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THE IOWA ORTHOPAEDIC JOURNAL

2010 • Volume 30

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The Iowa Orthopaedic Journal
INSTRUCTIONS FOR AUTHORS, 2011

Any original article relevant to orthopaedic surgery, orthopaedic science or the teaching of either will be considered for publication in The Iowa Orthopaedic Journal. Articles will be enthusiastically received from alumni, visitors to the department, members of the Iowa Orthopaedic Society, residents, and friends of The University of Iowa Department of Orthopaedics and Rehabilitation. The journal is published every June. **The deadline to receive articles for the 2011 edition is Monday, March 7, 2011.**

Published articles and illustrations become the property of The Iowa Orthopaedic Journal. The journal is peer reviewed and referenced in Index Medicus and MEDLINE. Articles previously published will not be accepted unless their content has been significantly changed.

When submitting an article, send the following:

1. The original manuscript with illustrations and **ABSTRACT**. The corresponding author must be clearly identified with mailing address, telephone/fax numbers and e-mail address. Manuscripts will not be returned unless requested.
2. The bibliography must list references **in the order of their appearance**, and be double-spaced. References must be presented in the text by superscript numbers.
3. Legends for all illustrations should be listed in order of appearance and single spaced.
4. Illustrations/Images:
   a. Color illustrations may not be used unless it is the opinion of the journal that they convey information not available in black and white.

b. Each image should be sent to diana-johannes@uiowa.edu as an individual .tif or .jpg file. All images **must have resolution of 300 pixels per inch (ppi)**. Web page images are to be avoided. Set digital cameras to their highest quality (ppi) setting for photographs.

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5. Send electronic copies of all items to diana-johannes@uiowa.edu. Special illustrations and photographs may be exempted from this electronic requirement and should be mailed to the address below.

**Preparation of manuscripts:** Manuscripts must be typewritten and double spaced using wide margins. Write out numbers under 10 except percentages, degrees or numbers expressed as decimals. Direct quotations should include the exact page number on which they appeared in the book or article. All measurements should be given in SI metric units. In reporting results of surgery, only in rare instances can cases with less than two years of follow-up be accepted.

+++++++

Additional copies of these instructions may be obtained at www.uihealthcare.com/depts/med/orthopaedicsurgery/research/ioj.html or by writing to Diana Johannes, University of Iowa Hospitals and Clinics, Department of Orthopaedics, Institute for Sports Medicine and Rehabilitation, 2701 Prairie Meadow Drive, Iowa City, Iowa, 52242 or by emailing diana-johannes@uiowa.edu.
Editors’ Note

It is with great pleasure that we present the 30th edition of The Iowa Orthopaedic Journal (IOJ) in 2010. As in previous years, this edition represents work and contributions from countless faculty, support staff and residents from the University of Iowa. Submissions were received from within our department and from across the nation and globe. The impact of the IOJ continues to increase, as the articles are freely available via Pub Med. A recent analysis demonstrated that more than 1,000 articles from the IOJ are downloaded from Pub Med on an average day. We are hopeful that the Pub Med exposure will continue to increase the IOJ readership and result in continued growth.

As per tradition, we would like to recognize the departing senior residents Drs. Donigan, Ilgenfritz, Karam, Malin, McKay, and Michalson. They have led by example and inspired younger resident classes to high achievement. We wish them well as they leave the department and embark on the next stage of their careers. We hope that their Iowa Orthopaedic roots will serve them well and keep them connected to the department throughout their promising careers.

Speaking of promising careers and Iowa roots, it is appropriate to introduce the recipient of this year’s dedication: Dr. Joseph A. Buckwalter IV. The intellect, passion, time, and energy he has given the department over the course of his career and lifetime have enriched the department’s place in Orthopaedic History. We are honored to have him lead us forward.

While Dr. Buckwalter takes us into the next decade, 2009 will be a year that will be remembered in the department. With the passing of Dr. Ignacio Ponseti, the department lost one of its icons. While Dr. Ponseti cannot be replaced, the department is committed to continuing his legacy through his foundation and the efforts of our current faculty and residents. To think that his career works led to awards such as the Kappa Delta Award, the Hektoen Award, the Alfred Shand’s Award, and the Maximis Meritis Medal (in addition to many other awards, some of which Dr. Ponseti won as an octogenarian!) should inspire us all to continue to ask and answer scientific questions and strive to make contributions to the field of orthopedics throughout our lifetimes. Dr. Ponseti received the dedication of the Iowa Journal multiple times throughout his career. This year we elected to choose one of his early pupils, Dr. Buckwalter, to receive the dedication and in that way honor a piece of Dr. Ponseti’s living legacy. Furthermore, the first section of the IOJ pays tribute to Dr. Ponseti by including a brief “in memoriam” and contains original articles discussing the continued progress in the treatment of clubfoot.

The IOJ would not be possible without the help of certain people. First, we are indebted to them for their input, leadership, and service. Diana Johannes continues to be a driving force behind the creation of the IOJ. Second, we would like to recognize the faculty who have overseen various projects, cases, and other efforts that have resulted in works that find themselves in this journal. Finally, we would like to thank our faculty adviser, Dr. Jose Morcuende, whose guidance continues to make the IOJ possible.

We hope this year’s edition of the IOJ continues in the same high standard as previous editions. It has been an honor to serve as the editors for the IOJ for 2010.

Christopher E. Henderson, M.D.
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2010
Christopher E. Henderson
Bryan A. Warme
Joseph Addison Buckwalter IV was born in Ottumwa, Iowa in June of 1947, where his father was stationed at the Ottumwa Naval Air Station. His mother, Carole, was one of three women in her class when she graduated from the UI College of Medicine in 1946. That's where she met Buckwalter's father, a Pennsylvania native who chose to do his residency in general surgery at University Hospitals. The couple got married in the Wheel Room at the Iowa Memorial Union, and by the time Carole had started her residency—also at UIHC, in psychiatry—she was pregnant with Joseph, whom she nicknamed “Jody.” She took the name from the book “The Yearling.”

While his parents completed residency in Iowa City, he remembers living in the wintertime in a corrugated metal Quonset hut originally built for Navy pilots in training in Iowa City during World War II. “They were supposed to be torn down after the war, but the university kept them for student housing,” he said. “Mom and Dad would stuff newspapers in the cracks to keep the wind out. I remember going to bed night after night absolutely freezing.” During that time, young Jody and his siblings spent a significant amount of time in Sigourney, Iowa with their grandparents, John and Peggy Kelley.

After their respective residencies, the family then moved to North Carolina for his father’s fellowship, and then on to England for his father’s additional year of surgical training before their return to Iowa City.

In his youth, Dr. Buckwalter was characterized as energetic and even a bit mischievous. His passion was motorcycle riding! He attended University High School where he was a football running back, track star and Senior Class President. His track prowess was evidenced by several Drake Relay records including one in the 440-yard dash that lasted for decades. Upon graduation he was awarded a track scholarship to the University of Wisconsin. Unfortunately, his track career was cut short during his freshman year by an avulsion injury of the hamstring. This career-ending injury brought Dr. Buckwalter into his first contact with the University of Iowa Orthopaedic Department when he came under the care of Dr. Michael Bonfiglio.

With his track career ended, Dr. Buckwalter transferred to the University of Iowa where he majored in Psychology. He was also a member of the SAE social fraternity. Dr. Buckwalter graduated Phi Beta Kappa and entered the University of Iowa Medical School in 1969. He took one year off during medical school to earn a masters degree in the Department of Pathology. During that year he teamed with Dr. Tom Kent, a perennial
teacher of the year award winner, to produce a highly acclaimed text for the teaching of pathology.

In medical school, Dr. Buckwalter lived in the attic of a College of Medicine icon, Dr. William Bean, who was then chairman of the Department of Medicine. When the Beans were away for a year, their home was rented by one of the new Orthopaedic Faculty, Dr. Bruce Sprague, and his family. Dr. Buckwalter developed a close friendship with Dr. Sprague, who further influenced him toward a career in Orthopaedic surgery. Lastly, as chance would have it, the faculty member who was assigned to Dr. Buckwalter as his advisor was none other than Dr. Ignacio Ponseti! This serendipitous pairing with Dr. Ponseti led to a lifelong mentoring relationship that would set the foundation for an eventual career in orthopedics and inspire Dr. Buckwalter to later become a mentor and teacher himself.

During his second year in medical school, Dr. Buckwalter developed a friendship with the roommate of one of his medical school classmates. This friendship eventually developed into romance and a lifelong commitment. The friend was Kathleen (Kitty) Coen, a local Iowa City girl who was a nursing student. They had actually attended the same high school but only knew each other casually. Unfortunately for their romance, Kitty had a 3-year commitment as a US Navy nurse. She was stationed in San Diego for one year and then on Guam for the next two years. From 1971 until 1974 they had the opportunity to see each other only twice. They maintained their relationship via letters and through amateur radio operators. Ultimately, they were married in 1974.

Dr. Buckwalter graduated from the University of Iowa College of Medicine in 1974 with AOA honors. After one year in Internal Medicine, he entered the Orthopaedic residency training program in 1975. He spent an additional year during residency on the Department’s National Research Service Award Research Fellowship (“training grant”), developing the foundations of his research career. In June 1979, he completed his Orthopaedic residency and joined the faculty.

Just as Dr. Buckwalter joined the faculty, Dr. Adrian Flatt left the University, and the Department was without expertise in hand surgery. Dr. Buckwalter was enlisted to function as the department’s hand surgeon. He spent his weekends learning to anastomose arteries and veins. He functioned adeptly in the hand arena until the department was able to recruit a new hand surgeon, Dr. William Blair (one of Dr. Buckwalter’s medical school classmates). With the Hand Service now adequately staffed, a new departmental void surfaced. Dr. Mike Michelson, who had been working with Dr. Bonfiglio on the tumor team, left the University for private practice in Idaho. Dr. Buckwalter was then chosen to take over the pathology service. Like all Iowa trainees, he had acquired a strong foundation in musculoskeletal pathology from Drs. Bonfiglio, Cooper, and Ponseti, but he needed a “crash course” in musculoskeletal oncology. For this, he traveled to the University of Florida to study with Dr. William Enneking. This also led to a close personal relationship between Dr. Enneking and Dr. Buckwalter. Other orthopaedic surgeons credited with influencing Dr. Buckwalter’s career include Drs. Larry Rosenberg, Henry Mankin and Reg Cooper.

In addition to the training and experiences he has had within the United States, Dr. Buckwalter has also acquired a number of international experiences and awards. In 1987, he was selected to the prestigious American British and Canadian Traveling Fellows. In 1991, Dr. Buckwalter took a sabbatical year from the University and served as the American Orthopaedic Association International Visiting Professor at the Nuffield Orthopaedic Surgery Unit at Oxford England from January to June. During that year he also served as a Visiting Professor at the University of Bern in Switzerland and as a Visiting Professor at the University of North Carolina in Chapel Hill. In 1992, Dr. Buckwalter served as the Sir Reginald Watson Jones Lecturer—Royal College of Surgeons of England. In 1997, he received the Bristol-Myers Squibb/Zimmer Award for Distinguished Achievement in Orthopaedic Research and in 1998 the State of Iowa Board of Regents Award for Faculty Excellence. In 2000, he was elected to the Royal College of Surgeons in Edinburgh and in 2007 he received the Alfred R. Shands Award from the Orthopaedic Research Society and the American Orthopaedic Association.

In the research arena, Dr. Buckwalter has contributed fundamental scientific and clinical insights, advancing our knowledge across a broad range of musculoskeletal science. Rarely can a single scientist impact such a diverse range of orthopaedic conditions at so many levels,
extending from structural biochemistry and molecular biology, to disease and aging processes, development of novel therapeutics, epidemiology, and health care delivery.

