as a significant factor in determining preference for physician attire. Younger respondents accept more casual attire and scrubs when compared with older patients, who favor more formal dress.[6, 11, 13] Again, authors point to a subconscious notion of how physicians should appear as the driving factor in determining preference, and that preconceived image of a physician varies with the age of the patient and evolves over time.[6, 16, 21] The majority of our study population fell within the age range of 35 to 54 years old; however, eighty percent of the patients surveyed were under the age of 55. Due to the relatively young cohort of respondents, it is not surprising that scrubs performed nearly equally as well as the white coat given the aforementioned evidence that younger patients are likely to favor scrubs and less formal attire.

The fact that this study was conducted at a single institution in an urban setting with relatively young patients is a potentially significant limitation to this study, as previous work has established the influence of location, culture, and age on patient preferences.[7, 10] Furthermore, the young age of the pictured physician, while held constant, could influence respondents preference for their attire. Finally, the use of a Likert scale has inherent limitations as an ordinal scale that is subsequently represented as numeric comparisons.

Certainly many factors of the doctor-patient interaction influence the first impression and can not be replicated without a face-to-face encounter. Regardless of the physicians appearance, attributes such as demeanor, empathy, tone of voice, hygiene and even smiling will shape the patients perception of their doctor.[1, 2, 4, 16, 22] With that in mind, one of the proven and changeable factors that contribute to both the first impression as well as overall patient trust and confidence is the attire of the physician. In the urban orthopaedic outpatient setting, a white coat or scrubs inspire patient confidence and are favored compared with formal or casual attire.

Future studies are needed to investigate the preferences of patients in a suburban or rural orthopaedic setting in order to elucidate the generalizablity of these results with regard to orthopaedic patients. Moreover, the influence of "bare below the elbow" guidelines enforced in the United Kingdom has not been established on patients in the United States and may further influence patients perceptions and preferences.

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Original Research

Septic Arthritis of the Wrist: Incidence, Risk Factors, and Predictors of Infection

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Abstract

Purpose: Septic arthritis of the wrist can result in permanent damage to the joint. Timely diagnosis is crucial as urgent surgical debridement and initiation of antibiotics is needed; however, previous studies failed to provide objective predictors of infection. Currently, the gold standard diagnosis is a thorough history and physical exam. This study aimed to establish the incidence of wrist septic arthritis and to identify objective laboratory data and patient factors which indicate infection.

Methods: A 10-year review was conducted at a single urban hospital for patients with complaints of a swollen, painful wrist without trauma. From those records, patients with a joint fluid analysis were examined with regards to history, demographic and laboratory data.

Results: Of 892 patients included in this study, 13 (1.5%) were found to have wrist septic arthritis. Of 72 patients with a wrist aspiration performed, 18% were consistent with septic arthritis. Elevation in serum white blood cells (WBC) and fever within 24 hours of aspiration predicted infection. When patients with septic arthritis were compared to those with crystalline arthropathy, positive serum blood cultures, elevated joint fluid WBC and positive joint fluid cultures were predictive of infection. Likewise, a history of active IV drug abuse and smoking were significant predictors of infection.

Conclusions: Wrist septic arthritis is rare, and the diagnosis is difficult; however, laboratory data and patient factors can help identify patients at risk. Findings most predictive of septic arthritis of the wrist included an elevated WBC and positive blood cultures from serum. In terms of joint fluid, our data suggest that when limited fluid is available, as is often the case with wrist aspirations, gram stain, culture, and examination for crystals should take priority.

Level of Evidence: II, Diagnostic

Introduction

Septic arthritis of the wrist can result in substantial wrist damage and must often be ruled out in a patient presenting with a warm and painful wrist without trauma. In the absence of trauma, the differential diagnoses includes osteoarthritis, inflammatory arthritis, crystalline arthropathy, cellulitis or soft tissue abscess.[1] Urgent open or arthroscopic surgical debridement is preferred when a septic wrist is identified, after which, treatment with parenteral antibiotics should be initiated.[2, 3]

The diagnosis of septic arthritis relies heavily on the history and physical exam, where a high level of suspicion must be maintained.[3, 4] While fluid analysis and cultures can also be very helpful in making the diagnosis, adequate joint fluid is required for analysis and diagnostic value. The wrist joint being a small joint often fails to yield adequate fluid for analysis. Furthermore, while laboratory values for both joint fluid and serum analysis have been well established for other joints such as the knee and hip, no specific parameters defining a septic wrist have been determined.[4, 5]

At this time, there is limited objective evidence to guide the empiric diagnosis of septic arthritis of the wrist. Moreover, for patients presenting with an atraumatic painful swollen wrist the incidence of true infection is not known.[2] In order to obtain clinical information to aid in the diagnosis of septic wrists, the goals of this study were to (1) establish the incidence of septic arthritis of the wrist, (2) identify objective laboratory data from fluid and serum analysis which indicate infection, and (3) establish risk factors for infection.

Methods

After securing institutional review board approval for this retrospective comparative study, the medical records from a single urban hospital from 2004–2014 were reviewed.

Inclusion criteria included a patient age of over 18 years old and a diagnosis with (ICD-9) codes of 274.03, 680.3, 712.83, 712.93, 719.43, 715.13 and 727.05. Patients were excluded if they were under the age of 18 or if a history of trauma to the area or fracture was identified.

A total of 892 patients met the inclusion criteria and were reviewed; from this cohort, a subset of 72 patients were identified who had joint aspiration performed. Demographic data was recorded (Table 1) as well as laboratory values from within the first 24 hours of arrival at the hospital, or within 24 hours of symptom onset for admitted patients with

Table 1. Baseline Demographic Data

Male	47
Female	25
Age	57.3
Caucasian	18
African American	39
Hispanic	15
Diabetes	22
Kidney disease	16
Immunocompromised	9
IV drug user	20
History of crystalline arthropathy	15
Active smoker	28

Table 1 represents baseline demographic data and patient characteristics. Seventy-two patients were included in the study.

Table 2. Comparison of P-values

	Septic Arthritis vs. All	Septic Arthritis vs. Crystalline Arthropathy
Blood Cx (+)	.74	**.01**
WBC (serum)	**.03**	.12
ESR	.37	.45
CRP	.94	.10
Aspirate Cx (+)	**.01**	**.01**
WBC (aspirate)	.07	**.02**
Neutrophils (aspirate)	.42	.86
Fever	**.04**	.06

Table 2 demonstrates the p values for comparisons between those with septic arthritis and all patients with wrist aspiration, as well as comparison between patients with final diagnoses of septic arthritis and gout. Significance was set at **$p < 0.05$.**

new symptoms. Laboratory values recorded included serum white blood cell count (WBC) and differential, erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP), as well as core temperature (Tc). A fever was defined as Tc greater than 100.4 degrees Fahrenheit (°F). If joint fluid was obtained and analyzed, then WBC and percentage of neutrophils, gram stain, culture, and crystals were recorded. From this group, 40 patients had received antibiotics prior to aspiration. Septic arthritis of the wrist was defined as a positive joint fluid cultures or gram stain at the initial aspiration or in the operating room.

All data was recorded in Microsoft Excel 2008 (Seattle, WA) and patient information was protected in accordance with the Health Insurance Portability and Accountability Act. Categorical data were analyzed with Fisher's exact test and the Wilcox Rank-Sum test was used for continuous data. Univariate and multivariate comparisons were performed using SAS software (Cary, NC) and significance was determined with a p-value at 0.05.

Results

Based upon the definition that a septic wrist requires a positive culture or gram stain from the initial joint aspiration or from an operating room joint fluid, a total of 13 wrists were deemed septic, resulting in a total incidence of 18% among all cases with aspiration data available, and 1.5% of all potential cases.

When comparing patients with septic arthritis against those with other causes for a painful wrist, statistically significant values which positively predicted a diagnosis of septic arthritis were a serum white blood cell count (WBC) greater than 11,000/mcL and fever within 24 hours of aspiration (Table 2). For patients with septic arthritis, a febrile range from 100.6 to 104.1°F was found, with an average temperature of 100.42°F overall. Those with crystalline arthropathy had a febrile range from 100.7 to 102.8°F with an average temperature of 99.64°F. There were no significant differences in demographic data between the two groups.

As the differentiation of a septic and crystalline arthropathy is both common and difficult clinically, further comparison between patients with aspirate-proven crystalline arthropathy and those with septic arthritis was secondarily conducted. Positive blood cultures, fevers and elevated aspirate WBC predicted septic arthritis. Demonstration of aspirate crystals was a significant predictor of crystalline arthropathy (Figures 1 and 2). Two patients had concomitant septic arthritis and crystalline arthropathy of the wrist.

When comparing patients with septic arthritis against those with other causes for a painful wrist, a history of smoking was the only statistically significant patient factor which predicted a diagnosis of septic arthritis. When patients with septic arthritis were specifically compared against those with crystalline arthropathy, smoking and a history of IV drug abuse predicted infection, whereas a history of gout or pseudogout predicted crystalline arthropathy.

For patients with septic arthritis, the isolated organisms are identified in Table 3. The most common offending organism was methicillin-resistant *Staphylococcus aureus* (MRSA) and one patient had concomitant MRSA and pseudomonal infections. The other common final diagnoses, determined by negative cultures and/or clinical exam, were: crystalline arthropathy (23.6%), cellulitis (18.0%), arthralgia (18.0%), abscess (12.5%) and tenosynovitis (9.7%) (Table 4).

Discussion

The clinical finding of fevers and laboratory data showing an elevated serum WBC were found to significantly predict septic arthritis of the wrist in the context of a warm, painful joint. While these findings are generally intuitive, more importantly, joint fluid culture, gram stain and crystal analysis are critical in making a timely and accurate diagnosis. By contrast, these findings show no conclusive diagnosis can be made from the cell count, a fact which is critical in the setting of wrist pathology where minimal joint fluid is typically obtained. Therefore, when limited joint fluid is available for analysis, joint culture, gram stain, and crystal analysis must take priority.

Laboratory Data for Septic Wrists Versus Crystalline Arthritis

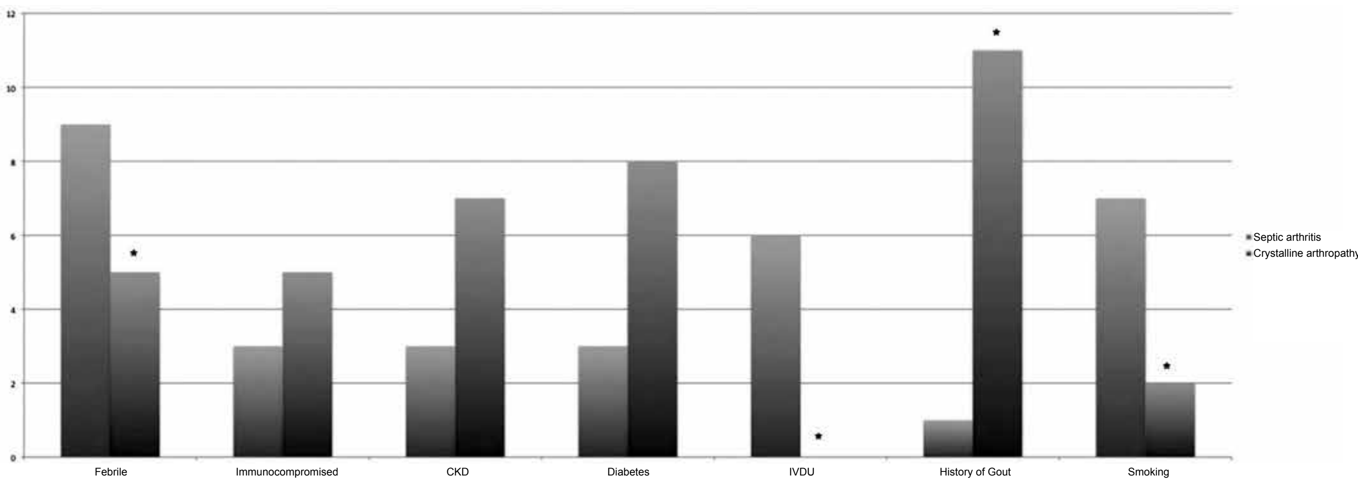

Figure 1. Objective laboratory data for patients with septic versus crystalline arthropathy. Blood Cx (+) = positive blood cultures represented as a percentage of patients in that group; WBC (serum) = average serum white blood cell count represented as one-thousandth of absolute value; ESR = average erythrocyte sedimentation rate; CRP = average C-reactive protein; Asp. WBC = white blood cell count in joint fluid, represented as one-thousandth of absolute value; Asp. Neutrophils = neutrophils in joint fluid, represented as percentage; Asp. Crystals = joint fluid crystals as a percentage of total in that group; Tc > 100.4 = patients with core temperature over 100.4 degrees Fahrenheit, as percentage of total. Standard deviation bars represented for all numerical categories.

*$p < 0.05$

Baseline Factors and Comorbidities for Septic Versus Crystalline Arthropathy

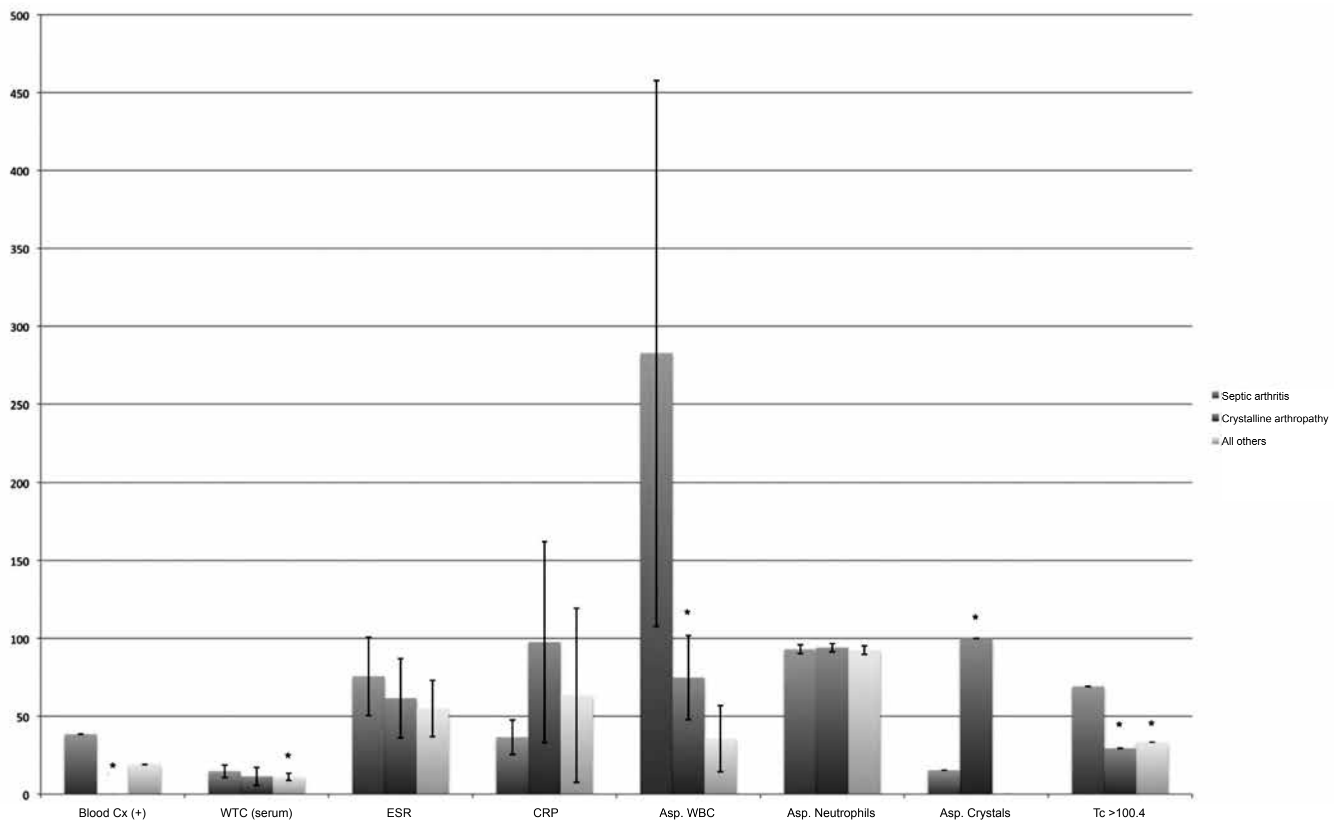

Figure 2. Differences in baseline characteristics and comorbidities between patients with septic and crystalline arthropathy. Febrile was characterized as a maximum oral temperature greater than 100.4 degrees Fahrenheit. CKD = chronic kidney disease; IVDU = active intravenous drug user.

*$p < 0.05$

Table 3. Isolated Organisms from Septic Wrists

MRSA	6
MSSA	2
Enterococcus	2
Strep pneumo	1
Pseudomonas	1
N. gonorrhoeae	1
GBS	1

Table 3 demonstrates isolated organisms from septic wrists. MRSA = Methicillin-resistant *Staphylococcus aureus;* MSSA = Methicillin-sensitive *Staphylococcus aureus;* Strep pneumo = Streptococcus pneumoniae; N. gonorrhoeae = Neisseria gonorrhoeae; GBS = Group B Streptococcus.

Table 4. Final Diagnoses

Crystalline arthropathy	17 (23.6%)
Cellulitis	13 (18.0%)
Arthralgia	13 (18.0%)
Septic arthritis	**13 (18.0%)**
Abscess	9 (12.5%)
Tenosynovitis	7 (9.7%)

Table 4 demonstrates the final diagnosis for patients included in this study. Number of patients is shown followed by percent representation in parentheses.

The true incidence of septic arthritis of the wrist is unknown. Skeete et al. reported on a series of 104 patients over two years with an incidence of septic wrist of 5% over the study period.[5] The incidence of septic wrist was not documented in a study by Rashkoff et al.; however, only 29 septic wrists were discovered over a 10-year period.[7] In the current study, a diagnosis of septic arthritis of the wrist was made in only 1.5% of patients with this presentation, further confirming the rarity of this diagnosis.

Not only is the diagnosis of septic wrist rare, but rigid criteria for confirming septic arthritis, as exists with large joints such as the hip and knee, do not exist for the wrist.[4, 8–10] Our results confirm the difficulty with laboratory diagnosis, as serum ESR and CRP as well as joint fluid WBC with neutrophil percentage did not predict a septic wrist joint. While this study was not able to detect a significant difference in joint fluid WBC, an elevated cell count may clinically raise suspicion for infection or a serious underlying pathology.

While an elevation in joint fluid WBC was not significant, this was the first study, to our knowledge, which identified an elevated serum WBC as predictive of a septic wrist. Skeete et al. identified increased serum WBC in two of five patients with septic wrist, which they deemed “not helpful.”[5] Mehta looked at septic arthritis of the shoulder, elbow, and wrist, and could not identify peripheral WBC elevation as predictive of septic arthritis.[3]

For patients with septic arthritis in any joint, Matthews found approximately 24% had positive blood cultures at the time.[10] Patients with either gout or septic arthritis may present with a swollen, painful joint with concomitant fevers. No previous studies have identified positive blood cultures predict septic arthritis when compared with crystalline arthropathy. Here, both positive blood cultures and elevated joint aspirate WBC count predicted infection over gout. Interestingly, two patients had concomitant crystalline and septic arthritis, which has been documented in several cases previously.[11–13]

Other studies suggested immunocompromised patients, including those with vascular disease and those with significant renal disease, were more likely to have a septic wrist; however, we did not confirm this finding.[1, 5] Given the relatively small number of patients with septic arthritis, this study may have been under powered to detect this finding. In this study population, however, the patient factor which predicted septic arthritis was a history of tobacco smoking.

For those patients with an infected wrist joint, *Staphylococcus aureus* was the most common organism isolated in other studies, although MRSA was most prevalent in our population.[1, 3, 7, 14] As such, we agree with these previous authors in the recommendation of gram-positive coverage beginning immediately after joint aspiration and culture, but would recommend empiric coverage for MRSA if their institution and community have a high prevalence of MRSA infections.

There were several limitations of the present study, chiefly, the retrospective nature of data collection and concurrent heterogeneous method of initial data collection. Furthermore, all patients included were from a large, single, urban hospital and, therefore, the results may not be generalizeable to the entire population with different local demographics. We believe our abnormally high incidence of MRSA infections is likely a direct consequence of this limitation.

In this study, 40 patients received antibiotics prior to joint aspiration. Septic arthritis was defined here as positive joint fluid cultures but was also considered positive if gram stain showed organisms, which should not be affected by prior antibiotics. Finally, as with many infection studies, the results are predicated upon the quality and technique with which the cultures were obtained by the various clinicians.

In conclusion, when evaluating a patient with a history and physical examination for septic arthritis of the wrist, presence of fevers and an elevated serum WBC count was most predictive of a septic wrist. The current data suggests that when limited joint fluid is available for testing, gram stain with culture and crystal analysis should be obtained with priority over a cell count analysis, which was found to have limited diagnostic utility. Patient characteristics such as smoking and IV drug abuse were also found to be risk factors for septic arthritis.

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Medical Student Research Project

Supported by The John Lachman Orthopedic Research Fund and Supervised by the Orthopedic Department's Office of Clinical Trials

The Caprini Risk Assessment Tool and Other Factors as Predictors of Thromboembolic Disease Risk Following Total Knee Arthroplasty or Below the Knee Traumatic Injury Repair Procedures

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Introduction

The development of venous thromboembolic disease (VTED), including deep vein thrombosis (DVT) and pulmonary embolism (PE), poses a significant risk to patients following surgery. These complications are especially prevalent in patients undergoing orthopedic procedures such as total knee arthroplasty (TKA) or below the knee traumatic injury repair.[1–4] Identifying patients at the highest risk for developing post-operative VTE can better assist the surgeon in managing prophylactic treatment.[5] VTED can have potentially life-threatening consequences that affect not only the success of the surgery, but also the patient's future quality of life.

Prophylactic management of VTED is essential because while VTED is one of the most common causes of death in the hospital, it is also one of the most preventable.[2, 6] The American College of Chest Physicians published guidelines that address the issue of VTED in patients admitted to the hospital, although the use of these guidelines in the orthopedic field have produced mixed reviews. Many orthopedists believe that these recommendations are suboptimal due to the lack of awareness for the increased risk of adverse bleeding reactions that is specific to patients undergoing orthopedic procedures. Furthermore, in the development of these guidelines, the ACCP used all cases of DVT, both symptomatic and asymptomatic, as an endpoint in their research.[7] However, there is no consensus among the orthopedic community as to the role of asymptomatic DVT in the orthopedic patient, with an asymptomatic DVT most commonly found below the knee. Therefore, the American Academy of Orthopedic Surgeons produced their own guidelines that use a risk-stratification approach to the prophylactic management of VTED, using symptomatic DVT as the endpoint in their research.[5] Tailoring a patient's prophylaxis according to their risk has been shown to significantly reduce the incidence of VTED in postoperative surgical patients.[8]

Since the development of the AAOS guidelines, there have been many attempts to stratify patients based on VTED risk.[9–11] Of the many tools available, the Caprini assessment scale is one that has been validated and recommended for hospital use.[6, 12] The Caprini scale separates patients into three categories: low risk, moderate, or high risk based on a variety of factors. A score of five is assigned to any patient undergoing elective arthroplasty or below the knee traumatic injury repair procedures, but a score of two or more on the scale puts a patient in the high-risk category, essentially categorizing all of these patients within this high-risk category. Therefore, there is still a significant gap in literature on how orthopedic physicians should risk-stratify within patients that undergo these procedures beyond the blanket categorization of high risk. This distinction is important to determine the need for further treatment beyond the current prophylactic regimens tailored towards an individual's risk factors.

This study seeks to look for common factors associated with the development of VTED in patients undergoing TKA or below the knee traumatic injury repair at a major urban hospital system — Temple University Hospital in Philadelphia, Pennsylvania. We intend to use this data to refine the Caprini risk assessment tool and prophylactic guidelines utilized as whole by this hospital system.

Materials and Methods

This study is a retrospective chart review. After receiving Internal Review Board Approval from Temple University Health Systems, researchers collected 395 patient records from the inpatient and outpatient electronic medical record systems from the years 2011–2013. Inclusion criteria included patients undergoing total knee arthroplasty or any open reduction of a fracture below the knee.

Data from the Caprini risk assessment scale as well as other variables of interest were collected on each patient, including age, type of surgery, BMI, presence of swollen legs, presence of varicose veins, pregnancy status, history of spontaneous abortion, use of oral contraceptives, sepsis, serious lung disease, history of myocardial infarction, congestive heart failure, history of inflammatory bowel disease, amount of time in bed post-op, presence of malignancy, use of a plaster cast, central venous access present, history of VTED, family history of VTED, Factor V Leiden, Prothrombin 20210A, Lupus Anticoagulant, anticardiolipin antibodies, elevated serum homocysteine, heparin-induced thrombocytopenia, other thrombophilias, history of stroke, hip, pelvis, or leg fracture, acute spinal cord injury, or multiple traumas.

Charts were then reviewed to determine if the patient developed a DVT or pulmonary embolism within two months post-operation. DVTs were then stratified as to whether they occurred below or above the knee. We only analyzed above the knee DVTs because of their known effects on the orthopedic patient.

Patients were then stratified according to their complete or actual Caprini score, as calculated using all factors in the Caprini tool, and a statistical analysis was performed to determine if patients with higher Caprini scores were at higher risk for VTED. A combination of the student's t-test, chi squared test, and Fisher's exact test were utilized to evaluate the significance of each variable depending on the type of variable being examined.

Table 1. Demographic Data of TKA or Below the Knee Trauma Patients from 2011–2013

Attribute	DVT = Yes	DVT = No	Total	p-Value
BMI ≥ 35, n (%)				0.2032
Yes	6 (4.9%)	117 (95.1%)	123	
No	6 (2.2%)	266 (97.8%)	272	
BMI ≥ 30, n (%)				0.0610
Yes	10 (4.4%)	215 (95.6%)	225	
No	2 (1.2%)	168 (98.8%)	170	
Age ≥ 75, n (%)				0.0456
Yes	4 (8.3%)	44 (91.7%)	48	
No	8 (2.3%)	339 (97.7%)	347	
Age ≥ 70, n (%)				0.0876
Yes	6 (5.8%)	97 (94.2%)	103	
No	6 (2.1%)	286 (97.9%)	292	
Age ≥ 65, n (%)				0.2250
Yes	7 (4.7%)	143 (95.3%)	150	
No	5 (2.0%)	240 (98.0%)	245	
Age ≥ 60, n (%)				0.2304
Yes	8 (4.1%)	188 (95.9%)	196	
No	4 (2.0%)	195 (98.0%)	199	
Gender, n (%)				0.5469
F	9 (3.7%)	237 (96.3%)	246	
M	3 (2.0%)	144 (98.0%)	147	
Race, n (%)				0.5545
African-American	6 (3.1%)	186 (96.9%)	192	
White	5 (4.2%)	115 (95.8%)	120	
Other	1 (1.2%)	82 (98.8%)	83	

Results

Of the 395 patients whose charts were reviewed, 12 patients had significant DVT/PE events and 383 patients did not experience significant DVT/PE events. In selected circumstances, continuous variables such as age and BMI were parsed into categorical variables. For example, age ≥ 75 is a derived categorical variable where "Yes" denotes that the patient age is great than or equal to 75. In other circumstances, categorical variables were aggregated to reduce the number of classifications. The association of select continuous and categorical variables was assessed based on the partition of patients by whether they had a DVT/PE or not. Continuous variables were assessed using the two-sample t-test. The categorical variables BMI ≥ 30, age ≥ 60, and smoker were tested using a χ^2-test, while the remaining were tested with the Fisher's exact test.

Of all variables tested, only age ≥ 75, previous malignancy, swollen legs, and "actual" Caprini score were found to be significant at the $p < 0.05$ level. BMI ≥ 30, age ≥ 70, and family history of VTE were found to be marginally significant at the $p < 0.05$ level. No other variables were found to be statistically significant.

Discussion

The motivating factor for this study was to find a better way to risk stratify patients according to their risk of developing a significant thromboembolic event. Our results demonstrated no significant correlations between many of the factors we studied in patients undergoing procedures that are considered high risk for VTED. Gender, race, diabetes, hypertension, hyperlipidemia, smoking, and alcohol use showed no correlations in risk for developing VTED, among many other variables analyzed. However, a marginal correlation was found for BMI ≥ 30, age ≥ 70, and family history of VTE, suggesting that these factors may contribute to VTED risk after a high-risk procedure.

Analysis demonstrated a significant correlation between previous malignancy, swollen legs, and actual Caprini score and incidence of VTE.

Previous malignancy was shown to be a significant risk factor for developing a significant VTE event following TKA or repair of a below the knee traumatic injury, as evidenced by our study. The hypercoagulable state associated with malignancy can have a role in this phenomenon, but further research needs to be undertaken to explore this hypothesis.

The significant correlation between post-operative swelling of the legs, defined as at least two days of 1+ swelling documented by the nursing staff, and VTE brings to light the need for careful observation of the lower extremity for signs suggestive of venous stasis, which is associated with an increased risk of a VTE event following orthopedic procedures.[12]

Table 2. Comorbidities of TKA or Below the Knee Trauma Treatment Patients from 2011–2013

Disease	DVT = Yes	DVT = No	Total	p-Value
Diabetes, n (%)				1.0000
Yes	3 (3.2%)	91 (96.8%)	94	
No	9 (3.0%)	292 (97.0%)	301	
Coronary artery disease, n (%)				1.0000
Yes	1 (2.7%)	36 (97.3%)	37	
No	11 (3.1%)	347 (96.9%)	358	
Hypertension, n (%)				0.3745
Yes	9 (3.8%)	226 (96.2%)	235	
No	3 (1.9%)	157 (98.1%)	160	
Hyperlipidemia, n (%)				1.0000
Yes	3 (2.5%)	118 (97.5%)	121	
No	9 (3.3%)	265 (96.7%)	274	
Smoker, n (%)				0.6962
Yes	5 (2.7%)	181 (97.3%)	186	
No	7 (3.4%)	201 (96.6%)	208	
Alcohol use, n (%)				0.6668
No	8 (3.6%)	217 (96.4%)	225	
Socially	3 (3.4%)	85 (96.6%)	88	
Yes	1 (1.2%)	81 (98.8%)	82	
Liver disease, n (%)				0.6105
Yes	0 (0.0%)	34 (100%)	34	
No	12 (3.3%)	349 (96.7%)	361	
Kidney disease, n (%)				1.0000
Yes	1 (2.1%)	46 (97.9%)	47	
No	11 (3.2%)	337 (96.8%)	348	
History of past VTE, n (%)				0.3131
Yes	1 (8.3%)	11 (91.7%)	12	
No	11 (2.9%)	372 (97.1%)	383	
Family history of VTE, n (%)				0.0599
Yes	1 (50.0%)	1 (50.0%)	2	
No	11 (2.8%)	382 (97.2%)	393	
HIV-AIDS, n (%)				0.1700
Yes	1 (16.7%)	5 (83.3%)	6	
No	11 (2.8%)	378 (97.2%)	389	
Previous malignancy, n (%)				0.0316
Yes	4 (9.3%)	39 (90.7%)	43	
No	8 (2.3%)	344 (97.7%)	352	
Swollen legs, n (%)				0.0046
Yes	10 (6.2%)	151 (93.8%)	161	
No	2 (0.9%)	232 (99.1%)	234	

Lastly, the focus of this project was to evaluate the Caprini risk assessment tool in its ability to accurately identify those patients at risk for a VTE event following the procedures mentioned above. The data showed a significant difference in Caprini scores between those that had a VTE event and those who did not (8.33 vs. 7.38, $p = 0.001$). An unfortunate consequence of studying the rates of symptomatic VTED in this patient population is that the overall incidence is relatively small. Although this is fortunate for patients, however, this poses a problem for the power of our study. Further study is warranted to look at a larger patient population in order to add power to the statistics found in our study and evaluate the true trends seen in the data.

It is hopeful that the Caprini risk assessment tool could be used to further stratify patients undergoing TKA or open treatment of below the knee traumatic injuries, beyond simply placing them all into high risk category based on the procedure they are undergoing, which has been done previously.

Further utilizing the Caprini risk assessment tool to stratify all patients undergoing TKA or below the knee traumatic injury repair can help guide physicians in determining whether to use standard protocols for post-operative management or to consider using more aggressive measures to protect their patients from a VTE event.

Table 3. Continuous Variable Data of TKA or Below the Knee Traumatic Injury Repair Treatment Patients from 2011–2013

Variable	N	Mean	Std Dev	Median	Parametric p-Value
Age					0.2263
DVT	12	63.4	16.2	68.0	
No DVT	383	57.9	15.5	59.0	
Weight					0.0963
DVT	12	221.3	67.4	199.0	
No DVT	383	197.3	48.5	190.0	
Height					0.3366
DVT	12	64.6	3.1	64.0	
No DVT	383	65.8	4.2	65.0	
BMI					0.1367
DVT	12	37.5	11.6	35.2	
No DVT	383	32.1	7.5	30.7	
Time under anesthesia					0.2257
DVT	12	207.2	100.5	175.0	
No DVT	383	181.1	72.2	165.0	
Tourniquet time					0.5770
DVT	12	84.8	42.4	88.0	
No DVT	383	78.1	41.1	69.0	
Blood loss					0.2045
DVT	12	220.8	113.7	200.0	
No DVT	383	164.3	152.7	150.0	
Days confined to bed rest					0.1855
DVT	12	2.88	4.45	1.25	
No DVT	383	1.06	1.34	0.50	
Actual Caprini score					0.0011
DVT	12	8.33	1.15	8.00	
No DVT	383	7.38	0.98	7.00	

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Medical Student Research Project

Supported by The John Lachman Orthopedic Research Fund and Supervised by the Orthopedic Department's Office of Clinical Trials

To Cut or Not to Cut? Patients Found Down with Crush Syndrome

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Abstract

Background: Drug and alcohol overdose is a cause of extremity compartment syndrome in the unconscious patient who is "found down" with prolonged compression of one or more limbs. The management of compartment syndrome (fasciotomy vs. observation) in this patient population is a subject of debate due to the uncertain time of onset and duration of this condition. Whereas some surgeons believe that immediate fasciotomy is indicated upon diagnosis, others argue that late fasciotomy does not lead to muscular or neurologic recovery yet creates a risk for surgical site infection and multiple subsequent surgeries.

Objective: To review the rates of post-operative complications (surgical site infection, amputation, and death) after performing fasciotomies in patients treated at our institution for compartment syndrome after being "found down" due to alcohol or drug intoxication.

Methods: A retrospective medical chart review of 22 patients who were admitted to our institution over a five-year period (June 2010–May 2015) with compartment syndrome secondary to prolonged limb compression due to alcohol or drug intoxication.

Results: Fasciotomies were performed on all 22 patients. There were five (22%) fasciotomy surgical site infections, two (9%) amputations, and one (4.5%) death. Including initial fasciotomy and debridement, there were an average of 4.8 surgical debridements per patient prior to final wound closure or coverage. The average time to diagnosis of infection was 25 days post-operatively.

Conclusions: We recommend performing fasciotomies in patients who present with compartment syndrome after prolonged limb compression from drug or alcohol intoxication, given the relatively low rate of post-operative complications observed in our study when compared to previous findings in the literature, particularly if there is a dysvascular extremity or if the patient is unconscious and unable to provide a neurologic exam. Further studies are needed to assess long-term functional outcomes.

Introduction

Crush syndrome is a life-threating medical emergency in which rhabdomyolysis develops after prolonged compression of the limbs. Protracted direct pressure initiates cell death through mechanical disruption of myocytes, followed by ischemic injury.[17] After the release of pressure, ischemia reperfusion injury combined with an increase in vascular permeability cause edema of the skeletal muscles and a rapid rise in intracompartmental pressures (ICP), leading to acute compartment syndrome.[7, 10] Elevation of ICP greater than 35–40 mmHg for several hours can lead to widespread muscle necrosis.[25]

Although more common during earthquakes and other disaster scenarios, crush syndrome is also seen in patients "found down" for many hours due to inebriation or drug overdose. The principal clinical feature of compartment syndrome in conscious patients is severe pain out of proportion to the injury which is aggravated by passive muscle stretch.[25] Paresthesias or complete sensory loss of the nerves traversing the affected area may also be present.[17] However, patients "found down" due to intoxication provide a unique diagnostic challenge to the treating clinician given multiple confounding factors such as mental impairment, nerve palsy from another etiology, vascular compromise, or frostbite.

Early diagnosis and immediate fasciotomy are necessary to improve the prognosis of patients with acute compartment syndrome.[18] Fasciotomy, when performed early, prevents muscle necrosis by improving circulation, decreasing harmful cytokine production, and decreasing the production of oxygen-free radicals.[21] The literature remains controversial on the course of treatment for patients with crush syndrome that present with a missed or delayed clinical diagnosis of compartment syndrome. A missed compartment syndrome can result in muscle necrosis that may be prone to infection if the tissue is exposed to the outside environment.[18, 21] Therefore, some surgeons caution against the use of fasciotomies when the recognition of an established compartment syndrome is delayed more that eight to 10 hours.[6, 19, 22] Even with aggressive use of antibiotics, sepsis is still a major cause of mortality in crush injuries.[12]

Despite the known risk of infection, fasciotomy compartment release remains the standard of care at many institutions for patients with compartment syndrome of unknown duration not associated with a fracture. Proponents of this approach emphasize the importance of relieving intracompartmental pressure and debriding dead muscle as soon as possible to avoid additional muscle necrosis, nerve damage, and systemic consequences such as kidney failure.[18] At our center, we have taken an approach to perform fasciotomies at the time of diagnosis for patients "found down," regardless of the duration since onset of compartment syndrome. The objective of this study is to retrospectively review the rates of infection, amputation, and death after performing fasciotomies in patients treated at our institution for compartment syndrome after being "found down" due to alcohol or drug intoxication. In presenting this data, we highlight six individual cases to discuss specific complications encountered.

Table 1. Patient Demographics

Variable	Description of Sample
Total	22
Mean age (years)	34.8 ± 14.1
Age group, n (%)	
18–29	9 (41.0%)
30–39	7 (32.0%)
40–49	2 (9.0%)
50–59	2 (9.0%)
60+	2 (9.0%)
Gender	
Male	15
Female	7
Toxin	
Alcohol	2 (9.0%)
Drugs	13 (59.0%)
Opiates	6
BZO	1
Opiates + BZO	2
Opiates + BZO + COC	2
Opiates + BZO + COC + BAR	1
Cocaine + BZO + Cannabinoids	1
Both	2 (9.0%)
Unknown	3 (14.0%)
None	2 (9.0%)

BZO, benzodiazepines; COC, cocaine; BAR, barbiturates

Methods

A retrospective study was performed at an urban academic medical center over a five-year period from June 1, 2010 through May 31, 2015. After approval was obtained from the institutional review board, all cases of crush syndrome encountered in the emergency room, outpatient office, or inpatient wards were reviewed. We identified patients by searching medical record codes relevant to crush syndrome, including codes for fasciotomy, rhabdomylolysis, crush injury and compartment syndrome. Only patients with crush syndrome after suspected or confirmed drug or alcohol abuse were reviewed via our electronic medical record system, scans of paper charts, and an orthopaedic departmental inpatient database. Altogether, 22 surgically-managed patients found down with subsequent compartment syndrome due to drug or alcohol abuse were recorded. The evaluation parameters collected include estimated time period unconscious on the ground, admission laboratory values, time to fasciotomy from presentation, and the presence of medical and surgical complications, such as surgical site infection, need for amputation, and death. A surgical site infection (deep or superficial) was defined according to CDC guidelines.[14] Acute renal failure was defined as a 0.5 mg/dL increase in serum creatinine within 48 hours.[15] Statistical analyses were limited to descriptive statistics for select continuous and categorical variables due to the small sample size.

Results

There were 312 patients initially identified in our retrospective review with diagnosed compartment syndrome, 290 patients were excluded and 22 patients met final inclusion criteria for the study. The patient demographics are described in Table 1. The median age of the patients was 22 years (range: 18–67), with a male-to-female ratio of 16:6. The most common intoxicant used were opiates (n = 12, 54.5%), often in conjunction with alcohol and other drugs such as benzodiazepines, cocaine. Table 2 details the results of our retrospective search with regard to the parameters discussed above. On hospital admission, lactate, creatine kinase (CK), white blood cell count, and potassium values averaged 4.1 mmol/l, 64.0 kU/L, 19.8 k/mm^3, and 5.8 mmol/l, respectively. The analysis of the case series showed that presentation to the emergency department occurred after being "found down" for an estimated average of 21.3 hours. An average of 10.0 hours passed from the time of arrival in the emergency room to the time of surgical incision for fasciotomies (median = 9 hours, range = 1.5–44 hours). Patients underwent fasciotomies of the upper extremity (n = 4, 18%), lower extremity (n = 10, 45.5%), and both sites (n = 8, 36.5%), with an average of four compartments released. These patients averaged 4.8 subsequent operating room fasciotomy site debridements (range: 0–10). Two patients required amputation of the affected extremity due to the presence of nonviable muscle, one of which was in the setting of a dysvascular limb.

The creatine kinase (CK), values in the context of rhabdomyolysis reached an average of 120.3 (range: 11.6–302.1) kU/L. Fourteen (64.0%) patients developed acute renal failure. Nine patients (41%) required hemodialysis during their hospitalization beginning an average of 3.3 days after admission. Fasciotomy wounds were closed via primary closure in 12 patients and skin grafts in nine patients. Surgical site infection developed in five patients an average of 25.2 days after fasciotomy. Other complications including sepsis (n = 4), pneumonia (n = 4), adult respiratory distress syndrome (n = 3), and death (n = 1) were also notable. The mean duration of the hospitalization was 30.5 days with an average of 4.1 days spent in the ICU.

Table 2. Results of Patients with Crush Syndrome

Variable	Description of Sample
Admission lactate (mmol/L)	4.1 ± 4.0
Admission CK (kU/L)	64.0 ± 67.5
Maximum CK (kU/L)	120.3 ± 81.8
Admission WBC (K/mm^3)	19.8 ± 7.2
Admission K (mmol/L)	5.8 ± 1.6
Time down (hours)	21.3 ± 18.0
Time to fasciotomy (hours)	10.0 ± 8.9
Fasciotomy location, n (%)	
Upper	4 (18.0%)
Lower	10 (45.5%)
Both	8 (36.5%)
Compartments released	4.4 ± 1.9
Number of surgical debridements	4.8 ± 2.9
Time to closure (days)	19.5 ± 16.8
Type of closure, n (%)	
Primary	12 (54.5%)
Graft	4 (18.0%)
Both	5 (23.0%)
Secondary	1 (4.5%)
Complications	
Surgical site infection (SSI), n (%)	5 (22.0%)
Acute renal failure, n (%)	14 (64.0%)
Sepsis, n (%)	4 (18.0%)
Pneumonia, n (%)	4 (18.0%)
ARDS, n (%)	3 (14.0%)
Death, n (%)	1 (4.5%)
Amputation, n (%)	2 (9.0%)
Time to SSI (days)	25.2 ± 21.5
Dialysis required, n (%)	9 (41.0%)
Time to dialysis start (days)	3.3 ± 1.1
Days in ICU	4.1 ± 3.4
Length of stay (days)	30.5 ± 15.3
Time to first follow-up (days)	21.4 ± 22.5

Case Review: Patients with Complications

Patient I (Male, 50 Years Old)

A male patient with a history of chronic depression presented after a fall while intoxicated with alcohol. He was unconscious for an unknown time period before being brought to the emergency department complaining of left upper and left lower extremity pain and swelling. His exam was notable for tense and swollen compartments of the left forearm, left thigh, and left leg. He had associated weakness of wrist and finger extension, as well as paresthesias of the median, ulnar, and radial nerve distributions. His left leg had global decreased sensation in the foot, with pain with passive stretch of the great toe and of the knee. His admission CK was 71.6 kU/L. The patient underwent immediate left leg, left thigh, and left forearm fasciotomies with four subsequent operative irrigation and debridements. Complete fasciotomy closures occurred on day 12. His creatinine continued to rise from admission reaching a maximum of 10 mg/dl before hemodialysis was started three days after admission. He was maintained on hemodialysis throughout his hospitalization. On hospital day 18, the patient developed a multilobar pneumonia and was transferred to the ICU where he became hypoxic and dyspneic. On hospital day 24, the patient developed a tension pneumothorax and expired.