Early in his scientific career, Dr. Buckwalter conceived of a novel method enabling detailed ultrastructural studies of individual proteoglycan molecules, which he utilized to study a number of tissues including growth plate, embryonic, and articular cartilages, intervertebral disk, meniscus, and tendon (Figure 1). The insights in correlating structure and function in these tissues were transformative in the matrix biology field, earning Dr. Buckwalter a Kappa Delta Award for his seminal discoveries in matrix structural biochemistry as a young scientist, and leading to his rapid prominence as a leader in musculoskeletal biology. His discoveries fundamentally changed our understanding of matrix function and organization in both physiologic and pathologic processes involving the growth plate, articular cartilage and the intervertebral disk (Figure 2).

The effect of the mechanical environment and aging processes on the structural biochemistry of musculoskeletal tissues became another focus of Dr. Buckwalter’s scientific investigation, leading to a career-long interest in the effects of aging, mechanical forces and trauma on articular chondrocyte biology and behavior. He discovered proteoglycan changes in articular cartilage with aging and degeneration, and demonstrated the control of chondrocyte senescence by telomerase, opening new directions in the fields of cartilage repair and regeneration. In addition, his basic molecular mechanistic studies of post-traumatic arthritis identified IGF-I dysregulation as an important factor in aging cartilage. More recently Dr. Buckwalter, through his decade-long leadership of two major NIH-sponsored Centers focused on posttraumatic osteoarthritis, has directed scientific teams in delineation of previously unknown molecular pathways leading to chondrocyte apoptosis after injury, clinically predictive imaging biomarkers for OA, and the exciting new area of molecular regulation of oxidative damage in cartilage following trauma as a novel chondroprotective approach.

Not surprisingly, as a clinician-scientist with a clinical focus in orthopaedic oncology, Dr. Buckwalter has made significant discoveries in the bone tumor field as well, including identification of alterations in proteoglycan structure and radioresistance mechanisms characteristic of chondrosarcomas, and the role of telomerase in the ability of these tumors to proliferate without senescence. He has also contributed many clinicopathologic studies of bone tumors, significantly influencing modern treatment paradigms and improving our understanding of the pathophysiology of these diseases as well.

Dr. Buckwalter has held many key leadership positions in the world of orthopaedic surgery including President of the Orthopaedic Research Society in 1989 and Secretary of the American Academy of Orthopaedic Surgeons in 1993. One of his most crucial assignments for AAOS (following in Dr. Cooper’s footsteps) was serving as Chairman of the AAOS Committee on Evaluations and Examinations, the committee that produces the Orthopaedic Inservice Training Examination (OITE) and the Orthopaedic Self Assessment Exam (OSAE). During Dr. Buckwalter’s tenure as committee chair, the important subspecialty examinations were initiated. From 1990 to 1993 he chaired the essential AAOS Council on Research and Scientific Affairs. From 1995 to 1998, Dr. Buckwalter was instrumental in having the
AAOS at the forefront of outcomes research serving as the Chair of the Task Force for Clinical Outcomes Data Management Programs. In 1995, Dr. Buckwalter served as President of the American Board of Orthopaedic Surgery and in 2000 he served as President of the American Orthopaedic Association. Dr. Buckwalter became the fourth Head of the Department of Orthopaedics and Rehabilitation at the University of Iowa in 1999. The other three Chairmen in Iowa Orthopedic history are Arthur Steindler, Carroll Larson, and Reg Cooper. In 2003, Dr. Buckwalter was named the Arthur Steindler Chair of Orthopaedic Surgery.

Dr. Buckwalter has participated in numerous scientific advisory boards, committees and councils and currently serves on the Board of Directors of the Musculoskeletal Transplant Foundation and the Canadian Arthritis Foundation Research Advisory Board. In 1994 and 1995, Dr. Buckwalter served on the Search Committee for the Director of the National Institute of Arthritis and Musculoskeletal and Skin Diseases and he has continued to serve on many review committees for NIH and NIAMS. Since 1993 he has served as Co-Editor in Chief of the Journal of Orthopaedic Research. Dr. Buckwalter was elected to the prestigious Institute of Medicine National Academies of Science in 2004.

Dr. Buckwalter’s leadership roles in orthopedics have not been limited to national and international positions. Within the Department of Orthopedics and Rehabilitation at Iowa, he has dedicated himself to the teaching and mentoring of both faculty and residents. As department chairman, Dr. Buckwalter has taken a nonjudgmental approach and created a sense of family and community to help bring out the best in the faculty and residents. Each year he invites the new residents and faculty to his home for a Winter Holiday party, and he maintains an open door policy for all residents that includes calling him “in the wee hours of the night” with any professional or personal concerns, if necessary. He maintains a proactive role in the residency program also by meeting yearly with each residency class over pizza at a local pizza establishment, The Wig and Pen, to discuss issues and to critique the residency as a program. He is committed to making the department and the residency the best possible.

Dr. Buckwalter’s commitment to mentoring goes beyond residency. He maintains relationships with alumni after graduation and ultimately the mentorships become lifelong friendships. The active role he plays in former residents’ lives and careers is evidenced by the following reflections:

“My research accomplishments in residency all began the same way, with the appearance on my desk of a funding announcement and a hand-written note: “You should apply—JAB.” Dr. Buckwalter always has your best interests in mind, even when you’re busy ignoring...
them. He is a true scholar, a gentleman, and an unwavering mentor who has been like a father to me.”

—Dr. Mohana Amirtharajah Iowa Orthopedic Residency Alum (2007)

“Jody’s unassuming way of teaching orthopedic surgery inspired me to enjoy the profession far beyond my years as a resident. We would joke with him as we coined him the Renaissance surgeon, as he was the jack of all trades when taking on some complex tumor case, a hand case (I recall hand surgery being his first interest!), or a sports medicine case. I am grateful that I had the exposure to his thought process of attempting to simplify even the most complex of cases. What was learned from this experience was that if one followed the basic steps of preoperative planning and surgical exposure that most orthopedic cases can be successfully accomplished.”

—Dr. Andrea Saterbak Iowa Orthopedic Residency Alum (1997)

“Jody has been a mentor to me for the past 18 years. He heavily influenced my decision to pursue a career in orthopaedic oncology. During my Iowa residency, I saw him as a compassionate physician and an excellent teacher. He had a way of making me think I was actually doing the complex tumor surgeries when I scrubbed with him. The courage of the tumor patients and the kindness of Jody made it easy to work hard on his service. We have become friends over the years since my training and I still call on him for advice. His picture is hanging among my 3 orthopaedic heroes on my office wall. He has the unique combination of true humility and exceptional intelligence. I consider it a real privilege to count him as a mentor and a friend.”

—Dr. Kristy Weber Iowa Orthopedic Residency Alum (1996)

The same year Dr. Buckwalter joined the UI faculty in 1979, he met Hayden Fry who would lead the Hawkeye football team through one of its most successful periods, including 14 bowl games. Buckwalter remembers being impressed and a bit intimidated during his first interview with the large man wearing dark glasses and cowboy boots, although the two would later become close friends. “He is one of the most uncannily intuitive people I’ve ever known in my life, and he taught me a lot,” Buckwalter says of Fry, who still lives in Iowa City part of the year following his retirement. Buckwalter still gets phone calls from former players whose injuries he treated.

Above all else, Dr. Buckwalter is a family man. He is an extremely proud father of three. His son Joseph Addison Buckwalter V, received his Ph.D from the University of Iowa in Neuroanatomy and did a post-doctorate at the University of California at San Diego. He is currently a third year medical student at the University of California at San Diego and with his wife Allie, an attorney, has one son, Joseph Addison Buckwalter VI. Daughter Andrea is a second year Otolaryngology resident at the University of Iowa and her husband, Marty Potash, is a second year resident in Pathology. They recently welcomed the arrival of twins, Vivian and Max. Daughter Abby is a Healthcare Account Executive with the Nestle Corporation in New Jersey. Dr. Buckwalter’s wife Kathleen (Kitty) is a Professor in the College of Nursing and Director of the Hartford Center of Geriatric Excellence.

Dr. Buckwalter’s hobbies include bicycling and reading. He particularly enjoys the bike trips he takes with his family. He enjoys history, good wine and travel. His passions are the University of Iowa, State of Iowa and the Iowa Hawkeyes.

Dr. Buckwalter’s impact on the field of orthopedics is both broad and profound. His Iowa roots and his intellectual curiosity are palpable throughout his various life experiences. Objectively, his career path has been laid out in this article; subjectively, he is a wonderful human being who still has his sense of humor and is always humble, honest, and hard-working. Operating with and learning from him are true privileges that few residents across the nation have the opportunity to experience. Words do not do him justice, so instead, we simply say, Thank You, Dr. Buckwalter.
2010-2011
DEPARTMENT OF ORTHOPAEDICS AND REHABILITATION
SCHEDULE OF LECTURESHIPS AND CONFERENCES

(Larson Conference Room, 01090 JPP, unless otherwise noted)

Carroll B. Larson Shrine Memorial Lecture
April 23-24, 2010
Dr. Vincent Mosca, Seattle Children's Hospital and
Department of Orthopaedic Surgery, Washington
University
*Spring 2011 to be arranged. Contact Nancy Love, (319) 356-1872.

2010 Senior Residents Day
June 4-5, 2010
VIP VISITING DISCUSSANTS:
Christopher D. Harner, M.D.
Professor, Department of Orthopaedic Surgery
UPMC Center for Sports Medicine
Pittsburgh, Pennsylvania

Charles L. Saltzman, M.D.
Professor and Chair
Department of Orthopaedics
Boston University School of Medicine
University of Utah School of Medicine
Salt Lake City, Utah

26th Annual Hawkeye Sports Medicine Symposium
December 3-4, 2010
Marriott Hotel and Conference Center
300 East 9th Street, Coralville
*Speakers to be announced. Contact Kris Kriener, (319) 353-7954.

Ponseti Clubfoot Treatment Symposium
October 2010
*Speakers to be arranged. Contact Gloria Yorek, (319) 356-3469.

*Please check with us later for exact dates, times, and speakers.
Department of Orthopaedics

Christina Ward 2008-2009
Heather Bingham 2008-present
Phinit Phisitkul 2008-present
Nicolas O. Noiseux 2007-present
Robert Yang 2007-present
Erika Lawler 2006-present
John E. Femino 2005-present
Joseph D. Smucker 2005-present
Jin-soo Suh 2004-2005
Neil A. Segal 2004-present
Brian Wolf 2003-present
Michael O’Rourke 2003-2007
Sergio Mendoza 2003-present
Jose Morcuende 2001-present
Annunziato Amendola 2001-present
Joseph Chen 2000-present
Todd McKinley 1999-present
R. Kumar Kadiyala 1998-2004
Leon Grobler 1996-1999
Brian Adams 1993-present
Charles Saltzman 1991-2005
John Calhoun 1990-present
David Tearse 1989-2000
Ernest Found 1987-present
Lawrence Marsh 1987-present
Curtis Steyers 1985-2006
James Nepola 1984-present
Fred Dietz 1984-present
James Weinstein 1983-1996
Barbara Campbell 1982-1984

Arthur Steindler 1912-1949
Theodore Willis 1917-1918
Joseph Milgram 1926-1932
Ernest Freund 1932-1936
Thomas Waring 1932-1939
James Vernon Luck 1936-1939
Ignacio Ponseti 1946-present
Eberly Thornton 1946-1952
Robert Newman 1948-1956
Michael Bonfiglio 1950-1995
Carroll Larson 1950-1978
Adrian Flatt 1956-1979
Reginald Cooper 1962-present
Howard Hogshead 1964-1965
Maurice Schnell 1964-1965
Donald Kettelkamp 1968-1971
Gerald Laros 1968-1971
Richard Stauffer 1970-1972
John Albright 1971-present
Doug Mains 1972-1973
Bruce Sprague 1972-1979
Richard Brand 1974-2002
Mike Mickelson 1976-1981
Stuart Weinstein 1976-present
Thomas Lehmann 1978-1987
Joseph Buckwalter 1978-present
Charles Clark 1980-present

The University of Iowa
Roy J. and Lucille A. Carver College of Medicine
Ryan M. Ilgenfritz, M.D.

Ryan was born in central Florida and grew up with his three brothers in the city of Apopka, Florida. His father is an automobile mechanic and his mother a homemaker and primary caregiver for his severely disabled youngest brother. Having a brother with disabilities, Ryan was exposed to many facets of health care beginning at an early age. It was in the seventh grade that he first began to develop his plans to become an Orthopaedic Surgeon, deciding to apply for the “Health Careers Academy” magnet program that was offered at his local high school.

It was also in the seventh grade that Ryan met his future wife, Lauren. They grew up in homes separated only by a few miles but did not meet until middle school because Lauren attended an elementary school out of town where her mother was a teacher. The two did not date in middle school, however. When Lauren is asked why that was, she commonly replies “because he was a dork.” This is something that is confusing to Ryan still today, especially given the fact that he was on the school basketball team (at a height of 5’3” at the time, it was pretty clear that his only real contribution was to boost the team GPA and help keep the talented players off academic probation).

In their senior year of high school, Lauren began to notice Ryan. They did not start dating until they each had decided to attend universities in different cities. Lauren left home for the University of North Florida in Jacksonville, and Ryan decided on the University of Miami (where he was fortunate to be able to continue helping to keep talented athletes off academic probation). They managed a long-distance relationship for 2 years until Ryan was accepted into a combined degree program with early entry into medical school, at which time Lauren transferred to Miami.

When the time came for orthopaedic residency interviews, the two decided they wanted to experience life outside Florida. Dr. Frank Eismont, Ryan’s orthopaedics mentor during medical school, suggested that Iowa was the place to go. They fell in love with Iowa City when Ryan interviewed in mid-December, despite the fact that during their trip the thermometer measured well below what they had previously thought was survivable by humans.

Jon Donigan, M.D.

Jon was born and raised in Hawai‘i on the island of Oahu. He was spoiled by the beautiful weather, diverse food and culture, and amazing outdoor recreation. His family moved away from Hawai‘i when he was 15 years old, and he finished high school in Logan, Utah. He then attended Utah State University for a year before serving a two year religious mission in the Philippines. His experiences in the Philippines working with the underserved convinced him to alter his planned career path from the legal field to medicine. Upon returning to the states he transferred to Brigham Young University in Provo, Utah, where he finished his degree in Philosophy while fulfilling the requirements for medical school application. During his junior year he made the best decision of his life and married fellow BYU student Heather Hawkley from Chico, California. He was fortunate to be accepted at Johns Hopkins University School of Medicine the next year, and he and Heather made the cross-country trek to Baltimore, Maryland.

Thanks to the guidance of Ed McCarthy and Kevin Jones, Jon was lucky enough to match at The University of Iowa for orthopaedic training. His five years at Iowa have been so enjoyable and rewarding that he has decided to stay at UIHC to complete a Hand Fellowship upon completion of his residency.

Jon wishes to thank his parents, Bob and Marie, his fellow residents, and the distinguished yet approachable faculty at The University of Iowa. Most of all, he is grateful to Heather and their children, Andrew, Luke, and Kate, for their patience and tolerance during the last 10 years of education and training.
Over the course of the last five years, Iowa has continued to grow on Ryan and Lauren. After completion of residency, they will welcome their first child, and then move to San Diego as Ryan completes a fellowship in Pediatric Orthopaedics. After fellowship training, they plan to move their family back to Iowa City where Ryan has accepted a faculty position at The University of Iowa.

**Matt Karam, M.D.**

Matt was born just up the road in Cedar Rapids, Iowa. As the son of a public school principal and a high school teacher, and as the younger of the two Karam boys, he was fortunate to be on the learning end of many teachable moments. Growing up in Iowa, Matt was able to enjoy the many changing seasons: with summer came baseball and trout fishing along the banks of numerous springfed streams in northeastern Iowa, and the fall/winter months brought about football and hunting pheasants/deer in one of many surrounding counties (including one famed baseball diamond). Having patient and supportive parents, more than anything, shaped Matt’s perspective. After graduating from Cedar Rapids Washington High School, Matt decided to move south to enjoy the warmer climate.

Upon enrolling at The University of Iowa, Matt quickly realized that it would be up to him to be more than a number. On September 18, 1999, a date some will remember as then-first-year Head Football Coach Kirk Ferentz’s first victory at Iowa, Matt was blessed to meet his lovely wife, Chenelle. After four years of courtship, Matt and Chenelle were married in Iowa City. After completing medical school in Chicago, Matt and Chenelle both felt it a great fortune to return “home.”

During residency, Matt and Chenelle have been overjoyed with the arrival of their most prized possessions, Mason and Evalynn. Their charisma lights up the room. They are a constant reminder of Matt’s favorite job title, and make coming home a daily delight.

Next year, the Karam’s will move north to Minneapolis where Matt will continue his education as an Orthopedic Trauma Fellow at Hennepin County Medical Center.

Matt would like to thank his family, colleagues and teachers who have and will continue to support him in his career.

**Andy Malin, M.D.**

Born and raised in Fond du Lac, Wisconsin, Andy attended the United States Air Force Academy and Harvard Medical School prior to beginning his residency at Iowa. He has appreciated the opportunity to train under a distinguished and dedicated faculty and alongside a great group of fellow residents.

Andy is forever indebted to his parents for their endless support and guidance. He recognizes that the greatest and most important accomplishment of his life was somehow convincing his wife, Mary Edith, to marry him. Andy and Mary Edith have had two children, Katelyn and Pierce, during residency. For this reason as well as the great friends they have made over the past five years, Iowa will always hold a very special place in their hearts.

Following completion of residency, Andy will have the privilege of serving his country as an officer and orthopaedic surgeon in the United States Air Force.
Scott McKay, M.D.

Scott grew up outside Seattle, Washington with dreams of being a college baseball player. It was clear after 2 years as a walk-on at Brigham Young University in Provo, UT that baseball would never pay any bills. He then graduated in Business Administration, and married Jessica two weeks before beginning medical school at Baylor College of Medicine in Houston, Texas. Their first daughter, Anne (6), was born in Texas, but the rest of the children, Megan (4), Riggs (2), and Naomi (8m), were all born during residency. It was nice to have biased, naive little fans to cheer for Scott in rec-league softball games, and to accompany him to Omaha to watch College World Series games.

Scott has always found inspiration in Latin American culture. In college he spent two years in Colombia as a Christian missionary, and a week in Guatemala translating for a primary care medical mission. While at Baylor, Scott found his Spanish skills useful almost every day at the county hospital, and spent two weeks in rural Honduras on a primary care medical brigade. While at Iowa, Scott returned to Colombia to serve on a week-long pediatric orthopaedic service trip. He hopes to continue regular trips to Latin America throughout his life.

Next year Scott and his family move to the east coast for a fellowship in Pediatric Orthopaedics at the Children's Hospital of Philadelphia. He looks forward to a career working with children.

Jared L. Michalson, M.D.

Jared was born in Fort Dodge, Iowa, and grew up in north central Iowa, the son of a grain farmer and a high school librarian. Most of his childhood time was spent outdoors with his brother enjoying baseball, fishing, and golf. Summers were spent “bean-walking” for his father beginning in early elementary school, and summer farm duties continued through his second year of medical school.

During high school, Jared was gently discouraged from further pursuit in the field of agriculture. He therefore attended Creighton University in Omaha, Nebraska, obtaining a degree in biology and becoming interested in medicine. During his third year at Georgetown University School of Medicine in Washington, DC, he decided on orthopaedics as a specialty. He was fortunate and thankful to match at Iowa after spending two months on the Red Team as a visiting sub-I.

After finishing residency, Jared will be completing an orthopaedic trauma fellowship at Grant Medical Center in Columbus, Ohio. The fellowship year will also bring his marriage to Alison Agner, a resident in Obstetrics and Gynecology at UIHC and Columbus native. Future practice plans are undecided at this time.

Jared would like to thank all members of the department for the opportunity to train at Iowa. He thanks his residency classmates for their support, friendship, and stimulation over the past five years, and to Drs. Marsh, McKinley, and Nepola for furthering his interest in orthopaedic trauma. He gives special credit to his parents for their unwavering love and support.
Dr. John Gaffey, M.D.

John hails from Pocahontas, a small town in northwest Iowa where he was born and raised. He proudly attended the University of Iowa for both undergraduate schooling as well as medical school. Here he majored in Exercise Science and later recognized his passion for orthopaedic surgery. After medical school, John moved to Chicago and completed his residency in orthopaedic surgery at Loyola University Medical Center in Maywood, Illinois. During his time in Chicago he met and married his wife, Julie. Julie is also from Iowa and a University of Iowa alumni. They enjoyed five exciting years of city living together. During his time at Loyola, John identified his excitement for hand surgery and decided to pursue a subspecialty in hand surgery. He then came back to the great state of Iowa to complete his training under the supervision of Dr. Brian Adams.

John currently lives in Iowa City with his wife Julie and dog Sonny and is pleased to be back in the land of the Hawkeyes! John has accepted a position as a hand surgeon at Des Moines Orthopaedic Surgeons in West Des Moines, Iowa. John is excited to be working in the Des Moines area for a well respected practice. He, Julie and Sonny look forward to being near family and beginning their own.

Keith Robert Wolstenholme, M.D., FRCSC

Keith is another of the Canadian members of the University of Iowa Orthopaedics community. After completing medical school and residency at the University of Calgary, in Calgary, Alberta, Canada, Keith started the Orthopaedic Surgery Sports Medicine Fellowship program at the UI. Accompanying Keith to Hawkeye country have been his wife Cleo and twin toddler daughters, Arwyn and Bronwyn. Covering the football team this Orange Bowl championship season has been incredibly rewarding and has turned the entire family into Hawkeyes for life. Cleo has already planned trips back for Hawkeye football games for the next several seasons.

Upon completion of the fellowship, Keith will be returning to Canada. He has taken a position in Red Deer, Alberta to be the Sports Medicine specialist with the Central Alberta Orthopaedics group. While there, Keith will be a consulting orthopaedic surgeon for the Red Deer Rebels Hockey Club of the Western Hockey League.
Like a sports team on the brink of a new season, University of Iowa Sports Medicine “ramped up its game” in late October. The new UI Sports Medicine Center opened its doors on Oct. 19, 2009, offering convenient access to UI specialists for athletes of all ages, from casual exercisers to intense college athletes. The new clinic is the main component of the Institute for Orthopaedics, Sports Medicine and Rehabilitation (IOSMR), located in the Hawkeye West Campus off Mormon Trek Boulevard. The Institute offers comprehensive patient care in a single location where all clinical, diagnostic imaging and rehabilitation services are provided in a world-class, multidisciplinary, patient-centered care facility. The current complex is phase 1, with phase 2 hopefully coming soon to complement and enhance the current Department of Orthopaedics and Rehabilitation clinical, academic and research missions.

For more than three decades, UI Health Care has provided an interdisciplinary approach to sports medicine clinical services for competitive and recreational athletes and educational programs for medical students, residents and allied health students. The Department of Orthopaedics and Rehabilitation at UI Health Care continues to be one of the nation’s top ranked academic orthopaedic programs and is a leader in many subspecialties. In 2001, recognizing the growing importance of sports medicine clinical and academic programs, UI Health Care strengthened its sports medicine program by establishing a three-phase strategy to create a comprehensive, coordinated sports medicine program for the University of Iowa and surrounding communities. This strategy includes: establishing a physical identity for the program, building a practice location to grow sports

* Dr. Amendola is the Director of the UI Sports Medicine Center, Professor in the Department of Orthopaedics and Rehabilitation, and holds the Kim and John Callaghan Chair in Sports Medicine.
medicine and lastly, to develop a comprehensive multidisciplinary, patient-centered approach where all members of the sports medicine team provide comprehensive care in a single facility. Opening and development of the IOSMR represents the third phase of this strategy.

In addition to providing complete care of all our Hawk-eye teams and student-athletes, the new Sports Medicine Center is accessible to athletes, teams and active individuals from the surrounding community, the state of Iowa and beyond. The key to the Center’s success is because of the interdisciplinary approach to the care of the athlete and the dedicated sports medicine clinic staff, physician assistants, nurses and research personnel. Physical therapists and athletic trainers also provide sport specific rehabilitation, performance therapy, and injury prevention strategies. Medical specialists, i.e. primary care physicians, pediatricians, internists, specialists in women’s sports participation, children’s injuries, also can treat medical problems such as concussions, asthma, cardiac difficulties, and issues of the older athlete. These services set the clinic apart from a typical sports clinic.
Ancillary services such as bracing, shoe wear modification, and custom orthoses are available or custom made on site, with adjustments and modifications made directly with patient and physician feedback rather than mail order.