Patient II (Male, 67 Years Old)

A 67-year-old male presented to the emergency room after being "down" for a period of two days after excessive alcohol consumption. The patient had a swollen, erythematous right arm with no palpable brachial pulse or Doppler signals, and no intact motor or sensation distal to the shoulder. His admission CK was 25 kU/L. Six hours after admission, the patient underwent a fasciotomy of the right arm and forearm. Intraoperatively, the forearm musculature was dusky, noncontractile; however, proximal deltoid, brachialis, and brachioradialis were contractile and of healthy color and consistency. Despite an attempted thrombectomy of the brachial artery by vascular surgery, the patient did not have a return of adequate arterial flow following the procedure. Given the poor vascularity of the arm and condition of the muscle tissue, the risk of gangrene of the distal extremity was extremely high; therefore, two days later, an above-the-elbow amputation was performed and the tissue was closed. The patient was discharged to a rehabilitation facility on hospital day 19. On hospital day 31, the patient was readmitted for sepsis likely secondary to the right upper extremity axillary wound which grew cultures of *Pseudomonas aeruginosa,* Klebsiella pneumonia, and *Staphylococcus aureus.* During subsequent irrigation and debridements of the wound, his right deltoid, teres major, teres minor, and latissimus dorsi were nonviable with active infection. Ultimately, 38 days from his initial presentation, the patient underwent a right forequarter amputation with wound closure. The patient returned to the hospital one additional time following this amputation with recurrent wound infection requiring formal debridement before his infection finally subsided.

Patient III (Female, 33 Years Old)

The patient was "found down" in a field after an unknown amount of time with polysubstance abuse. She was unresponsive at the time of hospital admission and was admitted directly to the ICU. On examination, the left arm, forearm, and leg were firm to palpation. Intracompartmental pressure readings revealed pressures of within 30 mmHg of the diastolic blood pressure in the left forearm volar and dorsal compartments as well as the lateral compartment of the left leg. The patient, therefore, was taken urgently to the OR for fasciotomies of the left arm, forearm, hand, and four-compartment fasciotomies of the left leg. The patient underwent subsequent irrigation and debridements on hospital days 4, 9, 13 and 18 with final wound closure on hospital day 18. The patient also presented with a rhabdomyolysis-induced acute kidney injury (CK of 121.6 kU/L and creatinine of 9.59 mg/dl) requiring hemodialysis. During the patient's stay in the ICU, she was treated for bacteremia from an unidentified source (fasciotomy wound cultures were negative) with empiric IV antibiotics and had successful resolution. The patient was discharged on hospital day 34.

Patient IV (Male, 31 Years Old)

The patient overdosed on narcotics and was "found down" unresponsive after an unknown period of time and presented with a firm left forearm and left lower extremity, with concern for compartment syndrome of both extremities. On admission, the patient had a CK of 115 kU/L and creatinine of 1.61 mg/dl in the context of rhabdomyolysis. Within one hour of presentation, the patient was taken to the OR for fasciotomies of the left thigh, leg, and forearm. During the intraoperative examination, it was determined that the left lower extremity muscles were nonviable. Given that the patient had no sensory or motor function of the leg below the knee and the appearance of the leg and distal thigh muscle tissue intraoperatively, the patient was brought back to the OR two days later for a left guillotine transfemoral amputation. The patient returned to the OR for 10 irrigation and muscle debridements. The amputation site and left arm developed infections with *Pseudomonas aeruginosa* and *Serratia marcescens* nine days after admission. After the infection was cleared through subsequent debridements and IV antibiotic therapy, the left forearm and left thigh amputation wounds were covered with skin grafts on day 52. The patient was discharged from the hospital two days later.

Patient V (Male, 19 Years Old)

The patient presented to the emergency room after being "found down" for an unknown period of time with polysubstance intoxication. He was arousable, yet physical exam was notable for a swollen, firm left leg with noncompressible compartments. Pain was present on passive stretch of the great toe and there was decreased sensation globally in the foot. Dorsalis pedis Doppler signals were present. Due to his exam, the patient was brought to the OR urgently for a four-compartment fasciotomy of the left leg. The patient had an acute kidney injury and a CK of 90 kU/L on admission; he was admitted to the ICU for fluid resuscitation and monitoring of kidney function. The patient returned to the OR for repeat irrigation and debridements on hospital days 2, 4, 7, and 9. On hospital day 18, the patient was discharged to home with nursing VAC changes and prophylactic empiric oral antibiotics. Eventually, the patient was scheduled for skin graft coverage, but could not undergo the procedure due to local infection of *Acinetobacter baumannii* and *Diphtheroid bacilli.* The patient was started on targeted IV antibiotic therapy and underwent surgical irrigation and debridement. The patient followed up with orthopedics in the subsequent months to monitor negative pressure wound closure; however, the patient was eventually lost to follow-up before granulation of the wound was complete.

Patient VI (Male, 21 Years Old)

The patient presented to the emergency room with progressive pain and swelling in his right hand and forearm after sleeping on his arm for about 12 hours the previous night while intoxicated. The patient had a significantly swollen right hand and forearm, firm dorsal and volar compartments, and pain on passive flexion and extension of his wrist and fingers. He had decreased sensation throughout all distributions in his hand. Four hours after presentation, the patient underwent fasciotomies of the right forearm and hand with carpal tunnel release and closure of the dorsal forearm and hand fasciotomy wounds (Fig. 1A). The patient was brought back to the operating room on hospital day two and eight for repeat irrigation and debridements of the volar fasciotomy wound. On hospital day 10, the patient received a split-thickness skin graft to the volar wound. During his hospital stay, the patient was treated for pneumonia, Clostridium difficile colitis, and a right arm volar forearm wound infection of *Pseudomonas aeruginosa* eight days after fasciotomies were performed. The patient was discharged on hospital day 12.

Discussion

The inherent issue surrounding the decision to perform fasciotomies for compartment syndrome in a patient "found down" is the inability to assess the extent of muscle ischemia. The literature agrees that early presentation, diagnosis and compartment release warrants the best chance of limb salvage.[3, 4, 7] However, the literature remains controversial on the course of action when the muscle may already be dead.[6, 8] Our study is a retrospective case review of the short-term outcomes of 22 patients who underwent fasciotomies for compartment syndrome after prolonged limb compression for an unknown, but estimated period of time. In our study, the average estimated time to diagnosis of compartment syndrome was 21.3 hours, which some clinicians may consider to be too long for fasciotomies to be beneficial. Our study had post-operative complications of five fasciotomy surgical site infections, two subsequent amputations and one death. One amputation was performed due to an avascular limb, and the other was performed for a non-viable limb, with dead muscle being a nidus for infection. Unfortunately, wound infections of the amputation sites occurred in both patients. For the patients that acquired an infection of the fasciotomy surgical site, the average time to infection was 25 days. This data encourages fasciotomy closure as soon as possible after sufficient muscle debridement and soft tissues allow.

In their case review, Finkelstein et al. describe five patients who presented with a compartment syndrome from a crush injury that was greater than 35 hours old.[6] All five were managed surgically with fasciotomies. One patient died from multiorgan failure after six days, and the other four eventually required limb amputation secondary to infection of the affected limb that was fasciotomized. Centers such as the University of Toronto have thus changed the management plan for patients with crush syndrome presenting with an established compartment syndrome longer than 8–10 hours. Medical care for acute renal failure is provided and no surgical intervention is pursued.

Figure 1. (A) Dorsal forearm and hand wounds eight days post-fasciotomy and closure. **(B)** Volar forearm fasciotomy at the second revision post-fasciotomy. Dead muscle tissue was sharply resected. There was no bleeding, no contractility, and poor consistency.

Reis and Michaelson also warn of performing fasciotomies in patients with a missed compartment syndrome.[19] Their retrospective review analyzed two groups of patients who developed crush syndrome. The first group consisted of seven patients who were trapped in a collapsed building for 12 hours with an additional 12 hours of delay in arrival to the hospital, and the second group consisted eight patients who were trapped in a different collapsed building for 3–27 hours with immediate medical care. Fasciotomies were performed on all patients in the first group and none in the second. The authors observed significant wound infections in almost all patients who underwent fasciotomies, two of whom eventually required amputation. The non-operative group had no extremity infections. The authors report that both groups had similar functional outcomes at follow-up. The authors concluded that fasciotomies should not be performed routinely in delayed presentation as the risk of infection is significant without additional benefit, with the exception of the pulseless extremity in which fasciotomy could restore blood flow and therefore prevent gangrenous necrosis of the distal limb. Similar conclusions were reached in a study by Sheridan and Matsen in which the complication rates for early (<12 hrs) vs. late (>12 hrs) fasciotomized extremities were 4.5% and 54% respectively.[22] Almost half of the late procedures went on to require amputation.

Conversely, Shaw et al. observed significantly less morbidity in their case review of 11 patients who were admitted to the hospital with crush syndrome and extremity compartment syndrome after drug or alcohol overdose.[26] Fasciotomies were performed on all patients. While three died of multiorgan failure and four required amputations for extensive muscle necrosis, there were no wound infections, and all but one survivor had full renal recovery. Their conclusion was that, in their hands, fasciotomies are not associated with increased morbidity and can optimize systemic recovery of the metabolic abnormalities that accompany this pathologic process; therefore, they recommend fasciotomies on all patients with compartment syndrome due to crush syndrome even if duration of symptoms is unknown. In a retrospective review of 88 patients undergoing fasciotomy for extremity trauma at the University of Cincinnati, 69% of patients had fasciotomies performed before 12 hours and 31% after 12 hours.[25] Although the rates on post-operative infection differed significantly between the two groups (7.3% for early and 28% for late), the rates of limb salvage and neurologic sequelae were similar, supporting the benefits of fasciotomy.

It is important to consider that these studies, like ours, are retrospective and have a small sample size. Additionally, several of these studies were conducted 20–30 years ago, and wound care management of fasciotomy incisions has changed over time. Our department routinely uses negative pressure wound therapy (NPWT) with or without vessel-loop closure for the sterile dressing of fasciotomy wounds. This technique is not universally utilized at all hospitals, and it was not used in the early studies sited here that observed significant surgical site infections. Therefore, the care of the open fasciotomy may be a confounding variable to this analysis.

There are several limitations to our study. As with any retrospective case review, there is a wide variability between patient characteristics (duration of compression on the extremity, baseline lab values, extent of muscle and neurologic damage); therefore, hard conclusions are difficult to ascertain. Fasciotomies were performed on all patients, so there is no data for patients managed conservatively. Given the relatively infrequent occurrence of compartment syndrome due to drug or alcohol abuse, only 22 cases are available for assessment. Unfortunately, this small sample size fundamentally limits the power of any hypothesis testing that might be performed using this data. A larger study would allow more accurate estimations of the impact of fasciotomy in these circumstances. Finally, because follow-up is considerably variable in this patient population, we have insufficient information regarding the long-term functional orthopaedic outcomes (motor strength, sensation, ability to perform activities of daily living, etc.) after discharge from the hospital. A study able to compare the functional outcomes in those patients managed with fasciotomy versus conservative management would be of great interest.

In compiling our findings with the literature, it is clear that there is still much to debate regarding the role of fasciotomies in the management of delayed presentation of compartment syndrome. Our current findings suggest that aggressive management of metabolic abnormalities and immediate compartment release are helpful in cases of compartment syndrome due to a crush injury, particularly if the patient's exam indicates threatened, but not necessarily absent, neurovascular status to the affected extremity. Our infection rate of 22% is less than what has been observed in other studies,[6, 25] and 17 of our patients who underwent surgery after being "found down" had limb salvage with motor and sensory function that at least did not worsen at the time of discharge. The argument for conservative non-operative treatment may still have a place in the treatment of crush patients with a missed compartment syndrome. As was the case with our patient that required amputation due to a perfused — yet insensate and paralyzed — limb, surgery may provide little to no benefit to patients that present with no motor or sensory function, and even carries an increased risk of infection.

The clinical dilemma in management of compartment syndrome of unknown duration remains determining the degree of irreversible muscular and neurologic damage.[8] Often these patients present in an unconscious state and are unable to provide a neurologic exam. In these instances, the treating physicians have only lab values, intracompartmental pressure measurements, and the vascular exam from which to make a clinical decision. We agree with previous authors who recommend fasciotomy in the context of a pulseless extremity for the prevention of distal limb necrosis.[19] Given the many unknowns surrounding this complex and rare clinical presentation, we recommend surgical management of compartment syndrome resulting from prolonged limb compression. In the future, the authors are interested in examining the effect of performing fasciotomies on the potential duration and resolution of acute renal failure and other medical complications of crush syndrome as compared to patients treated non-operatively. A further understanding of the medical consequences of surgical debridement would be paramount to appropriate clinical decision-making in this patient population.

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Supported by The John Lachman Orthopedic Research Fund and Supervised by the Orthopedic Department's Office of Clinical Trials

Comparing Outcomes of Tibial Intramedullary Nails: Suprapatellar Versus Infrapatellar

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Abstract

There are currently two major approaches to intramedullary nail insertion in the tibia, the infrapatellar approach and the suprapatellar approach. The purpose of this study is to compare outcomes between the infrapatellar nail insertion and the suprapatellar nail insertion, specifically with regard to post-operative pain, operative/fluoroscopic time, infection, and time to union. This is an IRB-approved retrospective study. Using detailed medical records, data was recorded for patients deemed eligible for the study based on specific exclusion criteria. The patients describing minimal or no overall pain were greater in the suprapatellar group (60%, n = 6) versus the infrapatellar group (22.2%, n = 6). This was statistically significant with a p-value 0.0486. This supports the literature which associates the suprapatellar approach with an outcome of decreased knee pain compared to the infrapatellar approach. Regarding time to union, the earliest time to three bridged cortices, the mean time for the suprapatellar approach is 27.8 weeks as compared to the mean time for the infrapatellar approach of 43.7 weeks (p = 0.0874). Few results from the study were deemed statistically significant, but potentially with a larger sample size, a significant trend could be observed. This limited retrospective study supports the association between the suprapatellar approach to intramedullary nailing and decreased post-operative pain, including knee pain. The data also suggests that suprapatellar IMN fixation leads to faster healing. We will continue to investigate which approach to tibial nail insertion provides the patients with the safest and most effective means of treatment as well as the best quality of life following surgery.

Introduction

The intramedullary nail has evolved extensively since its development by Kuntscher in the arena of World War II-related femur fractures. Advances in technology and design since its original conception have made the intramedullary nail the standard of care in treating long bone fractures, including tibia shaft fractures. Intramedullary nail fixation is advantageous over other treatment methods because it allows patients to begin weight bearing sooner and minimizes the size of incisions that need to be made over compromised soft tissue.[1] There are currently several major approaches to intramedullary nail insertion in the tibia, which include the infrapatellar approach and the suprapatellar approach. The standard infrapatellar approach requires an incision adjacent to or through the patellar tendon as well as a flexed knee for appropriate insertion of the nail into the intramedullary canal. The suprapatellar nail is inserted with the knee in a semi-extended position, potentially allowing for greater ease of insertion and fracture reduction (Figures 1–4). The infrapatellar approach has been the standard for several decades, and the outcomes of the suprapatellar approach have not been as widely documented. Current literature has shown that the suprapatellar approach resulted in excellent tibia alignment, union, and knee range of motion,[2, 6–10] but there has not been an established preferable approach. The aim of this retrospective study is to determine if there is a difference between the suprapatellar approach to the tibia intramedullary nail versus the infrapatellar approach to the tibia intramedullary nail regarding patient outcomes including surgical complications, infection, blood loss, time to union, and post-operative pain.

Materials and Methods

This is a retrospective study. After obtaining IRB permission, a list was compiled of all patients who have had tibia shaft fracture fixation utilizing intramedullary nailing in the past three years at a single level one trauma center, from 2012 to 2014. First, an inclusion data sheet was compiled consisting of each patient's medical record number, date of birth, date of surgery, age at surgery, the date of the last follow-up radiographs, and total follow-up time. Any patient not within the age range of 18 to 65 was excluded from the study. Any patient who did not have follow-up radiographs at least nine months post-operation was also excluded from the study. Subsequently, a second data sheet was compiled

Figure 1. External view of suprapatellar approach with protective sleeve passing through the patellofemoral joint.

Figure 2. Lateral radiograph of the start point for the tibial nail using the suprapatellar guide. Note the anatomic start point is the same for the infrapatellar approach and the suprapatellar approach.

Figure 3. AP radiograph of the start point for the tibial nail using the suprapatellar guide. Note the anatomic start point is the same for the infrapatellar approach and the suprapatellar approach.

for all patients deemed eligible for the study. This data sheet recorded the date of surgery, the surgical approach whether infrapatellar or suprapatellar, the operating room time, fluoroscopy time, blood loss, time to union, additional hardware needed, and whether or not the patient experienced chronic pain, pain with use, pain over the fracture site, pain over the screw sites, minimal or no pain, if painful hardware was removed, and any complications with the surgery noted within that time frame including infection. These categorical variables were analyzed using Fisher's exact test. Time to union was determined by studying post-operative radiographs. The radiographs were sent to a blinded third-party orthopedic surgeon for unbiased determination of time to union. For each radiograph, a RUST[3] score was provided as well as the number of bridged cortices. This study compared the earliest time to three bridged cortices and the RUST

Figure 4. Lateral radiograph showing tibial nail insertion using suprapatellar guide.

score between the two nail insertion approaches. In its original development, a RUST score >7 implies three bridging cortices. For this study, the requirement was a RUST score >9. Using the Student's t-test, the number of weeks that it took for the RUST to get to nine or above was compared between the suprapatellar and infrapatellar groups. The data was gathered from operative reports, anesthesia reports, and patient records. The research institution statistics department analyzed the data collected.

Results

There were 28 patients in the infrapatellar nail group (71.8%) and 11 patients in the suprapatellar nail group (28.2%). The patient age did not vary significantly based on approach type (mean 40.1 years for infrapatellar group and mean 38.3 for the suprapatellar group). The patients describing minimal or no overall pain were greater in the suprapatellar group (60%, n = 6) versus the infrapatellar group (22.2%, n = 6). This was statistically significant with a p-value 0.0486. For the specific focus of knee pain, there were marginally significant results with a p-value 0.0726, showing that less patients complained specifically of knee pain in the suprapatellar group (20.0%, n = 2) compared to the infrapatellar group (55.6%, n = 15). This supports the literature which associates the suprapatellar approach with an outcome of decreased knee pain compared to the infrapatellar approach. There was no significant correlation with incidences of infection, operative time, fluoroscopic time, long term or chronic pain, hardware removal, pain in knee, pain at screw sites, pain at fracture site, and pain with use. Regarding time to union, the earliest time to three bridged cortices, the mean time for the suprapatellar approach is 27.8 weeks as compared to the mean time for the infrapatellar approach of 43.7 weeks (p = 0.0874). Using RUST score greater than or equal to 9 for time to union, the mean time for the suprapatellar approach is 24.9 weeks, as compared to the mean time for the infrapatellar approach of 41.4 weeks (p = 0.0879).

Discussion

The suprapatellar approach has become accepted as an appropriate approach for tibial intramedullary nail fixation in tibial shaft fractures. Since the semi-extended suprapatellar approach relaxes the quadriceps pull on the proximal tibia and decreases the procurvatum deformity on proximal third tibia fractures, there have been proponents who deem those fracture types an indication for the suprapatellar approach.[4] Other proposed indications for the suprapatellar approach include soft tissue damage over the infrapatellar area, flexion deficit of the knee joint, patella baja, and patellar tendon ossification.[5] In general, however, there has not been a consensus on which approach — infrapatellar versus suprapatellar — demonstrates the most superior outcome.

When comparing the two methods, there were very few statistically significant differences in outcomes. Rates of infection, hardware removal, chronic pain, and pain with use did not have statistically significant trends. There was not a statistical significance in the length of fluoroscopic radiation used in each method. The semi-extended positioning that the suprapatellar approach allows was theorized decrease the amount of fluoroscopic time;[2] however, the absolute values were actually greater for the suprapatellar approach (mean 285 seconds versus 137 seconds). Perhaps in a larger sample size and a sample where a complete record of this variable was noted for all cases, one could further investigate whether there is a true difference in the intraoperative exposure of radiation. The patients describing minimal or no overall pain were greater in the suprapatellar group (60%, n = 6) versus the infrapatellar group (22.2%, n = 6). This was statistically significant with a p-value 0.0486. For the specific focus of knee pain, the results approached significance with a p-value 0.0726, showing that less patients complained specifically of knee pain in the suprapatellar group (20.0%, n = 2) compared to the infrapatellar group (55.6%, n = 15). This supports the literature which associates the suprapatellar approach with an outcome of decreased knee pain compared to the infrapatellar approach.[2, 6–8] However, more recently, there have been studies refuting the difference in knee pain outcomes. In a retrospective study by Courtney et al.,[9] there was no difference in Oxford Knee Score values between patients who underwent tibial nail fixation by suprapatellar and infrapatellar approach. Significantly, the suprapatellar approach did result in less fluoroscopic time in this study. A prospective randomized controlled pilot study sponsored by OTA[10] followed 25 patients over a 12-month follow-up

Table 1. Summary Statistics and Testing for Selected Continuous Variables

Classification Variable	N	Mean	Std Dev	Min	Q1	Median	Q3	Max	Parametric p-Value	Parametric Method
Age by surgery type									0.6971	t-test (equal variances)
Infrapatellar	28	40.1	12.4	19.0	30.5	40.0	49.0	65.0		
Suprapatellar	11	38.3	14.0	19.0	26.0	35.0	50.0	60.0		
OR time (min) by surgery type									0.1269	t-test (equal variances)
Infrapatellar	28	147	63	69	116	133	173	391		
Suprapatellar	10	186	81	98	140	165	206	389		
Fluoro time (sec) by surgery type									0.0594	t-test (unequal variances)
Infrapatellar	11	137	55	56	92	130	185	234		
Suprapatellar	7	285	168	171	206	231	284	659		
Blood loss (cc) by surgery type									0.3693	t-test (unequal variances)
Infrapatellar	20	176	69	25	125	200	200	300		
Suprapatellar	11	252	264	25	100	200	300	1000		

Distribution of available operative data comparing approaches. There was not a significant difference in age, operative time, fluoroscopic time, or blood loss when comparing the two surgical approaches.

Table 2. Statistical Testing of Selected Categorical Variables

Criteria	Infrapatellar	Suprapatellar	Total	p-Value	Test Method	Significance
Infection, n (%)				0.6548	Fisher's Exact	Not significant
Yes	5 (17.9%)	1 (9.1%)	6 (15.4%)			
No	23 (82.1%)	10 (90.9%)	33 (84.6%)			
Total	28 (100%)	11 (100%)	39 (100.0%)			
Proximal screws, n (%)				0.4899	Fisher's Exact	Not significant
2	27 (96.4%)	10 (90.9%)	37 (94.9%)			
3	1 (3.6%)	1 (9.1%)	2 (5.1%)			
Total	28 (100%)	11 (100%)	39 (100.0%)			
Distal screws, n (%)				0.4616	Fisher's Exact	Not significant
1	3 (10.7%)	0 (0.0%)	3 (7.7%)			
2	22 (78.6%)	11 (100%)	33 (84.6%)			
3	3 (10.7%)	0 (0.0%)	3 (7.7%)			
Total	28 (100%)	11 (100%)	39 (100.0%)			
Long term or chronic pain, n (%)				0.1621	Fisher's Exact	Not significant
Yes	6 (22.2%)	0 (0.0%)	6 (16.2%)			
No	21 (77.8%)	10 (100%)	31 (83.8%)			
Total	27 (100%)	10 (100%)	37 (100.0%)			
Hardware removal, n (%)				0.6884	Fisher's Exact	Not significant
Yes	9 (33.3%)	2 (20.0%)	11 (29.7%)			
No	18 (66.7%)	8 (80.0%)	26 (70.3%)			
Total	27 (100%)	10 (100%)	37 (100.0%)			
Pain in knee, n (%)				0.0726	Fisher's Exact	Not significant
Yes	15 (55.6%)	2 (20.0%)	17 (45.9%)			
No	12 (44.4%)	8 (80.0%)	20 (54.1%)			
Total	27 (100%)	10 (100%)	37 (100.0%)			
Pain at screw sites, n (%)				0.4395	Fisher's Exact	Not significant
Yes	11 (40.7%)	2 (20.0%)	13 (35.1%)			
No	16 (59.3%)	8 (80.0%)	24 (64.9%)			
Total	27 (100%)	10 (100%)	37 (100.0%)			
Pain at fracture site, n (%)				0.4395	Fisher's Exact	Not significant
Yes	11 (40.7%)	2 (20.0%)	13 (35.1%)			
No	16 (59.3%)	8 (80.0%)	24 (64.9%)			
Total	27 (100%)	10 (100%)	37 (100.0%)			
Pain with use, n (%)				0.2876	Fisher's Exact	Not significant
Yes	14 (51.9%)	3 (30.0%)	17 (45.9%)			
No	13 (48.1%)	7 (70.0%)	20 (54.1%)			
Total	27 (100%)	10 (100%)	37 (100.0%)			
Minimal or no pain, n (%)				0.0486	Fisher's Exact	Significant
Yes	6 (22.2%)	6 (60.0%)	12 (32.4%)			
No	21 (77.8%)	4 (40.0%)	25 (67.6%)			
Total	27 (100%)	10 (100%)	37 (100.0%)			

Distribution of categorical variables comparing approaches. The number of patients who denied pain at follow-up visits were statistically significant, with more patients in the suprapatellar approach denying postoperative pain. The different that patients complained of pain were not statistically significant when comparing the two approaches.

Table 3. Summary Statistics and Testing for Time to RUST >9

Classification Variable	N	Mean	Std Dev	Min	Q1	Median	Q3	Max	Parametric p-Value	Parametric Method
Time (weeks) to Rust GE 9, by surgery type									0.0879	t-test
Infrapatellar	27	41.4	26.5	6.0	20.0	43.0	57.0	125.0		
Suprapatellar	10	24.9	22.0	4.0	8.0	14.0	43.0	65.0		

Comparison by approach of the number of weeks to radiographic union, as defined by a RUST score >9. There is a trend toward a faster time to union with the suprapatellar approach (24.9 weeks versus 41.4 weeks) but this finding was not statistically significant.

course. Part of the study included arthroscopy assessment of patellofemoral joint quality pre and post supra patellar nail insertion. Results showed no significant differences with regard to pain, disability, or knee range of motion between the two insertion techniques. Three of the 11 suprapatellar nails showed a change in the quality of patellofemoral cartilage post operatively, but this did not manifest itself as patellofemoral joint pain at one year of follow-up.

In the current study, the time to union as evidenced by RUST score >9 was also marginally clinically significant, with a p-value 0.0879, showing suprapatellar union at mean 24.9 weeks compared to infrapatellar union at mean 41.4 weeks; however, a larger sample size and more uniform radiographic follow-up could potentially confirm or refute this evidence.

The theoretical disadvantages of suprapatellar tibial nail were not addressed. They include risk of injury to patellar or femoral trochlear cartilage, risk of iatrogenic injury to other intra-articular structures, and the difficulty with nail removal.[11] Biomechanically, the patellofemoral contact pressures are higher with suprapatellar nail insertion than infrapatellar nail insertion, but they remain below the values reported to be detrimental to articular cartilage.[12, 13]

The consistent trends demonstrated in this study, combined with the information available in the literature merit the continued study of the suprapatellar approach to tibia intramedullary nailing as compared to the infrapatellar approach.

A limitation of this study was a small sample size. There were originally 150 patients on the list of patients having received a tibia intramedullary nail at the institution where the study was performed in the past three years but a majority were unable to be included in the study due to eligibility requirements. Almost all patients excluded from the study were done so for failure to report for a follow-up radiograph at least nine months post-operative. Additionally, time to union was based off of all available radiographs from the postoperative period, rather than a protocol of radiograph frequencies. This leaves the time to union rounded up based on the patient's frequency of clinic visits. Another limitation was the recording of pain values. The pain data was obtained by reading through the records of each patient's visits to the outpatient clinic and noting when the patient or doctor remarked about or described any pain symptoms. From this information, pain categories were created that could be statistically analyzed. Utilization of a standardized pain and functional scale filled out by all patients on their follow-up visits could greatly enhance the quality of data obtained and bring a more objective nature to this data.

Conclusion

Intramedullary nailing is the standard of care for tibia shaft fractures. It is important and necessary to determine which approach for nail insertion provides the patients with the safest and most effective means of treatment as well as the best quality of life following surgery. With the suprapatellar approach, there are lower reported incidences of infection, long term or chronic pain, hardware removal, pain in knee, pain at screw sites, pain at fracture site, and pain with use. These trends are consistent with the observed statistically significant association of suprapatellar surgery with minimal or no pain. This limited retrospective study supports the association between the suprapatellar approach to intramedullary nailing and decreased post-operative pain, including knee pain. The data also suggests that suprapatellar IMN fixation leads to faster healing. It will be important to gather data from a larger sample size, potentially from a prospective study, to determine whether more of these outcomes could show a statistically significant association.

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Medical Student Research Project

Supported by The John Lachman Orthopedic Research Fund and Supervised by the Orthopedic Department's Office of Clinical Trials

Cost-Benefit Analysis of Utilizing Clinical Examination and Magnetic Resonance Imaging to Diagnose Anterior Cruciate Insufficiency

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Abstract

Introduction: The frequency of ACL tears in the United States has caused an increase in the use of magnetic resonance imaging (MRI) to diagnose these ruptures. However, this method may be overused, due to the accuracy of clinical exam techniques, specifically the Anterior Drawer test, the Pivot Shift test, and the Lachman test, to diagnose ACL insufficiency. The purpose of this study is to provide a cost-benefit analysis of using each method to diagnose ACL tears.

Methods: The MEDLINE database was utilized to identify studies in the past 20 years that provided diagnostic accuracy, sensitivity, specificity, positive predictive values (PPV), and negative predictive values (NPV) regarding MRI and clinical examination to diagnose ACL tears.

Results: In six studies totaling 439 patients, clinical examination with correlated arthroscopy reported mean values as follows: sensitivity of 90.1, specificity of 98.8, PPV of 95.1, NPV of 97.4, and accuracy of 96.8. MRI correlated with arthroscopy reported mean values as follows: sensitivity of 89.8, specificity of 95, PPV of 88.2, NPV of 95.9, and accuracy of 94.4.

Conclusions: The similarities in mean values between clinical examination and MRI display the benefit of using clinical exams before MRI, with regard to the costs of both procedures. While both are able to diagnose ACL tears effectively, clinical examination should be favored before the use of MRI in situations of possible ACL rupture due to the great difference in cost of both procedures relative to the benefit provided.

Introduction

Anterior cruciate ligament (ACL) injury is a common occurrence in the United States, with recent estimates showing that between 80,000 and 100,000 ACL repairs are performed each year. The structure of the knee joints predisposes it to injury, specifically due its intricate construction and weight-bearing function. Most central to the structural integrity of the knee is the ACL, which descends from the posterior femur and continues anteriomedially towards its insertion on the anterior aspect of the proximal tibia.[3] The primary function of the ACL is to provide rotary stability, and ruptures frequently result in circumstances where excess rotational stress is placed on the knee joint.[7]

Common clinical methods used to diagnose ACL ruptures are the Lachman test, the Anterior Drawer test, and the Pivot Shift test, with the Lachman test generally considered the most accurate for determining ACL status.[9] The Lachman test is performed with the patient supine and the knee flexed to about 15 degrees. The examiner stabilizes the femur with one hand and places the other hand behind the proximal tibia, then attempts anterior translation of the tibia relative to the femur. A soft or mushy endpoint upon anterior translation is considered a positive Lachman test and is characteristic of a ruptured ACL.[15]

The Anterior Drawer test is performed with the patient supine and the hip and knee flexed at 45 and 90 degrees, respectively. The examiner applies an anterior-directed force on the posterior aspect of the proximal tibia, and then compares the degree of anterior translation to the contralateral side. Anterior translation of more than 6 mm with a soft endpoint is considered a positive Anterior Drawer test correlating with a torn ACL.[10]

The Pivot Shift test is performed with the patient supine and the legs fully extended. The examiner lifts the injured leg at the ankle, internally rotates the knee, and then flexes the knee while simultaneously applying valgus force on the lateral aspect of the proximal tibia. A positive Pivot Shift test is indicated by a reduction of the anteriorly displaced lateral tibial plateau.[2]

Currently, magnetic resonance imaging (MRI) is frequently used in determining ACL status following a traumatic incident; however, some researchers believe MRI technology is overused and should be performed secondarily to the clinical tests described above, specifically to rule out a diagnosis rather than confirm one, or when clinical tests are inconclusive.[9] The goal of this study is to provide data on the cost-effectiveness of both MRI and clinical examination to diagnose ACL insufficiency.

Methods and Materials

Our study was performed utilizing the MEDLINE database to search for primary studies comparing the diagnostic accuracy, sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) of clinical examination and MRI to diagnose ACL ruptures. Inclusion criteria were that the study must be from the past 20 years, and it must use arthroscopy as the gold standard to confirm or deny the diagnosis made from clinical examination or MRI.

Searches were performed utilizing the keywords "diagnosis," "magnetic resonance imaging," "ACL," and "clinical examination." Studies not found as a result of the keywords above were identified using the "Related Articles" link on PUBMED, as well as looking through the citation list of other related studies.

The sensitivity of a diagnostic test was defined as how effective it is at identifying patients with ACL tears. The specificity of a diagnostic test was defined as how effective it is at identifying patients without ACL tears. PPV describes how likely it is that a patient has an ACL tear given the positive test, and NPV describes how likely it is that a patient does not have an ACL tear given a negative test.[1, 11] Only studies utilizing these parameters were included for data analysis.

Several Philadelphia hospitals and imaging centers were surveyed to determine the cost of performing a knee MRI. This information was used to provide an average cost for use in the cost-benefit analysis of using MRI versus clinical examination for diagnosing ACL tears.

Statistical analysis of the data involved compiling sensitivity, specificity, PPV, and NPV values from each of the included studies and reporting them in table format. In addition, mean values were calculated based on the experimental data. No further meta-analysis was performed.

Results

Out of all studies considered for inclusion in our review, ultimately six were chosen based on the criteria described above.

Clinical Examination Correlated with Arthroscopy

Gelb et al. reported accurately diagnosing ACL tears as a result of clinical examination in 100% of cases (n = 37). Twenty cases were found positive for ACL tear, and the remaining 17 were found to be negative for any ACL damage.[5] Jah et al. correctly diagnosed 18 torn ACLs and 47 intact ACLs when correlated with arthroscopy, and diagnosed three false-positives and two false-negatives, resulting in a clinical accuracy of 91.4% (n = 70).[4] Kocabey et al. reported an accuracy of 100% in diagnosing ACL tears with clinical examination following arthroscopy correlation. Twenty-six ACL ruptures were correctly diagnosed, and the remaining 24 were correctly determined to be intact (n = 50).[8] Rayan et al. reported an accuracy of 96% in diagnosing ACL ruptures when correlated with arthroscopy. Clinical examination correctly diagnosed 17 ruptured ACLs, and diagnosed five false-negatives (n = 131).[12] Rose and Gold reported an accuracy of 99% in diagnosing ACL tears utilizing the clinical examination when correlated with arthroscopy. Clinical examination correctly identified 13 torn ACLs, and a false-positive diagnosis was made in one case (n = 100).[13] Siddiqui et al. reported an accuracy of 94.1% in clinical examination correlated with arthroscopy. Clinical examination diagnosed two false-negatives and one false-positive (n = 51).[14] True-positive, true-negative, false-positive, and false-negative data from each study are summarized in Table 1. Diagnostic accuracy, sensitivity, specificity, PPV, and NPV data are summarized in Table 2.

Table 1. Clinical Examination Results Correlated with Arthroscopy

Study	Number of Subjects (n)	True Positive	True Negative	False Positive	False Negative
Gelb et al.	37	20	17	0	0
Jah et al.	70	18	47	3	2
Kocabey et al.	50	26	24	0	0
Rayan et al.	131	17	109	0	5
Rose and Gold	100	13	86	1	0
Siddiqui et al.	51	7	41	1	2

Table 2. Diagnostic Accuracy, Sensitivity, Specificity, PPV, and NPV Values for Clinical Examination Results Correlated with Arthroscopy (%)

Study	Accuracy	Sensitivity	Specificity	PPV	NPV
Gelb et al.	100	100	100	100	100
Jah et al.	91.4	85.7	95.9	90	94
Kocabey et al.	100	100	100	100	100
Rayan et al.	96	77	100	100	95
Rose and Gold	99	100	99	93	100
Siddiqui et al.	94.1	77.8	97.6	87.5	95.4
Mean values	96.8	90.1	98.8	95.1	97.4

MRI Correlated with Arthroscopy

In diagnosing ACL tears based on MRI findings, Gelb et al. reported an accuracy of 92%. Nineteen cases were positive for ACL rupture, with two false-positive diagnoses and one false-negative diagnosis.[5] Jah et al. reported 88.5% accuracy for diagnosis of ACL tears when correlated with arthroscopy. The study diagnosed 18 tears correctly, and reported five false-positive diagnoses and two false-negative diagnoses.[4] Kocabey et al. found an accuracy of 98% in diagnosing ACL ruptures when correlated with arthroscopy.

Twenty-six cases were correctly diagnosed, and one false-positive diagnosis was made.[8] Rayan et al. reported 93% accuracy in utilizing MRI to diagnose ACL ruptures when correlated with arthroscopy. Out of 131 subjects, 22 ACL tears were diagnosed, and four false-positive diagnoses were made.[12] Rose and Gold found 98% accuracy in diagnosing ACL tears. Twelve out of 100 subjects were correctly diagnosed with an ACL rupture, and two incorrect diagnoses were made, one false-positive and one false-negative.[13] Siddiqui et al. reported an accuracy of 94.1% in correctly diagnosing ACL ruptures. Out of 51 subjects, eight were correctly diagnosed in having a ruptured ACL. Two false-positive diagnoses were made, and one false-negative diagnosis was made.[14] Table 3 summarizes the true-positive, true-negative, false-positive, and false-negative data for each of the studies. Table 4 describes the diagnostic accuracy, sensitivity, specificity, PPV, and NPV data calculated for each study.

Table 3. MRI Results Correlated with Arthroscopy

Study	Number of Subjects (n)	True Positive	True Negative	False Positive	False Negative
Gelb et al.	37	19	15	2	1
Jah et al.	70	18	45	5	2
Kocabey et al.	50	26	23	1	0
Rayan et al.	131	22	105	4	0
Rose and Gold	100	12	86	1	1
Siddiqui et al.	51	8	42	2	1

Table 4. Diagnostic Accuracy, Sensitivity, Specificity, PPV, and NPV Values for MRI Results Correlated with Arthroscopy (%)

Study	Accuracy	Sensitivity	Specificity	PPV	NPV
Gelb et al.	92	95	88	90	94
Jah et al.	91.4	85.7	95.9	90	94
Kocabey et al.	98	96	96	96	96
Rayan et al.	93	81	96	81	95
Rose and Gold	98	92	99	92	99
Siddiqui et al.	94.1	88.9	95.2	80	97.6
Mean values	94.4	89.8	95	88.2	95.9

Discussion

The frequency of ACL injury in the United States, combined with the rising cost of health care, requires clinicians to constantly assess and adjust care to better suit current trends. The overuse of MRI in evaluating ACL insufficiency has been well-documented.[5, 8, 13, 14] The purpose of this review is to provide data in support of a clinical examination being just as effective as MRI in determining the status of the ACL.

Gelb et al. concluded that MRI usually confirms a clinical diagnosis of ACL insufficiency, and should be reserved for circumstances where there is reason to believe that the imaging could change the clinical diagnosis and therefore alter the treatment plan.[5] Jah et al. found that "skilled clinical examination rates similarly to MRI," suggesting that an experienced examiner can arrive at a similar diagnosis as through utilizing an MRI, without the costs associated with obtaining the imaging. The study also notes the importance of recognizing and considering the monetary burden that an MRI can place on the patient when making procedural decisions.[4]

Kocabey et al. determined the effectiveness of clinical examination being superior to MRI in diagnosing ACL tears, but also notes the importance of clinical experience in making the correct diagnosis. Because their study utilized only a single, experienced orthopaedic surgeon to clinically evaluate each patient, the results may be slightly biased as a result of the surgeon's highly developed skill. In any case, the point still remains that clinical skills can be highly accurate in diagnosing ACL tears without necessitating an MRI to confirm.[8]

Rayan et al., Rose and Gold, and Siddiqui et al. also agreed that a clinical examination performs just as well or better than MRI in diagnosing ACL insufficiency.[12, 13, 14] Rose and Gold further notes that because many acute knee injuries are seen by a primary care physician, the clinical examination is less accurate because of their lack of experience when compared to an orthopedic surgeon in evaluating the ACL status of an injured knee. Because of this, consulting an orthopedic surgeon rather than obtaining an MRI can be a more cost-effective treatment plan without sacrificing diagnostic accuracy.[13]

Kostov et al. concluded that the most accurate test for determining the ACL status of a deranged knee are the Lachman test, Anterior Drawer test, and Pivot Shift test. When used together, the Lachman test and the Anterior Drawer test give the most accurate predictive value for diagnosing an ACL tear. In contrast, MRI scans showed less accuracy when determining the existence of an ACL tear.[9] Ultimately, the study concluded the importance of favoring clinical diagnosis of ACL injuries over MRI due to its unlikely significance in altering the diagnosis.[9]

In addition to diagnostic accuracy, the Lachman test also provides the added benefit of a grading system to determine the severity of joint instability based on the degree of anterior tibial displacement when performing the test. Outlined by Gurtler et al.,[6] this system allows for guidelines in clinical management and gives reliable standards for both pre- and post-operative planning and evaluation. This additional advantage not provided by MRI allows for pinpointing treatment plans in concert with the severity of the tear, giving the patient the best chance for full recovery.

The importance of cost versus benefit in medicine cannot be overstated. One of the most crucial aspects of high value healthcare is affordability, and the overuse of MRI in diagnosing ACL tears is a perfect example of this disparity between the cost of a test and the benefit it provides. A survey of Philadelphia-area hospitals and imaging centers showed a wide range of MRI costs, from $318–$1,900. Even with insurance coverage, the average patient will most likely pay some out-of-pocket expense for the test, whereas the minimal cost of an office visit to an orthopedic surgeon would most likely yield the same result based on the above studies noted. Thus, MRI should not be used in situations when clinical examination would be sufficient in diagnosing ACL ruptures. This would not only help to keep healthcare costs down, but also would provide high-value healthcare by keeping patient affordability a top priority.

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Supported by The John Lachman Orthopedic Research Fund and Supervised by the Orthopedic Department's Office of Clinical Trials

Weight-Bearing on Tibial Shaft Fractures After Intramedullary Nail Placement Does Not Alter Time to Union

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Abstract

Introduction: Currently, there is no consensus regarding postoperative weight-bearing (WB) assignment after treatment of extra-articular diaphyseal tibial fractures with a statically locked intramedullary nail. The purpose of this study was to determine if the postoperative WB status after intramedullary nailing of tibial shaft fractures alters the course of fracture union.

Methods: After institutional review board approval, all AO type 42 fractures treated with a reamed statically locked IM nail at a single institution over a 10-year period were retrospectively reviewed from the time of injury at two-, three-, six-, nine-, 12-, and 15-month intervals. The Radiographic Union Score for Tibial Fractures (RUST), coronal/sagittal angulations, and length measurements were computed for immediate preoperative and all postoperative radiographs. Union was defined as a painless fracture site with RUST >9. Patients were categorized as either weight-bearing as tolerated (WBAT) or non-weight bearing (NWB) per postoperative discharge instructions and the immediate (<3 weeks) outpatient postoperative visit. Exclusion criteria were as follows: change in WB status prior to 6–8 week postoperative radiographs, did not follow-up until revision or diagnosis of union, delayed fixation >2 weeks, infection, pathologic fracture, ambulatory dysfunction, preoperative bone loss >1 centimeter, ipsilateral or contralateral lower extremity fracture, incomplete medical records, or no radiographs during >1 consecutive appointment prior to union.

Results: A total of 123 patients were included (35 WBAT, 88 NWB). Average age was 37 ± 13 years old. There were no significant preoperative differences between the WB groups with respect to fracture pattern (AO type A, B, or C), age, gender, or open fractures. There were no significant differences in time to union between NWB versus WBAT groups (median 180 vs. 176 days, respectively; $p = 0.70$), radiographic evidence of healing (RUST values) over time ($p = 0.89$), or maintenance of length or alignment at final follow-up ($p = 1.0$). Complication rates did not differ between groups.

Conclusion: Immediate weight bearing after treatment of extra-articular tibial diaphyseal fractures with a statically locked intramedullary nail does not significantly alter postoperative healing.

Keywords: tibia fracture, intramedullary nail, weight bearing, rehabilitation

Introduction

Intramedullary nailing is currently the standard treatment for most long-bone lower extremity diaphyseal fractures.[1] Proponents of early weight-bearing (WB) on intramedullary nails assert that mechanical loading of injured bone through a load sharing construct encourages fracture healing.[2] Brumback et al. provided landmark evidence (with both biomechanical and clinical data) that immediate weight bearing after femoral shaft fractures treated with statically locked intramedullary nails is safe and effective.[3] Currently, the postoperative WB status for tibial shaft fractures treated with an intramedullary nail depends on the individual surgeon. As expected, primary concerns with early postoperative WB include hardware failure, fracture malalignment, nonunion, and pain.[4, 5] However, several biomechanical studies have proposed that immediate WB after tibial intramedullary nail placement is safe.[6–8] Moreover, Hernandez-Vaquero et al. recently concluded that early WB is safe after minimally comminuted tibial shaft fractures are treated with immediately dynamized intramedullary nailing.[9] The purpose of this study was to compare bony healing-related outcomes associated with fractures assigned a postoperative WB status of either weight bearing as tolerated (WBAT) or non-weight bearing (NWB) after an isolated tibial shaft fracture was treated acutely with a reamed statically locked intramedullary nail.

Methods

After institutional review board approval, all AO type 42 tibial diaphyseal fractures treated with a reamed statically locked intramedullary nail at a single institution over a 10-year period were retrospectively reviewed for study inclusion. Recorded data included: age, injury date, surgery date, sex, open or closed fracture, additional injuries, mechanism of injury, and postoperative WB status (WBAT or NWB). Postoperative WB status was verified by reviewing the final inpatient progress note, discharge instructions after surgery, and outpatient records within the first 6–8 postoperative weeks. Any discrepancy among reviewed documentation regarding WB status resulted in exclusion from the study. After 6–8 weeks, treating physicians advanced their patient's WB status on an individual basis.

Roentgenograms were reviewed at the following time intervals until the diagnosis of union: immediate preoperative radiographs, immediate postoperative radiographs, and then at two, three, six, nine, 12 and 15 months after surgery. Radiographs within two weeks and closest to the designated month interval were accepted. All radiographs were interpreted by an orthopedic surgery chief resident who was blinded to the postoperative WB status at the time of data collection. Roentgenograms were assessed for the following: AO Fracture Classification (obtained from the immediate preoperative radiograph), bone loss, presence of intramedullary nail, and number of postoperative proximal and distal interlocking screws. The immediate postoperative and final follow-up images were assessed for coronal and sagittal plane angulation at the fracture site as well as tibial length (measured using electronic imaging software as a straight line from the center of the tibial eminence to the center of the tibial plafond). Radiographic evidence of fracture healing was determined using the radiographic union score for tibial fractures (RUST).[10] Briefly, the RUST total is a composite sum after each of the four cortices is graded (using anteroposterior and lateral films) as follows: one point for absent callus and a visible fracture line, two points for visible callus and a visible fracture line, or three points for visible callus and no visible fracture line.[10] RUST values have been found to have better inter-rater reliability than a surgeon's general impression of fracture healing or the number of cortices bridged by callus.[11] If multiple fracture lines were present (i.e., segmental fractures), the lowest applicable RUST score for each cortex was recorded. Union was defined as a painless fracture site with RUST >9.

Exclusion criteria were as follows: <18 years old, WB status other than WBAT or NWB, change in WB status prior to 6–8 week postoperative radiographs, discontinued follow-up prior to revision surgery or diagnosis of union, delayed fixation >2 weeks, infection, pathologic fracture, ambulatory dysfunction, preoperative bone loss >1 centimeter, additional ipsilateral or contralateral lower extremity fracture, incomplete medical records, or no radiographs during >1 consecutive time interval prior to union.

Medical records were also reviewed for adverse events. An adverse event was defined as loss of length or alignment, re-operation for symptomatic hardware failure, or aseptic nonunion. Asymptomatic autodynamization was not considered an adverse event. Maintenance of length was defined as a change less than 15 mm. Maintenance of alignment in either the coronal or sagittal plane was defined as a change less than five degrees.

Statistical analysis was performed using SAS 9.4 software. A p-value less than 0.05 represented statistical significance. Mean values for continuous variables were compared using either the two sample t-test or analysis of variance (ANOVA). Whereas the chi-square test was used to assess preoperative categorical variables, the Fisher's exact test was used to compare length and alignment variables instead of the chi-square test given the smaller number of patients who went on to malalignment. Due to skew in the time to union data, the non-parametric Wilcoxon test was utilized to assess the relationship between postoperative WB status and time to union. In order to assess the effect of WB status on RUST values at interval postoperative assessments, repeated measures ANOVA modeling was performed using PROC MIXED in SAS, thus the impact of missed visit data was accommodated for computationally. Estimated least squared means were calculated as a basis for comparison at a given interval.

Results

A total of 123 patients (35 WBAT, 88 NWB) were included. Average age among all patients was 37 ± 13.4 (range 18–65) years old. Summaries of continuous and categorical variables are presented in Tables 1 and 2. Preoperatively, there were no significant differences between the two WB groups with respect to fracture pattern (AO type A, B, or C), age, gender, or open fractures (Table 2).

There were no statistically significant differences between the two WB groups relative to overall change in length or alignment criteria. Two NWB (2.3%) and zero WBAT patients demonstrated >5 degrees change in the coronal plane. One NWB (1.1%) and zero WBAT patients demon-

Table 1. Analysis of Continuous Variables

	NWB	WBAT	All Patients	p-Value Test Method
Age at time of surgery (years)	37.1 ± 13.7 (18–65)	36.6 ± 12.6 (18–60)	37 ± 13.4 (18–65)	0.8654 t-test
Follow-up (days)	259 ± 119 (91–581)	246 ± 119 (36–531)	250 ± 119 (36–581)	0.5789 t-test
Coronal change (degrees)	1.2 ± 1.3 (0–7)	0.9 ± 1.1 (0–5)	1.1 ± 1.3 (0–7)	0.2927 t-test
Sagittal change (degrees)	1.3 ± 1.2 (0–7)	0.9 ± 0.9 (0–3)	1.2 ± 1.1 (0–7)	0.0678 t-test
Length change (mm)	6.1 ± 5.1 (0–21)	4.9 ± 4.6 (0–17)	5.8 ± 4.9 (0–21)	0.2621 t-test

Table 2. Analysis of Preoperative Categorical Variables

	NWB	WBAT	All Patients	p-Value Test Method
Gender				
F	30 (34.1%)	10 (28.6%)	40 (32.5%)	0.5555
M	58 (65.9%)	25 (71.4%)	83 (67.5%)	Chi square
Open or Closed				
Closed	68 (77.3%)	26 (74.3%)	94 (76.4%)	0.7247
Open	20 (22.7%)	9 (25.7%)	29 (23.6%)	Chi square
AO Classification				
42A	68 (77.3%)	24 (68.6%)	92 (74.8%)	0.5962
42B	6 (6.8%)	3 (8.6%)	9 (7.3%)	Chi Square
42C	14 (15.9%)	8 (22.9%)	22 (17.9%)	

strated >5 degrees change in the sagittal plane. Three NWB (3.4%) and one WBAT (2.8%) patients demonstrated >15 mm change in length. There were also no significant differences in adverse events between WB groups. One WBAT and two NWB patients underwent revision surgery for aseptic nonunion. One WBAT and two NWB patients underwent removal of symptomatic hardware failure. P-values for all above comparisons using Fisher's exact test were greater than 0.05.

There was no statistically significant difference in the median time to union between the NWB (180 days, range 56–844) and WBAT (176 days, range 91–790) groups ($p = 0.7016$).

Lastly, postoperative WB status was not associated with significantly different RUST values during each interval postoperative assessment ($p = 0.9098$, see Table 3). As expected, both WB groups did demonstrate statistically significant improvements in RUST values throughout the duration of their postoperative course ($p < 0.001$).

Table 3. Repeated Measures ANOVA and Least Squares Estimated Means for RUST Over Time

	WBAT		NWB	
Time (Months)	RUST Estimate	St Err*	RUST Estimate	St Err*
2	6.99	0.24	6.78	0.15
3	8.72	0.23	8.82	0.14
6	10.75	0.24	10.73	0.15
9	11.46	0.34	11.59	0.20
12	12.13	0.40	12.17	0.27
15	12.03	0.60	12.19	0.31

*df = 252, F = 0.30, p = 0.9098

Discussion

Intramedullary nailing of acute diaphyseal tibial shaft fractures is the currently the gold standard in most cases. Advantages over plate osteosynthesis include shorter operative times, less radiation, easier hardware removal, improved restoration of postoperative motion, and improved soft tissue healing.[12–14] Tibial shaft fracture union rate with intramedullary nail fixation ranges between 94–98% percent for both open and closed fractures.[15–17] Time to union averages from 18–26 weeks and union rates and times are similar when compared to other forms of tibia fracture fixation.[9, 15, 16, 18] Reoperation rates have been reported around 14% in order to address nonunion, malunion, knee pain, painful hardware, infection, and/or broken implants.[19] The data in this study are consistent with these aforementioned figures, and any differences are likely attributed to varied definitions of union, focused inclusion criteria, and the exclusion of septic implants.

There is concern that weight bearing too early may lead to avoidable complications. An increased risk of postoperative malalignment has been seen in fractures treated with intramedullary nail compared to plate osteosynthesis.[20, 21] Moreover, Vallier et al. found an increased rate of malalignment following immediate weight bearing, although weight bearing in his study occurred against medical advice.[21]

This study concludes that early postoperative WB after intramedullary nailing of isolated tibial shaft fractures does not alter radiographic evidence of healing, time to union, or adverse outcome rates when compared to a more restrictive WB protocol. Advocates of early WB aim to restore postoperative function and independence quickly. In theory, early postoperative weight bearing should increase function without altering time to fracture union. In animal studies, mild to moderate load bearing on acute lower extremity fractures leads to larger callus size and reduced time to union.[4] Biomechanical studies assert that early postoperative WB after tibial intramedullary nailing is safe.[6–8] Equivalent healing times of tibial shaft fractures treated with early weight bearing after external fixation, casting, or orthosis have also been reported without increased complications.[22–24] Furthermore, immediate weight bearing after bridge plating of tibial shaft fractures resulted in union at an average of 9.1 weeks without loss of reduction or increased rates of malalignment.[25]

Current evidence about postoperative WB after IM nailing of tibial shaft fractures stems from the Study to Prospectively Evaluate Reamed Intramedullary Nails in Patients with Tibial Fractures (SPRINT) trial, whereby 1,226 nonrandomized tibial shaft fractures were analyzed to investigate outcomes after reamed versus unreamed intramedullary nailing.[5] According to the SPRINT trial data, early postoperative WB (<10% of their study population) was not associated with an increased risk of adverse events (to include malunion, nonunion, and wound complications) when dynamization was removed as an adverse event from the analysis. The acceptability of this analytic methodology was supported by Hernandez-Vaquero et al., whereby dynamization of simpler fracture patterns and full WB within four weeks of surgery demonstrated faster times to union than statically locked nails (21 vs. 26 weeks) and less reoperations (although differences were not statistically significant).[9] Thus, early postoperative WB may be safe and equivalent to restricted WB protocols.

When investigating WB status assignments, patient compliance plays an uncertain role. In this study, we aimed to exclude patients with documented noncompliance or conflicting assignments. However, studies investigating patient compliance demonstrate that patients exceed their prescribed amount of restricted weight bearing even when they thought themselves to have been compliant.[26, 27] By contrast, gait analyses conducted on patients after undergoing fixation of femoral neck and intertrochanteric fractures suggest that patients self-limit weight bearing to safe levels in accordance with their pain.[28] Another important note is that we did not analyze the effect of weight bearing on early postoperative pain levels, primarily due to the inability to collect quantitative pain assessments via retrospective review. Avoiding postoperative pain may be a primary reason why surgeons assign NWB protocols. One patient in our series developed chronic regional pain syndrome (CRPS). We were unable to draw conclusions regarding the development of CRPS due to its low incidence after intramedullary nailing. However, since CRPS development has been associated with poorly controlled pain levels in the acute post-injury period (and early weight-bearing may increase postoperative pain), the assessment of a relationship between early postoperative pain and WB status is recommended as a subject for further study.[29]

We chose to define union using a combination of high RUST values (>9) and no pain at the fracture site. There is no gold standard for assessing union of tibial shaft fractures.[11] The RUST was chosen for this study because it is a validated scale that can assess radiographic progress over time and increased scores correlate with clinical outcomes.[30] We did not utilize the number of cortices bridged in isolation to identify bony union because such methods can predict eventual union better than time of union.[31] Of note, RUST values do not always correspond with the biomechanical state of healing fractures.[32] Additionally, a fracture with abundant callus but a small fracture gap can have an erroneously high RUST value. For this reason, our study incorporated assessment of pain at the fracture site into the final definition of union.

Our reported reoperation rate (5%) is lower than that reported in the SPRINT trial (14%).[19] This is because the SPRINT trial defined reoperation differently. The SPRINT trial defined reoperation as any subsequent surgery including treatment of infection, removal of hardware, overlying wound debridement or flaps, postoperative fasciotomies, etc. In order to best answer our study question, however, we excluded any cases that may act as confounders with regards to the healing process (i.e., fracture site infection). The primary goal of our study is to analyze clinical and radiographic fracture healing with regard to postoperative WB status, and therefore overall reoperation rates within our study can only be interpreted with regard to our specific inclusion criteria. The actual reoperation rate after intramedullary nailing of tibial shaft fractures is likely higher.

One concern for bias is the possibility that worse fracture patterns were more often designated NWB. However, our preliminary data analysis confirmed that age, gender and AO classification did not influence the surgeon's preference of weight bearing in a statistically significant way. Additionally, it is important to note that surgeons at our institution (a level 1 urban trauma center) have different WB protocols regardless of fracture severity. Therefore, it is unlikely that a majority of NWB designations were biased by patient or fracture characteristics. Another limitation is the lack of uniform follow-up inherent in a retrospective study. However, time intervals analyzed in our study are reflective of similar studies assessing time to union for tibial shaft fractures.[33] Moreover, the study design minimized the number of missed time intervals while maintaining an adequately-sized sample population and all patients included followed up until union was achieved. Lastly, since scheduled outpatient follow-ups always have slight variations (for example, a two-month postoperative follow-up may be scheduled for two months and four days postoperatively), the time to union in this study (and throughout the literature) is approximate.

Conclusion

Immediate postoperative weight bearing after treatment of extra-articular tibial diaphyseal fractures with a statically locked intramedullary nail does not significantly alter postoperative healing. Surgeons should take into account the entire clinical picture when assigning postoperative weight bearing protocols and the findings in this study should be considered especially applicable to less severe fracture patterns.

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Medical Student Research Project

Supported by The John Lachman Orthopedic Research Fund and Supervised by the Orthopedic Department's Office of Clinical Trials

Underinsured Patients Experience Delayed Access to Care and Higher Rates of Adverse Outcomes for Surgically Managed Rotator Cuff Disease

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Abstract

There are many time-dependent factors that influence the progression of rotator cuff disease and the success of surgical intervention. Insurance carrier status, however, seems to significantly affect access to prompt appointments with surgeons. The aim of this study was to assess the effect of insurance status on access to care and patient outcomes in surgically-managed rotator cuff disease. A retrospective study of 45 patients with full thickness tears was performed. They underwent a shoulder arthroscopy by a single surgeon at the same medical center between September 1, 2009–December 31, 2013. Information regarding insurance status, scheduling information and appointment dates was collected, as well as post-surgical outcomes. Underinsured patients experienced delay from first appointment request to first appointment with the surgeon (22 days (underinsured) vs. 12 days (privately-insured) p = .0001). At extended follow-up (>8 months post-op), underinsured patients had higher rates of adverse outcomes (14 patients (underinsured) vs. two patients (privately-insured) P < .0001). More studies are needed to elucidate the exact relationship of insurance status and surgical outcomes, but the results of this study conclude that a delay to initial evaluation and surgery may adversely affect long-term outcomes.

Introduction

Rotator cuff injuries are among the most common causes of shoulder pain and weakness. Both acute trauma and chronic degeneration can result in cuff tears, most commonly involving the suprascapularis tendon. Acute tears are often caused by direct trauma, heavy lifting or sudden falls onto an outstretched arm. Incomplete recovery of acute tears can result in pathological changes and chronic injury. In addition, repetitive motion, compromised vascular supply and impingement can result in chronic tears as well. Both acute and chronic tears can cause significant pain, weakness, and dysfunction of the shoulder, although if the tear is small, patients may be asymptomatic until the depth of the tear progresses.[1] With prolonged use of a torn muscle, compensatory mechanisms can accelerate damaging processes in other rotator cuff muscles. Diabetes,[2, 3] hypercholesterolemia[2, 4] and smoking[2, 5] exacerbate degenerative processes and inhibit successful recovery and regain of function after surgical intervention and rehabilitation. Age is also a significant predisposing and prognostic factor in rotator cuff disease due to the natural fraying of muscles over time.

Time from injury is another a critical component in rotator cuff pathology. After the initial damage, pathological degeneration can progress with continued use. The early inflammatory response can further damage tissue, but if the response is transient, patients can regain full strength and function. Prolonged damage, however, can result in irreversible changes, such as fatty infiltration[1, 2, 6, 7] and muscle fibrosis, retraction and atrophy.[1, 2, 6] These changes can ultimately prevent full recovery of the cuff, even after surgical intervention and rehabilitation. Because the severity of these pathological changes is time-dependent, there has recently been greater emphasis on early surgical intervention, especially for acute tears. Studies have shown that early surgical repair of acute tears significantly reduces rates of muscle atrophy and re-tears than those with delayed surgeries.[8–10] For chronic tears, the importance of early surgical repair still remains obscure. Early surgical intervention may be a defining prognostic factor for all rotator cuff disease.

Although researchers have established the benefits of early surgical intervention, insurance status and access to care prevent many patients from receiving prompt surgery. Fewer medical offices offer appointments to patients with Medicaid instead of private insurance, especially when practices are located in urban areas and near academic institutions.[11, 12] Patients with Medicaid are also less likely to be offered an appointment within two weeks of calling, as compared to patients with private insurance.[12–14] Inequalities inherent to the healthcare system prevent under-insured patients from receiving prompt medical care. At this time, the effect of insurance status on the success of surgically-managed rotator cuff disease is unknown.

Methods

Research Subjects

After IRB approval was obtained, a four-year retrospective study was performed and 98 patient charts were reviewed. All patients initiated care through the same access point and were treated by a single surgeon (E.K.J.) at Temple University Hospital. They were diagnosed with a full thickness rotator cuff tear with MRI confirmation and underwent a shoulder arthroscopy between the dates of September 1, 2009–December 31, 2013. We excluded patients: (1) without full thickness tears, (2) receiving workers compensation, (3) receiving >2 months care prior to surgical referral, (4) who underwent prior rotator cuff repair, and (5) who were non-compliant with follow-up care. Forty-five patients were included in the final cohort and subdivided based on insurance status (underinsured (Medicaid, medical assistance) vs. private (including Medicare programs)). The final Medicaid, Medicare and private insurance cohorts included 12, 14 and 19 subjects, respectively. No uninsured patients were included in this study. Age, gender, language preference, history of smoking, and diagnoses of diabetes and hypercholesterolemia were noted. Analysis of these factors allowed us to attribute a more accurate relationship between access to care and repair outcomes.

Data Collection

Access to care was determined by the time interval between calling to schedule an appointment with Temple Orthopaedics and the date of their first appointment with the surgeon. For patients that were referred to the orthopaedic department, the time between referral and calling to schedule was noted as well. Other time points recorded included date of injury and dates of appointments with physicians (emergency, general or orthopaedics) other than the surgeon of interest. The time points evaluated were: (1) date of calling to schedule an appointment, (2) date of first appointment with the surgeon, and (3) date of surgery. Outcomes were analyzed at: (1) immediate (≤3 months), (2) routine (~6 months), and (3) extended (≥8 months) follow-up.

The success of surgical repair was determined by analysis of post-operative complications and observable difficulties noted by the surgeon during post-operative visits. We defined post-operative complications as infections, muscular atrophy, neuropathy, tendinopathy, or revision surgery. We defined observable difficulties as patient-reported pain, weakness, or limited range of motion (ROM), as noted by the surgeon. The post-operative time intervals analyzed included immediate (≤3 months), standard (4–7 months) and extended (≥8 months) follow-up.

Patients were subdivided based on insurance status into Medicaid, Medicare and private insurance groups. Analyses based on gender, primary language, smoking status, diabetes status and hypercholesterolemia status were performed for the analysis of potential confounding factors. Additional groupings were made based on mechanism of injury resulting in "acute," "acute on chronic" or "chronic" tears. Because asymptomatic cuff pathology is common among older populations, some extent of chronic damage was assumed for all patients aged 55 years or older. Patients ≥55 years of age were determined to have "chronic" or "acute on chronic" tears depending upon the mechanism of injury. We defined "acute" rotator cuff injuries as damage that occurred from a single traumatic event within one year of complaint for subjects less than the age of 55.

Statistical Analysis

All analyses were conducted using SAS 9.4. Three-level insurance classification analyses (for Medicaid, Medicare and Private insurance as separate independent variables) and two-level insurance classification analysis (for conjoined Medicaid/Medicare and private insurance as independent variables) were conducted to illustrate the demographics, time intervals, complications and co-morbidities of each group. For all two-level analyses of continuous variables, comparisons were made using the two-sample t-test or the Wilcoxon test. For all three level analyses of continuous variables, comparisons were made using the ANOVA or the Kruskal-Wallis test, where appropriate. The Chi-Square test or Fisher's exact test was used to evaluate selected categorical variables based on three-level insurance classification, two-level insurance classification, English-speaking status and patients with acute or acute-on-chronic injury.

Results

Demographics

Demographic data is summarized in Table 1. There were no observable differences in age, gender or smoking status between the underinsured and privately insured groups. However, there was a significantly higher average age in the Medicare group (63.2 years (Medicare) vs. 53.6 (Medicaid) vs. 55.5 years (private) $p = 0.0027$). There were significantly more non-English speakers in the Medicaid and Medicare groups than in the group with private insurance (25.0% (Medicaid) vs. 35.7% (Medicare) vs. 0.0% (private) $p = 0.00075$). There were no differences in rates of diabetes, hypercholesterolemia or hypertension between groups. Due to the presence of outliers, the median value for each time interval was used to assess differences between insurance groupings. Underinsured patients experienced delay from first appointment request to first appointment with the surgeon (22 days (underinsured) vs. 12 days (privately-insured) $p = 0.0001$).

Table 1. Patient Demographics by Insurance Status

	Medicaid	Medicare	Private	p-Value
Average age (years)	53.6	63.2	55.5	0.0027
Average BMI	33.0	30.5	30.9	0.6236
# Female	6 (50.0%)	9 (64.3%)	8 (42.1%)	0.4504
# Non-English speaking	3 (25.0%)	5 (35.7%)	0 (0.0%)	0.00075
Smoking status	7 (58.3%)	9 (64.3%)	12 (66.7%)	0.6119
Diabetes	4 (33.3%)	5 (35.7%)	2 (11.8%)	0.2530
Hypercholesterolemia	3 (25.0%)	4 (28.6%)	2 (11.8%)	0.5177
Hypertension	9 (75.0%)	10 (71.4%)	11 (64.7%)	0.9162
Average time: scheduling to 1st appt (days)	22.5	6.5	6.0	0.0001
Average time: 1st appt to surgery (days)	41.0	27.0	34.0	0.6644

There were no observable differences in the number or type of post-surgical complications that occurred in each group. There were also no differences in the number of complications or observable difficulties immediately post-op (≤3 months) or standard follow-up (4–7 months). At extended follow-up (>8 months), underinsured patients had higher rates of pain, weakness or complications (14 patients (underinsured) vs. two patients (privately-insured) $p < 0.0001$). There were also significantly more patients in the Medicaid and Medicare combined group with post-operative pain (75.0% (Medicaid) vs. 78.6% (Medicare) vs. 26.3% (private) $p = 0.0007$) or any adverse outcome (83.3% (Medicaid) vs. 85.7% (Medicare) vs. 47.5% (private) $p = 0.008$).

Table 2. Post-operative Outcomes by Insurance Status

	Medicaid	Medicare	Private	p-Value
Extended care (>8 months)	8 (66.7%)	0 (0.0%)	2 (10.5%)	<0.0001
Complication	5 (41.7%)	2 (14.3%)	3 (15.8%)	0.1826
Pain	9 (75.0%)	11 (78.6%)	5 (26.3%)	0.0033
Limited ROM	8 (66.7%)	7 (50.0%)	9 (47.4%)	0.5512
Weakness	4 (33.3%)	3 (21.4%)	4 (21.1%)	0.7485
Any adverse outcome	10 (83.3%)	12 (85.7%)	9 (47.5%)	0.0345

Discussion

The results of this study illustrate the complexity of the relationship between access to care and outcomes of surgically-managed rotator cuff injury. In line with previous literature, our results confirmed that underinsured patients were receiving appointments much later than that of their Medicare and privately-insured counterparts. There was no significant difference, however, in the time from first appointment with the surgeon to surgery. These findings support previous studies showing that initial access to care remains a barrier for underinsured populations.

Underinsured patients were much more likely to experience an adverse outcome (e.g., pain, weakness, limited range of motion or complication) after eight months of post-operative care. This study failed to identify any particular complication that may result from delayed access to care, but this may be due to the limited number of subjects and complications that occurred. While significantly more underinsured patients experienced long-term adverse outcomes than Medicare or privately-insured patients, this difference cannot be solely explained by the minor delay in access to the surgeon. Because rotator cuff disease often involves underlying degeneration and irreversible pathological changes, these muscles are prone to injury over time. Rotator cuff disease can progress, even if the patient is asymptomatic. It is likely that the significant differences in outcomes seen in the underinsured population are caused by both a delayed access to care, as well as systemic, behavioral or cultural influences on seeking out medical treatment.

There are many factors that influence people's care-seeking behavior. It could be related to a patient's: (1) perceived need for treatment, (2) personal beliefs on the healthcare system, (3) familial and cultural influence, (4) health literacy, (5) perceived financial contribution and co-pay, (6) swiftness of diagnosis, (7) referral to the appropriate surgeon, and/or (8) available time to see primary care, emergency or general orthopedic physicians.[16] Likewise, patients who wish to utilize the healthcare system may have difficulty with (1) transportation, (2) taking time off of work, or (3) understanding how to find the proper specialist. Because of the time-dependent progression of rotator cuff disease, these factors may profoundly affect the severity of the tear and extent of irreparable damage.[17] Thus, resource availability, health literacy, English fluency, ethnic identification and personal beliefs may have a tremendous impact on outcomes of rotator cuff repairs.

Due to the complexity of these behaviors, we conducted a preliminary analysis on the effects of language on cuff repair outcomes. We found that there were significantly more non-English speakers in the Medicaid and Medicare groups, and non-English speakers were more likely to note mild-to-moderate post-operative weakness (50% (non-English speakers) vs. 13.5% (English speakers)). These results, however, are preliminary and must be followed up with more extensive data regarding effects of language, as well as health literacy, on rotator cuff repair outcomes.

In order to further understand the cause for time delays and overall poorer outcomes for under-insured patients with surgically-managed rotator cuff disease, several additional studies should be conducted. Firstly, retrospective studies with a greater number of subjects are needed. Furthermore, prospective studies using patient questionnaires should be conducted in the future in order to analyze the effects of (1) desire for treatment, (2) health literacy, (3) efficiency of referral, (4) impact of family and culture, (5) trust in the healthcare system, and (6) administrative barriers on receiving treatment for rotator cuff disease.

Conclusion

Underinsured patients experienced delayed access to the surgeon in our study. Underinsured patients experienced more long-term (>8 months post-op) adverse outcomes, but to an extent that cannot be explained by the minor delay in surgeon access. Further studies are needed to evaluate predictors of adverse outcomes after rotator cuff surgery. The delay to initial evaluation and surgery may adversely affect long-term outcomes, and further studies should be undertaken to understand the importance of this delayed access to care.

Acknowledgements

We would like to thank Dr. Joseph Torg, Ms. Joanne Donnelly and Ms. Sylvia Reynolds for their significant contributions to this study. Dr. Torg helped in the editing of this manuscript. Ms. Donnelly prepared this study for IRB approval and coordinated research training. Ms. Reynolds helped us to access data needed to complete this study.

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Supported by The John Lachman Orthopedic Research Fund and Supervised by the Orthopedic Department's Office of Clinical Trials

North American Spine Society (NASS) Spine Registry Pilot

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Abstract

National registries provide a way to evaluate the effectiveness and validity of various surgical and non-surgical interventions performed for similar diagnoses. While such registries are prevalent across various surgical and non-surgical sub-specialties, the spine field trails behind in the establishment of such a registry. The NASS Spine Registry Pilot aims to research quality improvement for spine care, thereby beginning to close the gap in the medical evidence for spine care. Specifically, this pilot program will collect de-identified data on spine care from multiple diverse sites relative to specialty and practice setting in order to strengthen the understanding of spine care treatments and the corresponding patient outcomes, while also investigating the natural history of spine disorders. As patients are treated according to their individual complaints, differences between the treatment modalities patients select will naturally exist and can thus be used to measure the relative value of different interventions for different patient populations. Additionally, as patients answer the registry questions at each subsequent follow-up visit, they will receive immediate feedback on their Oswestry Disability Index Score, providing them with both a way to track their health progress and an incentive to continue participating in the study. Once the pilot program has been completed, the final registry will allow NASS to track patient care and outcomes with the long-term goal of using the data to establish measures for quality improvement purposes.

Introduction

The spine field suffers from a lack of evidence-based research common to other major orthopaedic specialties. It is imperative that spine research progresses so that the value and effectiveness of various spine treatments can be assessed and compared. Yet, while prospective randomized clinical trials remain the gold standard for clinical research, these cost-prohibitive studies are dependent upon strict inclusion and exclusion criteria, thereby limiting external validation or extrapolation of the results.[2, 6] Moreover, randomized clinical trials and meta-analyses are often not reported in a timely fashion, further limiting their effectiveness.[4] The spine field must turn to observational studies, which are more properly suited to examine the link between clinical care and patient outcome.[6] Spine care in North America must adopt a spine registry and follow in the footsteps of the national joint registries that have become increasingly more prevalent.

A patient registry is defined as 'an organized system that uses observational study methods to collect uniform clinical and other data to evaluate specified outcomes for a population defined by a particular disease, condition or exposure, which serves predetermined scientific, clinical or policy purpose(s)'.[6] One of the earliest national registries began in Sweden in 1979 with the founding of the Swedish National Total Hip Arthroplasty (THA) Register, which combined data from all hospitals in Sweden, including over 205,000 hip arthroplasties. By collecting data from multiple diverse sites relative to various treatments and patients' outcomes, Swedish surgeons have been able to use the registry to decrease patient risks, increase implant safety and increase the overall efficacy of surgical and cementing techniques for total hip arthroplasty.[2] An early outcome of the voluntary Australian Orthopaedic Association National Joint Replacement Registry has been the accumulation of the method of fixation and types of prostheses used, which will be used to reduce the frequency of revision operations.[1] The National Joint Registry for England and Wales, established in 2003, has helped surgeons more effectively determine whether total or unicompartmental knee replacement (TKA/UKA) is more useful for end-stage knee osteoarthritis.[3] Additionally, a Global Orthopaedic Registry (GLORY) has made possible the collection of data from over 15,000 patients from 13 different countries to identify various surgical approaches to patient management, including the types of implants, length of hospital stay, and anesthetic and analgesic practices.[9]

National joint registries have proven effective, and though less prevalent, spinal registries have been established on other continents, further highlighting the need to create a universal spine registry in North America. Spine TANGO was the first international spine registry, consisting of 6,000 submitted datasets from 25 countries in and outside Europe.[5] By compiling information such as age, sex, main pathology, number of spinal segments of posterior fusion, level of fusion, number of previous spinal surgeries, operation time, center of intervention, surgeon credentials and type of fusion, Spine TANGO was able to use this information to conclude that the center of intervention and number of fused segments was a major predictor of the occurrence of dura lesions in posterior spinal fusion.[5] Additionally, data collected from Spine TANGO revealed that the center of intervention was a significant predictor of length of hospital stay.[5] This spinal registry demonstrates a simple way of benchmarking, which allows for the comparison of the effectiveness of procedures between different organizations.[6] Specifically, the North American Spine Society (NASS) Spine Registry Pilot would seek to achieve a similar goal to that of Spine TANGO, whereby surgeons can compare the quality of their own patients' outcomes to those of other surgeons so that problem areas can be identified and new, successful techniques can be implemented. A Swedish Lumbar Spine Register has also been created to describe the outcome of disc surgery, decompressive surgery and fusion surgery of the lumbar spine,[11] yet the NASS Spine Registry Pilot would gather data from a wider range of procedures. This study will describe the NASS Spine Registry Pilot program, which aims to enhance the knowledge of spine care treatments and consequently improve the effectiveness of spine care.

Materials and Methods

Participants

A diagnosis-based observational registry was designed for longitudinal analysis. The NASS Registry Pilot involves 13 different sites across North America, with different specialties and practice types. While the NASS Registry Pilot will include data for 1,000 consecutive patients presenting for treatment to a variety of spine care specialists, including surgical and medical specialists, this preliminary review included 34 patients at Temple University Hospital. Eligible patients were selected as those presenting at the start of an episode of care (and its later corresponding follow-ups). An episode of care begins as the first intervention of any kind occurs up to one year of care later. The episode of care includes care since the intervention, whether it was related or not, and each patient was considered one episode of care. Patients were recruited without regard to gender, race, age (as long as 18+), language preference or socioeconomic status. All potentially eligible patients were screened for enrollment to include consecutively eligible patients presenting to spine care specialists who will be treated according to individual complaints, anatomy and preferences. Patients with diagnoses of: Low back pain (724.2), Lumbar disc herniation (722.10), Lumbar radiculopathy (724.4), Lumbar facet syndrome (724.8), Lumbar instability (724.6), Lumbar spondylolisthesis (738.4), Lumber stenosis (724.02), Lumbar scoliosis (737.30) or any other related treatments associated with the lumbar spine were eligible. Cervical and thoracic spinal conditions were not included in this pilot. Extra-spinal conditions, such as visceral, vascular, or genitourinary conditions were excluded from the study. Additionally, patients with only one visit and no planned follow-up visits were not included. No payments were given for subject participation. Vulnerable populations, including pregnant women, prisoners, and adults unable to consent were also excluded from participation in the registry. Participation in the registry by eligible patients was strictly voluntary, as the subjects did not have to be in the study in order to be treated. Subjects were also free to withdraw from the study for any reason, at any time, and it would not affect their treatment with the attending surgeon or his staff. Additionally, NASS could terminate the pilot registry at any time for any reason.

Data Collection: Patient Enrollment-First Visit

New patients recruited on the Mondays and Fridays that the attending surgeon sees patients at Temple University Hospital were enrolled consecutively to avoid enrollment bias. To link physician and patient forms to the appropriate patient at each entry, the patient's last name, last four digits of the social security number, and year of birth were collected prior to the patient's first visit. Using the registry created by Ortech Systems, the aforementioned three identifiers were entered into the registry to generate a patient study ID number. The registry only recorded the study ID number, not the other items entered (year of birth, last four digits of social security number, last name). This was done to ensure that the registry only knows the subject by the assigned ID number and thus allow for de-identification of patient data. Local IRB approval was required, and for participating patients, a waiver of informed consent was presented to each patient at their first appointment, based on the fact that de-identified patient data was collected centrally for analysis. At the time of the first appointment, each patient who volunteered to participate in the registry completed a New Patient Universal form online via a clinic kiosk/computer. On the New Patient Universal form, patients filled out the following questionnaires in the registry: demographics, treatment and complications, patient-reported outcomes, Oswestry Disability Index, EQ-5D-5L, and NRS back and leg pain. The questions ask about a patient's physical, mental, and social health, before and after surgeries, and the answers generally relate to the patient's feedback on their feelings or what they are able to do as they are dealing with chronic diseases or conditions as they progress through their own treatment. At the end of the questionnaires, the patient will have the option of having a printed out graph, marking their initial status. The purpose of the graph is to track the patient's progress from follow-up appointment to follow-up appointment. No patient identifiers were present on the graph, but only the specific ID number that they were given when they enrolled in the registry.

After the patient completes the New Patient Universal form, the attending surgeon would see the patient and immediately following the intervention, he would fill out the Care Provider Entry Questionnaires on the registry provided by Ortech Systems to document the patient's specific encounter. Any time an intervention is performed (during the same episode of care), the attending surgeon would complete the Procedure Intervention Form or NonProcedure Intervention Form depending on the type of intervention.

Data Collection: Interventions and Follow-Ups

The duration of a subject's participation in the study spans 12 months, including the initial visit and three-, six-, and 12-month follow-up visits, plus any *ad hoc* visit. Any follow-up visit prior to the aforementioned scheduled times may take the place of the closest standardized follow-up visit time (three month, six month, 12 month), though all follow up visits will be documented. At each of the follow-up periods listed, the patient will be asked to complete the Patient Follow-Up Form via either a triggered email from the registry or at the onsite kiosk/computer in the office. Additionally, the physician will complete the Follow-Up Form, if applicable. Because this paper represents a preliminary report, patient follow-ups have not yet been collected, but will be as part of the NASS Spine Registry Pilot.

Results

A total of 31 consecutive patients over an eight-week period participated in the NASS Spine Registry Pilot. These patients completed the New Patient Universal Form, and after seeing each patient, the attending surgeon subsequently completed the Care Provider Entry Questionnaire. Of the 39 patients who completed the New Patient Universal Form, five were subsequently removed from the study as a result of them meeting the exclusion criteria following diagnosis by the attending surgeon. Of these five patients, one was removed due to thoracic spine; two were removed due to cervical spine; and two were removed because a follow-up with the attending was not scheduled or necessary. Thus, a total of 34 patients met the inclusion criteria and participated in the NASS Spine Registry Pilot. Also, it should be noted that of the 34 patients asked to fill out the registry, zero patients denied their participation in the study.

Of the 34 patients in the NASS Spine Registry Pilot, two patients completed their Follow-Up Form four weeks after the first appointment. Though not at the designated three-month interval, this visit can substitute for the three-month follow-up, assuming another follow-up appointment does not occur within three months of the first visit. Regardless, all future follow-up visits will be documented in the Registry.

Discussion

Though the results of this study are preliminary, they have confirmed the efficacy of the NASS Spine Registry Pilot in its ability to collect de-identified data on spine care. The success of data collection during first encounter and follow-up demonstrate that the goal of creating a spine registry is practical. Moreover, by accruing 34 patients in an approximately 12-week span at one of 13 host sites, this accomplishment has confirmed that the estimated date of completion of December 2016 for the Registry Pilot is indeed feasible.

The ultimate goal of the Spine Registry Pilot program is to expand upon evidence-based research in spine care by comparing the results of various treatment plans for similar diagnoses across North America. This aim was not met in 12 weeks, yet the number of patients fitting the inclusion criteria who consented to participate is encouraging in achieving such a goal. Though only one follow-up visit was completed during this time span, follow-up visits will be critical as the study progresses, as they provide the opportunity to assess whether the treatments prescribed by the attending surgeon have proven beneficial. When similar groups of patients choose different modalities of treatment, a comparison of relative effectiveness can be performed. Moreover, it is important to note that these groups of patients are not defined strictly according to the site of intervention but also to the individual preference on a patient-to-patient basis. Thus, the value of various treatments for similar diagnoses can be compared both between sites and within them.

As of yet, with limited number of follow-up data recorded, retrospective studies evaluating the efficacy of various treatment plans have not been investigated. Though there are not a set number of participants and corresponding follow-ups that must take place before such studies can be constructed, as the registry continues to expand, data for these retrospective studies will be significant. For example, the attending surgeon has expressed his desire to analyze the type and amount of care primary care providers provide for non-specific low back pain prior to referral to a tertiary care subspecialist. By utilizing the technique of benchmarking,[7] these retrospective analyses will be well within the scope of what the NASS Spine Registry Pilot will be able to provide.

Conclusion

National registries have demonstrated their effectiveness through the development of quality measures for best practices. For example, registry data from Spine Tango enabled researchers to identify key predictors of the occurrence of dura lesions in posterior spinal fusion, as well as predictors of subsequent length of hospital stay.[5] In addition, data from the Vermont Infant Spinal Registry allowed clinicians to confirm the efficacy of infant spinal anesthesia.[11] Moreover, the Swedish Lumbar Spine Register was used to refute the use of reoperation as the endpoint of an outcome of disc surgery, decompressive surgery and fusion surgery, an endpoint that was adopted by the Swedish hip and knee registers.[1] Instead, preoperative and postoperative outcome parameters were deemed more effective in assessing pain and function for the individual patient.[1] This result and any results that will be gathered from the NASS Spine Registry Pilot are limited to the degenerative lumbar spine, though a reasonable future goal may be to expand the pilot program to limit the exclusion criteria so that a more comprehensive view of spine disorders including those of the cervical and thoracic spine can be obtained. Nevertheless, as data on the efficacies of various treatments pertaining to the degenerative lumbar spine continue to accumulate, a comparison of the relative effectiveness of different treatment modalities will soon begin to address the overall goal of this study.

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Supported by The John Lachman Orthopedic Research Fund and Supervised by the Orthopedic Department's Office of Clinical Trials

Sudden Cardiac Death in Athletes: Two Decades in Review

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Abstract

Sudden cardiac death is a well-documented but poorly understood cause of untimely death in a small number of young, competitive athletes. Increased media attention and public scrutiny has led to acceleration in both clinical and scientific research into sudden cardiac events over the past 20 years. Although there has been a substantial amount of insight gained over the past two decades, a degree of uncertainty still remains regarding the leading cause of death and incidence rates. This uncertainty has likely played a role in the constantly adapting screening methods and protective measures currently in place to protect young athletes. This literature review seeks to gather and summarize the current predominant facts and opinions regarding sudden cardiac death in athletes and to discuss what, if any, changes in understanding there may have been regarding these events over the past 20 years.

Introduction

On April 18, 2015, a freshman football player at St. Joseph's Prep High School, suddenly and without warning, collapsed and died during the team's spring conditioning. An apparently healthy individual with no prodromal symptoms, he fell victim to what would later be referred to as a sudden cardiac death (SCD). Although it did not garner the same media attention as the similar cases of Lion's wide receiver Chuck Hughes in 1971 or NBA star Pete Maravich in 1998, the young man's death is the most recent in a string of deaths that have been the topic of extensive research in the scientific and medical communities for years.

Despite a long list of fallen athletes, sudden cardiac death in competitive athletes is fortunately a rare but nonetheless tragic event. Case reports of apparently healthy individuals unexpectedly dying during physical exertion were noted in the scientific literature as early as the late 19th century,[2, 23] but the scope of the problem did not fully begin to emerge until the final two decades of the 20th century.[2]

Despite their rarity, the tragic and unexpected nature of these deaths, along with society's perception of athletes as models of health and vitality, have made SCD a source of much public concern and media scrutiny. Whenever such an event occurs, people scrambling to find answers dust off old questions such as whether such a tragedy could have been avoided and what can be done to make athletes safer in the future.