Continuing to build on the historically ranked and well established orthopaedic and sports medicine program, the new Institute will ensure innovative care and exceptional service. By improving the clinical space and location, adding more resources, and most importantly allowing the various specialties and providers of sports medicine services to work side by side, the IOSMR has created efficient, seamless and optimal care for patients, athletes and teams. The comprehensive care, delivered in an easily accessed location, will support the vision to grow by offering the highest quality, patient-centered services available.

The Center is located at the Institute for Orthopaedics, Sports Medicine, and Rehabilitation, a new building at 2701 Prairie Meadow Drive in Iowa City (near the Roy G. Karro Hawkeye Hall of Fame building). It is one of the first energy-efficient, environmentally friendly “green” buildings on the UI campus.
The 2010 Michael Bonfiglio Award for Student Research in Orthopaedic Surgery

The 2010 Iowa Orthopaedic Society Medical Student Research Award for Musculoskeletal Research

The University of Iowa Department of Orthopaedics and Rehabilitation, along with the Iowa Orthopaedic Society, sponsors two research awards involving medical students.

The Michael Bonfiglio Award originated in 1988 and is named in honor of Dr. Bonfiglio who had an avid interest in students, teaching and research. The award is given annually at the medical convocation and consists of a plaque and a stipend. It is awarded to a senior medical student in the Carver College of Medicine who has done outstanding orthopaedic research during his or her tenure as a medical student. The student has an advisor in the Orthopaedic Department. However, the student must have played a major role in the design, implementation and analysis of the project. He or she must be able to defend the manuscript in a public forum. The research project may have been either a clinical or basic science project, and each study is judged on the basis of originality and scientific merit. The winner presents their work at the spring meeting of the Iowa Orthopaedic Society as well as at a conference in the Department of Orthopaedics and Rehabilitation.

The Iowa Orthopaedic Society Medical Research Award for Musculoskeletal Research is an award for a student in the Carver College of Medicine who completes a research project involving orthopaedic surgery during one of his or her first three years of medical school. The award consists of a $2000 stipend, $500 of which is designated as a direct award to the student and $1500 of which is designated to help defray continuing costs of the project and publication. The student must provide an abstract and a progress report on the ongoing research. The aim is to stimulate research in the field of orthopaedic surgery and musculoskeletal problems. This award is also presented at a medical convocation. In addition, the student presents his or her work at the spring meeting of the Iowa Orthopaedic Society and at a conference in the Department of Orthopaedics and Rehabilitation. This award is supported through the generosity of the Iowa Orthopaedic Society.

This year the selection committee consists of Dr. Matthew Weresh, the president of the Iowa Orthopaedic Society, and Drs. Charles R. Clark, Joseph A. Buckwalter, Jose Morcuende, John Femino, and Brian Wolf all members of the Orthopaedic and Rehabilitation Department. They recommended that Jennifer Moyer, M4, receive the 2010 Michael Bonfiglio Student Research Award. Jennifer’s award was based on her project, “Durability of Second-Generation Extensively Porous-Coated Stems in Patients Age 50 and Younger.” Her advisor was Dr. John Callaghan and co-investigators were Catherine M. Metz, M.D., Steve S. Liu, M.D., and David W. Hennessy, BS.

The selection committee recommended that the Iowa Orthopaedic Society Medical Student Research Award be given to Drew Newhoff, M2 for his research titled “Cam-type Impingement in the Ankle.” His advisor was Dr. Ned Amendola.

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

Charles R. Clark, M.D.
Michael Bonfiglio Professor of Orthopaedic Surgery
From left to right: Joseph A. Buckwalter, M.D., Department Chair, Department of Orthopaedics and Rehabilitation; Charles R. Clark, M.D., Michael Bonfiglio Professor of Orthopaedic Surgery; Ned Amendola, M.D., Professor and Callaghan Chair, Director, University of Iowa Sports Medicine, advisor to Drew Newhoff; Drew Newhoff, M2, winner of the Iowa Orthopaedic Society Medical Student Research Award for Musculoskeletal Research; Jennifer Moyer, M4, winner of the Michael Bonfiglio Award for Student Research in Orthopaedic Surgery; John J. Callaghan, M.D., Lawrence & Marilyn Dorr Chair in Hip Reconstruction & Research, advisor to Jennifer Moyer.
In Memoriam
Ignacio Ponseti, MD, 1914-2009

Ignacio Ponseti, University of Iowa orthopaedic resident, 1941
Worldwide hero to thousands with clubfoot

**Pioneer. Miracle worker. Angel.**

Accolades for Ignacio Ponseti, MD (‘44 R), UI professor emeritus of orthopaedics who died Oct. 18 of complications from a stroke, are as abundant as the patients who walk normally thanks to the nonsurgical, low-cost method he developed to treat clubfoot.

During the course of his UI career, Ponseti, his colleagues, protégés, and the global practitioners they trained treated tens of thousands of children with clubfoot, which affects up to 200,000 newborns worldwide each year.

"Dr. Ponseti was my mentor, colleague, and friend; truly my orthopaedic father," said Stuart Weinstein (’72 MD, ’76 R), UI professor of orthopaedics who holds the Ignacio V. Ponseti Chair of Orthopaedic Surgery. "It's a great loss for me and all of us who trained and worked with Dr. Ponseti, but through his students, his legacy will continue."

The clubfoot treatment Ponseti advocated, known as the Ponseti method, uses careful manipulation of the muscles, joints, and ligaments held in a series of casts to reposition the foot back to normal. It has become the "gold standard" for clubfoot treatment, after decades of positive follow-up results and numerous international, peer-reviewed studies showing success rates as high as 98 percent.

Historically, surgery had been the recommended treatment for clubfoot. During his first year of residency under Arthur Steindler, MD, UI head of orthopaedics, Ponseti reviewed the outcomes of Steindler's clubfoot surgeries over the previous 20 years. Analysis showed the surgeries often resulted in stiff, fixed ankles. The treated children could walk, but they almost always had a limp.

Ponseti's extensive examination of the anatomy and biology of infant feet led him to believe that physical manipulation and casting might be a more successful approach. In the 1950s he started putting his theory into clinical practice.

However, for the next 40 years, only Ponseti and a handful of orthopaedic surgeons would use the Ponseti method, treating more than 2,000 children. Frustrated by the under-use of his technique, Ponseti and the colleagues he trained began making a concerted effort in the 1990s to communicate the method and its successful results to as wide an audience as possible. Parents of children treated with the Ponseti method spread word of the cure via the Internet, directing families to Ponseti's clinic and worldwide practitioners trained in Ponseti's technique. His approach was endorsed by the American Academy of Pediatrics and the World Health Organization.

Ponseti also advanced basic research behind clubfoot and other deforming diseases, and established the first connective tissue lab dedicated to this effort. His research into collagen chemistry opened up the field of cell and molecular research in connective tissues, said Jody Buckwalter (’69 BA, ’72 MS, ’74 MD, ’79 R), UI professor and head of orthopaedics and rehabilitation.

"Dr. Ponseti was a role model for compassionate patient care but also for seeking a deeper understanding of the causes of deformities in children," said Buckwalter, the Arthur A. Steindler Chair in Orthopaedic Surgery. "He had an inspiring passion for science, and using science to improve treatment of children."

He is survived by his wife, Helena Percas-Ponseti of Iowa City; a son, Bill Ponseti of Novato, Calif.; seven grandchildren; and six great-grandchildren.
1914: Born June 3 on Spanish island of Minorca

1936: Earns medical degree from University of Barcelona

1939: Escapes homeland after serving as medical officer with Loyalist army during Spanish Civil War, when Franco’s fascist army claims victory; evacuates 40 wounded patients by mule over the Pyrenees to France; seeks refuge in Mexico, treats typhoid patients

1941: Arrives in Iowa City for orthopaedics residency at UI Hospitals and Clinics

1944: Completes residency, joins UI College of Medicine faculty

1950: Appointed to direct clubfoot clinic at UI Hospitals and Clinics; initiates Ponseti method of nonsurgical treatment for clubfoot

1960: Marries Helena Percas in Iowa City

1984: Retires as UI professor emeritus

1986: Resumes work in consultative practice at UI Hospitals and Clinics; continues treating patients, teaching, conducting research


2004: Receives UI Distinguished Alumni Award

2006: American Academy of Pediatrics endorses Ponseti method for treating clubfoot; Ponseti International Association for the Advancement of Clubfoot Treatment founded at UI

2007: Receives UI honorary doctorate degree; UI hosts International Clubfoot Symposium, where practitioners from more than 40 countries learn Ponseti method

2009: Dies Oct. 18 in Iowa City; memorial service Dec. 6, 3-5 p.m., Coralville Marriott Hotel and Convention Center

Opposite page, top: At the 2007 International Clubfoot Symposium hosted by the UI, Ignacio Ponseti, MD, reunites with three children he treated for clubfoot using the method that bears his name. Photo by Susan McClellan
ABSTRACT
In 2005, a nationwide clubfoot treatment program focused on the Ponseti method—an effective, affordable and minimally-invasive method—was initiated in China. The purpose of this study was to evaluate and identify barriers to the program. A qualitative study (rapid ethnographic study) was conducted using semi-structured interviews of 44 physicians who attended four of the 10 Ponseti training workshops, focus groups with parents of children with clubfoot, and observation. Several barriers to the Ponseti method are quite unique due to China’s size, socio-economics, culture, politics, and healthcare systems. The barriers were classified into seven themes: (i) physician education, (ii) caregiver compliance, (iii) culture, (iv) public awareness, (v) poverty, (vi) financial constraints for physicians/hospitals, and (vii) challenges of the treatment process. A number of suggestions that could be helpful in reducing or eliminating the effects of these barriers were also identified: (i) pamphlets explaining clubfoot and treatment for caregivers, (ii) directories of Ponseti providers, (iii) funding/financial support, and (iv) improving public awareness. The information from this study provides healthcare planners with knowledge to assist in meeting the needs of the population and continued implementation of effective and culturally appropriate awareness and treatment programs for clubfoot throughout China.

INTRODUCTION
Clubfoot is a complex deformity present at birth that results in complete inward turning of the foot. Clubfoot can be idiopathic or occur as part of other disorders, such as spina bifida, arthrogryposis, and others. It is the most common musculoskeletal congenital birth defect. Congenital clubfoot has a worldwide incidence of 1-6.8/1000 live births. In the People’s Republic of China, where the birthrate is more than 18.2 million births per year, it is estimated that over 18,000 children are born each year with clubfoot. If left untreated, neglected clubfeet result in physical, social, psychological, and financial burdens for individuals and their families.

Traditionally, clubfoot has been treated by several months of casting followed by surgical correction. However, this approach is very time consuming and expensive. In countries with limited health care resources, it has resulted in many patients not receiving treatment. In recent years there has been an increased interest in the Ponseti method of treatment of clubfoot. This method is a conservative procedure using a very specific manipulation and casting technique based on the functional anatomy of the foot. It is supported by a limited intervention (percutaneous Achilles Tenotomy performed under local anesthesia in the office) and a foot-abduction brace to prevent relapses (to be worn at night time up to the age of four years old). Complete correction can be achieved in >95% of patients in as little as 16 days. When the Ponseti method is properly performed, surgical release is indicated in <1% of patients. Over the last 10 years, the Ponseti method has become the gold standard of care for clubfoot.

In 2005, a nationwide clubfoot treatment program focused on the Ponseti method was initiated in China. Similar programs were established in other countries, but China, with a population of more than 1.3 billion people and an average annual income of only $2,025, presents some unique challenges. The purpose of this study was to evaluate and identify the initial barriers to the program in China. Understanding these barriers is essential for successful and culturally appropriate approaches for the continuation of the program.
MATERIALS AND METHODS

Qualitative methodology was used to collect data using semi-structured interviews, focus groups, and observation. The purpose of using multiple methods was to verify the data gathered and increase the validity of the study through triangulation. Ponseti-trained practitioners, who currently treat clubfoot patients in China, were recruited for phone interviews from lists of attendees of Ponseti training workshops. Since the workshops were sometimes part of a larger conference, not all attendees who were registered were trained. Since 2005, 10 Ponseti training workshops were organized as part of the national Ponseti training program. From a list of 341 potentially trained practitioners, contact information for 164 participants from four of these workshops were obtained. 44 physicians who treat clubfoot in 12 provinces were interviewed, but five of these physicians were not trained in the Ponseti method, and thus not included in the study. Therefore, the total interviewed was 39. Focus groups were conducted with eight sets of parents of children with clubfoot who sought treatment in the Departments of Pediatric Orthopaedics and Rehabilitation, Shanghai Jiaotong University, XinHua Hospital, Shanghai. Observation of healthcare in China, clubfoot patients and families, and clubfoot treatment took place at Jiaotong University, XinHua Hospital in Shanghai and Fourth Military Medical University, Xijing Hospital in Xian.

The interviews and focus groups were conducted by a medical student fluent in Chinese (Mandarin) and English. The data was collected in Chinese (Mandarin) and recorded in English over a period of 10 weeks. It was then coded manually and sorted into themes. The validity of the data was confirmed by summarizing the notes for the respondents at the end of each focus group/interview. A team approach was used to draw conclusions about the organized data. The proposal was passed through the University of Iowa Institutional Review Board. Informed consent was obtained by having interviewees read the consent form. No names were attached to the data and all data was stored in a secure location.

RESULTS

39 providers from 12 provinces were interviewed. These included: Henan (2) Hubei (13) Shanghai (2) Zhejiang (3) Jiangxi (1) Shaanxi (1) Guangdong (2) Hunan (4) Guangxi (1) Gansu (1) Beijing (1) and Shandong (4). They practice in the following specialties: Orthopaedics (24), Pediatric Orthopaedics (6), Rehabilitation/Physical Therapy (1), Surgery (1), Pediatric Surgery (2), and Pediatrics (1). These providers have treated patients from Henan, Hubei, Zhejiang, Jiangxi, Shaanxi, Guangdong, Guangxi, Shandong, Gansu, Hunan, Beijing, and “all over.” The interviewed physicians have treated a combined number of at least 823 clubfoot patients per year. At least 375 patients per year are treated using the Ponseti method, at least 270 patients per year are treated using a surgical technique, and at least 135 patients per year are treated using other methods.

Some of the barriers to the Ponseti method in China are quite unique due to China’s size, socio-economics, culture, politics, and healthcare systems. The barriers were classified into the following seven themes:

Physician Education

Eight of the 39 physicians interviewed identified physician education as a barrier to the Ponseti method in China. The training available at the Ponseti workshops usually includes theory and minimal hands-on practice. Many physicians felt that a couple hours of training was not enough. Physicians in some areas only see one to two cases of clubfoot annually. This results in Ponseti providers who are trained, but have very little experience. Some physicians felt that a high level of experience is required for effective treatment with the Ponseti method, especially for complex cases. Additionally, many physicians believe that a lot of physicians, especially in rural areas, still do not understand clubfoot, treatment options, and the Ponseti method. With the Ponseti method, results are better with earlier treatment. However, many physicians recommend for parents to wait until their afflicted children grow older and then have surgery. Some physicians even make modifications to the Ponseti method, rendering it less effective or ineffective.

Caregiver Compliance

Six of the 39 physicians interviewed identified an educational gap between families of patients and physicians as a major barrier to the Ponseti method. Many caregivers of clubfoot patients have not even completed middle school, especially in rural areas. This educational gap is believed by those interviewed to make it difficult for caregivers to understand each step of the treatment, leading to noncompliance. For example, some caregivers discontinue treatment after casting because they do not understand the purpose of the brace. They see the results of casting and believe that the patient is cured. Secondary illness (e.g., a cold) causes other caregivers to temporarily discontinue use of the brace, which may then be forgotten. Three out of eight sets of parents from the focus group were worried about their children’s comfort during treatment and difficulty holding their child with a brace.
The educational gap is compounded by the healthcare experience in China. Patients often go to larger hospitals to seek treatment and second opinions because they believe they will receive better quality of care there. Patients are seen on a first-come, first-served basis, so many arrive before the hospital even opens. Patients are seen according to the number given during payment of the office fee. Pediatric patients are accompanied by parents; often with one or two sets of grandparents, other relatives, or family friends. However, there is rarely privacy for most patients. Most people line up outside the single crowded exam room where a given doctor is seeing patients, but the line often spills into the room. Each patient only gets a few minutes with the doctor, while others in the room are also trying to get the doctors' attention. This makes thoroughly explaining clubfoot and the Ponseti method of treatment, and compliance, difficult. There are also families who do not understand or believe in the Ponseti method and choose a different method or no treatment at all.

Culture
China has a one-child policy that fines married couples for having more than one child. Since many families cannot afford these fines, they try “to make that one birth count.” As there is still a preference for male offspring, there is a high incidence of sex-specific abortions. In addition, many children with birth defects are given up for adoption. So within the population of orphaned children, many have some type of birth defect, and clubfoot is one of the most prevalent deformities in these children.

Two of the 39 physicians interviewed identified the stigma of clubfoot as a barrier to the Ponseti method. The family of the patient may feel shame and embarrassment about having “bad genes.” They do not want to publicize their “bad genes” by seeking treatment for the patient. The stigma of clubfoot also prevents word-of-mouth advertising of Ponseti method success stories.

Three of the 39 physicians revealed that many patients and caregivers do not believe in any type of surgical intervention. Although Western medicine considers an Achilles tenotomy to be a relatively minor surgery, caregivers who do not believe in surgical treatments do not allow it to be performed on their children as part of treatment. There are also those who believe only in Traditional Chinese medicine (TCM), which includes herbal remedies, acupuncture, and massage.

Public Awareness
Six of the 39 physicians identified lack of publicity and public knowledge of clubfoot and the Ponseti method as a barrier. Some caregivers do not know what methods of treatment are available, if any, or which ones have the highest success rates. They visit hospital after hospital seeking second and third opinions. Caregivers cannot seek out providers of the Ponseti method, or treatment at all, if they are not aware of their existence. Additionally, some parents and/or physicians may not recognize a foot defect until patients begin to walk.

Five of the eight sets of parents of children with clubfoot in the focus group discovered the Ponseti method and Ponseti providers on the Internet. The other three sets of parents were referred to a Ponseti provider by local doctors or a friend. One set of parents had their child diagnosed at birth, but the local doctor wanted them to wait until the child was 6 months old for surgery. Another was told by their local doctor to wait until their child was 100 days old before receiving treatment. The parents who were not immediately referred to a Ponseti provider felt they wasted valuable time.

Poverty
The average income for a family in China is $2,025. The cost of Ponseti treatment in China includes about 100 RMB ($15) per cast per foot with 4-10 castings required depending on deformity severity and physician experience; 4-20 RMB ($0.60 – 3.00) per office visit, and about 1,000 RMB ($150) for the brace. Total treatment costs are around 2,200 RMB ($320). According to the physicians interviewed, this is an affordable amount.

One of the eight sets of parents and nine of the 39 physicians interviewed identified convenience and overall costs of the treatment as a barrier. Families often have to travel long distances in order to reach a metropolitan area where the Ponseti method is offered. They must miss work and pay for transportation to the weekly casting or a place to live for the duration of the casting. Thus, the total cost of the entire treatment process can be much more than what the hospital charges. Moreover, although there are currently no documented studies on the incidence of clubfoot throughout different regions of China, a majority of the physicians said that their patients were primarily from rural, lower income areas.

Financial Constraints for Physicians and Hospitals
The majority of the cost of clubfoot treatment, regardless of method, is for materials and not the physician’s labor. Hospitals are pressured to improve their rankings, which improve with the number of surgeries performed each year. Thus, both hospital and physician incomes are greater for each clubfoot patient treated surgically, rather than with a non-surgical method like Ponseti. Five
of the 39 physicians interviewed identified the financial limits placed on physicians and hospitals as a barrier to the Ponseti method.

Challenges of the Treatment Process

Three of the 39 physicians interviewed felt that results with the Ponseti method are not quite as good with older patients. They felt that rural patients (many of the clubfoot patients in China) do not get diagnosed and begin treatment until they are older. Two of the 39 physicians felt that the Ponseti method results in decreased range of motion of the ankle joint, thus providing limited results. Two of the 39 physicians felt that it was difficult to prevent casts from falling off in younger patients. One of the 39 physicians was concerned about the comfort of the Ponseti patient. Two of the 39 physicians consider casting to be more tiring and difficult for a physician than surgery. They feel that treating a fussy patient while parents are watching for multiple weeks is much harder than treating a patient with anesthetics and surgery. In addition, fussy patients kick and move around, counteracting the specific manipulations of the physician during casting. Some physicians try to minimize this problem by anesthetizing patients, while others have the caregivers bottle-feed the patient during casting.

No Barriers?

Three of the eight sets of parents felt that there were no disadvantages to the Ponseti method. One set said that they had not experienced any negatives to the process, but were not very far into the treatment process. Another set felt that there were no negatives because it was a better alternative to surgery. Six of the 39 physicians also felt that there were no barriers to the Ponseti method in China.

Moving Forward

In an ideal situation, clubfoot patients would be identified at birth and begin receiving treatment within a week or two. However, due to the barriers identified in this study, this does not always take place. A number of suggestions that could be helpful in reducing or eliminating the effects of these barriers were also identified:

1. Four of the 39 physicians suggested that pamphlets explaining clubfoot and treatment could be given to the caregivers when the patient is diagnosed to provide detailed information about clubfoot, the treatment process, and success rates. This could educate and improve the understanding of caregivers by giving them information the physician may not be able to provide during each short office visit. In addition, these pamphlets could provide tips for successful casting, including suggesting to not feed the patient for a few hours prior to casting and feeding them instead during the casting.

2. Thirteen of the 39 physicians suggested providing pamphlets explaining clubfoot and the Ponseti method with directories of Ponseti providers. These directories should be given to public health organizations in each province, obstetricians and gynecologists, internists, and pediatricians so that clubfoot patients can be identified and directed to the appropriate treatment facility at birth (or at least at their first hospital visit).

3. Four of the 39 physicians believe it would be helpful to find more foundations to provide financial support for clubfoot patients and their families.

4. 20 of the 39 physicians believe that increasing awareness of clubfoot, signs of clubfoot, treatment options, and success rates is necessary to ensure that more children with clubfoot receive diagnosis and treatment earlier. Many of the websites detailing the Ponseti method are available only in English. In addition, many residents of rural areas may not have access to the internet, so increased advertisement in magazines, newspapers, and televised news programs would be helpful. 12 of the 39 physicians think it is important to make more physicians, especially rural physicians, aware of clubfoot, signs of clubfoot, treatment options, and success rates. By advertising broadly to the general public, some of the target audience will include physicians, as well.

DISCUSSION

In China, a country with an expansive geography and 1/5 of the world’s population, the public health implications of the Ponseti method are immense. For the 18,000+ children born each year with clubfoot, full correction is possible. Correction of the physical deformity can also alleviate social, psychological, and financial burdens for clubfoot patients and their families, treating the social determinants of health.

In addition to the physician education-related barriers we identified, we must also consider the process of becoming an orthopaedic surgeon in China. Medical licenses for either surgery or internal medicine are awarded to those who have completed medical school education programs ranging from 5 to 8 years. Those licensed to practice surgery can legally perform any type of surgery. There are no subspecialty licenses or certificates. Most orthopaedic training is on the job. Thus, the knowledge, skills, and experience of orthopaedists in China can vary greatly. Perhaps, once orthopaedic
education is standardized, it will be easier to ensure awareness and use of the Ponseti method for clubfoot treatment.5

Programs similar to the national Ponseti program in China have been established in many other countries, including Uganda and Malawi.6-8 Unlike China, however, Uganda and Malawi have much smaller populations, 32 million and 12 million, respectively. Thus, they also have much smaller populations of clubfoot patients (1,100 – 1,400 cases of congenital clubfoot annually). Malawi only has three orthopaedists. Uganda only has four medical schools, compared to the 100+ medical schools and the 32+ schools of Traditional Chinese Medicine in China.