The study of SCD has accelerated in recent years, but the general paucity of cases and difficult nature of quantifying and studying such events have made incidence rates[4, 5, 7, 9, 10–12, 15, 18, 20, 21, 23, 24] and leading causes[9, 11–13, 17, 18, 23–25] of SCD in athletes the subject of debate and uncertainty.

The purpose of this paper is to present a comprehensive and thorough review of the literature regarding SCD in athletes and to discuss the predominant opinions circulating in today's scientific and medical communities. Although several other topics will be addressed in order to give a comprehensive overview of the subject matter, this paper will primarily focus on three core topics. First, this report will discuss the incidence and etiology of SCD in athletes and whether opinions on either have changed in the past 20 years. Second, changes in pre-screening practices and the efficacy of current preventative measures will be addressed. Finally, this paper will explore the increased survivability following sudden cardiac arrest and possible explanations behind it.

Methods and Materials

A comprehensive search of the literature was conducted via PubMed and Embase. The following search terms were used: sudden cardiac death, sudden cardiac death AND athlete, sudden cardiac death AND football, death AND football.

Articles were reviewed with an overall goal of finding papers that focused specifically on SCD in athletes. Included articles consisted of experts' opinions, reviews, meta-analysis, and qualitative and quantitative studies. Articles had to be initially published in English and released between the years 1990 and 2015. Articles were excluded if the research design was unclear or of poor quality and/or if the article's source material was questionable and/or if the article's argument was poorly presented or unclear. Several hundred articles were initially found but were excluded based on the inclusion/exclusion criteria stated above. Of the initial articles, 25 met the criteria and were ultimately included in the review.

What Is Sudden Cardiac Death?

Although minor variations exist between definitions of SCD, the general consensus is that SCDs are sudden unexpected deaths due to cardiac causes or sudden death in a structurally normal heart with no explanation for death and a history consistent with cardiac-related death.[11, 23] Furthermore, the death need occur within one hour of symptoms in cases where the death is witnessed and in un-witnessed cases within 24 hours of the individual last being seen alive and well.[9, 11, 23] In most instances, SCD has not been preventable because it is the first indication of underlying heart disease.[1, 23–25] Athletes appear particularly susceptible to SCD since exercise-related, adrenergic stress has often been cited as a common trigger for arrhythmias and sudden cardiac arrests.[20, 23, 25]

Despite their relative rarity, SCDs are enough of a specter to warrant both public and scientific attention. Sports participation among America's youth continues to rise to all-time highs. In 2005, an estimated 2,000,000 high school, collegiate, and professional athletes played football with that number increasing by an additional 100,000 athletes each of the previous 10 years.[21] As sports participation numbers continue upward, logic warrants that the number of fatal sudden cardiac arrests will continue to climb as well and, in fact, this is the case.[5]

What Is an Athlete?

There does not appear to be definitive criteria in the scientific literature as to what precisely constitutes an athlete. This is one of several interesting dilemmas that arise when attempting to study cardiac deaths in the athletic population. A casual weekend golfer might qualify as an athlete in one study while being excluded in another. As most competitive professional athletes are usually under 35 years of age, this number is conveniently used as the upper age limit when studying SCD incidence. Coronary artery disease is the primary cause of SCDs in athletes over 35,[18, 23] whereas arrhythmic and congenital conditions are often the leading etiologies of SCDs in young people. These conditions are difficult to diagnose, since they are usually not associated with prodromal symptoms.[1, 2, 9, 11, 12, 17, 18, 23, 25]

We will define an athlete as someone who regularly participates in an organized sport requiring regular competition against others as a central component,[23] requires extensive and systematic training, and requires some level of physical exertion beyond normal resting limits. Although these criteria are relatively narrow, most athletes meet these measures.

Incidence

A clearly established incidence rate of SCD in U.S. athletes has proven evasive. There are major limitations that exist in providing reliable data on the absolute number of fatal events and in estimating the athletic population per year in the United States.[5] The accuracy in attempting to establish incidence rates over the past 30 years has been hampered by the inability to obtain a common denominator for the overall at-risk athletic population.[5] Complicating matters further are the aforementioned difficulties obtaining a reliable definition of an athlete as well as significant differences in incidence rates between genders, age, race, and sport.

One study following NCAA athletes concluded that men are four times more prone to SCD than women[11] while other studies report it as high as five.[7, 24] Either way, men have long been known to be at higher risk of SCD than women.[1, 9, 11, 16, 17, 23, 24] Any incidence study including both genders will naturally tend to reflect the males' incidence rate more so than the females'.

Age also contributes a significant amount to the uncertainty in establishing a specific incidence as various age groups vary widely in both incidence and etiology.[11, 23, 24] High school athletes with an estimated incidence rate around one in 200,000[7, 11, 21, 24] appear less at risk than their collegiate counterparts. Estimates of incidence in collegiate athletes frequently are between 1:43,000 to 1:69,000,[7, 11] with one retrospective study following NCAA athletes from 2003 to 2013 reporting the incidence to be 1:53,703.[11] Among professional athletes, the number of SCDs is particularly low. Of the 53,400 athletes who have historically played in the MLB, NBA, NFL, and NHL as of 2015, 205 have died while active and only 18.8% from cardiac diseases.[15]

Race is another factor where incidence rates appear to vary widely between individuals. Studies generally agree that individuals of African or Caribbean descent are the highest at-risk individuals.[1, 11, 17, 23, 24] Although specific numbers are difficult to locate, the same NCAA retrospective study referenced earlier reports that black people are approximately three times more prone to SCD.[11]

The type of sport must also be taken into consideration when attempting to establish incidence. Several sports have been historically reported as having higher rates of SCD events than others. These include basketball, football, and endurance sports.[1, 6, 11, 24] Basketball players appear to be particularly susceptible to SCD with one study finding the incidence to be one in 5,200 in NCAA division I male athletes.[11]

For the most definitive answer regarding incidence rates of SCD in athletes, most researchers turn to the landmark study conducted by Corrado et al. This population-based study in the Veneto region of Italy followed young competitive athletes aged 12 to 35 years old between 1979 to 2004 and found the incidence of SCD to be 0.79 in 100,000 athlete years. Although a well-conducted study, the results are difficult to apply to U.S. studies since the highest at-risk athletes (black, male basketball and football players) are largely absent from this study.[4]

Despite the inconsistencies among reports, several assumptions are readily made. SCD remains the most common cause of unnatural death in sports.[14] Although a true incidence rate for SCD in young, competitive athletes currently eludes researchers, this number most likely falls between 1:50,000 to 1:200,000. High school athletes represent the largest group of competitors affected by SCD, with a death occurring an estimated once to twice a week.[24] Males and people of African/Caribbean descent are at higher risk than other individuals, and endurance sports have historically produced a high number of SCDs. A registry of sudden death in the young launched by a joint effort of the National Institute of Health (NIH) and Centers for Disease Control and Prevention (CDC) in 2014 will track all unexpected deaths in youths up to 24 years of age and will expand upon the CDC's preexisting sudden unexpected infant death case registry.[19] This new registry will hopefully help current and future researchers establish a standardized incidence rate.[19]

Etiology

Although the various etiologies behind SCD have been known for years, uncertainty remains as to the predominant cause. In adult athletes over 35, coronary artery disease (CAD) has long been identified as the leading cause of SCD in athletes, and recent literature has revealed nothing to the contrary.[18, 23] Not limited to athletes, the general population over 35 is at fairly high risk for sudden heart attack, which is the leading cause of death in the industrialized, Western world with an estimated 250,000 to 300,000 people dying from sudden heart attack in the U.S. each year.[20, 22] The underlying pathology is overwhelmingly coronary artery disease in these cases.

These numbers are sharply contrasted with the comparatively smaller 10,000 SCDs in young adults and children in the U.S. each year.[10] While a rather small fraction of these deaths are due to CAD (6–10%),[2, 11] the vast majority appears to be due to underlying occult or arrhythmic diseases.[2] While hypertrophic cardiomyopathy (HCM) was generally agreed upon as the most common underlying pathology 20 years ago, recent papers suggest that arrhythmic diseases and channelopathies may play a larger role in SCDs in the young athlete than previously suspected. In a retrospective study of NCAA athlete deaths from 2003 to 2013, only 8% of SCDs were the result of HCM.[11] In a meta-analysis of 47,137 athletes between 1996 to 2014, one in 204 were found to have had some underlying heart abnormality. Of these individuals, only 11% (18 people) presented with HCM.

Several recent studies argue that autopsy-negative unexplained deaths with presumed arrhythmia is the most common cause of SCD.[11, 12, 23] This is in direct contradiction to a study of sudden death in young competitive athletes between 1985 to 1995.[17] In this study, 158 sudden deaths were documented with the most common cause being hypertrophic cardiomyopathy (38%). Perhaps the irregularity between past and current numbers lies in a more up-to-date definition of the "athlete's heart." Cases that were once previously diagnosed as HCM would in today's literature be characterized as athlete's heart, a benign and often beneficial electrical and structural remodeling of the heart due to exercise which can induce ECG changes considered normal in athletes but abnormal in non-athletes.[2, 6, 23, 25]

Despite new evidence, HCM remains one of the leading contributors to SCD. As with many cardiac diseases, HCM appears more prominent in people of African/Caribbean descent.[17, 24] Reports during the last 15 years support an autosomal dominant inheritance pattern for HCM, and estimates place the incidence somewhere in the range of one in 500 U.S. persons.[17, 24]

Support for arrhythmic diseases and channelopathies as the leading causes of SCD continues to gain momentum. Both of these etiologies are generally placed under the more general label of autopsy-negative unexplained deaths (ANUD). The list of cardiac diseases that can present as an ANUD is broad and includes Wolff-Parkinson White, T wave inversions, long QT, ST segment depression, pathologic Q waves, and several other conduction abnormalities, all of which result in a gross, anatomically normal heart.[12, 23] However, heart adaptions and exercise-induced, adrenergic stress can sometimes lead to fatal sudden cardiac arrest when these diseases are also present.[23] One U.S. study has ANUD as the cause of SCD in nearly half of individuals,[23] and some other countries support ANUD with presumed arrhythmias as the most common cause of SCD.[12]

Current literature has deemphasized previous opinions that HCM and congenital coronary anomalies are the leading causes of SCD. While both of these pathologies are still the underlying etiology in a large percentage of cases, recent research indicates that arrhythmic diseases and channelopathies are more prevalent than previously thought and are likely the underlying etiology in the majority of SCD cases.[9, 11–13, 17–18, 23–25]

Pre-Screening and Current Concepts

Pre-screening athletes before clearance for competition for underlying cardiac abnormalities and potentially life-threatening disorders has been commonplace in the United States for 50 years;[12] however, the traditional U.S. model of history and physical has proven to have low efficacy in detecting cardiovascular disorders that may lead to SCD.[1] One of the primary reasons for history and physical's low efficacy is that sudden death is often the first manifestation of underlying cardiac disease in approximately 80% of cases.[4]

Athletes are often of particular interest because many victims of SCD previously appeared healthy and asymptomatic,[12, 23, 25] and the risk of an SCD event occurring is three times greater during sports activities.[4] In a small number of cases, however, syncope, palpitations, chest pains, exercise-associated dizziness, exertional dyspnea, and sudden ventricular arrhythmias can be prodromal symptoms.[12, 23] Prodromal symptoms are warning signs that precede cardiac death and are documented to occur in approximately 36% of sudden cardiac deaths. This percentage is potentially lower than it should be, since athletes often underreport symptoms to clinicians in order to gain clearance for sports activities.[24] Pre-screening protocols with personal and family history and comprehensive physical exam have long been in place. Electrocardiogram (ECG), however, has frequently been dismissed by practitioners due to ECG's high false positive rates and cost.

This underlying opinion began to change in 2006 with Corrado et al.'s landmark 26-year period longitudinal study.[4] Corrado and his colleagues reported an 89% decrease in the incidence of SCD in Italian athletes between the ages of 12 to 35 after the implantation of mandated ECG pre-screening before competition. The following year, he and his colleagues estimated the current screening program was 77% more effective than the recommendations of the American Heart Association.[24] To be noted, a long-term analysis did reveal a high propensity of false positives in these screenings.[4, 25] ECGs are not required in the American Heart Association's (AHA) practice guidelines citing the number of athletes in the United States, the cost associated with screening each athlete, lack of standardized interpretation of ECG in the athlete, low disease prevalence, limited qualified practitioners to interpret ECG, and the risk of false positive readings;[11, 21, 24] however, many of these arguments have been dismissed.

For one, cost-effective ratios for ECG use in the U.S. continue to steeply decline.[1] A recent cost-decision analysis model by Wheeler et al. found the addition of the ECG to the standard history and physical pre-screening yielded a cost-effectiveness ratio of $42,900 per life year saved.[1] In a Swiss study using modern ECG, cost was $152 per athlete and a cost of $14,802 per life year saved.[1] In 2000, Fuller further supported the claim that ECG is the most cost-effective screening modality,[24] and in 2008, Drezner acknowledged health initiatives such as screening for phenylketonuria and cystic fibrosis are routine and cost millions of dollars and yet have a lower disease prevalence than SCD.[24]

Standardizing ECG interpretations for athletes has also come to the forefront in the past decade. In 2010, the European Society of Cardiology (ESC) developed their criteria that acknowledged the difference between "common and training" related ECG patterns and "uncommon/training unrelated" ECG patterns.[2] The overall goal of the new criteria was to improve accuracy and cost-effectiveness of ECG use.[25] Group 1, the "common and training" related group, included many findings typical of "athletes heart" such as sinus bradycardia, 1st AV block, incomplete right bundle block, and isolated QRS voltage criteria for left ventricular hypertrophy (LVH).[2] Group 2, the "uncommon/training unrelated" group, defined ECG patterns typical of occult disease like T wave inversions, ST segment depression, pathologic Q-waves and other conduction abnormalities.[2] Ultimately, the division of ECG patterns into two distinct groups led to a significant decrease in false positives with one study showing a reduction in false positives from 40% to 11% while still maintaining sensitivity for detection of cardiovascular diseases at risk of causing SCD.[25] To be noted, however, false positives remained high in particular endurance sports and black athletes. Using the 2010 recommendations from the ESC as a guide, a group of experts met in Seattle in 2013 to update and refine the 2010 criteria with an emphasis on the development of training modules for sports medicine practitioners. The "Seattle Criteria" provided refined quantitative definitions for numerous ECG patterns to increase specificity for occult diseases.[2] In 2014 and February of 2015, "revised criteria" were released which further improved the specificity of athlete ECG interpretation by using primary data derived from sizeable multi-ethnic athlete cohorts and reclassified several common isolated ECG patterns as benign including axis deviation, atrial enlargement, and right ventricular hypertrophy.[2, 14] Overall, application of modern ECG standards in several studies show less than 5% incidence of false positives.[1] In a large four-year investigation of over 32,000 high school students and athletes, new ECG criteria yielded a false positive rate of only 2.5%.[1] It appears that the most effective strategy for screening for cardiovascular disease is ECG since it is 15 times more sensitive than history and 10 times more so than physical exam.[12] For instance, ~95% of individuals with HCM and ~80% of those with arrhythmogenic right ventricular cardiomyopathy demonstrate ECG abnormalities that are detectable through screening and, more strikingly, the electrocardiogram has a high negative predictive value (99.9%) for essentially excluding athletes with underlying HCM.[1] Although ECGs have historically been associated with high false positive rates, modern athlete-specific criteria have dramatically reduced false positive rates to levels below other commonly used screening tests.[1]

Overall, new ECG criteria for athletes have actually reduced the incidence of false positives below that of standard history and physical exam.[12] Some groups such as African-American males and endurance athletes continue to have high false positives rates;[1, 24] however, further studies are needed to test the accuracy of ECG screening in relation to ethnicity, gender, age, levels of training, and sport.[25] Although the AMA is still hesitant to include ECGs in their athletic pre-screening protocols,[21] several countries and organizations such as the Olympic committee and various U.S. professional sports teams recommend a cardiovascular screening including ECG.[24] ECG participation screening can prevent SCD in athletes by early detection and disqualification of affected individuals.[25]

Prevention and Response

Although SCD is still the most common cause of death in athletes,[12] it is important to note survival trends have continued to increase since SCD was first pushed into the scientific forefront in the 1990s. This is especially important when taking into consideration that an SCD occurs once to twice a week among American high school athletes.[24] One study using an observational cohort design of men and women between the ages of five and 22 found a survival rate of only 11% following a sudden cardiac arrest; however, the researchers also noted a statistically significant trend toward improved survival in recent years.[7] Despite these findings, survival remains relatively poor.[7] In a 30-year review of cardiovascular-related SCAs in children and young adults aged zero to 35 years of age, the authors noted a survival rate of 26.9%. More importantly, the survival increased in the study period from 13.0% between 1989 to 1989 to 40.2% from 2000 to 2009.[18] Perhaps this low survivability rate would not be so disconcerting if there appeared to be a decrease in the number of SCA episodes occurring each year. This is not the case, however, since there appears to be a clearly increasing time trend of SCAs in U.S. athletes.[5] This increasing trend may have more to do with enhanced public recognition of SCDs due to increased media attention rather than an actual increase in numbers.[5]

How to Reduce Incidence and Improve Survivability?

Corrado's landmark Italian study definitively showed that pre-screening in athletes is a feasible and effective way of preventing SCD.[4] As athlete-specific ECG criteria become finalized, ECG pre-screening in American athletes could potentially increase and hopefully present similar findings. In professional U.S. sports teams where prescreening with ECG is required, SCDs remain consistently low.[15] Perhaps one of the most significant contributors to increased survivability and an area of increased emphasis in both scientific and lay communities is the use of the automatic external defibrillator (AED). Although there are no firm guidelines or regulations regarding AED placement on competitive fields of play, multiple studies show that early defibrillation along with cardiopulmonary resuscitation can lead to a significant improvement in survival.[13, 22] Studies have shown the single greatest factor in the likelihood of survival following a sudden cardiac arrest is defibrillation with a decrease of 7–10% for every minute of delayed shock.[13, 22] In the hands of trained lay people, AED use has proven to be remarkably effective. In casinos and airports where AEDs are required, survivability following an SCA is far above national averages, especially if shock is delivered within three minutes.[10, 22] Bystander cardiopulmonary resuscitation and initial use of cardiac defibrillation have shown to be the strongest predicators for survival to hospital after an event.[16] In Piacenza, Italy, there was a reported three times increase in survival after sudden cardiac arrest following lay defibrillation.[22] In response to these events, recent legislation has been proposed in both state and national legislatures protecting lay people using AEDs.[22] Presently, not every state requires an emergency response plan requiring defibrillation in the event of an SCA nor are there firm guidelines or regulations for emergency preparedness in case of such an event[10] despite studies demonstrating a significant improvement in survivability due to earlier access to defibrillation provided by AEDs.[22]

Discussion

Although extensive research regarding SCDs has been conducted in the past two decades, incidence rates and the leading cause of SCD are still a matter of uncertainty.[11] Based on the current literature, the incidence of SCD in high school athletes is likely somewhere in the range of 0.5–20:100,000. Collegiate athletes appear to be at increased risk with conservative estimates placing their incidence of SCD at approximately 1:50,000.

Several groups appear to be at greater risk than others. Males have long been known to be at a higher risk than females, and African Americans, endurance athletes, basketball, and football players all appear to have a higher risk than other athletes. Although coronary artery disease still seems to be the overwhelming pathology behind SCD in athletes over 35, the predominant etiology in athletes below 35 remains somewhat less established. Certainly HCM is still a major factor but new criteria defining the "athletes' heart" have led to a decrease in the reported incidence of HCM as the leading cause of SCD in young athletes. Several studies now report that occult, arrythmogenic diseases and cardiac channelopathies are the main culprit. Although there have long been major limitations that exist in providing reliable data on the absolute number of fatal events and in estimating the athletic population,[5] a joint U.S. registry for sudden deaths in the young launched by the NIH and CDC in 2014 will hopefully help researchers better define the scope of the problem, develop better diagnostic and prevention approaches, and set future research priorities.[19] The registry will be an undeniable asset to SCD researchers as there were previously no standards or definitions for reporting sudden deaths before this. Hopefully, the registry will help establish a standardized incidence.

Although current pre-screening for athletes has long consisted of a history and physical, relatively recent improvements in athlete-specific ECG criteria have led to ECG's incorporation into pre-screening guidelines worldwide. ECG's proven track record of excluding individuals at risk of experiencing fatal SCA have made them a cost-effective and life-saving option for many sport's medicine clinicians. Further studies are needed to test the accuracy of ECG screening in relation to ethnicity, gender, age, different levels of training, and type of sport, since most studies are done on male, elite, young athletes.[25]

Although there appears to be little headway in reducing the number of SCD events in American athletes each year, several studies show increasing survival trends following SCA. Increased public awareness, contingency plans, and increased access to AEDs appear to play some part in the recent increase in survival.[19] There is still a need for improvements in prevention, risk protection, resuscitation and therapy. Improved resuscitation techniques and advances in defibrillator technology have all improved treatment outcomes, but there is still work to be done. Although more research is needed, evidence supporting early intervention, a coordinated emergency plan, and rapid emergency medical care are strong enough to warrant mandatory AEDs in all school gyms and athletic facilities.[26]

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Medical Student Research Project

Supported by The John Lachman Orthopedic Research Fund and Supervised by the Orthopedic Department's Office of Clinical Trials

Administration of IV Antibiotics in Patients with Open Fractures Dependent on Emergency Room Triaging

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Abstract

Objective: The objective of this study is to evaluate the time to antibiotic administration after patients with open fractures treated at one level 1 trauma center.

Design: Retrospective, observational study.

Setting: Level 1 Trauma Center.

Patients/Participants: One hundred seventeen patients with open fractures from 1 January 2013 to 31 March 2015.

Main Outcome Measurement: Time to IV antibiotic administration.

Results: Patients received IV cefazolin on average 17 minutes after arrival. Eighty-five patients who were made trauma surgery activations received cefazolin 14 minutes after arrival while 24 non-trauma patients received cefazolin 53 minutes after arrival (p = <0.0001). There was no statistically significant difference between the timing to cefazolin based on Gustilo type. Patients with type I open fractures received antibiotics 17 minutes after arrival; type II, 18 minutes after arrival; type III, 19 minutes after arrival; type IIIa, 11 minutes after arrival; type IIIb, 11 minutes after arrival; and type IIIc, 27 minutes after arrival (P = 0.4689). The average time to gentamicin administration for all patients was 180 minutes. Patients not upgraded to a trauma activation received gentamicin 263 minutes after arrival, while patients upgraded to a trauma activation received gentamicin 176 minutes after arrival (P = 0.3750). Patients with type I fractures received gentamicin 165 minutes after arrival; type II, 198 minutes after arrival; type III, 430 minutes after arrival; type IIIa, 160 minutes after arrival; type IIIb, 146 minutes after arrival; and type IIIc, 424 minutes after arrival (P = 0.9198).

Conclusions: Overall, patients that arrive at our institution with open fractures receive IV cefazolin within one hour after arrival and receive IV gentamicin within three hours after arrival. Improvements can be made in the treatment of non-trauma patients and for patients requiring gentamicin.

Introduction

Open fractures usually result from high-energy traumatic mechanisms when bone or fragments of bone penetrate the skin and are exposed to the external environment.[1] Management of such injuries includes adherence to Advanced Trauma Life Support guidelines, wound coverage with a dressing soaked in sterile saline, fracture stabilization, prophylactic tetanus toxoid administration, therapeutic antibiotic administration, and wound debridement.[1–3] Antibiotics should be administered as soon as possible following the injury with the Gustilo and Anderson classification system of open fractures dictating the specific class and duration of antibiotic.[2] This system classifies open fractures based on the severity of soft tissue injury with type I corresponding to an open fracture with a less than 1 cm puncture wound, type II as a fracture with a greater than 1 cm laceration with moderate soft tissue damage and type III as a fracture with extensive soft tissue damage.[1, 4] Revision of this classification system by Gustilo et al. subdivided type III open fractures into type IIIA, corresponding to adequate soft tissue coverage of a fractured bone, type IIIB as fractures with extensive soft tissue injury with periosteal stripping and bony exposure and type IIIC as open fractures associated with arterial injury requiring repair.[5]

Open fracture injuries always result in soft tissue damage, subsequently presenting a risk of infection. Risks of developing a fracture-related infection include fracture location, fracture severity, timing to antibiotic administration, and time to operative management.[6–9] Harris et al. found that the most common complication from severe limb-threatening lower extremity trauma, including Gustilo type IIIB, IIIC and selected type IIIA fractures, was wound infection.[10]

Empirically, type I fractures correlate with a 0–2% clinical rate of infection, type II fractures correlate with a 2–10% rate of infection and type III fractures correlate with a 10–50% rate of infection.[1, 6–8, 11]

Current Eastern Association for the Surgery of Trauma (EAST) guidelines state that antibiotic coverage for gram-positive bacteria (e.g., cefazolin) should be started as quickly as possible after injury with concomitant gram-negative coverage (e.g., aminoglycosides) for more severe open fractures (type III).[2] This initial course of antibiotics has been shown to significantly lower the risk of infection from open fractures in accordance with proper wound management.[1–3, 9, 12, 13] In a study of 137 patients with type III open tibia fractures, increased time to antibiotic administration correlated to a rise in infection rate, specifically an infection rate of 6.8% for antibiotics administered within the first hour after injury, as compared to 18% for antibiotics between 60 and 90 minutes and 27.9% for antibiotics longer than 90 minutes.[14] Though antibiotics should be given as soon as possible after injury, the duration of prophylactic antibiotic therapy is not related to the risk of infection.[12]

Current protocol at our institution aims to give antibiotics as soon as possible following patient arrival with cefazolin (1 g) given for type I and II fractures, and concomitant cefazolin and gentamicin (5 mg/kg body weight) for type III fractures. For open fractures of any type with soil contamination, penicillin (3 million units) is given every four hours. Other institutions have a similar goal, but some have reported that the actual timing is not as optimal as it can be. Specifically, a study by Lack et al. showed that despite improved transportation times, only a minority of patients received antibiotics within an hour of injury, and in fact only 50% of patients arrived to the hospital within one hour of injury.[14] This points to how vital it is for patients to get antibiotics immediately upon arrival. We have anecdotally noted that at our institution, despite our intentions, antibiotic administration is not always done as quickly as we would like in these circumstances. The purpose of this retrospective study is to determine the timing to IV antibiotic administration to patients with open fractures presenting to our level 1 trauma center and to identify any possible reasons for delay.

Method and Materials

A retrospective study was performed at our level 1 trauma center over a two-year period from January 1, 2013 to March 31, 2015. Institutional Review Board approval was obtained. All adult patients who presented to the Emergency Department with open fractures of the extremities and/or pelvis were considered for this study. Subjects were identified using our departmental database by searching both procedures and diagnoses for open fractures as well as cross referencing with patients treated at our institution using the CPT codes 11010, 11011, and 11012 (Debridement including removal of foreign material associated with open fractures). Only those patients age 18 and older were analyzed with the following items being obtained from the medical record: age, gender, BMI, transportation method to the hospital, fracture location, Gustilo Type, side of injury, presence of poly-trauma (>1 long bone or pelvic fracture, head injury, chest injury, or abdominal injury), any other associated orthopaedic or non-orthopaedic injuries, mechanism of injury, antibiotics administered in the emergency department, the presence of a penicillin or cephalosporin allergy requiring use of an alternative antibiotic, post-operative antibiotic regimen ordered, the number of repeat debridements (if indicated), the need for and type of soft tissue coverage, and whether there was a reported infection at the operative site. We also analyzed which patients were upgraded to a "trauma activation," meaning the patient was formally evaluated by the general surgery trauma team in the trauma bay as opposed to being cared for by the emergency department physicians.

The time after arrival to administration of cefazolin, gentamicin (if applicable), or penicillin (if applicable), as well as the time to surgical debridement were calculated based on the patient's arrival time to the Emergency Department (defined as the time they arrived to the triage area) and the documented time the specific antibiotic was given and the documented operative start time, respectively. The transportation time to the hospital was calculated based on EMS records. No patients in our data set arrived in private vehicles. Exclusions for this study include undocumented timing of antibiotic administration, patient transfers from non-affiliated hospitals, patients less than 18 years old and patients who presented more than 24 hours after injury. Patients allergic to antibiotics given as part of the standard protocol were included with the appropriate recommended alternative antibiotic as a surrogate for cefazolin. Patients transferred from our hospital's satellite emergency room were included if the original emergency department record was available. Patients with fractures from low velocity gunshot injuries were considered Gustilo type 1 injuries unless specified otherwise by the treating physicians.

Statistical Analysis

Descriptive statistics were calculated for both categorical and continuous variables. Data was presented as mean with standard deviation, minimum, maximum, median, and percentages. Select variables were then analyzed using both parametric (t-test and Analysis of Variance) and non-parametric (Wilcoxon and Kruskal-Wallis) testing for the timing to administration of cefazolin, and the timing to administration of gentamicin, respectively. Statistical significance was defined as a probability value (p-value) less than 0.05 and high statistical significance was defined as a p-value less than 0.01. P-values that exceeded 0.05 were still considered or evaluated. Although both mean and median were reported for this study, the presence of outliers could skew the data with mean calculations. Therefore, the median values were used as the most representative descriptor of central tendency. Data were analyzed using SAS 9.4.

Results

The final cohort consisted of 117 patients with open fractures following exclusions for undocumented timing of antibiotic administration,[1] patient transfers from non-affiliated hospitals,[11] patients less than 18 years old[1] and patients who presented more than 24 hours after the injury.[1] The 117 patients consisted of 29 females (24.8%) and 88 males (75.2%) with 53 patients age 18–29 (45.3%), 27 patients age 30–39 (23.1%), 19 patients age 40–49 (16.2%) and 18 patients age 50 or older (15.4%). Summary of patient demographic data is presented in Table 1.

Table 1. Summary of Patient Demographic Data Including Age Ranges and Average BMI

No. of patients	117
Age (years)	35.2 ± 13.9
Gender	
Female	29 (24.8%)
Male	88 (75.2%)
BMI (kg/m^2)	29.5 ± 7.3
Transportation time (min.)	23.8 ± 9.1
Transportation method	
EMS	83 (70.9%)
Police	13 (11.1%)
Transfer	7 (6.0%)
Walk-in	14 (12.0%)

Patient injury data are summarized in Table 2. Out of the 117 patients included, 36 (30.8%) had an open fracture of the upper extremity while 81 (69.2%) had an open fracture of the lower extremity. Based on the treating physicians' Gustilo-Anderson classification of open fractures, 49 (41.9%) were type I; 15 (12.8%) were type II; five (4.3%) were type III with no further classification; 17 (14.5%) were type IIIa; eight (6.8%) were type IIIb; two (1.7%) were type IIIc; and 21 (17.9%) were not classified by the physician in the medical record.

Table 2. Summary of Patient Injury Statistics Including Site of Injury and Gustilo Classification

Fracture location	
Upper extremity	36 (30.8%)
Lower extremity	81 (69.2%)
Gustilo-Anderson classification	
Type I	49 (41.9%)
Type II	15 (12.8%)
Type III	5 (4.3%)
Type IIIa	17 (14.5%)
Type IIIb	8 (6.8%)
Type IIIc	2 (1.7%)
Unclassified	21 (17.9%)

The number of patients that were upgraded to trauma surgery activation was 91 (77.8%), with 17 (14.5%) having polytraumatic injuries. When patients arrived to our institution, 109 (93.2%) received IV antibiotics while still in the Emergency Department. One-hundred (85.5%) patients received cefazolin, per protocol, while 17 (14.5%) received an alternative antibiotic (e.g., clindamycin, metronidazole, vancomycin, ampicillin/sulbactam), not including gentamicin or penicillin, eight (6.8%) of which were due to cephalosporin/penicillin allergy. Patients with allergies were included in the data series, and the alternative antibiotic used in lieu of cefazolin was used to calculate administration time.

Timing of the administration of cefazolin is summarized in Table 3 and illustrated in Graph 1. Cefazolin was given to 109 patients with a median time to administration of 17 minutes with a range of two to 448 minutes. Males received cefazolin on average (median) 14 minutes after arrival to the emergency department, while females received cefazolin on average 31 minutes after arrival (P = 0.0105). Patients given antibiotics in the emergency department received cefazolin 15 minutes after arrival while those not given antibiotics in the emergency department received cefazolin 214 minutes after arrival (P = 0.0009). Patients upgraded to a trauma team activation received cefazolin 14 minutes after arrival; those not upgraded to trauma received cefazolin 53 minutes after arrival (P = <0.0001).

The timing to administration of gentamicin is summarized in Table 4. Gentamicin was administered to 47 of 117 patients a median of 180 minutes after arrival with a range of 28 to 2852 minutes, illustrated in Graph 2. The time to gentamicin administration for females was 208 minutes (median), and for males was 167 minutes (P = 0.1893). Out of the 47 patients who received gentamicin, 43 received antibiotics in the emergency department and subsequently received gentamicin 175 minutes after arrival. The four patients who did not receive any antibiotics in the emergency department received gentamicin on average 625 minutes after arrival (P = 0.0256). Patients who were not activated as a formal trauma received gentamicin 263 minutes after arrival, while patients that were upgraded to a trauma activation received gentamicin 176 minutes after arrival (P = 0.3750). Patients with type I fractures received gentamicin 165 minutes after arrival; type II, 198 minutes after arrival; type III, 430 minutes after arrival; type IIIa, 160 minutes after arrival; type IIIb, 146 minutes after arrival; and type IIIc, 424 minutes after arrival (P = 0.9198). In addition to cefazolin and gentamicin, penicillin was given to five patients an average of 184 minutes after arrival. Seventeen patients received alternative antibiotics 44 minutes after arrival.

Discussion

Prompt antibiotic administration to patients with open fractures has been shown to reduce wound infection rates. Lack et al. demonstrated that a delay to antibiotic administration of greater than 66 minutes from time of injury was a major predictor of infection.[14] In order to minimize the risk of infection, our institution aims to administer antibiotics as quickly as possible.

The median time to administration of cefazolin after patient arrival was 17 minutes, showing that our institution is successful at identifying open fractures in the emergency department and providing the first dose of prophylactic antibiotics against gram-positive bacteria. However, partition-

Table 3. Summary of Timing to Cefazolin Administration

Classification Variable	N	Mean	Std Dev	Min	Q1	Median	Q3	Max	Parametric p-Value	Parametric Method	Non-Parametric p-Value	Non-Parametric Method
Time to cefazolin by gender									0.3467	t-test	0.0105	Wilcoxon
Female	26	55	63	7	15	31	81	266				
Male	83	40	71	2	10	14	30	448				
Time to cefazolin by Gustilo type									0.6564	ANOVA	0.4689	Kruskal-Wallis
1	46	54	85	2	10	17	58	448				
2	15	32	29	10	11	18	53	89				
3	5	57	89	6	11	19	33	214				
3a	12	34	58	5	8	11	33	214				
3b	8	14	7	6	9	11	19	26				
Time to cefazolin by if antibiotics given in ER									0.0464	t-test	0.0009	Wilcoxon
Yes	102	34	49	2	10	15	31	292				
No	7	177	151	22	41	214	245	448				
Time to cefazolin by trauma team activation									0.0593	t-test	<0.0001	Wilcoxon
Yes	85	37	71	2	10	14	26	448				
No	24	67	59	4	28	53	89	266				

As compared to variables including gender, Gustilo grade, if antibiotics were given in the emergency department and if the patient was upgraded to a trauma team activation.

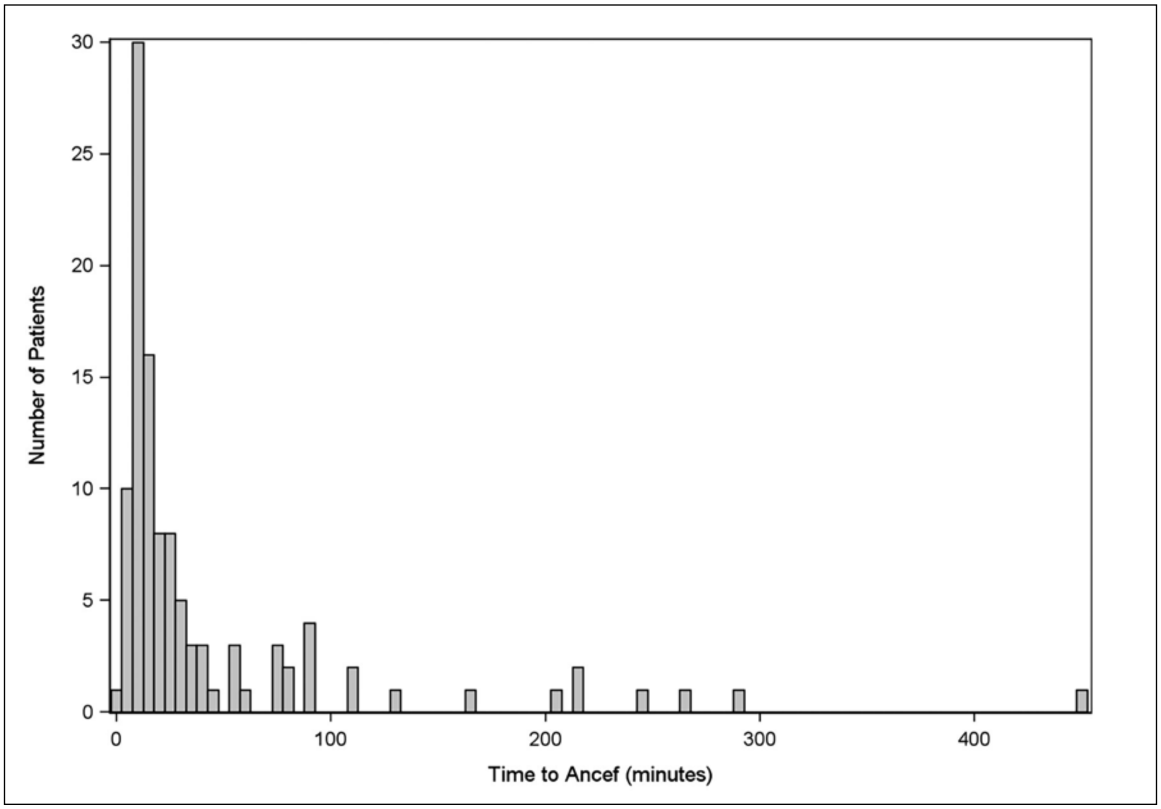
Table 4. Summary of Timing to Gentamicin Administration

Classification Variable	N	Mean	Std Dev	Min	Q1	Median	Q3	Max	Parametric p-Value	Parametric Method	Non-Parametric p-Value	Non-Parametric Method
Time to gentamicin by gender									0.1893	ANOVA	0.7294	Wilcoxon
Female	16	249	177	45	131	208	354	675				
Male	31	423	657	28	93	167	477	2852				
Time to gentamicin by Gustilo type									0.9856	ANOVA	0.49198	Kruskal-Wallis
1	3	271	266	74	74	165	574	574				
2	9	278	188	45	180	198	346	705				
3	4	393	318	36	125	430	661	675				
3a	11	424	817	28	70	160	362	2852				
3b	8	479	746	88	111	146	476	2280				
Time to gentamicin by if antibiotics given in ER									0.2851	t-test	0.0256	Wilcoxon
Yes	43	299	414	28	93	175	346	2280				
No	4	1078	1199	212	393	625	1764	2852				
Time to gentamicin by trauma team activation									0.8600	t-test	0.3750	Wilcoxon
Yes	43	370	569	28	93	176	365	2852				
No	4	319	188	175	178	263	460	574				

As compared to variables including gender, Gustilo grade, if antibiotics were given in the emergency department and if the patient was upgraded to a trauma team activation.

ing the time to cefazolin administration by variables such as gender, Gustilo type, if a patient was activated as a trauma patient, and if a patient received antibiotics in the emergency department, identified several areas for improvement regarding the care of open fractures at our institution. Preliminary statistical analysis showed that males and females received cefazolin at different times: 14 minutes and 31 minutes, respectively. After further analysis (Table 5), accounting for

Graph 1. Histogram of Time to Cefazolin Administration (Minutes)



Graph 2. Histogram of Time to Gentamicin (Minutes)

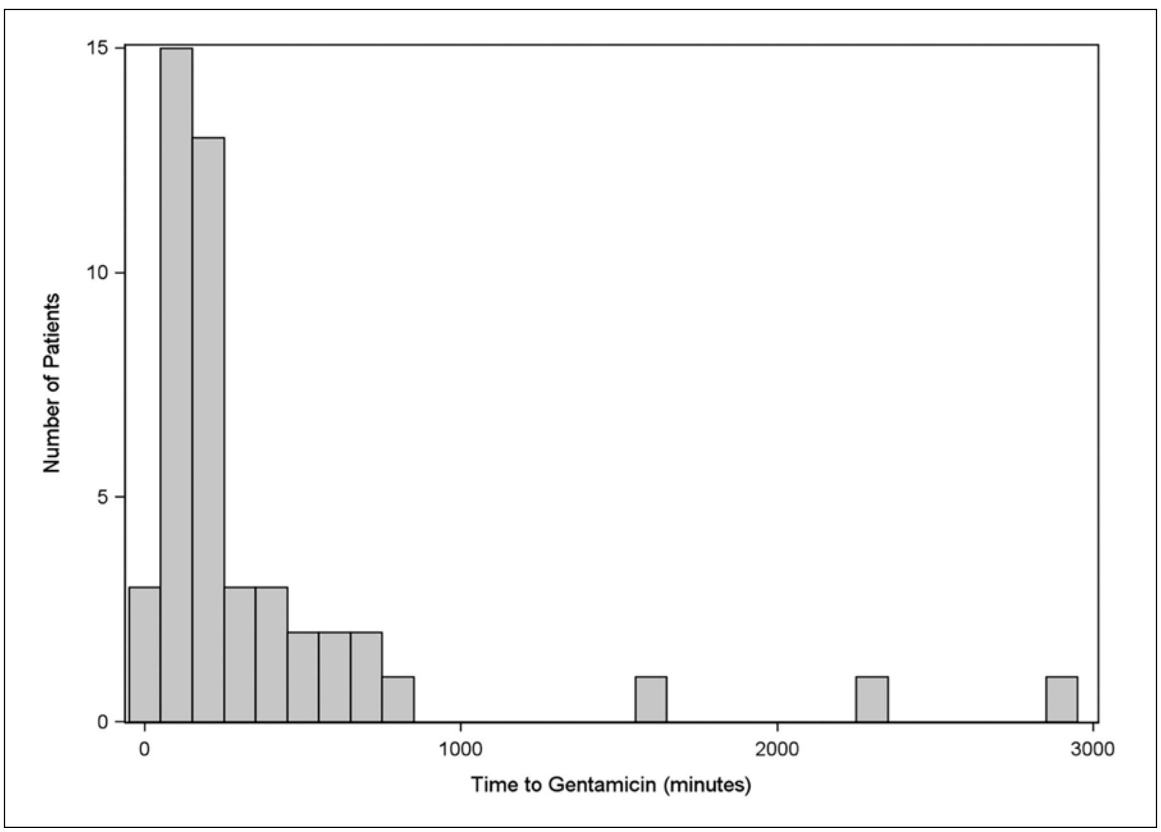


Table 5. Time to Cefazolin Partitioned by Trauma Team Activation and Gender

Variable	N	Mean	Std Dev	Min	Q1	Median	Q3	Max
Time to Ancef (minutes)								
Trauma & male	68	36	75	2	9	13	23	448
No trauma & male	15	56	46	4	19	41	76	166
Trauma & female	17	39	52	7	10	19	36	214
No trauma & female	9	85	75	13	36	81	89	266
Total	109	43	69	2	10	17	40	448

the confounding variable of whether or not the patient was upgraded to a trauma, there was no statistical difference between the timing of cefazolin administration for males and females ($p = 0.3673$). There was no statistical difference in timing to cefazolin based on the Gustilo type of the open fractures, demonstrating that protocol is being followed to provide prompt antibiotic administration regardless of the severity of the open fracture injury.