Despite the differences in population, the Ponseti programs in all three countries encountered similar difficulties. Poverty was a concern in all three countries. The costs of travel to treatment sites and costs of treatment itself are barriers to successful treatment in these countries. Caregiver compliance has also been an issue in all three countries. Caregivers often have other responsibilities, like farming or other jobs. It is difficult to take time off from these responsibilities to take the clubfoot patients to receive treatment each week. In addition, the treatment process is quite long and uncomfortable for the patient, resulting in difficult caregiver compliance with use of the brace, as well.

In both Malawi and Uganda, it was the mothers who were responsible for the healthcare of children with clubfoot. In Uganda, lack of paternal support was identified as a barrier to successful treatment with the Ponseti method. However, in China, it was common for both parents to be present for diagnosis and treatment. In Malawi, there were also problems with a shortage of supplies for treatment at the clinics, which are unique in that they attempt to fund most of the costs of treatment. In both China and Malawi, poor record keeping makes it difficult to keep track of individual patients. Follow-ups in China were dependent on whether or not patients returned.

The program in China could benefit from some of the findings from the other programs. For example, in Uganda, the push for all healthcare schools to modify their curricula to include education on clubfoot identification and the Ponseti method of treatment has resulted in such a change in five schools. In addition, it has been found that ‘massive’ training of health workers to provide treatments at remote locations resulted in difficulties maintaining expertise and access to materials. Currently, in Uganda, there are 15-20 well-acquainted clinics that perform the procedures with a high success rate and follow up. Therefore, more ‘targeted’ training followed up by the development of clinics specialized on the treatment of this deformity seems to be a next step in the development of the program in China.

CONCLUSIONS

Our study highlights the impact of and barriers to the Ponseti method of clubfoot treatment, in some aspects comparable to those in Uganda and Malawi, but in others specific to China. In addition, we have identified suggestions that could be helpful for overcoming these barriers, whether they are financial, educational, or cultural. This information provides healthcare planners with knowledge to assist in meeting the needs of the population and implementing effective and appropriate awareness and treatment programs for clubfoot in China.

REFERENCES


PONSETI CLUBFOOT MANAGEMENT: CHANGING SURGICAL TRENDS IN NIGERIA

Adegbefingbe, OO, FWACS, FICS, Oginni, LM, FWACS, Ogundele, OJ, FWACS, Ariyibi, AL, FMCS, Abiola, PO, FWACS, Ojo, OD, FWACS

ABSTRACT

Background: Congenital clubfoot treatment continues to be controversial particularly in a resource-constrained country. Comparative evaluation of clubfoot surgery with Ponseti methods has not been reported in West Africa.

Objectives: To determine the effects of Ponseti techniques on clubfoot surgery frequency and patterns in Nigeria.

Methods: This was a prospective hospital-based intention-to-treat comparative study of clubfoot managed with Ponseti methods (PCG) and extensive soft tissue surgery (NPCG). The first step was a nonselective double-blind randomization of clubfoot patients into two groups using Excel software in a university teaching hospital setting. The control group was the NPCG patients. The patients’ parents gave informed consent, and the medical research and ethics board approved the study protocol. Biodeata was gathered, clubfoot patterns were analyzed, Dimelgio-Bensahel scoring was done, the number of casts applied was tallied, and patterns of surgeries were documented. The cost of care, recurrence and outcomes were evaluated. Kruskal-Wallis analysis and Mann-Whitney U technique were used, and an alpha error of < 0.05 at a CI of 95% were taken to be significant.

Results: We randomized 153 clubfeet (in 105 clubfoot patients) into two treatment groups. Fifty NPCG patients (36.2%) underwent manipulation and extensive soft tissue surgery and 55 PCG patients (39.9%) were treated with Ponseti methods. Fifty-two patients of the Ponseti group had no form of manipulation, and 35 patients (69.2%) of the NPCG group had no form of surgery (41.4%, p<0.000). Extensive soft tissue surgery was indicated in 17 (34.0%) of the NPCG group, representing 8.9% of the total of 191 major orthopaedic surgeries within the study period. Thirty-five patients (70.0%) from the NPCG group required more than six casts compared to thirteen patients (23.6%) of the PCG (p<0.000). The mean cost was high within the NPCG when compared to the Ponseti group (48% vs. 14.5%, p<0.000). The Ponseti-treated group had fewer treatment complications (p<0.003), a lower recurrence rate (p<0.000) and satisfactory early outcome (p<0.000).

Conclusion: Major clubfoot surgery was not commonly indicated among patients treated with the Ponseti method. The Ponseti clubfoot technique has reduced total care costs, cast utilization, clubfoot surgery frequency and has also changed the patterns of surgery performed for clubfoot in Nigeria.

INTRODUCTION

Divergent views exist as to what proportion of clubfeet may be successfully managed by closed non-operative methods and how long an orthopedic surgeon should persist in non-operative treatment if the appearance of the foot does not improve.1 In Nigeria, clubfeet often present for treatment beyond twelve weeks of age, with persistent deformity that is unlikely to yield to manipulation. The orthopedic clinical treatment choices for an incompletely corrected clubfoot are more difficult when the parents and patients are already frustrated. Little progress had been made in treatments since surgical approaches were described in the early 1980s.2-3 Extensive early surgery did not prove to be of any real advantage and may have even been harmful. One point of agreement among experts has been that those clubfeet requiring multiple operations became stiff, were smaller and weaker than the contralateral foot, and that they functioned poorly in the long term.4 Competent surgical management of clubfeet should yield about 90% satisfactory results at skeletal maturity. In the context used here, good results imply a flexible, plantigrade foot with the ability to bear weight on the forefoot through strong gastrocnemius muscle contraction, minimal cavus and a slightly externally rotated foot-progression axis. When the re-operation rate is more than 5 to10%, the surgical method employed requires re-evaluation.1

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The effects of the Ponseti clubfoot technique on clubfoot surgery in Nigeria have not previously been reported. We comparatively evaluated the Ponseti method as it was introduced in the pattern of clubfoot surgeries performed in Nigeria. The research hypothesis was that no difference exists between the traditional methods of clubfoot treatment via extensive soft tissue/bony surgery and the Ponseti method. The outcome measures included frequency of major surgery, the number of casts applied, and total cost of clubfoot treatment.

**PATIENTS AND METHODS**

**Inclusion Criteria**

All cases of consenting clubfoot were recruited, at any age, presenting with idiopathic, syndromic/asyndromic, unilateral or bilateral clubfoot, with or without previous treatment and/or post surgical recurrence. All clubfoot patients were enrolled and treated using either the Ponseti (Iowa) technique (PCG), or manipulation and extensive soft tissue/bony surgery (NPCG) within the study period. All patients with a minimum follow-up of three months post last casting were included. The following were documented: biodata, birth history, clubfoot pattern, body side, laterality (unilateral/bilateral), age at onset of treatment, mode of treatment offered, total numbers of casts applied, care cost (low or high) and treatment complications.

**Exclusion Criteria**

Clubfoot patients who were not primarily treated at, or operated upon at the participating institution were excluded. Also excluded were patients who had defaulted during treatment prior to the study’s inception, or were discharged against medical advice, as well as those with acquired clubfoot.

**Setting**

Clubfoot patients were recruited into the study between October 1, 2007 and November 30, 2009 at the orthopaedics and antenatal clinics of the Obafemi Awolowo University Teaching Hospital Complex, Ile Ife, (OAUTHC) Nigeria.

**Study Blinding**

All clubfoot patients were first seen and assigned to a study group by a voluntary chief nursing officer at the orthopaedic clinic who was blinded to the managing team and study protocol. A senior registrar and a consultant orthopaedic surgeon acted as blinded clinical outcome evaluators. Both the nursing officer and senior registrar/consultant orthopaedist scored the clubfeet independently using Dimeglio-Bensahel Severity Score. Any differences were reconciled before treatment and after completion of treatment at the last follow-up clinic. The voluntary chief nursing staff and blinded evaluators were not part of the study group. A consultant radiologist with seven years experience, with a neutral status in the study, screened the plain x-rays of patients and confirmed radiological features of clubfoot. The orthopedic managing teams were blinded to the clubfoot patient’s selection, and surgical treatment methods chosen were not influenced. No clubfoot subjects had previously been exposed to Ponseti techniques.

**Study Design**

A twenty-six month prospective, intention-to-treat, nonselective randomized, double-blind comparative study of clubfoot managed with Ponseti techniques (PCG) and non-Ponseti methods (NPCG) was undertaken. The clubfoot patients in the PCG and NPCG formed the study population.

The study protocol was approved by the institutional medical ethics review board. A written or informed consent from the patient’s parents was obtained that fulfilled the inclusion criteria before randomization. The patient’s parent’s informed consents were obtained by video recording or photographs without facial covering with the understanding that after participation in the study, all results were to be used only for scientific meetings or publication. Written consents were not applicable for all of the patients’ parents because of illiteracy.

**Study Randomization**

The first step was a nonselective randomization of clubfoot patients into two groups (PCG and NPCG) using computer-generated random numbers (Excel 5.0). Both the assessors and patients/parents were blinded to the allocations and were not informed of the block size until after completion of the study on December 3, 2009. The patients who served as our control group were those in the NPCG group, and they were treated with manipulation and extensive soft tissue or bony surgery.

**Clubfoot Managements**

**Non-Ponseti Clubfoot Group Management:** This group (NPCG) received routine clubfoot manipulation and soft tissue (tendon and ligament) stretching at the orthopedic clinic. Clubfoot patient mothers were taught to do manipulation on their own and the patients were evaluated weekly. Robert Jones strapping,5,6 Denis Browne splints and Kite’s7 methods were the non-operative treatments utilized. The clubfeet that failed these
corrections ended up receiving extensive soft tissue/bony surgery. Prolonged physiotherapy was relied upon to correct most of the post surgical recurrences.

**Ponseti Clubfoot Method Group Management:** A description of the Ponseti method was documented earlier.\(^{8,9,10}\) The Ponseti clubfoot technique was introduced at our study center. This corrective method was explained to parents and adolescents. Manipulation was performed and retention casts were changed weekly. The manipulations performed lasted about 10 to 15 minutes. Long-leg casts were applied with the knee flexed to about 110-120 degrees. Correction of neglected idiopathic clubfeet by the Ponseti method was done with minimal modification.\(^{11}\) Casts were changed every two weeks to allow for remodeling of the soft tissues and osteocartilaginous structures. The foot was abducted to approximately 30 to 40 degrees instead of the 70 degrees recently recommended for younger children.\(^{12}\) Equinus was corrected via percutaneous tenotomy of the tendo-Achilles performed under local anesthesia using 3-5mls of 1% plain Lidocaine. The skin incision was closed with a single 3/0 Vicryl stitch.

**OBJECTIVES**

The number of patients treated without extensive soft tissue surgery was viewed as the primary effect of the Ponseti technique on clubfoot surgery. The secondary outcome measures included the number of plaster casts above six, the cost of care and complications of treatment.

**CLINICAL ASSESSMENT**

Clubfoot severity was graded using the Dimeglio-Bensahel classification.\(^{13}\) This incorporated eight components including equinus, varus, position of the talo-calcaneal forefoot unit (supination/pronation), forefoot adduction, the presence of abnormal musculature, cavus, a medial crease, and a posterior crease. A total of 20 points was possible; the higher the number, the more severe and rigid the clubfoot. Type I consisted of benign feet (0-5 points), Type IIA consisted of moderately affected feet (6-10 points), Type IIB consisted of severely affected feet (11-15 points) and Type III consisted of very severely affected feet (16-20 points).

All patients had pre-treatment, post-correction and last follow-up plain radiographs that included anteroposterior (AP) and lateral standing (LS) views of the feet. The talocalcaneal and talar/first metatarsal angles were obtained from the AP view. The talocalcaneal angle was recorded from the LS view. Magnetic Resonance Imaging (MRI) and Computerized Tomography (CT) scans were excluded as assessment methods because both were not financially accessible for all clubfoot patients.

A mobile phone was used to monitor patients’ follow-up and to improve clinic compliance.

Any variations in clinical assessment were controlled by using a single sheet of paper containing comprehensive classifications and ratings for all patients. All plaster of paris retention casts were applied under the direct supervision of attending orthopaedic fellows to allow for consistency in casting and ratings.

In each orthopedic clinic, all feet were scored prior to application of each retention cast, surgery and/or placement of foot abduction orthoses. Percutaneous or open Achilles tenotomy was classified as a minor surgery. Extensive soft tissue surgery, anterior tibialis tendon transfer and/or posterior capsulotomy, and triple arthrodesis were documented as major clubfoot surgeries. A relapse was defined as the appearance of slight equinus and varus deformity of the heel, often without increased adduction or cavus deformities of the forefoot. The sum of the talocalcaneal angle in the AP and LS views (referred to as Beatson-Pearson index)\(^{13}\) was used to determine radiological outcome. Clubfoot treatment was judged as satisfactory if the Dimeglio-Bensahel score was ≤6 at the last follow-up clinic.

The cost of clubfoot treatment was judged as low when a patient received a maximum number of six casts with or without minor surgery. Individuals requiring more than six casts and/or major surgery were recorded as having a high cost of care for the purposes of this study.

**Statistical Analyses**

All analyses were performed on the basis of the intention-to-treat cohort, defined as all clubfoot patients who received at least one form of clubfoot treatment within the study period. Data was analyzed using the Statistical Package for Social Sciences (SPSS) version 16.0 for Windows. The comparability of patients in the two groups of clubfoot treatment was determined from the demographic data and baseline values. The Kruskal-Wallis analysis was used for data generation. Changes in the mean hospital care cost and mean Dimeglio-Bensahel points were evaluated using two-way ANOVA for parametric data and Mann-Whitney U technique was used to compare the two clubfoot groups for non-parametric data. A confidence interval (CI) of 95% p<0.05 was taken to be significant.

**Study Limitations**

Within these two main groups, there were a limited number of clubfoot patients and a lack of long-term follow-up results for complications and functional evaluation.
153 clubfeet in 105 patients met the inclusion criteria representing 76.1% of congenital malformations. Fifty (36.2%) NPCG patients had manipulation and extensive soft tissue surgery, while 55 (39.9%) were treated with the Ponseti method. The number of PCG patients with congenital limb malformation that was managed was significant (p<0.000). The age at presentation was unique at 32 patients (58.2%) of the PCG group presenting before six months as compared to 14 patients (28%) of the NPCG group (p<0.024). The patient’s age at presentation was not related to clubfoot etiology (p>0.077) and treatment complication (p>0.331). Also, no significant difference existed between the Dimeglio-Bensahel scoring severity of clubfeet in the two treatment groups as depicted in Table 1. In the Ponseti group, sixteen (29.1%) patients had previous treatment compared to 13 (26.0%) of the NPCG patients. At presentation, three (5.4%, 2 male, 1 female) of the Ponseti group patients had recurrent clubfoot post surgery. These were found in five feet at ages seven months, four years and 14 years.
The oldest patient in the Ponseti group was an 18-year-old girl with unilateral neglected clubfoot, Dimeglio-Bensahel type IIb (12 points) from Igede Ekiti. She underwent Ponseti manipulation with long-leg retention casting technique. Casts were changed biweekly for 12 weeks before percutaneous tendo Achilles tenotomy was done. Early recurrence occurred at five months after her last cast application. She had two further consecutive talocalcaneal joint manipulations and Ponseti casts applied to correct the varus and equinus. Open tendo-Achilles lengthening was performed. At the last follow-up clinic visit at twenty months post retention cast, she had satisfactory outcome of her affected foot, Dimeglio-Bensahel 5 points. There was no significant residual abnormal appearance of the foot and full functionality. The natural progress is shown in Figure 1.

A total of 161 major orthopaedic surgeries were performed during the study period of which major clubfoot surgeries were 10.6%. Table 2 shows the various surgical patterns for clubfoot patients. Significant clubfoot surgeries were indicated in 17 patients (34.0%) in the NPCG group. These include extensive soft tissue surgery/posterior capsulotomy for 10 patients (58.8%), tibialis anterior transfers for 3 patients (17.6%), and two patients (11.8%) requiring a McEvans operation and triple arthrodesis respectively. Five of the 17 patients (29.4%) who had extensive soft tissue/bony surgery subsequently required at least one repeat surgery related to an unsatisfactory

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### TABLE 2. Surgical Intervention Related to Treatment Methods

<table>
<thead>
<tr>
<th>Factors affecting surgery</th>
<th>No surgery (%)</th>
<th>Minor surgery (%)</th>
<th>Intermediate surgery (%)</th>
<th>Major surgery (%)</th>
<th>Level of Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode of Treatment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPCG</td>
<td>17.0 (34.0%)</td>
<td>16 (32.0%)</td>
<td>7 (14.0%)</td>
<td>10 (20.0%)</td>
<td>p&lt;0.000</td>
</tr>
<tr>
<td>PCG</td>
<td>52.0 (94.5%)</td>
<td>3 (5.5%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td></td>
</tr>
<tr>
<td>Clubfoot etiology</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Idiopathic</td>
<td>59</td>
<td>17</td>
<td>3</td>
<td>2</td>
<td>p&lt;0.000</td>
</tr>
<tr>
<td>Neuromuscular</td>
<td>10</td>
<td>2</td>
<td>4</td>
<td>8</td>
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</tr>
<tr>
<td>Surgery complication</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes complication</td>
<td>0.0</td>
<td>5</td>
<td>4</td>
<td>7</td>
<td>p&lt;0.000</td>
</tr>
<tr>
<td>No complication</td>
<td>69.0</td>
<td>14</td>
<td>3</td>
<td>3</td>
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</tbody>
</table>

### TABLE 3. Clubfoot management outcome: Ponseti methods vs Non-Ponseti methods

<table>
<thead>
<tr>
<th>Factors affecting outcome</th>
<th>Non-Ponseti Clubfoot</th>
<th>Ponseti Clubfoot Method</th>
<th>Significance level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Cast</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤ 6</td>
<td>15 (30.0%; range 3-6)</td>
<td>42 (76.4%; range :2-6)</td>
<td>p&lt;0.000</td>
</tr>
<tr>
<td>&gt; 6</td>
<td>35 (70.0%; range:7-13)</td>
<td>13 (23.6%;range: 7-10)</td>
<td></td>
</tr>
<tr>
<td>Dimeglio-Bensahel score at last clinic follow up (mean point ≤ 6)</td>
<td>29 (58.0%)</td>
<td>55 (100.0%)</td>
<td>p&lt;0.000</td>
</tr>
<tr>
<td>Interval of recurrence</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No recurrence</td>
<td>26 (52.0%)</td>
<td>53 (96.4%)</td>
<td>p&lt;0.000</td>
</tr>
<tr>
<td>1.0-3.0 months</td>
<td>12 (24.0%)</td>
<td>0 (0.0%)</td>
<td></td>
</tr>
<tr>
<td>&gt; 4.0-6.0 months</td>
<td>12 (24.0%)</td>
<td>2 (3.8%)</td>
<td></td>
</tr>
<tr>
<td>Treatment complication</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>29 (58.0%)</td>
<td>53 (96.4%)</td>
<td>p&lt;0.000</td>
</tr>
<tr>
<td>Yes (Ugly scar, recurrence, blister, infection)</td>
<td>21 (42.0%)</td>
<td>2 (3.6%)</td>
<td></td>
</tr>
<tr>
<td>Early Clinical Outcome</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Satisfactory</td>
<td>29 (58.0%)</td>
<td>53 (96.4%)</td>
<td>p&lt;0.000</td>
</tr>
<tr>
<td>Fair</td>
<td>14 (28.0%)</td>
<td>2 (3.6%)</td>
<td></td>
</tr>
<tr>
<td>Poor</td>
<td>7 (14.0%)</td>
<td>0 (0.0%)</td>
<td></td>
</tr>
<tr>
<td>Follow up(months)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.0-12</td>
<td>8.0 (16.0%)</td>
<td>35.0 (63.6%)</td>
<td>p&lt;0.000</td>
</tr>
<tr>
<td>13.0-36.0</td>
<td>24.0 (48.0%)</td>
<td>20.0 (36.4%)</td>
<td></td>
</tr>
<tr>
<td>37.0-60.0</td>
<td>11.0 (22.0%)</td>
<td>0.0 (0.0%)</td>
<td></td>
</tr>
<tr>
<td>61.0-120.0</td>
<td>7.0 (14.0%)</td>
<td>0.0 (0.0%)</td>
<td></td>
</tr>
<tr>
<td>Satisfactory= No recurrence</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fair= Recurrence corrected with casts/foot abduction brace</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor= Recurrence with repeat intermediate/major surgery</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The oldest patient in the Ponseti group was an 18-year-old girl with unilateral neglected clubfoot, Dimeglio-Bensahel type IIb (12 points) from Igede Ekiti. She underwent Ponseti manipulation with long-leg retention casting technique. Casts were changed biweekly for 12 weeks before percutaneous tendo Achilles tenotomy was done. Early recurrence occurred at five months after her last cast application. She had two further consecutive talocalcaneal joint manipulations and Ponseti casts applied to correct the varus and equinus. Open tendo-Achilles lengthening was performed. At the last follow-up clinic visit at twenty months post retention cast, she had satisfactory outcome of her affected foot, Dimeglio-Bensahel 5 points. There was no significant residual abnormal appearance of the foot and full functionality. The natural progress is shown in Figure 1.
outcome. Fifty-two patients of the Ponseti group were treated successfully with the Ponseti method (94.5% vs. 34%, p<0.000). Three (5.5%) of the Ponseti patients had four minor surgeries, tendo-Achilles tenotomies (3 percutaneous, 1 open). There was no indication for major soft tissue/bony surgery among all the clubfeet (100%) treated with Ponseti method.

Table 3 shows NPCG patients who required more than six casts as compared to the Ponseti group (70% vs. 23.6%, p<0.000). The mean duration of time to achieve satisfactory clubfoot correction was 13.7 +/- 1.7 weeks among the NPCG and 9.3 +/- 3.5 weeks for the Ponseti group (p<0.000). The number of casts applied was not related to patient age (p=0.159). There was no indication for post-correction physiotherapy within the Ponseti group of patients. Twenty-eight (56.0%) of the NPCG patients received passive physiotherapy and the duration of treatment was related to the age of the patient at presentation (p<0.000).

Locally fabricated abduction foot braces were made available for the Ponseti patients. The duration of use and timing varied with each patient’s age. There was an initial problem getting an appropriate local shoemaker to produce functional foot braces with consistency in quality. The patient’s compliance with the abduction foot braces was generally good.

The Ponseti-treated group, when compared to the NPCG patients, had fewer treatment complications (42% vs. 3.6%, p<0.001), lower recurrence rates (p<0.000) and more satisfactory early full correction outcomes (100.0% vs. 53.8%, p<0.000). The mean cost of care was S419,900 Naira (US $3683.33) were spent on 17 extensive soft tissue surgery among all the clubfeet (100%) treated with Ponseti method.

NPCG treatment complications could be related to a poor understanding of the clubfoot with the forces causing the deformity remaining unaltered after manipulation and extensive clubfoot surgery. Most clubfeet in the PCG were successfully corrected without surgery within a short time.