A statistical difference between the timing to cefazolin between trauma activation patients and non-trauma patients was found with the former receiving cefazolin 14 minutes after arrival and the latter receiving cefazolin 53 minutes after arrival. At our institution, cefazolin is stored in the trauma bay and is provided to all trauma patients immediately if there is clinical suspicion of an open fracture. When patients arrive to the emergency room and are not upgraded to a trauma activation, they are evaluated by the emergency department physicians in a time frame that is less predictable than those who are brought to the trauma bay urgently. Additionally, after evaluation of the patient and recognition of an open fracture, the physician must order the antibiotics through the standard medication system, which may prolong administration. Our review of the records reveals that a common delay in cefazolin administration in non-trauma patients occurs between the emergency medicine physician initial evaluation of the patient and the time that the order for cefazolin was placed. One possible explanation for this delay is that the emergency medicine physicians wait until imaging results confirmed a fracture before placing the antibiotic order. Additionally, six patient charts showed that the emergency medicine physician ordered antibiotics after consulting the orthopaedic service, which may suggest that antibiotics were forgotten until inquired by the orthopaedic team. To address this issue and reduce the timing of cefazolin administration for all patients with open fractures, our institution could consider initiating a new protocol in which all patients with open fractures are upgraded to formal trauma activations, though this may be considered an overutilization of resources.

A significant difference between the timing to cefazolin administration and the timing to gentamicin administration of 163 minutes was found, with the average time to gentamicin administration after arrival being 180 minutes. We expected a discrepancy when comparing administration times between the two antibiotics because unlike cefazolin, gentamicin is not stored in the emergency department at our institution, but rather is sent from the main hospital pharmacy following a physician's orders. Because gentamicin is dosed based on patient weight, our pharmacy had been reluctant to stock multiple different dosing preparations of gentamicin in their emergency department Pyxis medical supply system (CareFusion Corp). 180 minutes to antibiotic administration after patient arrival does not follow recommendations by Lack et al. for antibiotic administration less than 66 minutes after injury.[14] During our investigation, we found several potential reasons for this delay. First, some patients were transferred out of the emergency department prior to a physician ordering gentamicin. In other cases, when gentamicin was ordered in the emergency department, no documentation was found that it was actually administered by the nurses. Moreover, gentamicin was often given in the operating room by anesthesia, per surgeons' orders, or it was ordered postoperatively. Perhaps in these cases, the surgeon was unsure on initial consultation if the open fracture indicated gentamicin, but once the definitive diagnosis was made in the OR, it was ordered and given. It is known that the Gustilo-Anderson classification was initially designed as an intraoperative assessment tool; therefore, giving gentamicin in the OR seems reasonable if a fracture type was upgraded. However, the average time to surgical debridement was 403 minutes, so if there is a high suspicion for a high-grade fracture based on fracture pattern or obvious soft tissue damage, then gentamicin should be ordered promptly prior to debridement. Emergency department staff should be educated on the importance of providing prompt antibiotic administration with new guidelines being implemented. Perhaps if EMS reports a severe fracture during pre-hospital transport, gentamicin can be sent from the pharmacy to the emergency department in preparation for administration if the physician believes it is indicated.

There were several limitations in this current study. Due to its retrospective design and the relatively small sample size, data was limited and could only be obtained from what was presented in the medical record. Missing data and inconsistencies could contribute a source of error in data collection. Additionally, since the timing of antibiotics was determined retrospectively, common sources of delay could only be speculated.

Patients who arrive to our institution and are designated as a "trauma activation" with open fractures receive antibiotics on average in an appropriate amount of time, but there is room for improvement in the treatment of non-trauma patients and those requiring gentamicin. Further studies with a larger sample size are necessary to validate the results of this study and help identify sources of delay at our institution. Designing a prospective study exploring the timing to antibiotic administration in the emergency department and if applicable, time to wound infection based on close patient follow-up, could further establish more effective institutional protocols.

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Medical Student Research Project

Supported by The John Lachman Orthopedic Research Fund and Supervised by the Orthopedic Department's Office of Clinical Trials

Intraoperative Diagnosis of Ankle Syndesmosis Injuries

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Abstract

The distal tibiofibular syndesmotic ligaments are important for ankle stability after ankle fractures. Diagnosis of syndesmotic disruption changes treatment, postoperative rehabilitation, and prognosis in these injuries, even after successful surgical fixation of the bony fractures. Failure to recognize injury or inadequate treatment of syndesmotic injuries can lead to early degenerative arthritis of the ankle joint and limitation of long-term function. We will review the anatomy of the syndesmotic ligaments and mechanism of injury that produces instability. Preoperative and intraoperative diagnostic testing will be discussed. Technical considerations for syndesmotic fixation will be examined. Two patients will be presented who had suspicion of injury that was not definitively proven at the index surgery; subsequent x-rays showed the true diagnosis of disruption, requiring reoperation. A change in intraoperative testing will be suggested.

Introduction

Joint instability due to syndesmotic disruption after ankle fracture is an important topic for consideration for practicing orthopedic surgeons. Not only can this create issues with gait, but it has also been associated with early onset osteoarthritis.[3, 18] Unfortunately, accurate diagnosis of ligament injury and resulting instability remains an elusive goal for diagnosticians as there is no concensus in the literature as to appropriate methods of diagnosis.[2, 15] In this paper, we present a review of the relevant literature on syndesmotic injury after ankle fracture in an effort to combine and provide recommendations for diagnosis and treatment. Technical considerations for accurate reduction will also be discussed. In addition, two interesting cases of syndesmotic joint diastasis occurring in the early post-op period following anatomic open reduction and internal fixation of the ankle fractures with negative intra-operative stress testing will be presented.

The distal tibiofibular syndesmosis is made up of four main ligaments (Figure 1). The anterior inferior and posterior inferior tibiofibular ligaments are the major stabilizers;

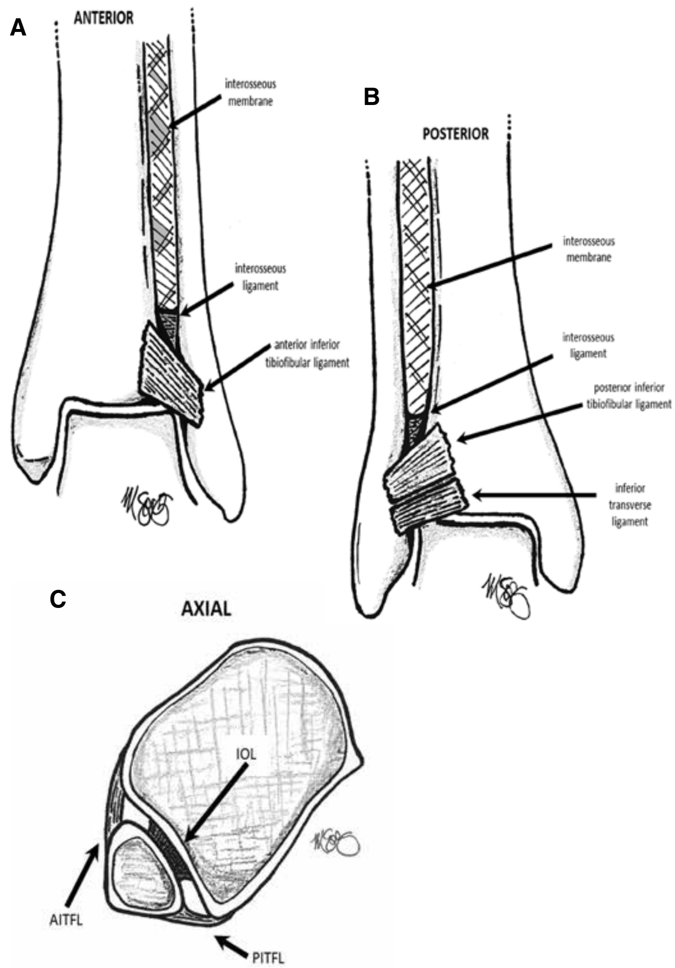

Figure 1. Anatomy of Tibiofibular Syndesmotic Ligaments. (A) Anterior view of syndesmosis. **(B)** Posterior view of syndesmosis. **(C)** Axial view of syndesmosis. IOL — interosseous ligament, AITFL — anterior inferior interosseous ligament, PITFL — posterior inferior interosseous ligament.

the interosseous ligament, a thickening of the distal interosseous membrane, and the transverse ligament, a thickening of the distal portion of the posterior inferior tibiofibular ligament, complete the syndesmotic complex.

The posterior inferior tibiofibular ligament with the tranverse ligament provides most of the strength of the complex. Note that this attaches to the posterior malleolus of the tibia and is often involved with posterior malleolar fractures.

The anterior inferior tibiofibular ligament originates from the Chaput tubercle of the anterior lateral tibia. The posterior inferior tibiofibular ligament originates from Volkmann's tubercle on the posterior lateral tibia and both ligaments insert into the distal medial fibula on their respective surfaces. The distal fibula articulates into the incisura fibularis on the posterior lateral aspect of the distal tibia; this does provide a small amount of bony support, but syndesmotic ligament integrity is critical for stability. The syndesmosis not only stabilizes the ankle joint, but also allows the fibula to translate, rotate, and proximally migrate during ankle dorsiflexion. It allows the fibula to share 16% of the axial load during weight bearing.[21]

Radiographic measurements provide one method of evaluating the anatomy of the tibiofibular syndesmosis. Frequently used measurements include tibiofibular clear space (TFCS), tibiofibular overlap (TFO), and medial clear space (MCS). Hermans et al. define TFCS as the horizontal distance between the posterolateral border, the anterolateral border, or the incisura fibularis of the tibia and the medial border of the fibula.[2] TFO is defined as the horizontal distance between the medial border of the fibula and the lateral border of the anterior tubercle, 1 cm above the tibial plafond. MCS is the widest distance between the medial border of the talus and the lateral border of the medial malleolus, 0.5 cm below the talar dome. The normal values for TFO were 8.3 mm on the AP view and 3.5 mm on the mortise view. Values for the TFCS were 4.6 on the AP and 4.3 on the mortise views. These values were determined by Shah et al. in a retrospective study of over 1400 patients.[19] In a study of 564 ankle radiographs, a normal value on the mortise view for MCS was determined to be 2.7 mm with a standard deviation of 0.5 mm.[20]

Besides radiographic evaluation, fracture classification type heightens suspicion of syndesmotic injury. Danis-Weber classification is based on the level of fibular fracture. Type A fractures are below the level of the syndesmosis, Type B fractures are at the level of the syndesmosis, and Type C fractures are above the level of the syndesmosis and these later fractures imply frequent disruption of the tibiofibular ligaments. The Lauge-Hansen classification is based on the position of the foot at the time of injury, as well as the direction of force applied to the ankle. They are also graded from one to four based on the extent of the injury. Supination adduction fractures cause a vertical fracture of the medial malleolus with a transverse fracture of the fibula below the level of the syndesmosis or a tear of the lateral collateral ligaments and are not associated with syndesmotic injuries. Supination external rotation injuries start at the anterior tibiofibular ligament, progress to a spiral fracture of the fibula at the level of the syndesmosis, produce an injury to the posterior tibiofibular ligament or a fracture of the posterior malleolus, and a transverse fracture of the medial malleolus or a deltoid ligament disruption. Pronation abduction injuries start with a transverse fracture of the medial malleolus or a deltoid ligament disruption, then progress to injury of the syndesmotic ligaments, and end with a horizontal or comminuted fracture of the fibula above the level of the syndesmosis. Pronation external rotation injuries also begin with a transverse fracture of the medial malleolus or deltoid ligament injury, then progress to an anterior inferior tibiofibular ligament injury, then an oblique fracture of the fibula above the syndesmosis and finally, a posterior inferior tibiofibular injury or posterior malleolar fracture. Syndesmotic injuries are most common in pronation external rotation, pronation abduction, and supination external rotation injuries.[21]

The diagnosis of pre-operative syndesmotic stability is important for all ankle fractures. There are some physical findings which can help in the diagnosis of syndesmotic injury in non malleolar ankle fractures, but are impractical when the malleolus is fractured. These include the squeeze test or manual compression of the tibia and fibula above the joint level, tenderness over the anterior syndesmotic ligaments, and pain with dorsiflexion and external rotation.[23] Evaluation of plain radiographs should follow the physical exam. Obvious syndesmotic disruptions, such as Maisonneuve fractures, pronation external rotation injuries with high fibular fractures, and fracture/dislocations with gross tibiofibular separation clearly indicate syndesmotic ruptures. Somewhat more difficult to evaluate are supination external rotation fractures or Weber B fractures at or just above the level of the syndesmosis. Specific radiographic measurements can aid in the diagnosis of syndesmotic injuries. Nielson et al. showed that a medial clear space measurement greater than 4 mm was correlated with deltoid and tibiofibular disruption.[8] They also showed that tibiofibular clear space and tibiofibular overlap did not correlate with syndesmotic injury.[6, 8] Hermans et al. echoed these findings of no correlation between tibiofibular clear space and tibiofibular widening and syndesmotic disruption.[2] Interestingly, they also showed that medial clear space widening did not correlate with deltoid ligament injury contrary to the previous study. In a systematic review, van den Bekerom advised that these radiographic measurements are of limited clinical value and using any one on its own for diagnosis would be ill advised.[16] Hermans also tested diagnostic reliability of the fracture classification symptoms mentioned previously. They showed that the Weber classification system had a sensitivity of 47% and specificity of 100% when detecting syndesmotic injuries. The Lauge-Hansen classification system demonstrated both sensitivity and specificity of 92%.[2] Boden stated that rigid medial and lateral fracture fixation should acceptably stabilize the syndesmosis without further stabilization.[25] This has not been clinically supported.[26]

Current teaching states that stress testing under fluoroscopy has been the main clinical exam performed to evaluate intra-operative syndesmotic stability. The Cotton or hook test involves grasping the plated fibula with an instrument and attempting to laterally translate the fibula, while observing the tibiofibular clear space on the AP view, which reveals the least amount of variability due to rotation.[24] In a prospective study, Pakarinen et al. showed the hook test to have a sensitivity of 0.25 and a specificity of 0.98 when evaluated against a standardized 7.5 Nm external rotation stress test.[1]

The second intra operative stress test used is the dorsiflexion-external rotation test. Position is important in performing this test and the leg should be stabilized in approximately 10 degrees of internal rotation to get a good mortise view. The ankle is then put up on a bolster with the heel free and the foot dorsiflexed to neutral. An external rotation force of eight to 10 pounds is then applied to the ankle. The leg must be stabilized by grasping higher on the proximal tibia or knee to avoid inadvertent fibular compression. Instability is determined by talar subluxation or medial clear space widening, comparing pre/post external rotation stress. Talar subluxation can be measured by comparing the lateral edge of the talar dome to the lateral edge of the tibial plafond. A positive result was defined as a side to side difference of greater than 2 mm in the tibiotalar or tibiofibular clear space on the mortise view (Figure 2). Pakarinen et al. showed a sensitivity of 0.58 and a specificity of 0.96 for the external rotation stress test.[1] Many surgeons utilize live fluoroscopic images to evaluate these tests; however, better comparisons can be made with spot fluoroscopic images before and during the stress testing.

Intra-operative CT scanning has been reported to yield higher diagnostic accuracy of syndesmotic injury, but this modality is not readily available in most centers.[6, 13] MRI appears to be the most reliable technique for detecting syndesmotic injury, even compared to direct visualization of the syndesmosis via arthroscopy. Oae et al. demonstrated sensitivity and specificity of 93 to 100% for syndesmotic disruption.[9] Obviously, MRI is limited in its clinical use due to issues of price and availability and may be useful for further research on the subject.[4]

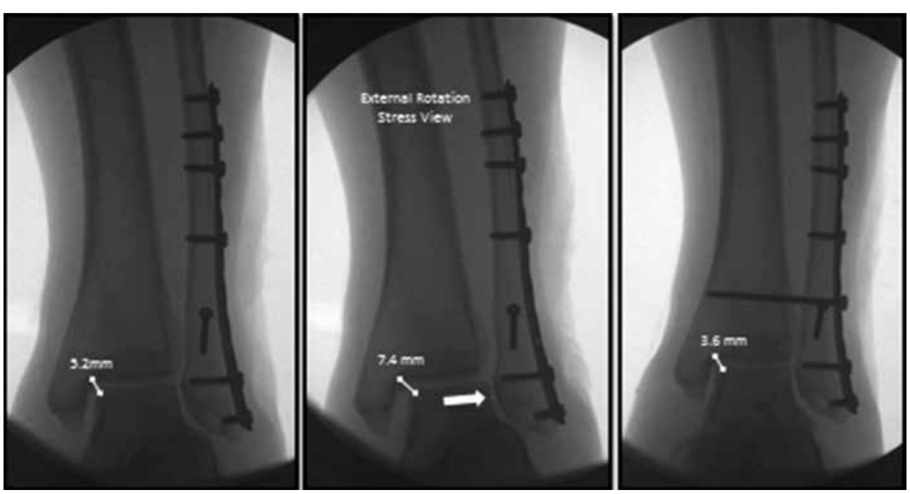

Figure 2. Dorsiflexion-External Rotation Stress Testing of Syndesmosis. (A) Medial clear space (arrow) after ORIF of lateral malleolus. **(B)** With dorsiflexion-external stress applied. Note widening of medial clear (small arrow) space and talar subluxation (large arrow). **(C)** After reduction of syndesmosis and screw fixation with restoration of medial clear space.

The technique of reduction of syndesmotic disruptions is important to prevent malreductions. Malreductions are quite common and have been reported to be as high as 50%. Major factors to consider include fibular length, rotation, sagittal plane translation and over compression.[6] Anatomic fibular reduction normally will correct length and aid in obtaining proper rotation; comparison to the opposite normal ankle can often be helpful. Application of a large reduction clamp is commonly used. The vector should be at the level of the syndesmosis, not proximal or distal. The tines of the clamp should be placed at the mid point of the fibula and at the center of the AP width of the tibia. It should be perpendicular to the long access of the tibia. This results in the most accurate reduction of the syndesmosis.[23] Even 1 cm of displacement of the clamp either anterior or posterior can lead to malreduction. Foot position during fixation has been challenged by Tornetta,[27] but most surgeons still dorsiflex the ankle to neutral to bring up the widest portion of the talus into the mortise to prevent over tightening.

There are a number of controversies regarding syndesmotic fixation. One of the major issues is the number of screws used for fixation. Peek et al. wrote a thorough literature review on the subject and determined that there was no difference in outcome using one screw as opposed to two.[22] In a cadaveric study, Thompson et al. concluded that there was no evidence of biomechanical advantage of a 4.5 mm screw compared to a 3.5 mm screw.[12] Peek in his review also reached the same conclusion with the added recommendation that the 4.5 mm screw may provide more resistance against breakage due to shear stress. Three or four cortical fixation is also controversial, although four cortical fixation has been shown to have more screw breakage if left in permanently. Some orthopedic surgeons have been using a TightRope® suture button system as an alternative to screw fixation. In a retrospective review, 37 patients who had undergone either 4.5 mm syndesmotic screw fixation or TightRope® fixation were evaluated. There was no statistically significant difference in outcomes between the two groups.[11] These findings were confirmed in a prospective randomized controlled trial by Kortekangas et al.[7] Concerns remain regarding strength when used with ligament-only disruptions, failure with load, and the high cost of the suture button technique. Whether or not to remove the syndesmotic screw after a period of time is a vexing issue for many practicing surgeons. Time to weight bearing, as well as screw breakage with or without symptoms, can also be problematic. Unfortunately, there is a lack of randomized controlled trials on this subject. Schepers et al. and Peek et al.

report similar outcomes in patients who retain the screw compared to patients who had the screw removed. The authors argue that screw removal seems to be only justified if there are patient complaints on the issue and that broken screws did not provide any worse outcomes.[10, 22]

Case Studies

We have two case studies that bring to light many of the issues previously discussed in the intra-operative diagnosis and management of syndesmotic injuries. Case 1 is that of an 81-year-old female who fell and sustained a bimalleolar equivalent Weber B fracture or supination external rotation 4 injury to the right ankle (Figure 3A–B). She was initially treated with a cast and elevation to minimize swelling and control her pain. There was lateral talar shift with an increased medial clear space seen on the initial x-rays. Because she had minimal swelling, she underwent ORIF of the lateral malleolus the next day with anatomic reduction obtained. Intra-operative fluoroscopy showed anatomic reduction of the fracture and reduction of the medial clear space (Figure 3C). A Cotton test and dorsiflexion external rotation test were both performed under fluoroscopic guidance and showed no widening of the medial clear space and no apparent tibiofibular diastasis. The syndesmosis was determined to be stable and the patient was placed in a short leg cast non weight bearing. At her two week follow up visit, an x-ray in the cast showed loss of reduction of the joint with widening of the medial clear space (Figure 3D). There was no hardware failure. The patient was taken back to the operating room and the ankle was reduced and held with a large bone clamp with the tines perpendicular to the long axis of the tibia. A four cortical 3.5 mm screw was placed across the syndesmosis and reinforced with a TightRope® suture button (Figure 3E). Post reduction x-rays showed restoration of the normal medial clear space. There was no instability on repeat stress testing and the patient was casted. Ankle range of motion was started in a removable boot at least six weeks post op, but weight bearing was delayed till four months post injury due to her osteoporotic bone. Serial x-rays showed maintenance of the reduction, weight bearing was progressed gradually, and she went on to uneventful healing. The syndesmosis screw was not removed and it remained intact on her one-year follow-up x-rays (Figure 3F).

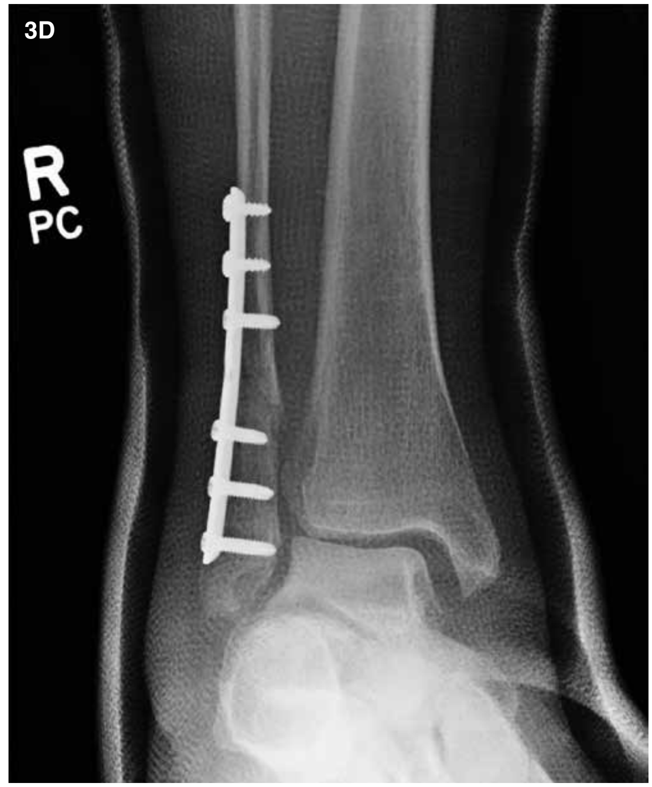

Figure 3. Patient 1. (A–B) Original mortise and lateral x-ray views showing supination external rotation 4 injury pattern. **(C)** Intraoperative fluoroscopic view after ORIF lateral malleolus. **(D)** Office x-ray at two weeks postoperatively showing increased medial clear space and loss of reduction. **(E)** Intraoperative fluoroscopic view after syndesmotic fixation at second procedure with screw and TightRope® suture button. **(F)** Office x-ray at one year postoperatively showing holding of reduction.

Case 2 is that of a 57-year-old female who twisted her ankle when she fell at home. She sustained a pronation abduction Weber C trimalleolar fracture of her left ankle (Figure 4A). She had significant swelling and was treated with a cast, elevation, ice, analgesics, and non weight bearing for 10 days. X-rays revealed a lateral talar shift with displacement of the medial malleolus and a small posterior malleolar fragment compromising 10 to 15% of the posterior articular surface. After the swelling decreased significantly, she was taken to the operating room where open reduction internal fixation was done of both malleoli using a 1/3 tubular neutralization plate laterally and two 4.0 cannulated screws medially (Figure 4B). Post reduction fluoroscopic x-rays showed anatomic reduction of the fracture and both Cotton and dorsiflexion external rotation tests were negative. She was kept non weight bearing and at her two week post op visit, x-rays in the cast revealed a lateral talar shift and an increase in the medial clear space (Figure 4C). She was taken back to the operating room where two 4 cortical 3.5 mm screws were inserted after reduction of the syndesmosis with a large bone clamp. Post-op x-rays showed anatomic reduction of the ankle and syndesmosis and she was started on non weight bearing ambulation (Figure 4D). Early follow up x-rays showed holding of the reduction and no hardware breakage, but the patient did not return for long-term follow-up (Figure 4E).

Figure 4. Patient 2. (A) Initial mortise x-ray view consistent with pronation abduction type injury pattern with transverse Weber C fibular fracture. **(B)** Postop mortise x-ray demonstrating internal fixation of medial and lateral malleoli. **(C)** Office x-ray at two weeks postoperatively showing loss of reduction and widening of medial clear space. **(D)** After repeat procedure with reduction and fixation of syndesmosis with two cortical screws. **(E)** Office x-ray at one month postoperatively showing good position of ankle mortise.

Discussion

The diagnosis of syndesmotic injury after ankle fractures remains a difficult diagnostic challenge. Maisonneuve fractures and obvious fracture dislocations are clear cut, but supination external rotation 4 injuries, especially with posterior malleolar fractures, remain problematic. Fracture classification systems are a commonly-used option for the diagnosis of potential syndesmotic disruption. Unfortunately, the Danis-Weber system, when combined with radiographic measurements, yielded low sensitivity but a high specificity.[2] The Lauge-Hansen classification performed much better in these respects, although using it as a sole criteria for diagnosis may be inadvisable.[2, 16] Adding intra operative stress testing, such as the Cotton test and dorsiflexion external rotation test help in diagnosis and while having high specificities, also show low sensitivities making them not totally reliable for diagnosis.[1, 14, 16, 17] CT scanning is more accurate but not readily available in most settings.[6, 13] MRI gives high sensitivity and high specificity, but it does not provide evidence of syndesmotic instability, only injury. Its use is better for pre-op evaluation of questionable injuries or for clinical research.[4, 9]

Once the diagnosis is made intra operatively, treatment options also are not definitive. Our review of the literature has shown that the number of syndesmotic screws, screw size, the number of cortices used for fixation, and the use of a suture button all seem to have no effect on outcome. Screw removal seems not to influence the ultimate result.[7, 10, 11, 22] More surgeons now are fixing larger posterior malleolar fractures, the site of attachment of the posterior inferior tibiofibular ligament, when associated with syndesmotic instability, to anatomically stabilize the syndesmosis.

Our two patients have provided examples of the problems associated with intraoperative diagnosis of syndesmotic instability. Although rigid anatomic fixation of the lateral malleolar fracture was obtained in both cases and neither patient had instability on fluoroscopic stress testing, both of the patients exhibited medial clear space widening at their two-week post-op visit, indicating true syndesmotic instability. Intraoperative comparison of spot fluoroscopic mortise x-ray views after internal fixation and then after stress testing may have demonstrated the true instability better. Technical application of the clamp, screw positioning, and avoidance of over compression is also important in avoidance of malreduction.

Further research and long-term studies of the effects of syndesmotic disruption will continue to improve orthopedic surgeons' treatment of these difficult injuries.

The authors gratefully acknowledge the anatomic drawings provided by Mark Solarz, MD used for illustration.

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Medical Student Research Project

Supported by The John Lachman Orthopedic Research Fund and Supervised by the Orthopedic Department's Office of Clinical Trials

Efficacy of Robotic-Assisted Total Hip Arthroplasty

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Abstract

Total hip arthroplasty (THA) has become a common procedure and robotic-assisted techniques are being implemented to help improve outcomes. These robotic-assisted systems are thought to increase accuracy of acetabular component placement and, therefore, may decrease rates of dislocation. This study compares radiographical and clinical outcomes in robotic-assisted vs. traditional THA techniques. This retrospective chart review studied 102 patients who underwent THA by traditional techniques and 58 patients who underwent robotic-assisted THA. The two groups were matched for age, sex, BMI, rates of DM, and rates of HIV/HCV. Variables analyzed from the operative report included operating time (OR) and estimated blood loss (EBL) while post-surgical radiographs yielded measurements of acetabular component anteversion and inclination. Other variables included length of hospital stay and dislocation rates between the two groups. The results indicate that OR time was significantly longer in the robotic-assisted group ($p < 0.05$). The number of dislocations was greater in the robotic-assisted group, though these conclusions merely approached significance ($p = 0.0583$). There was no significant difference in anteversion and inclination between the two groups. Increased OR times can potentially lead to increased costs to providers and increased risks for patients. With this in mind, and no guaranteed increase in accuracy of placing the acetabular component, use of robotic-assisted systems should be carefully considered in THA.

Introduction

Total hip arthroplasty (THA) is an increasingly successful procedure and the indications are expanding to include younger and younger patients as a result. As the quest for perfection continues, the advent of robotic-assisted techniques works to improve one of the most vital aspects of the THA: placement of the acetabular component. Improving acetabular cup position reduces the risk of complications from THA including early dislocation, component impingement, leg length discrepancy, and revision among others.[2, 10] Proper inclination of 40° ± 10 and anteversion of 15° ± 10 place the acetabular component in the desirable safe zone as described by Lewinnek,[9] in an effort to mimic the patient's natural anatomy and significantly decrease the risk of dislocation.

The robotic-assisted system uses computer navigation technology to provide advantages in acetabular cup placement.[18] Pre-operative planning and intraoperative feedback from the system is designed to increase the surgeon's accuracy in placing the acetabular component by guiding the surgeon during both the acetabular-reaming and cup implantation steps. The Robotic Arm Interactive Orthopedic System utilized during the procedure restricts the reaming process to a predetermined area while the computer provides feedback regarding depth. This area is determined pre-operatively using a Computed Tomography (CT) scan. Use of the system may eliminate the need for a trial cup before final cup placement[13] During the cup implantation step, the robotic arm holds the acetabular cup component at the desired anteversion and inclination angles, which are determined pre-operatively. The goals of robotic-assisted arthroplasty are intended to increase accuracy and decrease the number of complications.

The null-hypothesis for this study is robotic-assisted THA (RA) does not increase accuracy of acetabular cup placement nor improve clinical outcomes such as dislocation compared to manual implantation THA (MA) techniques. A secondary goal of this study was to identify variances in outcomes such as operative time, estimated blood loss, and length of hospital stay in robotic-assisted vs. manual implant THA.

Materials and Methods

After Institutional Review Board approval was obtained, a retrospective chart review was conducted at an urban, academic medical center. A list of subjects was generated using International Classification of Diseases Ninth Revision code

81.51 to identify patients who underwent total hip arthroplasty. The study examined individuals who had THA over a four-year period between January 1, 2011 and January 1, 2015. Only patients over the age of 18 were included in the study. Those patients who were lost to follow-up within six months after surgery were not included in the study. All patients included in the study had anterior-posterior (AP) X-rays taken immediately following the surgical procedure.

Patients were divided into control and experimental groups. The control group consisted of patients who had total hip arthroplasty using traditional, manual implant technique. The experimental group consisted of patients who received total hip arthroplasty using robotic-assisted implant technique. One attending surgeon performed all of the procedures.

Demographic and clinical data were obtained from patients' medical records. Demographic information consisted of patients' age at the time of the surgery and gender. Pertinent comorbidities were also obtained from patients' medical records and included BMI, smoking history, diabetes mellitus, rheumatoid arthritis, Human Immunodeficiency Virus (HIV), and Hepatitis C virus (HCV). Operative variables were obtained from the operative report including estimated blood loss and total operative time. Post-operative variables included acetabular component anteversion and inclination, length of hospital stay and reason for readmission if applicable. Anteversion was measured on post-operative X-rays using the technique described by Lewinneck[9] and confirmed by Nho.[12] Measurements were taken of the short and long axis of the acetabular component ellipse and anteversion was calculated using the equation anteversion = arcsin (short axis/long axis). Inclination was measured on the same AP radiographs as the angle between the line of the long axis of the ellipse and the inter-teardrop line. Length of hospital stay was measured as the day of admission for the surgery to the day of discharge.

Descriptive statistics were calculated to characterize both continuous and categorical variables. Data was presented as a mean with standard deviation, or percentages where applicable. Each variable was compared between both the RA and MA group using univariate analysis. Association of continuous variables and a specific group were assessed using the two sample independent t-test. Association of categorical variables with a specific group was analyzed using the Chi-Square test (or Fisher's exact test where appropriate). Statistical significance was defined as $P < 0.05$. In some circumstances, P values greater than 0.05 were considered for discussion. All statistical analyses were conducted using SAS® 9.4

Results

A total of 160 patients were included in the study with 102 assigned to the MA group and 58 included in the RA group. Characteristics of all patients receiving total hip arthroplasty are expressed in Table 1. 53.1% of patients were male and the average age of the cohort was 59.8 ± 11.0. The average patient included in the study was classified as obese with a mean body mass index of 30.4 ± 7.0. The incidence of diabetes mellitus in the cohort was 23.8% and rheumatoid arthritis was seen in 2.5% of patients. Patients diagnosed with either HIV or HCV were considered high risk and made up 13.1% of the cohort. A total of 66.3% of patients identified as either current or former smokers.

Table 1

Variable	Description of Cohort
Age (years)	59.8 ± 11.0
Male (%)	53.1
Female (%)	46.9
BMI	30.4 ± 7.0
Diabetes mellitus (%)	23.8
Rheumatoid arthritis (%)	2.5
High risk (%)	13.1
Current or former smoker (%)	66.3

Table 2 shows univariate analysis of THA patients separated into MA and RA groups. There was no statistical difference between the MA and RA groups on the basis of age, gender, and BMI. Comorbidities such as diabetes and rheumatoid arthritis were not statistically different between the two groups. There was no statistical difference in the number of high risk surgeries performed. The difference in the number of smokers was statistically significant with 75.5% of the MA group and 50.0% of the RA group reportedly smoking ($p = 0.0010$).

Table 2

Variable	MA	RA	P-value
Age (years)	58.7 ± 10.3	61.5 ± 12	0.1262
Male (%)	53.9	51.7	0.7889
Female (%)	46.1	48.3	0.7889
BMI	30.0 ± 6.3	31.1 ± 8.1	0.3469
Diabetes mellitus (%)	25.5	20.7	0.4927
Rheumatoid arthritis (%)	3.9	0	0.2974
High risk (%)	11.8	15.5	0.4992
Current or former smoker (%)	77.5	50.0	0.0010

Table 3 reports operative and post-operative variables compared between the MA and RA groups. Analysis of estimated blood loss and length of follow up revealed no statistical difference between the two groups. There was a highly significant difference in OR times ($p < 0.0001$) with a mean time of 113.3 minutes ±41.7 in the MA group compared to a mean time of 142.4 minutes ±42.3 in the RA group. Length of hospital stay was also significantly different between the two groups ($p = 0.0184$) with the MA group averaging a longer stay at 4.1 days compared to just 3.2 days for the RA group. The difference in post-operative dislocation incidence between the two groups is marginally significant ($p = 0.0583$) with 1.0% of the MA group experiencing dislocations compared to 6.9% of the RA group.

Table 3

Variable	MA	RA	P-value
Estimated blood loss (mL)	504 ± 330	565 ± 401	0.3089
Length of follow-up (months)	4.9 ± 2.9	4.3 ± 2.4	0.2045
OR time (minutes)	113 ± 41.7	142 ± 42.3	< 0.0001
Length of hospital stay (days)	4.1 ± 3.1	3.2 ± 1.0	0.0184
Dislocation (%)	1	6.9	0.0583

Table 4 reports the percentage of patient implants measured within the safe zone of anteversion and inclination. Anteversion was considered safe between ≥15° and ≤35°. Inclination was considered safe between ≥30° and ≤50°. There was no significant difference in the number of implants in the anteversion safe zone (p-value 0.1206) or the inclination safe zone (p-value 0.8292).

Table 4

Variable	MA	RA	p-value
Anteversion safe zone (%)	80.2	89.7	0.1206
Inclination safe zone (%)	83.2	84.5	0.8292

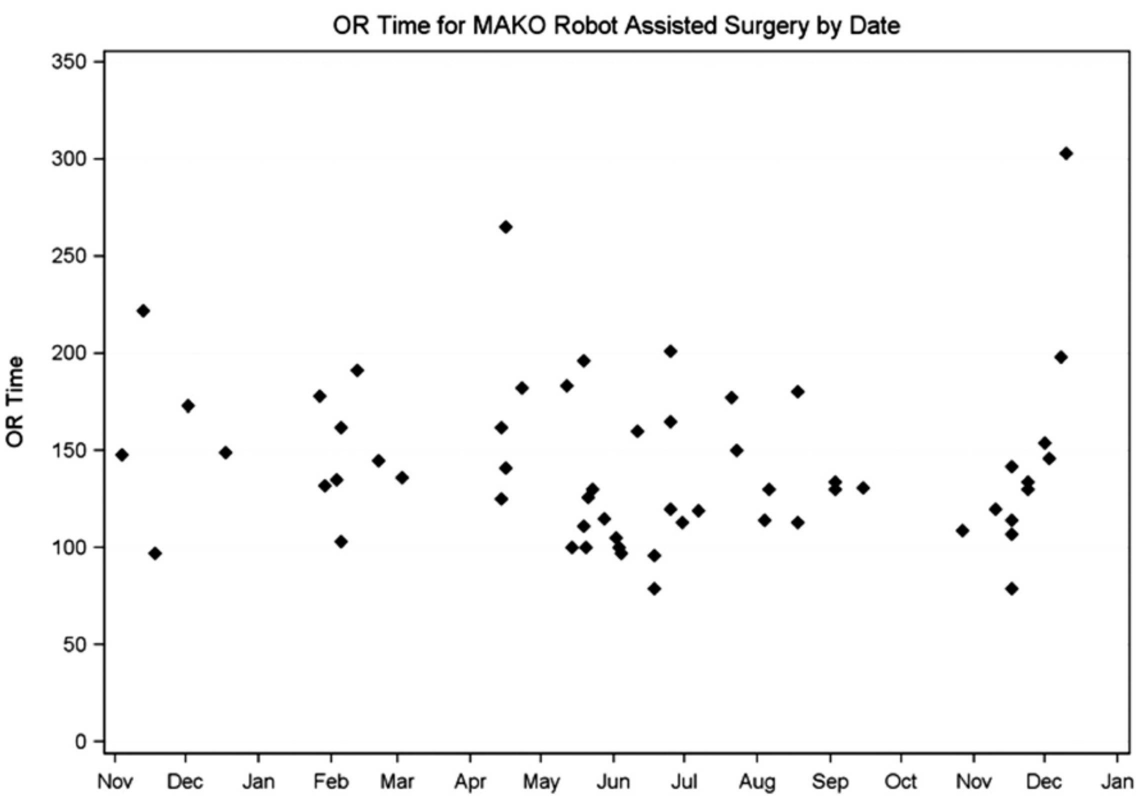
Graph 1 shows OR time compared with the date of surgery for the RA group. Correlation analysis was performed using three separate tests: Pearson Correlation Coefficient (p = 0.5539), Spearman Correlation Coefficient (p = 0.3197) and Kendall Tau b Correlation (p = 0.3755). All three tests showed no significant correlation between OR time and date of surgery.

Discussion

Although studies have reported increased accuracy[4, 18] and OR times[8, 16] using robotic-assisted arthroplasty, few studies have discussed outcomes such as dislocation rates among patients. This study analyzed data from 160 patients receiving total hip arthroplasty over a four-year period at an urban, tertiary academic hospital. Although there was a significant difference in length of hospital stay between the MA and RA groups, further investigation revealed a change in department policy regarding required length of stay post THA, indicating the source of the difference in time.

There were significantly longer OR times for robotic-assisted arthroplasty compared to traditional arthroplasty techniques. This may be attributed to multiple factors including physician learning curve and use of the GPS marking system for placement of the acetabular component. Correlation analysis between OR time and date of surgery showed no significant correlation between these two variables, suggesting the physician learning curve may not have had a role in longer OR times in the RA group. Notably, as patients continue to meet inclusion criteria for this study and a larger sample size for the RA group is obtained, a learning curve may be appreciated. Regardless of the source, longer OR times can lead to increased costs and increased risk for patients.

A greater percentage of patients in the RA group had acetabular components placed in the anteversion and inclination



Graph 1

safe zones compared to the MA group; however, this difference was not found to be significant. Further studies with larger patient populations are certainly indicated. The RA group saw a higher rate of dislocations compared to the MA group and this difference was found to be marginally significant ($p = 0.0583$). It is interesting that the group with a greater percentage of patients within the safe zone had a greater percentage of dislocations. This may suggest that these dislocations are multifactorial and may not be adequately predicted by the safe zone alone as some studies have described.[1, 5, 14]

Some limitations to this study include the fact that this was a retrospective study performed on one group of patients who had THA performed by one surgeon. The RA group was smaller than the MA group; however, as new patients meet the inclusion criteria, follow-up studies may be indicated.

With longer OR times and no assurance of increased accuracy of acetabular cup placement, the use of the RA system should be carefully considered in total hip arthroplasty patients. These findings provide valuable information for surgeons and reveal the need for future studies regarding robotic-assisted total hip arthroplasty.

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Review Article

The History of Femoral Intramedullary Nailing

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Abstract

The development of the intramedullary nail is among the most important innovations in last century for the treatment of long bone fractures. Almost 80 years after Dr. Gerhard Küntscher popularized the femoral nail, this device has become one of the most commonly used implants in orthopaedic trauma surgery. The intriguing history of this technique for fracture care dates back to the 16th century and includes numerous advances in radiology, antibiotics, metallurgy, engineering, and the understanding of fracture biology. Although Küntscher's efforts were no doubt instrumental in the development of intramedullary nailing, numerous surgeons over the last century are responsible for furthering this marvelous invention. Fascinatingly, while nail designs and surgical techniques have evolved greatly since Küntscher's initial efforts, the basic principles of fracture care with intramedullary nails remain the same. As modern innovators continue to improve upon the intramedullary nail, it is important not to lose touch with its captivating history.

Introduction

"Amazing Thighbone," was a *Time* magazine article from March of 1945 reporting on an American soldier captured during World War II (WWII) who required surgery by German doctors for a fractured femur.[1, 2] The soldier was astonished to find a mere 2.5-inch incision over his thigh after surgery; furthermore, he was able to walk on the leg only a few days later.[2] Radiographs revealed a metallic rod in the soldier's femur, similar to findings in other American soldiers returning from WWII reporting the same treatment.[2] The article went on to illustrate the skepticism of American surgeons regarding this new technique which was yet to be described in the English medical literature.[1, 2] Almost 80 years later, it is clear that the development of the modern intramedullary nail (IMN) by Dr. Gerhard Küntscher in Germany is one of the most important contributions to orthopaedic surgery in the last century.

Early Intramedullary Nails

Spanish conquistador, Hernando Cortes, and anthropologist, Bernardino de Sahagun, first reported the use of intramedullary nails in the 16th century.[1, 3, 4] When exploring the Americas, they observed that Incas and Aztecs placed resinous wooden pegs inside the medullary canal of long bones to treat fracture non-unions.[1, 3, 4]

In 1886 in Germany, H. Bircher reported the use of ivory pegs in fracture care, and F. König again noted this technique in 1913.[1, 4–6] In the absence of infection, the ivory pegs were noted to gradually resorb by the body over a period of years.[1, 4–6] This was in contrast to metallic or other devices that were found to become encapsulated in fibrous material.[1, 4]

The German surgeon, Themistocles Gluck, reported the first interlocked intramedullary device in the 1890s. His invention was an ivory peg that contained holes in the ends through which ivory interlocking pins could be inserted.[1, 7] In 1917, U.S. surgeon, Emil Hoglund, reported the use of autologous bone pegs made from a length of cortex in place of ivory pegs.[1, 4, 8]

In Belgium in 1907, Albin Lambotte reported the use of long metallic screws in the medullary canal for intertrochanteric and subtrochanteric femur fractures. These screws were inserted through the tip of the greater trochanter.[4, 9]

Julius Nicolaysen of Norway outlined the principles of intramedullary nailing for fracture treatment in 1897 and is considered by some to be the true "father of intramedullary nailing."[4, 10] His work is notable for emphasizing longer nails that spanned the length of the medullary canal for improved biomechanical stability.[1, 4, 10]

During World War I (WWI), English surgeon, Ernest William Hey Groves, used intramedullary nailing on femur fractures caused by gunshots.[4, 11] His nails extended only three inches into the distal fragment and were inserted in an open, retrograde fashion through the fracture site.[4, 11] His method was a failure secondary to high infection rates, however, causing him to abandon this technique.[4, 11]

In 1931, Norwegian-born American physician, Marius Nygaard Smith-Petersen, reported success utilizing triflanged, stainless steel nails for treatment of acute femoral neck fractures.[12] Stainless steel is an alloy of iron and at least 11% chromium (as well as nickel, molybdenum, etc.) producing a relatively inert metal that resists corrosion, making it ideal for medical implantation.[13, 14] Its discovery is often attributed to Harry Brearley, an English metallurgist who first produced stainless steel in Sheffield, England in 1913.[14, 15] Smith-Petersen's successful use of the corrosion-resistant metal in implants led to the expanded use of metallic implants in bone surgery.[1]

Albin Lambotte in 1924 and Joly in 1935 described intramedullary nailing of the upper extremity.[4] These Belgian surgeons used Kirschner wires in the medullary canal to stabilize forearm fractures. Similarly, Leslie and Lowry Rush of Mississippi in 1937 used Steinmann pins in the medullary canal of the ulna to treat forearm fractures making them the first U.S. surgeons to describe metallic IMN use.[1, 4, 16] They also described IMN fixation of femur fractures with pins in 1939.[1, 16] Leslie Rush went on to manufacture larger, flexible, stainless steel pins ("Rush Rods") for treatment of fractures throughout the body.[4, 17]

Küntscher's Intramedullary Nail

The modern IMN with a design and insertion technique similar to contemporary nails was first described by Küntscher in 1940.[4, 18] Inspired by Smith-Petersen's stainless steel femoral neck nail, Küntscher believed that similar nails could be used in diaphyseal fractures as a load sharing device.[1] His original stainless steel IMN developed in 1939 had a "V" cross-sectional shape (Figure 1).[1, 4, 18, 19] It was placed antegrade in the femoral shaft away from the zone of injury and inserted at the tip of the greater trochanter to avoid femoral neck fracture, intracapsular infection, and avascular necrosis.[4, 20] He used a system of slings as reduction tools and head fluoroscopy for radiographic visualization of the bone (Figure 2).[1] The V-shaped nail was later replaced by a hollow, slotted, cloverleaf-shaped nail that provided more strength and passed more easily over a guide wire (Figure 3).[1, 4] Both nail designs were more flexible than modern nails allowing these straight nails to conform to the bow of the femur; however, if the nails were not pre-bent prior to insertion, they did risk straightening the femur at the fracture causing a malunion.[4, 20, 21] The cloverleaf-shaped nail was engineered to wedge into the diaphysis of the fractured bone by compressing in its cross-section and thus exerting pressure on the inner walls of the medullary canal causing a compressive fit and lending increased stability to the construct (Figures 1, 3).[4, 20, 21]

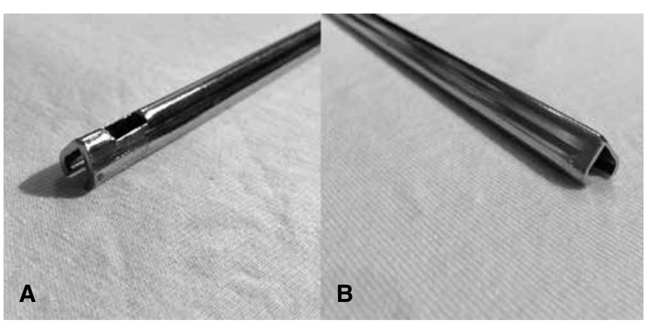

Figure 1 illustrates the design of early Küntscher nails. These stainless steel nails have a V-shaped cross section, are hollow and slotted, and are completely straight. They are designed to conform to the shape of the femur as they are passed down the medullary canal, thus achieving a wedge-fit. Implant courtesy of Dr. Christopher Born.

Figure 2 demonstrates the use of a head fluoroscopy unit. The x-ray tube is located beneath the operating table and the fluoroscope is worn by the surgeon. This setup causes substantial exposure of the surgeon to radiation. Image courtesy of Kaempffert, W. *The Book of Modern Marvels.* (Leslie-Judge Company, 1917). This image is in the public domain of the United States (published prior to January 1, 1923).

The Küntscher nail was initially not widely adopted in Germany.[1, 4, 22] However, during WWII while working in the northern Finnish front, Küntscher continued to improve his technique in collaboration with Finnish surgeons leading to the publication of 105 cases using the V-shaped nail in 1947.[1, 23] The technique quickly gained attention during WWII and spread throughout Europe due to its ability to mobilize patients quickly.[4] Early adopters of the IMN included Küntscher, C. Haebler (Germany), Richard Maatz (Germany), Lorenz Boehler (Austria), and R. Soeur (Belgium); all of whom published on the topic in the 1940s.[18, 24–27]

Küntscher's nail was not known to American surgeons until prisoners of war who were treated with this method returned to the United States after WWII.[18] Initially, the intramedullary nail was considered with great skepticism in the United States.[1, 4, 18] This was likely due to the inability of American surgeons to take advantage of Küntscher's experience, as his works and publications had not yet been translated into English.[18]

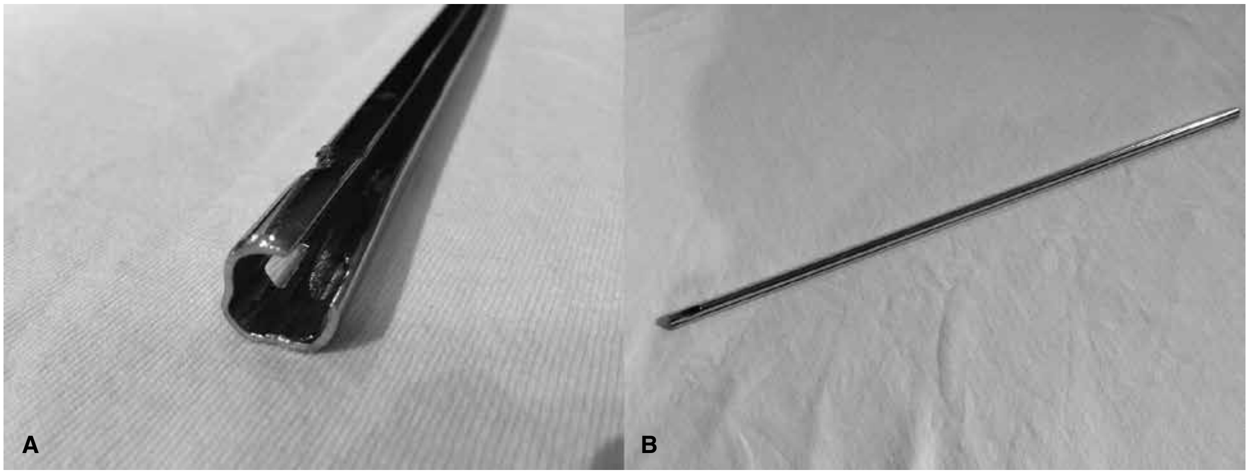

Figure 3 represents early intramedullary nails similar to Küntscher's "cloverleaf" nail. Figure 3A is actually a Booker-Willis nail; however, it demonstrates the cloverleaf cross-sectional design inspired by Küntscher's cloverleaf nails. Figure 3B displays a V-shaped Küntscher nail similar to his original design to demonstrate the straight nature of these nails. Note that the nails are hollow and not completely circumferential. Thus, they are capable of bending and achieving a wedge-fit in the medullary canal. Implants courtesy of Dr. Christopher Born.

The Medical Section of the U.S. Naval Technical Unit, Europe was founded in June 1946 with a major interest in investigating the usefulness of the intramedullary nail and reviewing indications, contraindications, hazards, complications, and any special considerations of the technique.[18] The first task of the Medical Section was the translation of Richard Maatz's IMN technique guide from the Kiel clinic in Germany where he worked with Dr. Küntscher.[18] Dr. Maatz used his engineering background to help develop mechanical principles for the design and application of intramedullary nails and published his techniques with Küntscher.[4, 28]

In 1946, Dr. Küntscher agreed to share his findings with the U.S. Navy Medical Corps so that they could be made available to English-speaking surgeons.[18] At this time, Dr. Küntscher was busy working in Schleswig-Holstein in post-war Germany and many of his original materials, radiographs, case-histories, etc. had been destroyed in the war.[18] He did, however, manage to produce a manuscript outlining his procedure with the help of the U.S. Navy Medical Corps.[18] On New Year's Eve of 1948, Harry J. Alvis, a commander in the U.S. Navy Medical Corps, submitted the translation, writing, "It is fitting that this large task should be concluded with this exhaustive work by the man who is the father of the entire idea . . . The particular virtue of this work . . . is that there has been no glossing over of failures, no reluctance to admit mistakes and no claims for the marrow nail as a cure-all for fractures."[18]

Dr. Küntscher felt that his work would be well-received by U.S. surgeons who more frequently operated on fractures in the 1940s compared to European surgeons.[18] He outlined that the most important advantage of his technique from the patient's perspective was early mobilization and an early discharge.[18] Dr. Küntscher's chief at the Kiel clinic, Albert Wilhelm Fischer, echoed this sentiment in his preface to the 1945 Küntscher and Maatz manual, writing, "Through the use of a . . . properly constructed nail-like splint . . . the greatest possible stability of the fracture should be achieved, so that a . . . plaster cast or traction apparatus is not required. By this the disadvantage of a prolonged immobility of the limb is avoided."[4, 28]

Post-Küntscher Intramedullary Nail

In 1947, the Hansen-Street nail was introduced in the United States by Dana Street (California) and H. Hansen (Figure 4).[1, 29] This solid nail was diamond-shaped, designed to obtain an interference fit to prevent fracture rotation, and was initially introduced antegrade through the piriformis fossa.[1, 4, 29] The widespread use of penicillin later reduced infection risks allowing for open insertion methods (exposure and insertion at the fracture site) and retrograde techniques.[4] While open methods did have a higher infection rate despite penicillin, they were preferred due to the unavailability of portable fluoroscopes and radiolucent fracture tables at the time. In 1947, Dr. Street reported an x-ray burn of a patient's skin from a nailing procedure spurring a drive towards open nailing to reduce the large radiation exposure to the physician and patient from contemporary head fluoroscopy.[4, 30]

During the 1950s, Küntscher, Homer Stryker of Michigan, and others began to promote the use of intramedullary reaming with flexible reamers or broaches to widen the femoral canal allowing it to receive larger diameter and hence stronger and more stable nails.[1, 4, 21, 31] This technique was originally described by Albert Wilhelm Fischer in 1942.[1, 24]

In 1953, Michael Modny and John Bambara (New Jersey) helped introduce interlocking screws to modern intramedullary nailing (Figure 5).[32] Their nail featured multiple holes throughout its length for screws to be placed at 90-degree angles to nail (Figure 5).[1] Modny and A.H. Lewart would go on to report excellent outcomes with this nail in 261 femur fractures.[1, 33] This technique, also explored by the Livingston

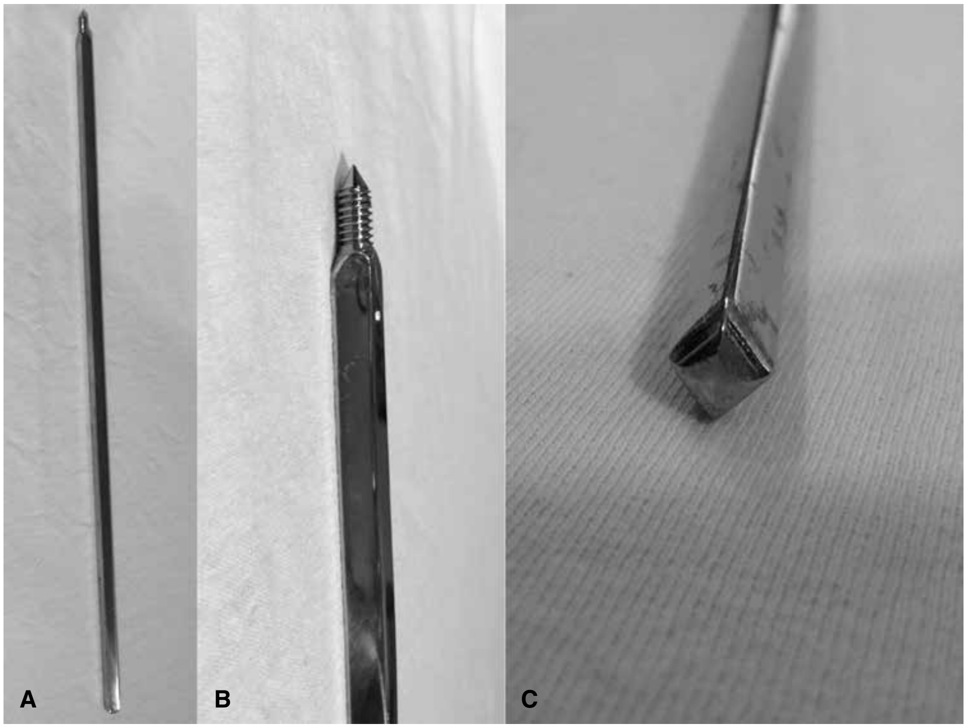

Figure 4 demonstrates a Richards nail, similar to early Hansen-Street intramedullary nails. This nail is notably straight, akin to early Küntscher nails, requiring it to conform to the shape of the femur as it is passed down the medullary canal. In addition, the nail is solid and does not allow for passage over a guide-wire. As shown in Figure 4C, it has a diamond cross-sectional shape meant to wedge into the cortices of the femur and prevent rotation of the femur after fixation. Implant courtesy of Dr. Christopher Born.

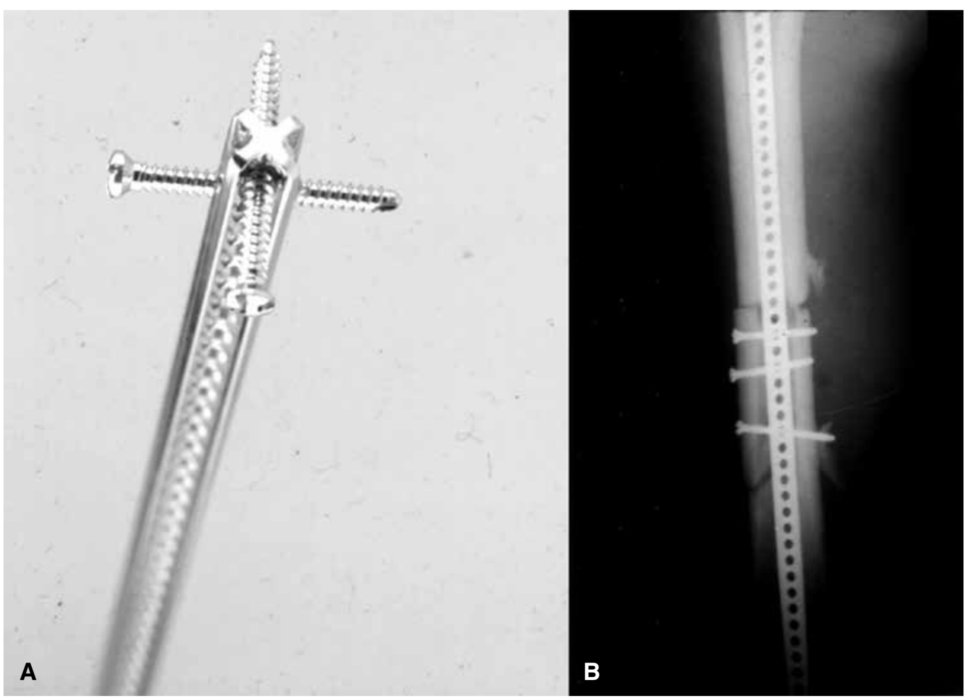

Figure 5 displays the Modny nail, one of the earliest nails with interlocking screw capability. This nail, first reported in 1953, was X-shaped in cross section and had holes along its length one centimeter apart. It allowed for interlocking screws anywhere along the nail, which could be placed in either of two planes 90 degrees from each other. Figure 5A is a picture of the nail with interlocking screws passed through the nail's holes. Figure 5B shows how this nail could be used to treat comminuted diaphyseal fractures. Photographs courtesy of Dr. Bruce Browner.

nail in 1952, improved rotational and axial control of intramedullary nails and had unique advantages in treating supracondylar and comminuted or complex fractures, and holding bones out to length for lengthening procedures.[4, 34]

While the Modny and Livingston nails required open techniques for interlocking, Kurt Herzog (Germany) was the first to demonstrate intramedullary nailing with closed interlocking using a targeting device.[35] Furthermore, F.P. De Camargo of Brazil published in 1952 a closed nailing technique with a nail that deployed wings into the inner cortex of the femur to hold it in place which avoided the need for distal interlocking screws.[36, 37] The Brooker-Wills nail, introduced by Andrew F. Brooker and Robert P. Wills of Johns Hopkins in 1986, also utilized internal wings for distal locking of the nail in addition to a proximal interlock screw for proximal fixation (Figures 6, 7).[37]

In 1968, Dr. Küntscher presented the idea of a Küntscher nail with transfixion bolts for added stability in comminuted fractures, highly oblique fractures, and fractures with bone loss (Figure 8). Klaus Klemm collaborated with Küntscher on this idea and would subsequently go on to work with W.D. Schellmann on using locking Küntscher nails.[38] This nail featured holes for two distal transverse transfixion screws and a single proximal screw at a 60 degree angle to the nail aimed distally and medially towards the lesser trochanter (Figure 7).[4, 38] Arsène Grosse and Ivan Kempf in Strasbourg, France went on to modify this nail design including adding a threaded proximal core for attachment of insertion devices, moving the distal interlock holes closer to the tip of the nail, and changing the proximal screw angle of insertion to 45 degrees to improve pullout resistance (Figure 7).[4, 39]

Contemporaneous to Küntscher's locking nail, compression nailing was introduced by Hans-Jurgen Kaessman (Göttingen, Germany) in 1966 in response to the increasing popularity of compression plating for femur fractures.[4, 40] Ronald Huckstep in Sydney, Australia soon after developed a guided, interlocking nail that applied compression across the fracture site (Figure 9).[41, 42]

In 1967, Robert Zickel in New York introduced an intramedullary nail featuring a hole in its proximal portion allowing for the passage of a separate triflanged nail through the lateral cortex of the proximal femur into the neck and head (Figure 10).[43] The device featured a set-screw which prevented the proximal pin from backing out.[4, 43] This fixation device was primarily designed for unstable intertrochanteric and subtrochanteric femur fractures and helped to usher the cephalomedullary nail into fracture treatment.[1]

In addition to pioneering efforts by Robert Zickel, Küntscher's "y-nail" was one of the earliest successful designs for nail fixation of unstable intertrochanteric fractures.[4, 43, 44] This nail included a tubular femoral neck component shaped like a trough that was inserted into the femoral neck/head and had an oval opening through which a

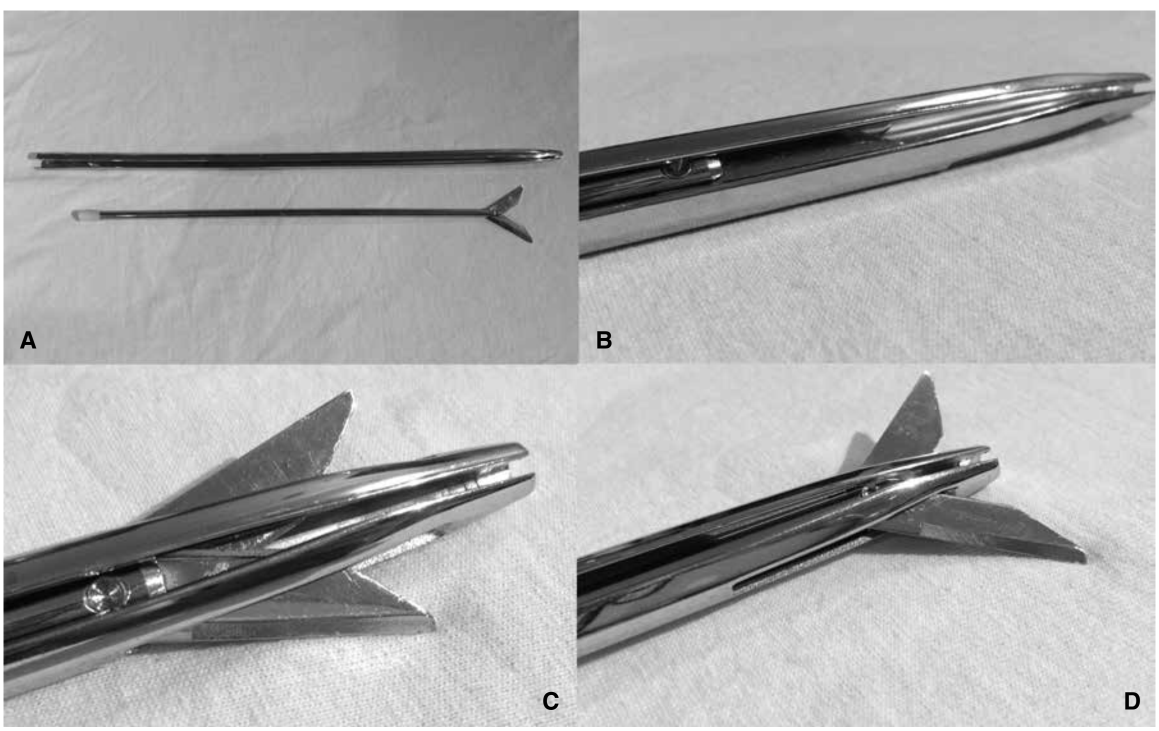

Figure 6 illustrates a Brooker-Wills nail with deployable distal wings instead of distal interlocking screws as first described by F.P. De Camargo. This nail was designed to reduce surgical and fluoroscopy time by allowing the surgeon to deploy distal wings into the medullary canal to achieve distal fixation of the nail to the femur. The nail also allowed for placement of a proximal interlocking screw. Figure 6A demonstrates the nail adjacent to the wing device. Figures 6B–D demonstrate the wings being deployed. Implant courtesy of Dr. Christopher Born.

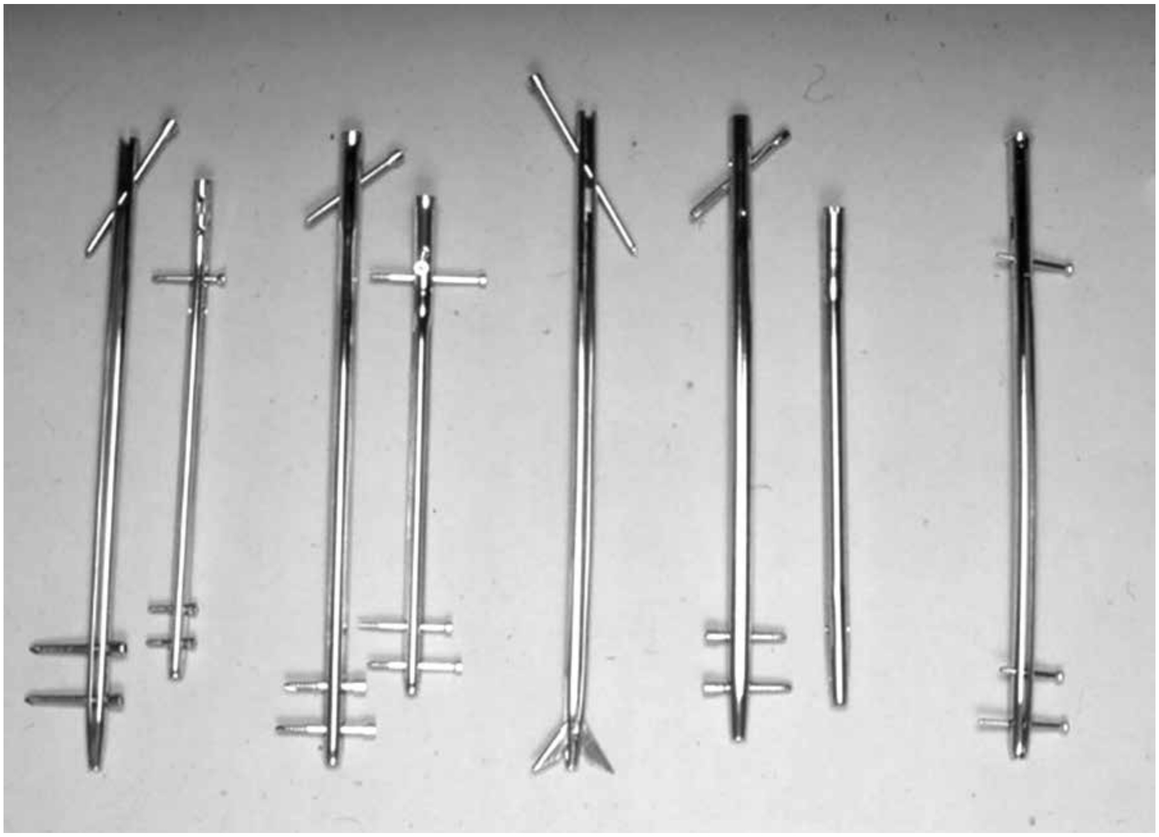

Figure 7 illustrates a variety of Grosse-Kempf and Klemm-Schellmann nails. Distinguishing features include the angled proximal interlocking screw aimed at the lesser trochanter and two transverse distal interlocking screws. In addition, the nail at the center of the picture is similar to a Brooker-Wills nail with deployable distal wings for distal interlocking. Photograph courtesy of Dr. Bruce Browner.

Küntscher cloverleaf nail could be inserted into the femur via a guide.[4] When the femoral head bears weight, the neck component of the y-nail locks onto the nail by friction thus supporting the construct.[4] When unloaded, the neck component can slide down nail component allowing for compression of the fracture.[4]

The fluted Sampson intramedullary rod was introduced in 1978 to address strength and torsional control of femur fractures.[4, 45, 46] These nails were tubular with eight equally spaced elevated ridges running down the nail designed to cut into the inner cortical surface of the femur to control rotation.[4, 45, 46] The flutes also made the nail particularly strong with increased bending strength and torsional rigidity compared to contemporary nails.[4, 45]

Improvements in radiograph techniques around this time (1970s) with the development of image intensification allowed for better and safer methods of closed intramedullary nailing (nailing without exposure of the fracture) with the advantages of reduced physiologic insult, lower risk of infection, and improved healing compared to open nailing.[1, 4, 47] After a two-decade lull in excitement for intramedullary nailing due to the high infection and malunion rates of open nailing in the 1950s and 1960s, D. Kay Clawson, R.F. Smith, and Sigvard T. "Ted" Hansen (Seattle) reintroduced the technique to North America in 1971 with their milestone paper, spurring renewed interest.[47]

Frederic W. Rhinelander's microvascular work on bones in the 1960s–1980s demonstrated that the medullary blood supply of bone is responsible for the inner two-thirds of cortical blood supply and is the most important blood supply for healing non-displaced fractures.[4, 48, 49] However, in displaced fractures (which disrupt the medullary canal) and those fractures that have been treated with reamed nailing, the blood supply from the periosteum and surrounding tissues can take over as the main blood supply for healing the fracture.[4, 48] Furthermore, given enough time, the medullary blood supply does reconstitute and does so more rapidly in loose fitting nails and those that have flutes as this allows for space for medullary vascular ingrowth.[4]

During the 1980s, Robert Winquist from Seattle helped to further increase the popularity of the intramedullary nail for treatment of femur fractures making it the treatment of choice for such injuries.[50, 51] His landmark paper in 1984 called for the lateral decubitus position for patients undergoing femoral nailing and recommended the piriformis fossa starting point to avoid eccentric medial reaming and varus malalignment seen with trochanteric starting points.[50, 51] As a result of his paper, these techniques became widely used in

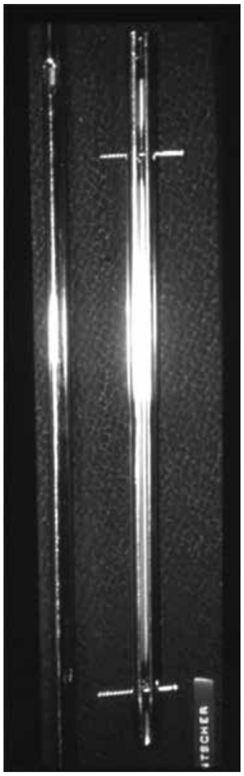

Figure 8 illustrates Dr. Küntscher's "Detensor Nail," developed in 1968 with proximal and distal interlocking screws for the treatment of comminuted fractures. This nail would go on to inspire the Klemm-Schellmann and later Grosse-Kempf interlocking nails. Photograph courtesy of Dr. Bruce Browner.

the United States until the 1990s/2000s when supine positioning and greater trochanter entry nails became popular.[51, 52]

The cephalomedullary nail was modified heavily during the 1980s and 1990s to become the device familiar to present-day orthopaedic surgeons.[1, 53, 54] The Gamma Nail (Stryker Corporation; Kalamazoo, Michigan) was developed during this time to provide stable fixation for intertrochanteric and subtrochanteric fractures.[53, 54] The first Gamma Nail was short (200 mm) and differed from the Zickel device by using a screw instead of a triflanged nail inserted into the femoral neck and by having two interlocking screw holes distally for rotationally unstable fractures.[4, 54] Improvements including increased length options for subtrochanteric fractures, addition of dynamic distal interlocking, and reduced valgus angle made the Gamma Nail the device that is used today.[53, 55]

Concurrent to the development of the Gamma Nail in the 1980s and 1990s was the production of the Russell-Taylor reconstruction nail designed for the treatment of subtrochanteric and complex proximal femoral fractures (Figure 11).[56–59] This nail featured two distal holes for transverse interlocking screws and two angled proximal holes for screws to be placed into the femoral head and neck.[56] Prior to the reconstruction nail, some authors reported the use of Grosse-Kempf interlocking nails for these injuries; the nails were reversed so that the proximal screw could be placed into the femoral neck (the proximal hole when reversed allowed for screw placement in a proximal-medial direction

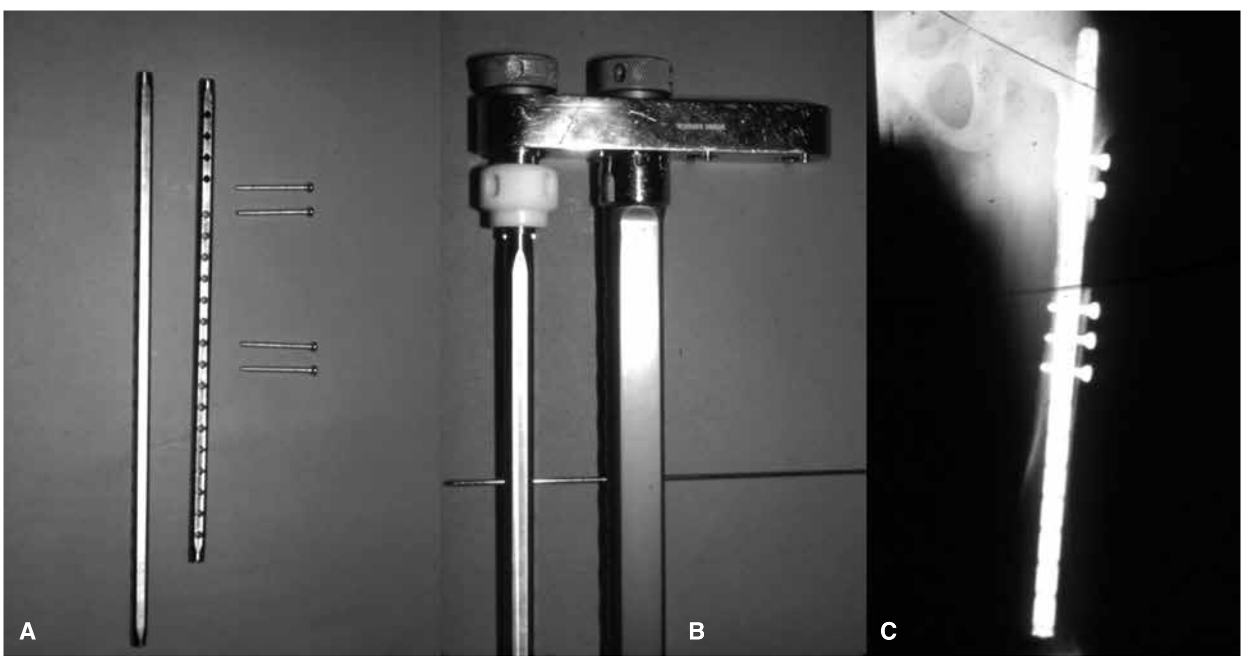

Figure 9 illustrates the Huckstep nail designed to apply compression across femur fractures. Figure 9A represents the nail with interlocking screws, Figure 9B shows the insertion/compression device, and Figure 9C shows a femur fracture treated with the Huckstep nail. Photographs courtesy of Dr. Bruce Browner.

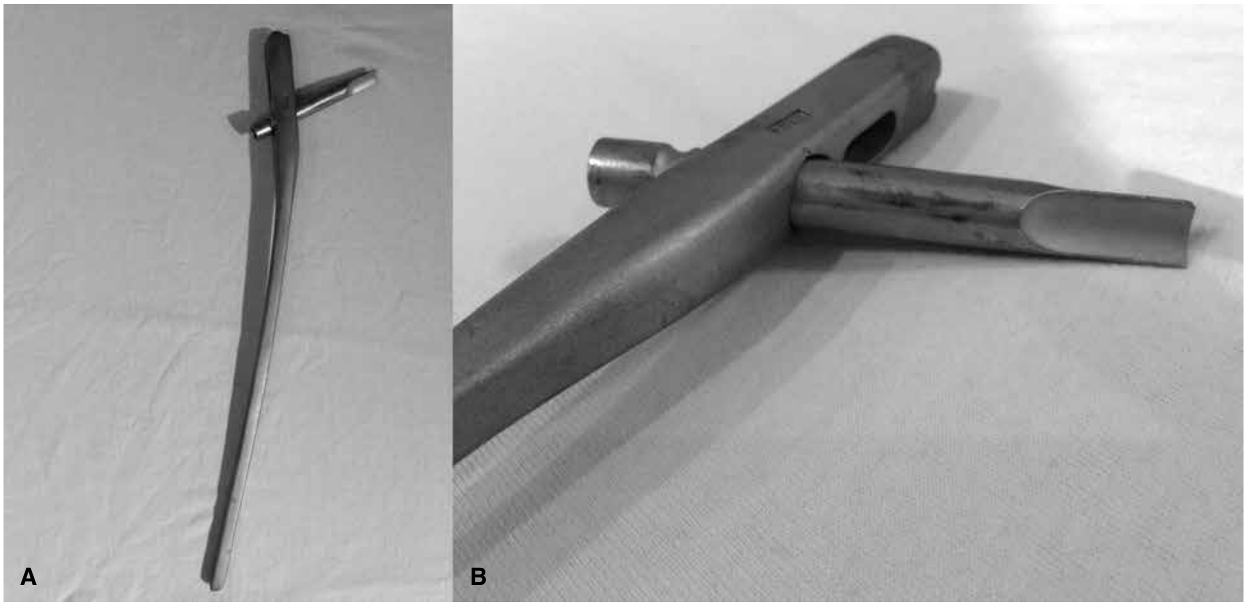

Figure 10 demonstrates Robert Zickel's nail designed for the treatment of subtrochanteric femur fractures. Arguably the first cephalomedullary nail, the Zickel nail featured a triflanged nail that passed through the femoral medullary nail into the femoral neck/head. This nail also had a set-screw at the top of the device to prevent the triflanged nail from backing out. Implant courtesy of Dr. Christopher Born.

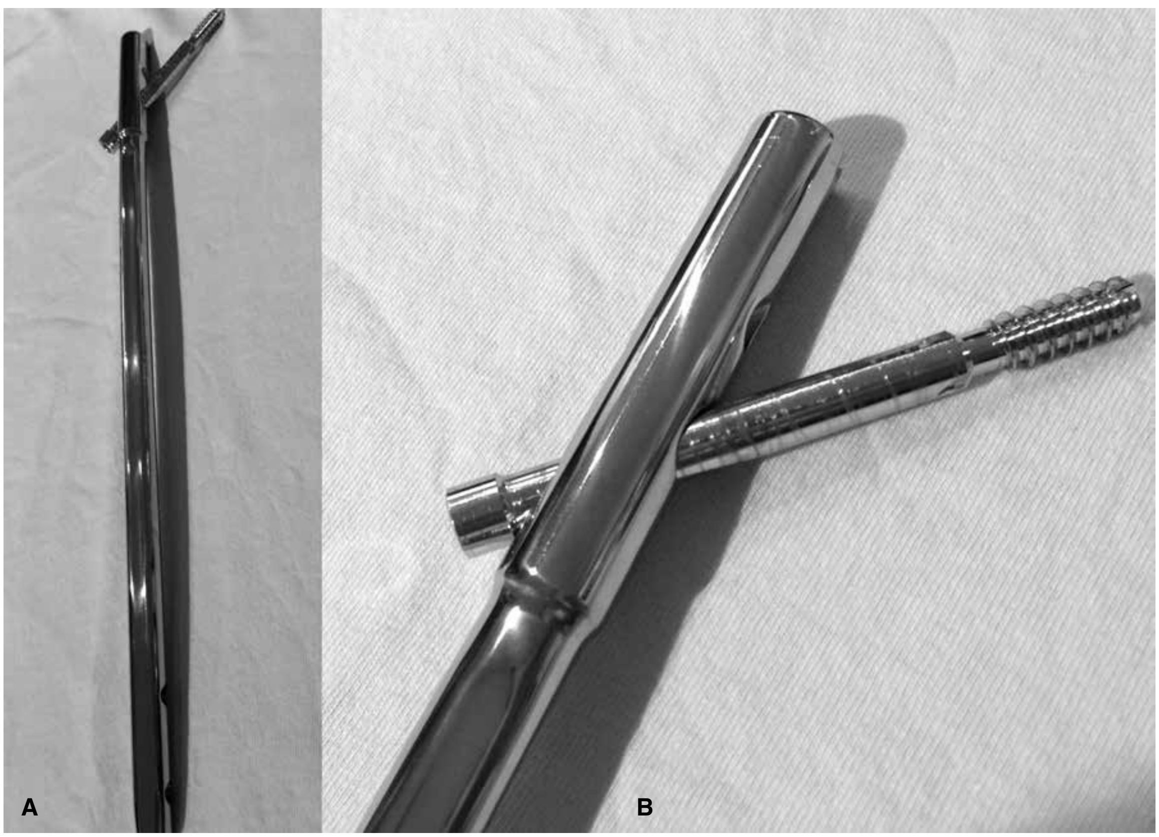

Figure 11 illustrates the Russell-Taylor reconstruction nail. This stainless steel device was curved to mimic the bow of the femur and featured up to two proximal screws that passed through the nail into the femoral neck/head. The proximal screws were partially threaded to accommodate compression of femoral neck fractures. The nail also included holes for two distal interlocking screws. Implant courtesy of Dr. Christopher Born.

towards the femoral neck as opposed to a distal-medial direction towards the lesser trochanter).[56, 60] The Russell-Taylor nail improved on this technique by using a targeting device to assist with the placement of the two proximal screws which were partially threaded to allow for compression of femoral neck fractures.[56] Furthermore, since the Russell-Taylor nail was not reversed (such that its bow matched that of the femur), it had less issues with causing iatrogenic fracture and comminution.[56]

In the 1990s and early 2000s, extreme proximal and distal femur and tibia fractures once thought untreatable by nailing were found to have good results when fixed with intramedullary nails both due to improved nail design and improved techniques.[1] In addition, reaming was shown to have beneficial effects on union rates with similar rates of fat embolization when compared to unreamed techniques.[61–64] Titanium nails were introduced in the 1990s as were long cephalomedullary and retrograde supracondylar nails.[1, 53, 65] Roy Sanders (Tampa, Florida) in 1993 reported successful use of AO Universal Tibial Nails in retrograde fashion to fix femur fractures in patients where proximal access to the femur is undesirable, such as those with ipsilateral pelvis or femoral neck fractures, polytrauma patients requiring simultaneous procedures, and pregnant patients.[66] In addition, the retrograde Green-Seligson-Henry nail introduced in 1991 by Stuart A. Green (California), David Seligson (Kentucky), and Stephen L. Henry (Kentucky) was useful for comminuted distal femur fractures and those with intra-articular extension.[67] Since then, retrograde nailing has been shown to be equivalent to antegrade nailing with respect to fracture healing with improved alignment of distal and supracondylar femur fractures, reduced operating room time, improved ease of treatment when combined with tibial nailing for floating knee, and reduced blood loss compared to antegrade techniques.[61, 68–70]

In the last 20 years, the radius of curvature of the IMN was altered to better match the radius of curvature of the femur, and greater trochanteric entry nails gained popularity.[71–75] Early nails were relatively straight, which led to issues including distal anterior cortex penetration, iatrogenic fracture, and fracture angulation during nail placement.[21, 73, 76] Küntscher's earliest nails had no curvature; however, they were more flexible than modern nails allowing the nail to deform and wedge in the medullary cavity to prevent rotation (as interlocks had not yet been invented).[20] As nails became more rigid, modernization of the IMN had to take into account the radius of curvature of the femur.[71–75, 77–80]

Furthermore, femoral nails are often inserted through the piriformis fossa which has a collinear trajectory with the femoral shaft yielding high healing and low complication rates.[4, 29, 50, 51, 61] However, greater trochanteric entry nails have advantages including an easier to find starting point in the tip of the greater trochanter (especially in obese patients), less risk to the blood supply of the head of the femur, less hoop stresses applied to the femoral shaft during nail insertion, and less risk of femoral neck fracture.[50, 61, 78, 81, 82] The recent popularity of the greater trochanteric entry nail was spearheaded by novel inventions in nail technology. Namely, placing a proximal lateral bend in nails to facilitate greater trochanter entry has proven to be successful in eliminating angular malunion and iatrogenic fracture comminution seen in trochanteric entry of nails designed for insertion at the piriformis fossa.[51]

Conclusion

Almost 80 years after Dr. Gerhard Küntscher developed the modern intramedullary nail, this device has become one of the most important tools in fracture care. While nail designs and placement techniques have continued to evolve, the basic principles of fracture care with intramedullary nails remain the same.

Source of Funding: There was no external source of funding for the production of this manuscript.

Human/Animal Studies Statement: The manuscript does not contain clinical studies or patient data.

Acknowledgement: The authors would like to thank Dr. Bruce Browner for his contributions and kindness during the production of this manuscript.

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Case Report

Profunda Femoris Pseudoaneurysm Following Total Hip Arthroplasty Revision: A Case Report

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Abstract

Vascular injuries following total hip arthroplasy (THA) are very rare, with pseudoaneurysm being a small subset. We report a case of profunda femoris artery (PFA) pseudoaneurysm in a 61-year-old male following a posterior approach revision left THA. Presentation involved continued blood transfusion requirements several weeks post-operatively. Diagnosis was confirmed with CT and IR angiography. A successful embolization was achieved with selective coiling and Gelfoam. Presenting complaints of such complications are often vague, and therefore lead to delayed diagnosis. Causes of such complications are not completely understood, particularly with PFA injuries in THA. Possible mechanisms are discussed in this paper. Vascular complications following THA can be difficult to diagnose. High suspicion in the setting of continued post-operative pain or bleeding may allow prompt diagnosis and avoidance of serious limb-threatening complications.

Introduction

Total hip arthroplasty (THA) is one of the most commonly performed orthopedic procedures, and has consistently relieved pain and improved function in patients.[1] The procedure has a low complication rate of 6%,[2] where the incidence of vascular injury is even lower.[3] However, vascular injuries may lead to catastrophic complications, including perioperative bleeding or critical limb ischemia.[4] Vascular injuries occur at a reported rate of 0.25% of all complications following hip surgeries.[3] Pseudoaneurysms are a very rare complication in the subset of vascular injuries.

We present a case of a profunda femoris artery (PFA) pseudoaneurysm following THA revision surgery. Profunda femoris aneurysm has only been reported a handful of times in recent literature and never from a posterior approach for a revision THA.

Case Presentation

A 61-year-old male presented with complaints of pain in his left hip following an anterior approach for a THA, which was performed eight months prior at an outside institution. Per the operative report, there were no complications encountered with the surgery, including no femoral cortex perforation during reaming. He had undergone appropriate rehabilitation following the index procedure, but his symptoms remained refractory to analgesics and physical therapy. Upon arriving to our practice, a workup was begun for septic loosening of the femoral and/or acetabular component. Initial radiographs at our practice showed a well-aligned femoral and acetabular component without obvious evidence of loosening and no periprosthetic fracture (Figs. 1, 2, 3). Appropriate laboratory tests, including hip aspiration arthrogram, excluded infection as the etiology of his symptoms. A bone scan demonstrated hyperemia in the left thigh and increased uptake surrounding the femoral prosthesis. A subsequent x-ray arthrogram showed mild extravasation of contrast to the proximal aspect of the femoral component (Fig. 4), suggestive of aseptic loosening of the femoral stem.

Figure 1. AP pelvis of the primary THA showing good alignment without fracture.

The patient underwent revision of the femoral stem for THA without immediate complication. A standard, posterior approach was performed and blunt, Hohmann retractors were placed anteriorly and medial around the proximal femur for exposure of the femoral canal for reaming and cement removal. There were no complications encountered intra-operatively. Post-operative radiographs show the femoral and acetabular components in good positioning without

Figure 2

Figure 3. AP and lateral of the primary THA showing good alignment without fracture.

Figure 4. X-ray arthrogram showing mild contrast tracking along the proximal lateral aspect of the femoral component.

periprosthetic fracture or femoral cortex perforation (Figs. 5, 6). He was discharged in stable condition on the third post-operative day to a skilled nursing facility.

Ten days post-operatively, he presented to the emergency room for tachycardia. Workup in the ER included INR (3.6), basic labs and a CT of his left lower extremity. CT showed concern for possible underlying hematoma in the operative field. He was admitted for symptomatic anemia (Hb, 7.9 mg/dL). On hospital day one, his hemoglobin dropped to 6.9 mg/dL and he underwent transfusion of packed red blood cells. His Coumadin was discontinued because of the concern for hematoma. Following this transfusion, his hemoglobin stabilized at 8.2 mg/dL and he was discharged on hospital day four to his skilled nursing facility.

He presented four weeks later for routine follow-up at which time he was progressing well.

At seven weeks post-operatively, however, he was referred from an outside hospital for left thigh pain, swelling, and symptomatic anemia (tachycardia). The patient reported he had received two blood transfusions at the outside hospital in the previous three weeks since his follow-up. Hemoglobin at time of presentation was 8.8 mg/dL. Due to continued need for transfusions, further investigation at the outside hospital was performed. A CT scan of his left thigh from the outside hospital was suspicious for a pseudoaneurysm (Fig. 7). Diagnosis was confirmed at our institution by conventional angiography, which identified a 13 mm pseudoaneurysm in the left profunda femoris artery. The patient under-

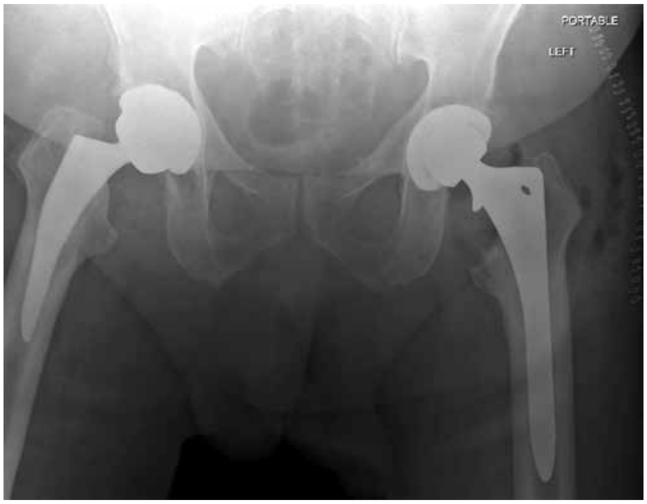

Figure 5. AP pelvis post operatively showing good alignment without fracture or femoral cortex perforation.

Figure 6. AP hip post operatively showing no fracture or femoral cortex perforation.

went embolization of the pseudoaneurysm via one coil and Gelfoam (Pfizer, Wayne, PA) without issue (Figs. 8, 9, 10). Following the procedure, the patient's pain improved and hemoglobin levels stabilized. He underwent a left thigh hematoma evacuation and drainage the following day to remove the large thigh hematoma, following which he expe-

Figure 7. Contrast CT of the left lower extremity showing a suspected pseudoaneurysm of the left profunda femoris artery.

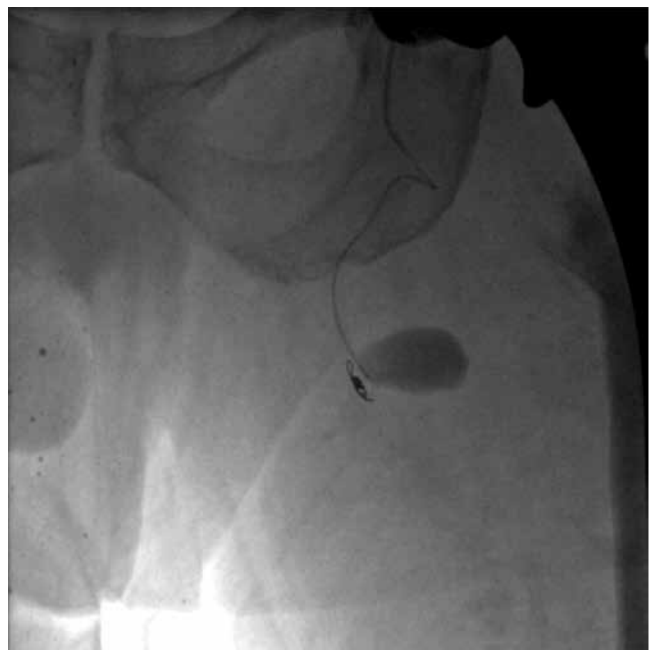

Figure 8. IR angiogram demonstrating a 13 mm pseudoaneurysm of the profunda femoris artery.

rienced no further complications. He was discharged to his rehabilitation facility following the procedure.

Discussion

This case report is, to our knowledge, the only reported profunda femoris pseudoaneurysm following a revision total hip arthroplasty. It is only the third reported case in any total hip arthroplasty.[5, 6] Despite being a rare complication, delayed or undetected vascular injuries following any procedure may be significant. Complications from vascular injuries include intraoperative or perioperative bleeding, critical limb ischemia, pain, pulsating mass or swelling, and hematoma development.[4] Additionally, the relationship between hematoma and early infection after THA has been well docu-

Figure 9. Imaging of embolization of the pseudoaneurysm by coiling and Gelfoam performed by IR.

Figure 10. Angiogram showing coil in profunda femoris artery with elimination of the pseudoaneurysm previously demonstrated.

mented.[7] Hematoma acts as a source of infection and, if fascial defects are present, can quickly become a deep infection.[7] Postoperative THA infections have been associated with a higher number of hospitalizations, total number of hospital days, total number of operations, and increased hospital costs in both the inpatient and the outpatient settings.[8] Therefore, hematoma development associated with presentation of pseudoaneurysm needs to be identified promptly.

The lower extremity vasculature around the hip is complex, with many branches crossing the surgical field. The common femoral artery enters the leg through the femoral triangle, where it divides into the profunda femoris and superficial femoral arteries (SFA). The SFA gives off further five branches (superficial circumflex iliac, superficial epigastric, superficial external pudendal, deep external pudendal, and descending genicular artery). The profunda femoris artery runs between the pectineus and the posterior side of the adductor longus.[9] It gives off the lateral femoral circumflex artery, medial femoral circumflex artery (MFCA), and adductor perforating arteries as it traverses the thigh.[10] The MFCA gives off further five branches (superficial, ascending, acetabular, descending, and deep arteries) that provide the majority of the blood supply to the femoral head.[11]

Profunda femoris pseudoaneurysms have been previously reported in femoral shaft fractures[4, 12, 13] and hip core decompression,[14] with slightly more prevalence than THA. The more common arteries injured during total hip arthroplasty include external iliac, common femoral, and femoral circumflex arteries.[4, 15, 16] Causes of PFA lesions in other studies were suspected to be from an avulsion injury likely during manipulation,[17] injury during placement of hardware for a DHS,[4] and violation during drilling for placement of an intramedullary nail.[13] Different causes of pseudoaneurysm of all vessels following THA have been reported in literature, including retractor placement,[12, 17] screw encroachment,[4, 14] drill encroachment,[12, 13] reduction techniques,[17] removal of hardware,[4] and cement exothermic reactions.[17]

Cases reported presentation of pseudoaneurysm at the time of revision surgery for various reasons,[17, 18] including pain,[18] swelling,[4] bleeding,[5, 14, 16] vascular insufficiency,[4] and chronically draining sinus development.[4, 16] Previous studies have reported unresolving pain following surgery in the presentation of pseudoaneurysms in other locations.[4, 12, 13, 15] This has been proposed as one of the possible causes of the patient's pain at initial presentation. Average detection time in these patients ranged from four months to six years after index procedure.[4, 15, 16] Further need for transfusions postoperatively was cited as the presenting or primary complaint in previous case reports.[12, 14, 17] The common delayed presentation can be attributed to the nature of how pseudoaneurysms form by incomplete vasculature damage and subsequent progressive expansion or embolism at the site of injury. This also can be attributed to the often asymptomatic course of a pseudoaneurysm.

In our patient, the cause of this pseudoaneurysm remains unknown. Placement of the femoral retractors, hip positioning during dislocation, and delayed presentation from the initial, anterior approach THA have been proposed. During a posterior approach, retractors are often placed medially and laterally around the proximal femur after the hip is dislocated. Retractor placement medially around the femoral neck during a posterior approach may compress or injure the PFA as it travels between the pectineus and adductor longus after branching laterally from the common femoral artery.[9] Alternatively, previous case reports have shown damage to the common femoral artery with retractor placement on the anterior acetabulum.[19]

The PFA injury may have occurred during the anterior approach at the time of his index THA. The patient's surgery was originally performed on the HANA table (Mizuho OSI, Union City, CA). A standard interval between the tensor fascia lata (TFL) and sartorius muscle was used. For surgeons who are perhaps unfamiliar with the approach, it is possible to dissect the plane too far medially and encroach onto the neurovascular bundle.[20] Similar to the posterior approach, retractor placement around the proximal femur may have caused vascular damage. During preparation of the femur on the HANA table, a hook is placed posteriorly behind the proximal femur and the leg is brought into hyperextension. Once hyperextended, the hook around the posterior aspect of the proximal femur is activated by a foot pedal, which displaces the proximal femur anteriorly, further accentuating the hyperextension of the hip and elevating the femur for better visualization and preparation of the femoral canal. In this position, the PFA, an anteriorly-based structure, is placed on stretch. This position has been documented to cause lateral femoral cutaneous nerve palsies[21] and theoretically could cause similar stretch injuries to local vasculature. Other studies have shown that stretching of vascular structures, whether on a HANA table or during dislocation or manipulation, may result in an avulsion-type injury to vasculature structures in the area.[17]

The early failure of the primary THA is difficult to explain, as there were no issues regarding alignment or infection at the time of revision surgery. Multiple papers have stated that heavier (BMI > 25) males are at greater risk of aseptic loosening of THA, particularly the femoral stem, in the early postoperative period.[22, 23] Alternatively, the PSA may have been present from the initial surgery (as mentioned above), and the regional bleeding in the area may have led to early aseptic loosening. Studies have shown that regional hematomas can lead to bone absorption and osteolysis around THA implants.[24]

Conclusion

Vascular injury during THA is a rare but serious complication. Despite its infrequent occurrence, the clinician should always consider a vascular injury in the setting of post-op complications. High suspicion in the setting of unresolving blood loss or continued need for blood transfusions may allow for earlier diagnosis and avoidance of serious limb-threatening complications. Care during the procedure for accurate retractor placement and careful manipulation may help avoid serious complications.

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Case Report

Anterior Vertebral Body Tethering in the Lumbar Spine: A Case Report

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Abstract

Study Design: Case Report

Objective: This case report describes the principles and technique of anterior vertebral body tethering and documents its use in the treatment of a thoracolumbar curve.

Summary of Background Data: Vertebral body tethering (VBT) is a fusionless technique that utilizes a child's growth potential to progressively correct deformities in idiopathic scoliosis. Tethering is an alternative for skeletally immature patients, especially those who are not amenable to bracing. In principle, tethering also has advantages over other surgical techniques, such as growing rods, vertebral body stapling, or posterior spinal fusion. Two-year data has shown VBT to be safe and effective for use in the thoracic spine. We present the first report in the literature of a patient treated with tethering in the thoracolumbar spine. Her treatment included thoracolumbar VBT from T10–L2 and concomitant thoracic VBT from T5–T9. This patient is also the first patient at our institution with thoracolumbar VBT to reach skeletal maturity.

Methods: We reviewed the medical record, operative report, and radiographs from the perioperative period, as well as from the 1.5-month and 12-month follow-up visits. The greatest Cobb angles were used to determine the magnitude of the coronal curves. Thoracic kyphosis was measured from the superior endplate of T5 to the inferior endplate of T12, and lumbar lordosis was measured from the superior endplate of L1 to the superior endplate of S1. Rib rotation was determined clinically via scoliometer.

Results: A 13-year-old girl with adolescent idiopathic scoliosis presented with a thoracolumbar curve measuring 43° and a compensatory thoracic curve measuring 30° (Lenke 5C). VBT resulted in immediate and progressive correction of the patient's thoracic and thoracolumbar curves. Over the 12-month follow-up period, the patient's thoracolumbar curve demonstrated 74% correction (43° to 11°) and her thoracic curve displayed 47% correction (30° to 16°). Her lumbar rotation improved 67% (15° to <5°) and her thoracic axial rotation improved 38% correction (8° to <5° on scoliometer). The patient is now skeletally mature and her curve is at low risk for progression.

Conclusion: From this initial report, it appears VBT can be safely and effectively utilized in correcting thoracolumbar curves. Further study is necessary to clarify the relationship between the patient's remaining growth potential and the final magnitude of correction achieved with tethering.

Level of Evidence: N/A

Key Words: idiopathic scoliosis, fusionless scoliosis surgery, anterior vertebral body tethering, thoracolumbar scoliosis

Introduction

Bracing can be an effective means of preventing curve progression for patients with adolescent idiopathic scoliosis.[10] When bracing fails, spinal fusion has been the surgical technique of choice. Despite its efficacy in correcting the curve, spinal fusion can have undesirable consequences. It has been suggested that fusion can lead to intervertebral disc degeneration, limited growth, restricted mobility, and pain.[3,6] This has spurred the investigation of fusionless options for treating idiopathic scoliosis.

Animal models have shown that anterior vertebral body tethering (VBT) is capable of inducing significant changes in spine curvature without damaging the intervertebral discs. Newton et al. reported no change in disc water content or gross morphological character of the discs after flexible anterior body tethering.[7,8] An early case report demonstrated tethering's utility in a clinical setting.[5] More recently, two-year outcomes tentatively show that VBT is effective in correcting curves in skeletally immature patients with flexible thoracic curves measuring 35° to 60°.[9] These results suggest that patients with moderate structural thoracolumbar or lumbar curves, or curves with structural characteristics (e.g., Lenke 3-6 or curves with a Lenke C modifier), may benefit from VBT. The patient presented is the first patient at our hospital to reach skeletal maturity after a thoracolumbar tethering procedure. This is also the first documented use of VBT for a thoracolumbar curve in the literature.

Case Study

A 13-year-old girl presented with a 43° left-sided thoracolumbar, and a 30° right-sided compensatory thoracic curve (Lenke 5C). The thoracolumbar curve was flexible to 7° and the thoracic curve bent down to 21°. The patient had a 15° lumbar prominence and an 8° thoracic prominence as measured via scoliometer. Her lumbar lordosis measured 57° and her thoracic kyphosis measured 35°. Coronal balance measured 39 mm left and sagittal balance 48 mm forward. She was a Risser 2, and her Sanders digital hand score was a six. The patient was eight months post-menarchal. Despite this, her family growth history and her Risser score suggested that she had significant growth remaining. Thoracolumbar and thoracic anterior VBT were presented as options because of her skeletal immaturity and the magnitudes of her curves.

Description of the Index Procedure

After induction of anesthesia, the patient was positioned in the lateral position, right side up. The surgeon placed 5-millimeter thoracoscopic portals in the mid axillary line at approximately T6, T9, and T11. Then, 15-millimeter portals were placed. Under fluoroscopic guidance, the surgeon (AFS) inserted a specialized vertebral body staple, followed by a tap, and then a standard pedicle screw across the anterior aspect of the vertebral body. Care was taken to place the screw anterior to the rib head so as to avoid any potential neurologic injury. All screws were placed in this fashion. AP and lateral fluoroscopy was used to verify the screw placement. A flexible polyethylene tether (Zimmer Dynesys, Warsaw, IN) was then passed inferior to superior. The tether was tensioned and locked down to achieve maximal correction. Finally the surgeon trimmed the tether, leaving two centimeters on each end in case an expansion is needed. The chest was then irrigated, followed by placement of a chest tube in the inferior anterior portal. The patient was then repositioned in lateral decubitus, this time with the left-side up. A 3-centimeter incision was made at level of T10 through which a 15-millimeter portal was introduced. Additionally, two 5-millimeter portals were placed. This allowed thoracoscopic placement of a screw at T12, using the same sequence described previously. A 5-cm thoracolumbar incision was made to approach L2 and L1 retroperitoneally. The surgeon reflected the iliopsoas and ensured that nerve roots were not in danger. Screws were then placed as previously described, placement was checked fluoroscopically. A second tether was passed through a small opening in the diaphragm and locked into T12. The tether was placed in each subsequent vertebral screw head, the construct was sequentially tensioned and locked down with set screws. The wounds were irrigated and then closed.

Results

Immediate and progressive correction of the patient's thoracolumbar and thoracic curves was observed. The thoracolumbar curve corrected to –11° intraoperatively (measured supine on the operating table). Over the 12-month follow-up period, the patient demonstrated 74% correction of her thoracolumbar curve (43° to 11°), her thoracic curve displayed 47% correction (30° to 16°), 69% correction of coronal balance (39 mm left to 12 mm left), and 79% correction of sagittal balance (48 mm forward to 18 mm forward). Throughout the follow-up period, the patient had 38% correction of thoracic rib hump (8° to <5°), and 67% correction of lumbar rotation (15° to <5°). No major or minor complications were observed. At this point, the patient's curve was unlikely to progress due to her skeletal maturity (Risser 4, postmenarchal) (Table 1).

Discussion

This case report suggests that VBT can correct thoracolumbar deformities similarly to tethering the thoracic spine. The patient showed immediate and progressive correction in the coronal, sagittal, and axial planes during the 12-month follow-up period. The radiographic changes observed are secondary to the tension caused by the tether on the convexity of the scoliotic curve. As the patient grows longitudinally, the tether limits convex growth, allowing for asymmetric growth of the concavity and causing the spine to straighten. Improvements in coronal and sagittal balance are secondary to the reduction in curve magnitude. The correction of rib rotation is likely due to a coupling effect of the coronal and axial planes.

At this time, anterior VBT appears to have advantages over other surgical techniques for thoracolumbar curves. Fusion has been associated with restricted growth, stiffness, and adjacent level disc degeneration. Because it is a fusionless treatment, VBT is thought to preserve growth, mobility, and disc health in and around the instrumented levels. VBT usually involves a single surgery when a patient's residual growth is accurately assessed. Vertebral body stapling controls and corrects scoliotic curves with a mechanism similar to VBT; however, due to the mechanical limitations of the staples, it is a technique best suited for thoracic curves measuring less than 35° and thoracolumbar curves less than 45°.[5] VBT has been used successfully in curves over 60° with no observed hardware failures.[9]

An important topic to investigate is how much correction the surgeon should attempt to achieve during the initial procedure versus how much correction will be achieved utilizing the child's remaining growth potential. This decision is informed by chronological age, menstrual status, skeletal maturity, flexibility, and family history. VBT is capable of producing overcorrection when a child's residual growth is underestimated,[9] and it is important to emphasize this possibility and the potential need for a second procedure to loosen the tether. With longer follow-up of tethering patients, surgeons will develop a better understanding of the growth modulation that occurs and the risk of overcorrection will likely be reduced. Furthermore, preserving motion in the

Table 1

Follow-Up	Thoracic Curve (Bend)	Thoracolumbar Curve (Bend)	Thoracic Kyphosis	Lumbar Lordosis	Thoracic Rib Rotation	Lumbar Rib Rotation	Coronal Balance (mm)	Sagittal Balance (mm)
Pre-Op	30° (21°)	43°, (7°)	35°	57°	8°	15°	–39	48
1st Erect	16°	7°	16°	35°	N/A	N/A	–56	59
1.5 Mo	20°	14°	24°	47°	N/A	N/A	–32	20
12 Mo	16°	11°	19°	50°	<5°	<5°	–12	18

*Negative values indicate that the midpoint of C7 is left of the midpoint of the sacrum.
**Positive values indicate that the position of C7 is anterior to the posterior superior corner of the sacrum.

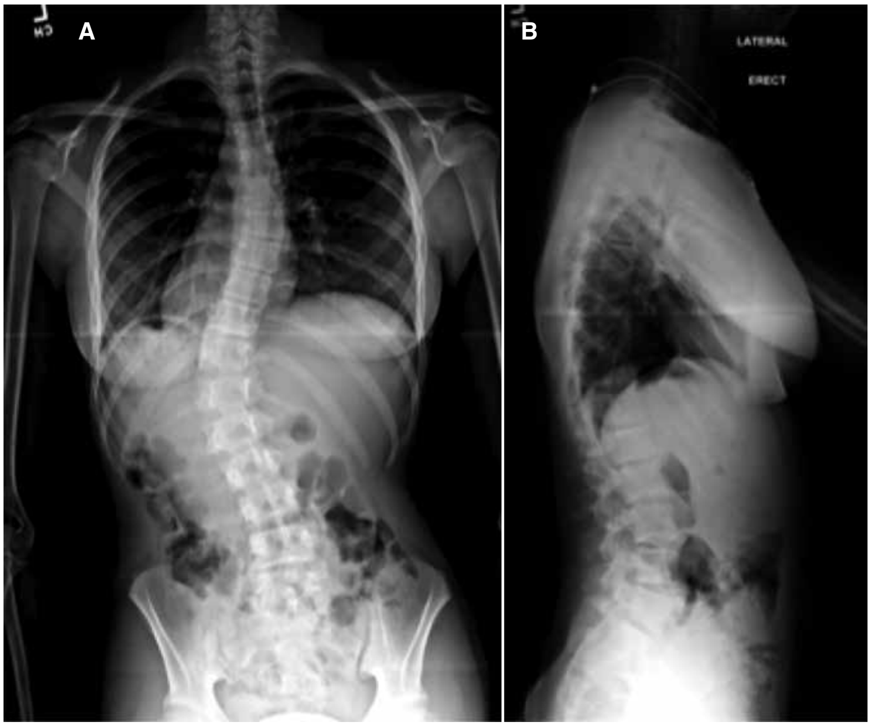
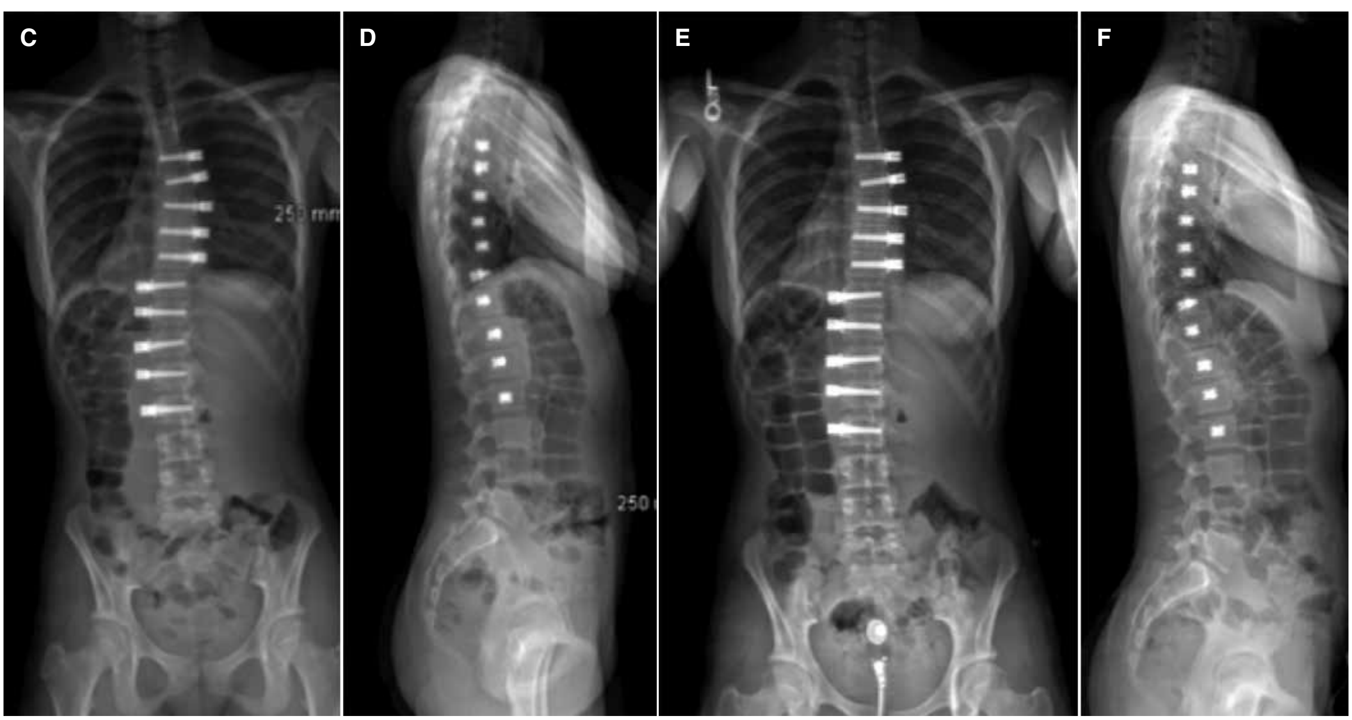


Figure 1. A and **B,** preoperative radiographs displaying 30° thoracic and 43° thoracolumbar curvatures. The patient underwent thoracic and thoracolumbar anterior vertebral body tethering. Films taken one month postoperatively show correction to 20° and 14° respectively **(C** and **D).** At one year, her thoracic curve measures 16° and her thoracolumbar curve measures 11° **(E** and **F).** No major or minor complications were observed.



instrumented spine places stress on the hardware and opens the door to loosening and potential hardware failure. While we have yet to observe a tether fail, long-term follow-up will clarify the relationship between motion preservation and hardware integrity. There is scant data available on tethering the lumbar spine; however, this case demonstrates the promise of VBT for treating appropriately selected children with thoracolumbar curves. Ultimately, comprehensive studies are required to analyze its usefulness in this patient population.

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Case Report

Unrecognized Osteoid Osteoma of the Proximal Femur with Associated CAM Impingement: A Case Report

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Eric J. Kropf, MD[1]

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Abstract

Femoro-acetabular impingement is a common cause of hip pain in young athletes. Routine workup includes plain radiographs and magnetic resonance imaging (MRI). However, it is important to appreciate other uncommon diagnoses and the role of complimentary imaging studies. Computed tomography (CT) can better define osseous anatomy and pathology. The purpose of this clinical vignette is to emphasize the need for comprehensive workup and complete imaging with CT in the setting of atypical anterior hip and groin pain.

We present the case of a 19-year-old male recreational soccer player who underwent seemingly successful arthroscopic FAI surgery but returned with pain. Computed tomography (CT) revealed osteoid osteoma of the lesser trochanter. The lesion failed to respond to medical treatment and was ultimately successfully treated with percutaneous CT-guided radiofrequency ablation.

Introduction

Femoro-acetabular Impingement (FAI) is a common cause of hip pain in young active patients as abnormal contact occurs between the acetabulum and femoral head neck junction. Resultant injury to acetabular labrum and cartilage is a frequent cause of pain.[1] Evaluation of patients with athletic hip pain includes standardized radiographs and magnetic resonance imaging (MRI) or MRI arthrography. Computed tomography is applied at some centers and in certain clinical scenarios. While MRI (+/– arthrogram) can clearly define changes in the labrum or articular cartilage, osseous pathology may be underappreciated with these studies alone.[1] We present the case of an unrecognized proximal femur osteoid osteoma in a young athletic male with evident CAM impingement and labral injury to emphasize the need to maintain a high index of clinical suspicion for this atypical cause of hip pain.

Case Report

A 19-year-old male soccer player presented with right anterior hip and groin pain for 18 months. He failed to respond to NSAIDs and two courses of physical therapy. On physical examination, the patient walked with a mildly antalgic gait. Range of motion was limited on the right side to 30º of internal rotation vs. 40° on the uninvolved side. Tenderness was elicited at the adductor tubercle and anterior hip capsule. Mild muscle weakness (4+/5 hip flexion strength) was noted. FADDIR and Stinchfield maneuvers were positive. Radiographic examination revealed CAM morphology (α angle = 74º) with slight acetabular retroversion as seen as a cranial crossover sign (Fig. 1A–B).

Incidentally noted was the atypical but well defined appearance of the lesser trochanter believed to represent secondary changes of chronic lesser trochanter apophysitis. MRI arthrogram confirmed anterosuperior labral tear and partial thickness chondral injury. Iliopsoas tendonitis was noted and mild bone marrow edema at the insertion into the lesser trochanter. The patient reported transient pain relief with the anesthetic at the time of MR arthrogram.

Surgical intervention was planned for arthroscopy, labral repair and femoral osteoplasty with minimal acetabuloplasty. Diagnostic arthroscopy confirmed chondrolabral delamination consistent with CAM impingement. Chondroplasty, osteoplasty and labral resuspension with three anchors was performed. Initial postoperative course was uneventful and return to activity and sport occurred five months postoperatively.

The patient returned one year later with complaints of low back/buttock pain. He specifically denied anterior hip or groin pain. Physical examination confirmed snapping iliotibial band syndrome. Physical therapy reduced the snapping but pain persisted. Repeat radiographs and MRI arthrogram revealed appropriate bony resection, healed labrum and no evidence of heterotopic bone formation. Computed tomography with 3D reconstruction was ordered to confirm the extent of bony resection. This study clearly defined the osteoid osteoma nidus at the level of the lesser trochanter (Figure 2).

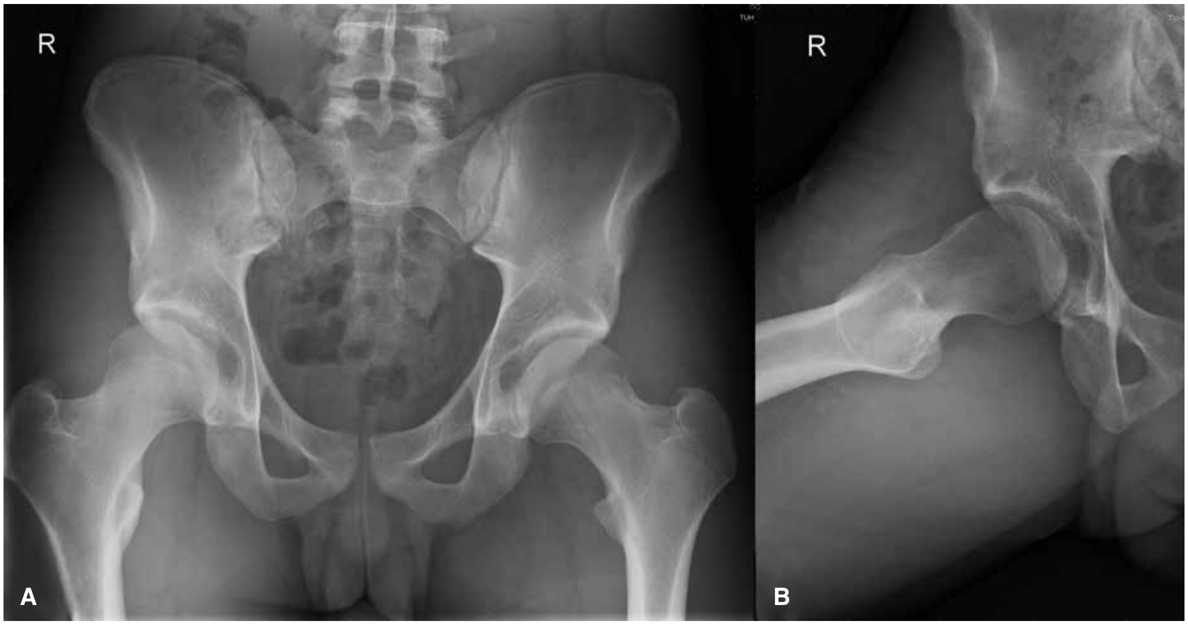

Figure 1. (A–B) AP Pelvis and right hip Dunn elongated neck lateral radiographs.

Figure 2. Computed tomography of patient's right hip revealing osteoid osteoma at the lesser trochanter.

After a trial of salicylic acid failed to relieve the patient's pain, he was referred to interventional radiology for consideration of radiofrequency ablation of the osteoid osteoma.[2] The procedure was performed under CT guidance with the patient prone. Via a posterolateral approach, a 10-gauge bone biopsy needle and drill was advanced to the nidus of the osteoid osteoma and through the anterior periosteal reactive bone. Radiofrequency ablation was successfully performed at both the proximal and distal termini of the nidus and the surrounding periosteum and tissue using a DFINE, Inc. STAR™ Tumor Ablation system at 50 degrees Celsius (Figure 3). Immediate post procedure recovery was uneventful and at three months post-procedure, the patient had returned to all activities and denied any further hip pain.

Discussion/Conclusion

We present the case of an initially unrecognized osteoid osteoma of the lesser trochanter in the setting of apparent CAM-type femoroacetabular impingement. Our case emphasizes the need for complete evaluation and advanced imaging in the setting of any incompletely-defined morphologic abnormality of the proximal femur or acetabulum. In retrospect, the patient may have benefited from CT scan to define the changes seen at the lesser trochanter prior to undergoing surgery. Due to inherent limitations of x-ray and MRI alone, the bony changes were inaccurately attributed to benign apophysitis as opposed to osteoid osteoma.[2] Also, we draw attention to the complete lack of response to salicylic acid and NSAIDs for the entirety of this patient's treatment course. Recent literature has shown that the response to NSAIDs in osteoid osteoma may be overstated. The lack of response to NSAIDs certainly does not rule out osteoid osteoma as the cause of pain.[3, 4]

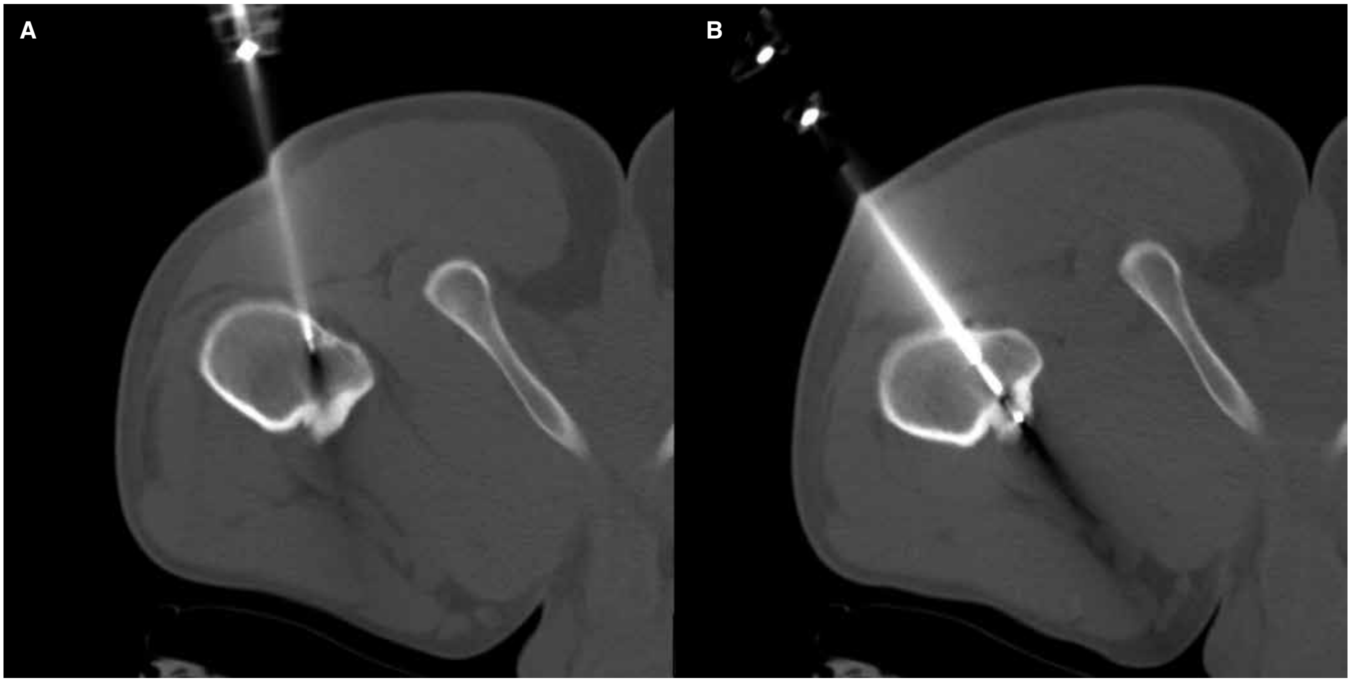

Figure 3. (A–B) Right hip CT scan in prone position with needle and radiofrequency ablation system at level of the osteoid osteoma.

Conflict of Interest

None declared.

Acknowledgements

No external sponsors.

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Senior Abstract

Senior Bio Questionnaire

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- Birthdate: 6/30/1982
- Hometown: Coatesville, PA
- Undergraduate University: Drexel University
- Undergraduate Degree: BS, Biomedical Engineering 2005
- Medical School: Temple School of Medicine 2010
- Fellowship: USF Sports Medicine
- Significant Other: Valerie Lynn Fuller
- Hobbies: Lifting, running
- Interesting Fact: Shares same birthday with Justin Iorio and Dr. Joseph Eremus

Assisted Closure of Fasciotomy Wounds: A Descriptive Series and Caution in Patients with Vascular Injury

John R. Fowler, MD; Matthew T. Kleiner, MD; Rupam Das, MD; John P. Gaughan, PhD; Saqib Rehman, MD

Introduction

Negative pressure wound therapy (NPWT) and vessel loop assisted closure are two common methods used to assist with the closure of fasciotomy wounds. This retrospective review compares these two methods using a primary outcome measurement of skin graft requirement.

Methods

A retrospective search was performed to identify patients who underwent fasciotomy at our institution. Patient demographics, location of the fasciotomy, type of assisted closure, injury characteristics, need for skin graft, length of stay and evidence of infection within 90 days were recorded.

Results

A total of 56 patients met the inclusion criteria. Of these, 49 underwent vessel loop closure and seven underwent NPWT assisted closure. Patients who underwent NPWT assisted closure were at higher risk for requiring skin grafting than patients who underwent vessel loop closure, with an odds ratio of 5.9 (95% confidence interval 1.11 to 31.24). There was no difference in the rate of infection or length of stay between the two groups. Demographic factors such as age, gender, fracture mechanism, location of fasciotomy and presence of open fracture were not predictive of the need for skin grafting.

Conclusion

This retrospective descriptive case series demonstrates an increased risk of skin grafting in patients who underwent fasciotomy and were treated with NPWT assisted wound closure. In our series, vessel loop closure was protective against the need for skin grafting. Due to the small sample size in the NPWT group, caution should be taken when generalising these results. Further research is needed to determine if NPWT assisted closure of fasciotomy wounds truly leads to an increased requirement for skin grafting, or if the vascular injury is the main risk factor.

Senior Abstract

Senior Bio Questionnaire

- Full Name: Kazimierz (kah-zhee-myehsh) [Kasey] Walter Komperda
- Birthdate: 9/23/1983
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- Undergraduate University: University of Illinois, Urbana
- Undergraduate Degree: BS, Molecular and Cellular Biology, Minor Chemistry
- Medical School: University of Pittsburgh School of Medicine
- Fellowship: Sports Medicine, Congress Medical Associates; Pasadena, CA
- Hobbies: Snowboarding, camping, guitar, cigars
- Interesting Facts: I'm the first and only doctor in my family, and I speak fluent Polish

The Effects of Glucosamine Sulfate on Intervertebral Disc Annulus Fibrosus Cells *in Vitro*

Kasey Komperda, MD

Abstract

Background Context

Glucosamine has gained widespread use among patients, despite inconclusive efficacy data. Inconsistency in the clinical literature may be related to lack of understanding of the effects of glucosamine on the intervertebral disc and, therefore, improper patient selection.

Purpose

The goal of our study was to investigate the effects of glucosamine on intervertebral disc cells *in vitro* under the physiological conditions of inflammation and mechanical loading.

Study Design

Controlled *in vitro* laboratory setting.

Methods

Intervertebral disc cells isolated from the rabbit annulus fibrosus were exposed to glucosamine sulfate in the presence and absence of interleukin-1β and tensile strain. Outcome measures included gene expression, measurement of total glycosaminoglycans, new proteoglycan synthesis, prostaglandin E2 production, and matrix metalloproteinase activity. The study was funded by NIH/NCCAM and the authors have no conflicts of interest.

Results

Under conditions of inflammatory stimulation alone, glucosamine demonstrated a dose-dependent effect in decreasing inflammatory and catabolic mediators and increasing anabolic genes. However, under conditions of mechanical stimulation, although inflammatory gene expression was decreased, PGE2 was not. In addition, matrix metalloproteinase-3 gene expression was increased and aggrecan expression decreased, both of which would have a detrimental effect on matrix homeostasis. Consistent with this, measurement of total glycosaminoglycans and new proteoglycan synthesis demonstrated detrimental effects of glucosamine under all conditions tested.

Conclusions

These results may in part help to explain the conflicting reports of efficacy, as there is biological plausibility for a therapeutic effect under conditions of predominate inflammation but not under conditions where mechanical loading is present or in which matrix synthesis is needed.

Senior Abstract

Senior Bio Questionnaire

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- Birthdate: 12/7/1983
- Hometown: Seattle, WA
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- Medical School: Temple University School of Medicine
- Fellowship: Sports Medicine Fellowship at USC, Los Angeles, CA
- Hobbies: Snowboarding, travelling, wakeboarding, soccer, tennis, scuba diving
- Interesting Fact: Before medical school, I worked marine construction full time after returning from living abroad in South Africa

CT Radiation Dosing Can Be Substantially Lowered While Still Providing Sufficient Information for the Operative Surgeon

Colin Mansfield, MD; Sayed Ali, MD;
Kasey Komperda, MD; Saqib Rehman, MD

Objectives

The goal of this study is to determine if CT scans of pilon fractures done with a significantly lowered radiation protocol would provide satisfactory information for evaluation and surgical planning compared with the CT radiation protocol currently used.

Methods

Adult cadaveric distal tibia specimens were utilized to create AO/OTA 43C type distal tibia fractures with varying displacements in two planes. Each specimen was then scanned three times at sequentially lowered radiation dosing as determined by an attending radiologist, which were then subsequently read by both qualified attending orthopedists and mid-level residents. Observer reliability was evaluated, as well as confidence levels of identifying fracture pattern and treatment protocols.

Results

There was significant variability in the measured gap to true gap as a whole (mean = 0.74 $p < .0001$); however, attendings measurements were not significantly more accurate (0.73 $p < .0001$) compared to residents (0.75 $p < .0001$). No significant difference was found between standard radiation dosing and low radiation dosing measurements in gap, pattern or treatment protocols (mean SD 0.011 + .6876, p = .95, 0.2414 + 1.2721, p = .32, .3103 + 1.0725, p = .13, respectively). Furthermore, no significant difference was found in measuring step-off across high-standard, medium and low radiation doses (0.21 + 1.3507, p = .46, 0.28 + 1.5948, p = 0.39, –0.16 + 1.106, p = 0.48 respectively).

Conclusion

The results of this study show no significant difference when evaluating current standard and low-dosed CT scans using less than one-half the amount of exposure being read by experienced readers. This suggests that in complex extremity fractures, a new CT protocol may potentially be utilized that can significantly reduce radiation exposure. Our initial data shows promise that we may retain satisfactory imaging to both identify a fracture pattern and formulate a treatment plan while also to reducing the collective radiation burden to the population.

Senior Abstract

Underinsured Patients Experience Delays in Treatment and Higher Rates of Irreparable Meniscal Injury Following Acute Anterior Cruciate Ligament Rupture

Mark Solarz, MD

Senior Bio Questionnaire

- Full Name: Mark Keenan Solarz
- Birthdate: 10/2/1984
- Hometown: Malvern, PA
- Undergraduate University: University of Notre Dame
- Undergraduate Degree: BS, Biological Sciences and Anthropology
- Medical School: Jefferson Medical College
- Fellowship: Hand and Upper Extremity, University of Florida
- Significant Other: Kristi Solarz
- Children: Madison and Brady
- Hobbies: Home renovation, Irish football
- Interesting Fact: Backpacked through 16 European cities in 2005

Purpose

To determine if patients who are uninsured or covered by Medicaid would experience delays at different stages of care compared to their privately-insured counterparts following acute anterior cruciate ligament rupture, and whether this would ultimately lead to higher rates of meniscal and chondral pathology at the time of surgery.

Methods

Demographic and clinical data was compiled for all ACL reconstructions performed by a single surgeon at an urban academic medical center during a consecutive 52-month period. After excluding those with work-related injuries and those who delayed treatment for personal reasons, 68 patients were sorted by insurance status into privately insured (35) and underinsured/Medicaid (33) groups. Intervals at various stages of treatment from the time of injury to ACL reconstruction and findings at the time of arthroscopy were recorded for all patients.

Results

The underinsured patient population experienced statistically significant delays at every time interval tested with the exception of the time from the initial appointment with the treating surgeon to surgery. While the rates of arthroscopically-confirmed chondral and meniscal injuries were not statistically different between groups ($p = 0.99$), there was a significantly increased rate of irreparable meniscal tears in the underinsured group (I: 23.8% v. U: 61.9%, $p = 0.02$) that required partial meniscectomy.

Conclusions

Privately-insured patients are able to more efficiently navigate the healthcare system following acute ACL rupture, resulting in shorter durations to see providers, complete diagnostic tests, and receive treatment. Delays to ACL reconstruction in the underinsured group correlate with a higher rate of irreparable meniscal tears requiring partial meniscectomy.

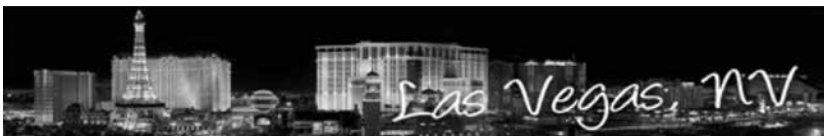
Special Event

American Academy of Orthopaedic Surgeons Annual Meeting 2015

March 24–28, 2015 — Las Vegas, NV

Orthopedic surgeons from around the globe convened this year at the beautiful Venetian and Sands Expo Center, in the backdrop of world-famous Las Vegas, Nevada.

AAOS
American Academy of Orthopaedic Surgeons



The Temple Department of Orthopaedics and Sports Medicine was well represented, and once again had the opportunity to showcase projects that demonstrated the hard work and dedication of our faculty and residents.

Below is a list of the showcased investigations accepted this year:

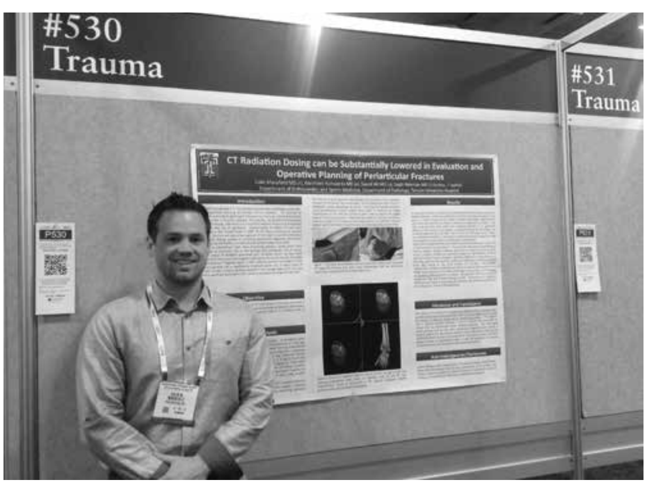
Minimally Invasive Total Hip Arthroplasty: Can We Reduce the Likelihood of Intraoperative Fracture?
By D. Greenhill, K. Darvish, A. Star
Poster presentation

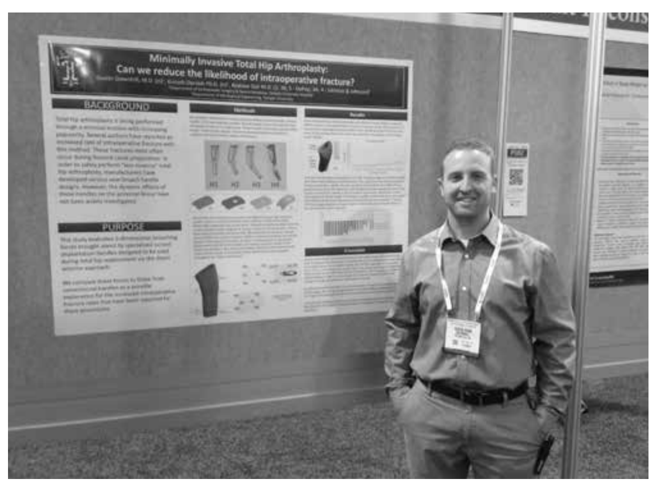
CT Radiation Dosing Can Be Substantially Lowered While Still Providing Sufficient Information for the Operative Surgeon
By C. Mansfield, S. Ali, K. Komperda, S. Rehman
Poster presentation

Ulnar Distraction Osteogenesis for Treatment of Ulnar Based Forearm Deformities in Multiple Hereditary Exostoses
By S. Refsland, S.H. Kozin, D. Zlotolow
Podium presentation

Biomechanical Comparison of the Laterjet Procedure Wth and Without Capsular Repair
By M. Kleiner, W. Payne, M. McGarry, J. Tibone, T. Lee

Colin Mansfield, MD





Resident Research Day

May 30, 2015

Presented in Conjunction with Grand Rounds Speaker

Dr. Alan H. Maurer, MD
Professor of Radiology and Medicine, Director of Nuclear Medicine, Temple University Hospital

"Bone Scintigraphy in Evolution — Planar Bone Scan vs. Hybrid SPECT CT"

The 2015 edition of Temple Orthopedics' Resident Research Day proved to be another successful event that showcased the hard work and scientific contributions from many of the current residents. This year was prefaced with a Grand Rounds talk by Dr. Alan Maurer, highlighting the continued role of the planar bone scan, as well as the more recent advanced imaging modalities now available to improve the way we diagnose and care for patients. This encouraged discussion and debate amongst the attendees, which was then followed by podium presentations of current Temple resident research projects. The series of presentations displayed the ongoing energy and ever growing commitment of both the residents and their supporting faculty members to the study and advancement of the practice of orthopaedics. Following the presentations, the panel of judges met to select first through third place prize winners; however, each individual project was met with congratulations and encouragement for a job well done.

Below is a list of our top three winners. Dustin Greenhill took home the top prize, presenting interesting data on the use of Botox in children with brachial plexus birth palsy, while at the same balancing preparations for the birth of his first daughter only one day later. Special recognition was also given to all of the winners at the Alumni Day Banquet, where again they were able to show their research pursuits to our many alumni in attendance.

1. Dustin Greenhill: "The Modern Role of Botulinum Toxin During Treatment of Children with Brachial Plexus Birth Palsy"
2. Justin Iorio: "Spinal Fusion for Cerebral Palsy Scoliosis: A Prospective Controlled Study"
3. Richard Tosti: "Developing a Pollicization Outcomes Measure"

William Smith, MD

Special Event

Alumni Day 2015

The storied annual meeting of the Temple-Shriner's alumni took place at the picturesque Old York Road Country Club on Monday, May 18. The day was preceded by a fantastic social gathering of cocktails and heavy hors d'oeuvres generously provided by Dr. and Mrs. Clancy at their home on Sunday night.

Dr. Michael Romash commuted from Virginia and was the keynote speaker for the morning's academic session. As a leader in foot and ankle surgery as well as a long-time friend of the department, Dr. Romash illuminated several well-received topics. This was followed by Dr. Christopher Kestner, Class of 2011, who presented topics in treatment of achilles tendon injuries. We ended with a roundtable discussion describing the current research projects the department has been undertaking, as well as reflecting on the recent Amtrak train derailment and the exemplary performance of the Temple faculty and residents involved with caring for the victims of this mass casualty disaster.

The perfect weather lent itself to another famous, or dependent on the score card, infamous day of golfing. All around, 2015 Alumni Day was a successful and well-attended event that set a high bar in anticipation of our future gatherings.

Colin Mansfield, MD

Special Event

2015 Philadelphia Orthopaedic Trauma Symposium

The 7th annual Philadelphia Orthopaedic Trauma Symposium was held on June 12–13th, 2015 at Temple University Hospital. The event was organized by course chairmen Dr. Saqib Rehman, MD and Dr. Gene Shaffer, MD (Einstein Medical Center). The meeting featured two distinguished keynote speakers, including Temple's own Dr. Joseph Thoder, MD, and Dr. Frank Liporace, MD (Chief of Orthopaedic Trauma and Reconstruction at Jersey City Medical Center). The course faculty included 29 orthopaedic surgeons from the greater Philadelphia area, including presentations from Temple faculty and alumni including Dr. Saqib Rehman, MD, Dr. Christopher Haydel, MD, Dr. Joseph Thoder, MD, Dr. Kristofer Matullo, MD, and Dr. William DeLong, MD. The symposium continues to grow, with this year's event successfully drawing another large group of participants including faculty, residents, physician assistants, nurses, and educators from 16 different institutions.

The theme of the 2015 symposium was "Acute Care Challenges in Orthopaedic Trauma," with a focus on principles of acute management of skeletal injuries of the extremities, spine, and pelvis. The educational program also included skills development for reduction and fixation of periarticular fractures, as well as a discussion of management controversies with respect to open fractures, nerve and vascular injuries, compartment syndrome, and infections. A series of formal presentations provided a current concepts review with rousing case-based group discussions following each session. The expert faculty provided detailed instruction on a variety of topics including pelvic ring injuries, open fractures of the upper and lower extremities, compartment syndrome, pediatric trauma challenges, spinal trauma, concussions, and acute nerve and vascular compromise.

Back by popular demand, this year's symposium featured a series of hands-on learning labs, providing technique demonstrations for several highlighted trauma topics, including distal femoral and proximal tibial fracture plating. A number of trauma-related research projects submitted by area residents and medical students were displayed throughout the atrium, providing another source of discussion between formal lecture presentations.

Once again, the 7th annual Philadelphia Orthopaedic Trauma Symposium proved to be a great success. The event is led by a full compliment of the area's finest orthopaedic trauma faculty and serves as a local forum for education, research, and discussion.

William R. Smith, MD

Special Event

Ponderosa Bowl 2015

Sunday, December 6th, 2015 marked the 5th annual Ponderosa Bowl. As in years past, the anticipation of the mud-filled grounds of Dr. Thoder's backyard and designated hallowed football field struck both fear and excitement into the hearts of those playing. However, this year was not one that left the winning team covered in muddy glory. In fact, it was one of the more pristine days the Ponderosa Bowl has ever seen.

Despite the limited players available for this year's game, it certainly did not disappoint. The Cherry Team was represented by Peter Eyvazzadeh, MD, Justin Kistler, MD, Colin "Mac" Vroome, MD, and an alumni appearance by John Fowler, MD. The White Team was represented by James Bennett, MD, Will Smith, MD, Jim Lachman, MD, and another alumni performance from Moody Kwok, MD, along with his two sons, who displayed vastly greater skills than any of the seasoned orthopaedic residents. As always, another tight game was brilliantly officiated by Dr. Thoder.

The first half saw rapid scoring between the two teams in a tightly-fought back and forth battle. The White Team took their lead by one touchdown into halftime despite numerous penalties to Will Smith, MD, including two consecutive penalties for false starts. During the second half, the Cherry Team used youth to their advantage. The elaborate and fast-paced offensive run by the veteran John Fowler, MD was too much for the White Team to compete with and at times was even too confusing for Peter (distracted by the thought of post game refreshments), Justin (suffering from post-call delirium), and Mac (the intern). The Cherry Team also gained a huge advantage in the second half with the hamstring injury to Jim Lachman, MD, former division I college football standout.

In the end, the Cherry Team emerged victorious. Although, it can be argued that all were victorious given that they walked away with only one minor hamstring pull despite the residents being far removed from their athletic primes. In keeping with tradition, the post-game festivities were held in the basement of the Ponderosa consisting of NFL Red Zone, food, beer, cigars, darts, and Dr. Thoder's legendary hospitality. The plans for the 2016 Ponderosa Bowl were already being formulated.

Justin Kistler, MD

Special Event

TEMPLE WINS AGAIN!!

Philadelphia Orthopaedic Society
15th Annual John R. Gregg Memorial Resident Bowl

Every year to conclude their academic program, the Philadelphia Orthopaedic Society hosts the Annual John R. Gregg Memorial Resident Bowl — an always well-attended event wherein residents from each of the city's six orthopaedic surgery residency programs compete against one another in a game-style setting. One chief resident from Temple, Drexel, Jefferson, Penn, Einstein and PCOM compete in an "orthopaedic bar-trivia" format for the grand prize. Temple has historically come out on top in this intellectual competition, with seven champions in the last 15 years. This year, **Rick Tosti, MD** (Class of 2015) once again brought the trophy back to Temple, proving that we are, in fact, Temple-Strong.

Arianna Trionfo, MD

Temple Resident Bowl Winners
2015 — Rick Tosti, MD
2014 — Emeka Nwodim, MD
2007 — Robert Purchase, MD
2006 — Matthew Reish, MD
2004 — Sue Y. Lee, MD
2000 — Richard Savino, MD
1999 — Christopher Mancuso, MD

Departmental News

Eric J. Kropf, MD

Appointed
Chair, Department of Orthopaedic Surgery and Sports Medicine

On January 1, 2016, Eric Kropf, MD became the new chairman of the Department of Orthopaedic Surgery and Sports Medicine. Dr. Kropf has been a faculty member with Temple Orthopaedics since 2008 and currently serves as the Director of Sports Medicine and Associate Professor of Orthopaedic Surgery at the Lewis Katz School of Medicine at Temple University. He takes over for Pekka Mooar, MD, who had served as interim chair for the past two years. We thank Dr. Mooar for his hard work and dedicated service to the department and its residency program and welcome Dr. Kropf into his new role.

The tradition of excellence in clinical care, resident education, and research in the Department of Orthopaedic Surgery and Sports Medicine began with John Lachman, MD and was continued by Michael Clancy, MD and Joseph Thoder, MD. Dr. Kropf will certainly carry on the rich tradition that has been fortified by the department's former chairmen.

A native of Allentown, PA, Dr. Kropf completed his undergraduate degree at Villanova University, where he was a member of the varsity baseball team earning Academic All-Big East Honors. He then continued to Georgetown University (much to the surprise of the Villanova faithful) where he completed his medical degree. As fate would have it, the Big East tradition continued, and he went on to complete his residency in orthopaedic surgery and a fellowship in sports medicine and shoulder surgery at the University of Pittsburgh under the direction of Freddie H. Fu, MD.

Dr. Kropf's clinical and research interests include hip injuries and hip arthroscopy in athletes, shoulder injuries in throwing and overhead athletes, and knee injuries and ACL reconstruction. He has authored numerous book chapters and peer-reviewed journal articles and delivered lectures on both the national and international stage. He is an active member of many professional organizations including the Arthroscopy Association of North America, the American Academy of Orthopaedic Surgeons, and the American Orthopaedic Society for Sports Medicine.

With his energy and enthusiasm for resident education and research, a love of athletics, and dedication to outstanding clinical care, Dr. Kropf will uphold and enhance the tradition of the Department of Orthopaedic Surgery and Sports Medicine at Temple University.

Justin M. Kistler, MD

Faculty

Temple University Department of Orthopaedic Surgery and Sports Medicine

Chairman

Eric J. Kropf, MD

Professors

Joseph Thoder, MD, *The John W. Lachman Professor*
William DeLong, MD
Pekka Mooar, MD
Ray Moyer, MD, *The Howard H. Steel Professor*
Joseph Torg, MD
F. Todd Wetzel, MD, *Vice Chairman*

Associate Professors

Saqib Rehman, MD
J. Milo Sewards, MD
Bruce Vanett, MD
Albert Weiss, MD

Assistant Professors

Leslie Barnes, MD
Joseph Eremus, MD
Christopher Haydel, MD
Cory Keller, DO
Matthew Lorei, MD
Michelle Noreski, DO
David Pashman, MD

Adjunct Faculty — Philadelphia Shriners Hospital

Scott Kozin, MD, *Chief of Staff*
Randal Betz, MD, *Emeritus Chief of Staff*
Philip Alburger, MD
Patrick Cahill, MD
Richard Davidson, MD
Corinna Franklin, MD
Howard Steel, MD, *Emeritus Chief of Staff*
Joshua Pahys, MD
Amer Samdani, MD
Harold van Bosse, MD
Daniel Zlotolow, MD

Adjunct Faculty — Jefferson Health–Abington Memorial Hospital

Andrew Star, MD, *Chief of Orthopaedics*
Shyam Brahmabhatt, MD
David Craft, MD
Matthew Craig, MD
Greg Galant, MD
Michael Gratch, MD
Victor Hsu, MD
Moody Kwok, MD
Guy Lee, MD
Thomas Peff, MD
T. Robert Takei, MD
Jeffrey Vakil, MD

Adjunct Faculty — St. Christopher's Hospital for Children

Peter Pizzutillo, MD, *Chief of Orthopaedics*
Alison Gattuso, DO
Megan Gresh, MD
Martin Herman, MD
Michael Kwon, MD
Joseph Rosenblatt, DO
Shannon Safier, MD
Michael Wolf, MD

Temple University Hospital
Department of Orthopaedic Surgery and Sports Medicine
Faculty 2015–2016

Leslie Barnes, MD
Shoulder and Elbow Surgery

Joseph Eremus, MD
Foot and Ankle
General Orthopaedics

Christopher Haydel, MD
Orthopaedic Trauma
General Orthopaedics

Cory Keller, DO
Sports Medicine

Eric Kropf, MD
Sports Medicine
General Orthopaedics

Matthew Lorei, MD
Joint Reconstruction
General Orthopaedics

Pekka Mooar, MD
Sports Medicine
Joint Reconstruction
General Orthopaedics

Ray Moyer, MD
Howard Steel Professor
Sports Medicine

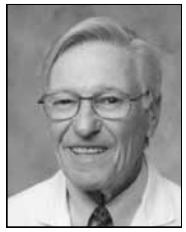
Michelle Noreski, DO
Sports Medicine

David Pashman, MD
General Orthopaedics

Saqib Rehman, MD
Orthopaedic Trauma
General Orthopaedics

J. Milo Sewards, MD
Sports Medicine

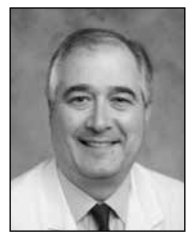
Joseph Thoder, MD
John W. Lachman Professor
Hand & Upper Extremity
General Orthopaedics



Joseph Torg, MD
Sports Medicine

Bruce Vanett, MD
General Orthopaedics

Albert Weiss, MD
Hand & Upper Extremity
General Orthopaedics



F. Todd Wetzel, MD
Vice-Chairman
Spine Surgery

Temple University Hospital
Department of Orthopaedic Surgery and Sports Medicine
House Staff 2015–2016

Colin Mansfield, MD

Hometown: Seattle, WA

Undergraduate: University of Washington

Medical School: Temple University School of Medicine

Fellowship: Sports, University of Southern California

Kasey Komperda, MD

Hometown: Chicago, IL

Undergraduate: University of Illinois

Medical School: University of Pittsburgh School of Medicine

Fellowship: Sports, Congress Orthopaedics (Pasadena, CA)

Rupam Das, MD

Hometown: Coatesville, PA

Undergraduate: Drexel University

Medical School: Temple University School of Medicine

Fellowship: Sports, University of South Florida

Mark Solarz, MD

Hometown: Malvern, PA

Undergraduate: University of Notre Dame

Medical School: Jefferson Medical College

Fellowship: Hand and Upper Extremity, University of Florida

Arianna Trionfo, MD

Hometown: Glassboro, NJ

Undergraduate: Loyola College in Maryland

Medical School: UMDNJ – Robert Wood Johnson

Interest: Pediatrics

James Lachman, MD

Hometown: Bryn Mawr, PA

Undergraduate: Bucknell University

Medical School: Temple University School of Medicine

Interest: Foot and ankle

Anastassia Newbury, MD

Hometown: Omaha, NE

Undergraduate: University of Iowa

Medical School: University of Nebraska College of Medicine

Interest: Hand/upper extremity

Dustin Greenhill, MD

Hometown: West Palm Beach, FL

Undergraduate: U.S. Military Academy (West Point)

Medical School: Temple University School of Medicine

Interest: Pediatrics

Temple University Hospital
Department of Orthopaedic Surgery and Sports Medicine
House Staff 2015–2016 *(cont.)*

Katherine Harper, MD

Hometown: London, Ontario, Canada

Undergraduate: McMaster University

Medical School: Royal College of Surgeons in Ireland School of Medicine

Interest: Adult reconstruction, foot and ankle

John Jennings, MD

Hometown: Allentown, PA

Undergraduate: Pennsylvania State University

Medical School: Temple University School of Medicine

Interest: Hand/upper extremity

James Bennett, MD

Hometown: Charlotte, VT

Undergraduate: Colby College

Medical School: St. George's University School of Medicine

Interest: Pediatric spine

William Smith, MD

Hometown: Havertown, PA

Undergraduate: Pennsylvania State University

Medical School: Jefferson Medical College

Interest: Hand/upper extremity

Justin Kistler, MD

Hometown: Horsham, PA

Undergraduate: University of Pittsburgh

Medical School: Temple University School of Medicine

Interest: Hand/upper extremity, adult reconstruction

Courtney Quinn, MD

Hometown: Potomac, MD

Undergraduate: University of Southern California

Medical School: Georgetown University School of Medicine

Interest: Undecided

Megan Reilly, MD

Hometown: Longwood, FL

Undergraduate: University of Florida

Medical School: Georgetown University School of Medicine

Interest: Undecided

Peter Eyvazzadeh, MD

Hometown: Bethlehem, PA

Undergraduate: Bucknell University

Medical School: Penn State University College of Medicine

Interest: Undecided

Temple University Hospital
Department of Orthopaedic Surgery and Sports Medicine
House Staff 2015–2016 *(cont.)*

Dayna Phillips, MD

Hometown: Rosenhayn, NJ

Undergraduate: University of the Sciences

Medical School: Rutgers – New Jersey Medical School

Interest: Undecided

Colin "Mac" Vroome, MD

Hometown: Havertown, PA

Undergraduate: Villanova

Medical School: Jefferson Medical College

Interest: Sports

Jeffrey Wera, MD

Hometown: Villa Hills, KY

Undergraduate: The College of William & Mary

Medical School: University of Louisville School of Medicine

Interest: Undecided

Robert Ames, MD

Hometown: Dallas, TX

Undergraduate: Rutgers University

Medical School: Temple University School of Medicine

Interests: Spine, pediatrics

Temple University Department of Orthopaedic Surgery and Sports Medicine: Research Update 2015–2016

Podium Presentations

Greenhill D, Comstock D, Torg J, Navo P, Zhao H, Boden B. Inadequate Helmet Fit Increases Concussion Severity in American High School Football Players. *American Academy of Orthopaedic Surgeons Annual Meeting,* Orlando, FL, March 2016.

Solarz M, Richmond J, Ramsey FV, Kropf E. Underinsured Patients Experience Delays in Treatment and Higher Rates of Irreparable Meniscal Injury Following Acute Anterior Cruciate Ligament Rupture. *Eastern Orthopaedic Association Annual Meeting,* Maui, HI, June 2015.

Greenhill D, Kozin S, Zlotolow D. The Modern Role of Botulinum Toxin During Treatment of Children with Brachial Plexus Birth Palsy. *American Society for Surgery of the Hand Annual Meeting,* Seattle, WA, September 2015.

Trionfo A, Thoder JJ, Tosti R. Do Pre-Operative Antibiotics Reduce Bacterial Culture Growth from Hand Abscesses? *American Academy of Orthopaedic Surgeons Annual Meeting,* Orlando, FL, March 2016.

Samdani AF, Ames RJ, Asghar, Orlando, Pahys J, Yazay B, Miyanji, Lonner B, Lehman, Newton P, Cahill P, Betz RR. Intraoperative Neurophysiological Monitoring Changes in Surgically Treated AIS Patients. *Scoliosis Research Society Meeting,* Minneapolis, MN, September 2015.

Samdani AF, Bastrom T, Ames RJ, Miyanji F, Pahys J, Marks M, Lonner B, Newton PO, Shufflebarger H, Cahill P, Betz RR. What Is Different About Patients with AIS Who Achieve a Minimal Clinically Important Difference (MCID) in Appearance? *22nd International Meeting on Advanced Spine Techniques (IMAST),* Kuala Lumpur, Malaysia, July 2015.

Pahys J, Khatri V, Samdani AF, Ames RJ, Kimball JS, McLarney M, Grewal H, Pelletier G, Betz RR. Perioperative Complication Rate in Patients Treated with Anterior Vertebral Body Tethering: Single Institution Results the First 100 Patients. *22nd International Meeting on Advanced Spine Techniques (IMAST),* Kuala Lumpur, Malaysia, July 2015.

Greenhill D, Van Bosse H. Bilateral Congenital Hip Dislocations in a Patient with Arthrogryposis: Case Presentation and Literature Review. *International Pediatric Orthopaedic Symposium,* Orlando, FL, December 2015.

Greenhill D, Van Bosse H. Does Open Reduction of Arthrogrypotic Hips Cause Stiffness? *Pediatric Orthopaedic Society of North America Annual Meeting,* Indianapolis, IN, April 2016.

Greenhill D, Wissinger K, Trionfo A, Solarz M, Kozin S, Zlotolow D. External Rotation Predicts Outcomes after Glenohumeral Joint Reduction with Botulinum Toxin Type A in Brachial Plexus Birth Palsy. *Pediatric Orthopaedic Society of North America Annual Meeting and Narakas Symposium XIX,* Barcelona, Spain, February 2016.

Greenhill D, Tomlinson-Hansen S, Kozin S, Zlotolow D. Relationships between Three Classification Systems in Brachial Plexus Birth Palsy. *Narakas Symposium XIX,* Barcelona, Spain, February 2016.

Trionfo A, Greenhill D, Solarz M, Kozin S, Zlotolow D. Risk Factors for Loss of Midline Function in Patients with Brachial Plexus Birth Palsy. *Narakas Symposium XIX,* Barcelona, Spain, February 2016.

DeFrancesco C, Quinn C, Ramsey F, Rehman S. To Cut or Not to Cut? Patients Found Down with Crush Syndrome. *Pennsylvania Orthopaedic Society Spring Meeting,* Boca Raton, FL, April 2016.

Iorio J, Harper K, Quinn C, Rehman S. Percutaneous Sacroiliac Screw Fixation of the Posterior Pelvic Ring. *Pennsylvania Orthopaedic Society Spring Meeting,* Boca Raton, FL, April 2016.

Reilly M, Kripke L, Greenhill D, Ramsey F, Haydel C. Outcomes in Tibial Intramedullary Nailing: Suprapatellar Versus Infrapatellar. *Pennsylvania Orthopaedic Society Spring Meeting,* Boca Raton, FL, April 2016.

Lachman JR, Haydel CL, Balasubramanian E. Robotic Assisted Total Hip Arthroplasty: Is It the Future Yet? *American Academy of Orthopaedic Surgery Annual Meeting,* Orlando, FL, March 2016.

Wetzel FT. The Diagnosis and Treatment of Discogenic Pain. Visiting Professor, Keynote Speaker, Presidential Line Representative of the North American Spine Society, *Association of Spine Surgeons of India, 28th Annual Meeting,* Pune, India, January 2015.

Wetzel FT. Characterization and Treatment of Post Fusion Transitions Syndromes. Visiting Professor, Keynote Speaker, Presidential Line Representative of the North American Spine Society, *Association of Spine Surgeons of India, 28th Annual Meeting,* Pune, India, January 2015.

Poster Presentations

Trionfo, A, Makowski AL, Latta, L, Ouelette EA. Characterizing Ulnocarpal Instability in the General Population. *Orthopaedic Research Society Annual Meeting,* Orlando, FL, March 2016.

Greenhill D, Van Bosse H. Surgical Management of Bilateral Congenital Hip Dislocations in Patients with Arthrogryposis. *International Pediatric Orthopaedic Symposium,* Orlando, FL, December 2015

Greenhill D, Darvish K, Star A. Minimally Invasive Total Hip Arthroplasty: Can We Reduce the Likelihood of Intraoperative Fracture? *American Academy of Orthopaedic Surgeons Annual Meeting,* Las Vegas, NV, March 2015.

Ames RJ, Kimball J, Pahys JM, Grewal H, Pelletier GJ, Betz RR, Samdani A. Anterior Vertebral Body Tethering for Immature AIS: Initial Clinical Results. *American Academy of Orthopaedic Surgeons Annual Meeting,* Las Vegas, NV, March 2015.

Eccles J, Harper K, Quinn C, Ramsey F, Rehman S. Factors Affecting Timing of IV Antibiotic Administration for Patients with Open Fractures. *Pennsylvannia Orthopaedic Society Spring Meeting,* Boca Raton, FL, April 2016.

Harper K, Quinn C, Iorio J, Rehman S. Percutaneous Sacroiliac Screw Fixation of the Posterior Pelvic Ring. *Pennsylvannia Orthopaedic Society Spring Meeting,* Boca Raton, FL, April 2016.

Harper K, Rehman S. Orthopaedic Disaster Management in the 2015 Amtrak Derailment. *Pennsylvannia Orthopaedic Society Spring Meeting,* Boca Raton, FL, April 2016.

Jennings, JD, Haydel C, Rehman S. Management of Adult Elbow Fracture Dislocations. *American Academy of Orthopaedic Surgeons Annual Meeting,* Orlando, FL, March 2016 (Scientific Exhibit).

Greenhill D, Poorman M, Pinkowski C, Ramsey F, Haydel C. Weight-Bearing on Tibial Shaft Fractures After Intramedullary Nail Placement Does Not Alter Time to Union. *Pennsylvania Orthopaedic Society Spring Meeting,* Boca Raton, FL, April 2016.

Greenhill D, Lukavsky R, Tomlinson-Hansen S, Kozin S, Zlotolow D. Relationships Between Three Classification Systems in Brachial Plexus Birth Palsy. *Pediatric Orthopaedic Society of North America Annual Meeting,* Indianapolis, IN, April 2016.

Lachman JR, Haydel CL, Eremus JL. Intra-osseous Fixation for Hindfoot Fusions; Is It Really Less Painful? *AOFAS Annual Meeting,* Toronto, Canada, July 2016.

Publications in Peer-Reviewed Journals

Jennings JD, Solarz MK, Haydel C. Application of Tranexamic Acid to Trauma and Orthopaedic Surgery. *Orthop Clin North Am.* 2016 Jan; 47(1):127–136. PMID: 26614928.

Solarz MK, Thoder JJ, Rehman S. Management of Traumatic Upper Extremity Amputations. *Orthop Clin North Am.* 2016 Jan;47(1):137–143. PMID: 26614927.

Harper K, Iorio J, Balasubramanian E. Profunda Femoris Pseudoaneurysm Following Total Hip Arthroplasty Revision. *Case Rep Orthop.* 2015; 2015, PMID: 6347839.

Greenhill D, Lukavsky R, Tomlinson-Hansen S, Kozin S, Zlotolow D. Relationships Between Three Classification Systems in Brachial Plexus Birth Palsy. *J Ped Orthop.* EPub ahead of print December 2015.

Greenhill D, Haydel C, Rehman S. Management of the Morel-Lavallée Lesion. *Orthop Clin North Am.* 2016 Jan;47(1):115–25. PMID:26614926.

Trionfo A, Thoder JJ, Tosti R. The Effects of Preoperative Antibiotics on Culture Growth in Hand Abscesses. Accepted at Hand. *Hand.* EPub ahead of print Feb 2016.

Tosti R, Trionfo A, Gaughan J, Ilyas AM. Risk Factors Associated with Clindamycin Resistance in Methicillin Resistant *Staphylococcus Aureus* in Hand Abscesses. *J Hand Surg Am.* 2015 Apr;40(4):673–676. PMID: 25707549.

Samdani AF, Belin E, Bennett JT, Miyanji F, Pahys J, Shah SA, Newton PO, Betz RR, Cahill PJ, Sponseller PD. Major Perioperative Complications after Surgery for Cerebral Palsy: Assessment of Risk Factors. *Eur Spine J.* 2016 Mar;25(3):795–800. PMID: 26148567.

Samdani AF, Bennett JT, Singla A, Marks MM, Pahys J, Lonner B, Miynaji F, Suken S, Newton PO, Asghar J, Betz RR, Cahill P. Do Ponte Osteotomies Enhance Correction in AIS? An Analysis of 191 Lenke 1A and 1B Curves. *Spine Deformity.* 2015 Sept; 3(5):483–488.

Samdani AF, Asghar J, Mijanji F, Bennett JT, Hoashi JS, Lonner BS, Marks MC, Newton PO, Betz RR. Recurrence of Rib Prominence Following Surgery for Adolescent Idiopathic Scoliosis with Pedicle Screws and Direct Vertebral Body Derotation. *Eur Spine J.* 2015 Jul;24(7):1547–54. PMID: 25550103.

Harper K, Rehman S. Orthopaedic Disaster Management in the 2015 Amtrak Derailment. *J Trauma Acute Care Surg.* Epub ahead of print April 2016.

Jennings JD, Hahn A, Rehman S, Haydel C. Management of Adult Elbow Fracture Dislocations. *Orthop Clin North Am.* 2016 Jan;47(1):97–113 PMID: 26614925.

Lachman JR, Rehman S, Pipitone PS. Traumatic Knee Dislocations: Evaluation, Management, and Surgical Treatment. *Orthop Clin North Am.* 2015 Oct;46(4):479–93. PMID: 26410637.

Greenhill D, Wissinger K, Trionfo A, Solarz M, Kozin S, Zlotolow D. External Rotation Predicts Outcomes After Glenohumeral Joint Reduction with Botulinum Toxin Type A in Brachial Plexus Birth Palsy. *J Pediatr Orthop.* 2016 Feb 15. [Epub ahead of print.]

Schofferman JS, Wetzel FT, Bono CM. Ghost and Guest Authors. You Can't Always Trust What You Read. *Pain Medicine.* 2015;16:416–420. PMID: 25338945.

DePalma MJ, Slipman CW, Wetzel FT. The Mechanism of Action of Non-endoscopic Percutaneous Disc Decompression Treatment of Discogenic Lumbosacral Radiculopathy. *The Spine Journal* (in press).

DePalma MJ, Slipman CW, Wetzel FT. The Efficacy and Safety of Non-endoscopic Percutaneous Disc Decompression Treatment of Discogenic Lumbosacral Radiculopathy. *The Spine Journal* (in press).

Kang Q, Sun MH, Cheng H, Peng Y, Montag AG, Deyrup AT, Jiang W, An N, Luu H, Szatkowski JP, Vanichakarn P, Park JY, Gupta P, Wetzel FT, Haydon RC, He TC. Distinct Bone Forming Activity of the Bone Morphogenetic Proteins (BMPs). *Journal of Biological Chemistry* (in press).

Peng Y, Kang Q, Cheng H, Li X, Sun MH, Jiang W, Luu H, Luo J, Luo Q, Park JY, Wetzel FT, Haydon RC, He TC. Transcriptional Signature of Bone Morphogenetic Proteins (BMPs)-Mediated Osteogenic Signaling. *Spine* (in press).

Textbook Chapters

Dakwar E, Bennett JT, Samdani AF. Diastematomyelia in Severe Spinal Deformity: Treatment with Vertebral Column Resection. A Case Presentation In: Gupta MC, Vaccaro AR, eds. *Complex Spine Cases: A Collection of Current Techniques.* 1st ed. New Delhi, India: Jaypee Brothers Medical Publishers, Ltd.; Jan. 2015.

Ames RJ, Samdani AF, Pahys J, Betz RR. *Growing Spine Section: Fusionless Scoliosis Surgery and Anterior Vertebral Body Tethering.* Scoliosis Research Society E-Text. 2015.

Lachman J, Rehman S. Tibial plateau Schatzker V/VI treated in ex fix/circular frame. In Tejwani NC editor: *Fractures of the Tibia, A Clinical Companion.* Springer, 2016

Lachman JR, Rehman S. Chapter 3–Bone Healing. In Hoppenfeld S, Murthy VL: *Treatment and Rehabilitation of Fractures.* 2nd Edition. Lippicott and Williams. 2016.

Joseph J. Thoder
Orthopaedic Excellence Award

"In recognition of Dr. Thoder's steadfast dedication to the Temple Orthopaedic Surgery Residency. Through his mentorship, we pursue academic and clinical excellence, while learning the importance of heritage, teamwork, and family. This award, presented by the chief residents, honors the orthopaedic resident who best exemplifies the standards of scholarly achievement and personal excellence set forth by Dr. Thoder."

Given as a graduation gift by the class of 2010, Drs. Abi Foroohar, Allan Tham, Ifran Ahmed, and John Parron fund a yearly award given to the resident that demonstrates qualities commensurate with Dr. Thoder's vision of a Temple Orthopaedic Surgeon. Selected from the graduating chief resident class, the recipient is presented with a cash prize and a plaque.

This year, **Katharine Harper** (Class of 2018) was selected by Justin Iorio, Steve Refsland, Craig Steiner, and Rick Tosti (Class of 2015).

Previous Winners:
2014 — Arianna Trionfo, MD
2013 — Rupam Das, MD
2012 — Matthew Kleiner, MD
2011 — Richard Han, MD
2010 — John Fowler, MD

Katharine Harper, MD

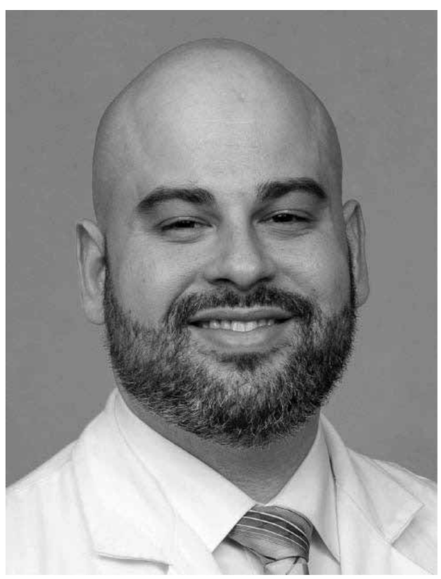
Faculty Award for Excellence in Orthopaedic Education

"Give a man a fish and you feed him for a day.
Teach a man to fish and you feed him for a lifetime."

The graduating residency class recognizes a faculty member who has stood out as an influential mentor throughout their path to become competent orthopaedic surgeons. The recipient is presented with a plaque and a lifetime of appreciation.

This year, **Christopher Haydel, MD** (Orthopaedic Traumatologist) was selected by Justin Iorio, Steve Refsland, Craig Steiner and Rick Tosti (Class of 2015).

Previous Winners:
2014 — Joseph Thoder, MD
2013 — Saqib Rehman, MD
2012 — Joseph Thoder, MD
2011 — Eric Kropf, MD
2010 — Saqib Rehman, MD
2009 — Joseph Thoder, MD
2008 — Michael Clancy, MD
2007 — Easwaran Balasubramanian, MD
2006 — Joseph Thoder, MD
2005 — Christopher Born, MD



Christopher Haydel, MD

Snapshots from 2015–2016

Temple Strong — Spartan Race 2015


Temple Alumni reunite at Matt Kleiner's wedding


Bringing Pediatric Orthopaedics back to Temple — International Pediatric Orthopaedics Symposium in Orlando, FL


Ron Burgundy (aka Dr. Thoder) and the ladies of Temple Orthopaedics


Mid-game jersey purchase at the 2nd Annual Flyers outing for Temple Ortho!


Preop planning in the trauma room doesn't wait for broken scrub machines

Snapshots from 2015–2016

Three generations of chiefs grabbing a drink! (John Parron, Joe Dwyer and Colin Mansfield)

Trauma Team…always prepared for the worst…weather

The second best-looking intern class in Temple history (in height order)

Rounding with the Pope during the Philadelphia Papal Visit 9/2015

Dr. Sewards, Marianne Kilbride and Joe Rudy showing their Temple pride at a Temple vs. Notre Dame tailgate (not pictured: resident and Notre Dame graduate, Mark Solarz)

Rising second years, looking rather excited for the upcoming year of q4 in-house call

Instructions to Authors

Editorial Philosophy

The purpose of the *Temple University Journal of Orthopaedic Surgery & Sports Medicine (TUJOSM)* is to publish clinical and basic science research performed by all departments of Temple University that relate to orthopaedic surgery and sports medicine. As such, *TUJOSM* will consider for publication any original clinical or basic science research, review article, case report, and technical or clinical tips. All clinical studies, including retrospective reviews, require IRB approval.

Editorial Review Process

All submissions will be sent to select members of our peer review board for formal review.

Manuscript Requirements

Manuscripts are not to exceed 15 double spaced type-written pages and/or 5,000 words (minus figures/tables/pictures). The manuscript should contain the following elements: Title page, Abstract, Body, References, and Tables/Legends. Pages should be numbered consecutively starting from the title page.

(1) Title Page — The first page, should contain the article's title, authors and degrees, institutional affiliations, conflict of interest statement, and contact information of the corresponding author (name, address, fax, and email address).

(2) Abstract — The second page, should be a one-paragraph abstract less than 200 words concisely stating the objective, methods, results, and conclusion of the article.

(3) Body — Should be divided into, if applicable, Introduction, Materials & Methods, Results, Discussion, and Acknowledgements. Tables and figures (in JPEG format) with their headings/captions should be listed consecutively on separate pages at the end of the body, not continuous within the text.

(4) References — Should be listed following the format utilized by *JBJS.* For example: Smith, JH, Doe, JD. Fixation of unstable intertrochanteric femur fractures. *J Bone Joint Surg Am.* 2002;84:3553–58.

Submissions

All submissions are now digital. Please submit the manuscript in a Microsoft Word document to templejournal@gmail.com.

***Disclaimer:* This journal contains manuscripts that are considered interpersonal communications and extended abstracts and not formalized papers unless otherwise noted.**

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