Complex clubfoot deformity of a syndromic type, severe recurrence post extensive clubfoot surgery, and neglected clubfoot all partially relapsed status post Ponseti technique. These patients presented late (beyond six weeks after birth). It has been recognized that relapses occur in severe clubfeet whether these were treated surgically or nonsurgically. The Ponseti technique is flexible in that it provides an opportunity to recast patients who lose their corrections. The relapsing cases within the PCG patients were related to a delay in procurement and use of fabricated abduction foot braces. However, relapses were not related to the patient’s age at presentation or to the number of casts required for correction. The PCG relapse rate was comparable (7%) to that reported by Ponseti in noncompliant patients with the straight-laced shoe and abduction bar protocol. Our results and those of Ponseti suggests that the importance of maintaining correction with the foot abduction bar is paramount to successful treatment. There was no virgin clubfoot patient treated with the Ponseti method who relapsed. All the relapsed clubfeet patients were successfully treated with further manipulations and recastings for two to six weeks with or without tendo-Achilles tenotomy/lengthening and foot abduction bar regimens.

In the NPCG, 34.0% ended in extensive soft tissue release and bony surgery despite early serial casting similar to Lloyd-Roberts report. The primary disadvantages of intermediate and major clubfoot surgery are high complication rates and the difficulty of treatment when this occurs. A 48.0% recurrence associated with NPCG patients agrees with other reports in the 13-50% range. Other surgical complications include infection, noncosmetic scar formation, skin flap necrosis and wound dehiscence. The high cost of clubfoot care in NPCG was in contrast to the lower cost of the Ponseti method. The major clubfoot surgical care cost was eliminated with the use of Ponseti’s methods. There was a significant reduction in the number of retentions castings required for complete deformity correction in the Ponseti patients compared to the NPCG patients.

The frequency of indication for major clubfoot surgery which was 100.0% has been reduced to minor operations, similar to that reported by Morcuende et al. from Iowa, USA. Our findings are supported further by Ippolito
et al.,22 where they concluded after thirty years that extensive surgery is not the right approach to the management of congenital clubfoot, but proper manipulation techniques initiated by Ponseti are. In addition, open surgery weakened ankle plantar flexion and prevented some patients from being able to walk on their toes.22 The clinical correction achieved by using the Ponseti technique has produced a functional, plantigrade foot without requiring postero medial release in the fifty-five (100%) clubfoot patients managed. Some of the patients who were followed after three years sustained their correction.

Intermediate/major surgery was indicated in 34.0% of NPCG. 29.4% of these patients subsequently required at least a repeat surgery related to unsatisfactory outcome. This was similar to unpublished data from Dr. O Onabowale23 on 555 clubfoot patients at the National Orthopaedic Hospital, Igbobi, Lagos, Nigeria. He found that 146 patients (26.3%) had surgical treatment and 19.2% ended unsatisfactorily. Dobbs et al.24 also demonstrated significantly fewer excellent or good outcomes in their surgically treated group.25,26 The oldest clubfoot patient treated with the Ponseti method at age 18 years is a first, as reported in this study. Our results show that a strict Ponseti technique protocol can salvage or treat clubfoot even after several months or years of unsuccessful traditional casting or neglect, without extensive soft tissue surgery.

CONCLUSION

Ponseti clubfoot management techniques have reduced the need for extensive soft tissue release and major clubfoot surgery, and has changed clubfoot operation patterns in Nigeria.

REFERENCES

23. Onabowale BO. (Unpublished data on 555 Clubfoot management presented at the Nigerian Postgraduate Medical College, Faculty of Surgery Revision Course, Lagos 1998).


ABSTRACT

Bracing is a critical component of the current standard of treatment for clubfoot. Adherence to the bracing protocol is the main factor for the long-term success of the treatment. The purpose of this paper is to provide a review of clubfoot braces, best practices in brace design and recommendations for bracing in order to improve adherence with the bracing phase of the clubfoot treatment. There are a number of designs and offerings of braces available in various regions of the world. Although many new brace designs are being proposed and developed, evidence in the literature regarding biomechanical effects, clinical outcomes, functionality and patient adherence is limited. The current research that is available regarding brace design focuses on increasing patient comfort and satisfaction to improve adherence. Although the currently available braces are widely distributed in developed countries, access is limited to many parts of the world. When considering the future of the clubfoot treatment and prevention of relapses, since 80% of the cases are in developing countries with limited resources, brace cost and availability needs to be assessed.

INTRODUCTION

Congenital talipes equinovarus, or clubfoot, is a common deformity where the affected foot is turned inward. It occurs in every 1.2 in 1000 live births and is the most common musculoskeletal congenital birth defect. Males are more commonly affected than females and up to 50% of cases are bilateral. The etiology of congenital clubfoot is largely idiopathic, however, it can be associated with other conditions such as spina bifida, arthrogryposis or other syndromes in approximately 20% of the cases.

Over the past few decades, there has been extensive research regarding the appropriate treatment for clubfoot. Historically, surgical correction, specifically an extensive postero-medial soft tissue release, was the mainstay treatment option. This intervention, however, has been shown to result in severe scarring, joint stiffness, muscle weakness, gait disturbances and relapses. Additionally, complications including wound infections, skin necrosis and neurovascular injuries have been reported. Furthermore, the deformity can be over- or under-corrected and the talus may be flattened or even result in necrosis.

Given the potential devastating complications and discouraging long-term results, treatment preferences have since changed to primarily a non-operative approach through the Ponseti method. The method has become the standard of care and completely eliminates the need for extensive operative correction in over 98% of patients if applied correctly. The treatment involves manipulation, a series of castings, percutaneous Achilles tenotomy and foot bracing. With correct application of the procedure and appropriate patient adherence, complete correction can be achieved in as little as 16 days with an accelerated casting protocol. The treatment involves manipulation, a series of castings, percutaneous Achilles tenotomy and foot bracing. With correct application of the procedure and appropriate patient adherence, complete correction can be achieved in as little as 16 days with an accelerated casting protocol. The treatment involves manipulation, a series of castings, percutaneous Achilles tenotomy and foot bracing. With correct application of the procedure and appropriate patient adherence, complete correction can be achieved in as little as 16 days with an accelerated casting protocol.

While the casting phase of the treatment is relatively short and has the most visible effect on the correction of the deformity, the bracing phase that last for 4-5 years is actually essential for the success of the method. Bracing must be done every night, is mainly the responsibility of the parents, and is done with limited clinical supervision. Importantly, adherence to the bracing protocol is critical for the long-term success of the treatment as demonstrated by the high relapse rate in non-adherent parents (10 times greater). Adherence to bracing is a better predictor for relapse than severity of the deformity at birth, which is not a reliable indicator of the odds of relapse. Because of the critical importance of bracing in the success of the Ponseti method, we will describe an overview of past and current clubfoot braces with specific information on the key points about design.
and wearing protocols. We believe a historical perspective combined with a scan of the current state of practice can be utilized to guide future directions of research, education and practice.

HISTORICAL PERSPECTIVES ON BRACING

The 1895 publication by Walsham and Hughes on the deformities of the foot provides an early account of bracing for the prevention of clubfoot relapse. In this book, the authors divide bracing into two categories, (1) instruments for use during the night, and (2) instruments for use during the day. They further breakdown the daytime bracing options into three subsets, including (a) instruments for holding the foot in a restored position, (b) those that, in addition to (a), are designed to overcome the tendency for the whole limb to roll inwards, and (c) those that have the purpose of further improving a partially corrected clubfoot.

Figure 1 is an example of a category (1) brace for use at night. This brace was intended for the recently corrected clubfoot. The authors state a tendency for the weight of bedclothes to press back the foot to a deformed position. The brace consists of a calf-piece for the back and outer side of the calf, and a foot-piece, bent at right angles and turned up on the inner side to prevent the foot from rolling inwards. An oval hole is placed opposite the internal malleolus to prevent pressure at this spot. This splint was softly padded and covered with leather, the foot being held in place with bandage.

Figure 2 shows examples of category (2), subset (a) as described by the authors for holding the foot in a restored position. The authors suggest using such an apparatus only after varus has been completely overcome and dorsiflexion of 30 degrees is achieved.

Figure 3 shows examples of category (2), subset (b) as described by the authors for not only the maintenance of corrected clubfoot, but to also control inversion of the limb. The authors state that after clubfoot correction, children beginning to walk still have their toes pointing inwards. They suggest that this may be due to the laxity of the ligaments of the knee joint, allowing the tibia to roll inwards on the femur, or, more often, from the whole lower limb rolling in at the hip joint due to a “faulty direction of the neck of the femur.”

Also included in this category is Sayre’s appliance for correcting inversion in bilateral clubfoot, shown in Figure 4. This is the only brace depicted in this nineteenth century book that resembles the standard-of-care bracing used today.

Figure 5 shows examples of category (2), subset (c) as described by the authors for having the purpose of further improving a partially corrected clubfoot. They further divide these braces into two categories, (i) those that retain the foot in a corrected position and for further correcting the equinus (plantarflexion); and (ii) those for continuing the eversion as well as dorsiflexion of the foot. They are shown in Figure 5 together, due to their similarity. Note that each employs a strategy (belt,
Bracing in the Treatment of Children with Clubfoot: Past, Present, and Future

The braces most commonly used today employ a connecting bar and are often referred to as a ‘Denis Browne Bar’ or ‘Denis Browne Splint’ regardless of manufacturer or setup specifications. These braces are likely an evolution and adaptation of that described by Denis Browne in his 1934 publication, “Talipes Equino-Varus.” Here Browne states that maintaining the clubfoot correction “can be obtained by connecting the feet horizontally at the desired angles to the Sagittal plane.” He describes, “the desired angles,” to be external rotations of 20-degrees for unaffected feet and up to 90-degrees for clubfeet. His original brace included an L-shaped bracket to hold the foot, “bending up one side to clear the external malleolus and bear against the outer side of the leg.” The foot is also described by Browne to be held in significant dorsiflexion, connected to the bar via “sticking-plaster” for babies, and open-toe straight last boots for walking children.

In 1952, in The British Encyclopaedia of Medical Practice, Browne describes a “night-splint” in greater detail. The splint, he states, “consists of a central grip around the ankle, from which there runs forward an open-ended shoe to hold the foot, and upwards 2 struts to hold a band below the knee.” The front part of the shoe can be pulled upwards by a strap to the upper band, bringing the foot into calcaneus. Varus or valgus was adjusted by rotation of a lever through which a strap passed. Browne believed that equinus was the most common factor in all foot deformities, and that, “there is at present no other splint that will counter it.” He concludes, stating that, “If necessary, the feet can be turned outwards as well as held in calcaneo-valgus position by connecting the feet together with a jointed bar of metal.”

In a correspondence written in The British Medical Journal in 1956, Browne claimed difficulty in getting his work on the splint published due the opposition of orthopaedic surgeons. He states in this correspondence that, “The splint was first described in the U.S.A. with the lateral lever cut down to useless proportions, and from thence copied into various English textbooks.” Browne was clearly upset by the modifications; stating that, “Before improving a technique, first find out what it actually is and how it developed.” He also states, “If the originator is still available, get his opinion on the modifications before publishing it.”

In the 1997 book, Atlas of Orthoses and Assistive Devices, a figure is shown under a section on clubfoot correction with the following caption, “Eleven-month-old child in reverse last shoes and Denis-Browne bar after bilateral clubfoot repair. The combination (of shoes and bar) helps maintain external rotation, the corrected abducted position, and prevents turning in of the feet.” (Figure 6).

The brace from Figure 6 shown above is similar to that of the current standard-of-care brace. The standard of care brace and additional modern day clubfoot bracing are discussed in detail in the next section.

CURRENT BRACING DESIGNS

Presently, there are three major categories of brace designs: Ankle Foot Orthosis (AFO), Wheaton Brace or similar braces, and Foot Abduction Brace (FAB). The AFO design follows a similar concept to braces described in the historical review, such as the tin rectangular varus night shoe. It fully covers both the foot and ankle, thus providing only the dorsiflexion built into the brace, which is usually set at neutral. Importantly, it does not provide abduction, which is important for the stretching of the medial structures. In addition, because of the lack of motion at the ankle, it contributes to calf muscle atrophy which is already abnormal in clubfoot. In specific circumstances, an AFO can be useful in combination...
with an abduction brace, i.e., when the child’s foot has relatively limited dorsiflexion (i.e., spina bifida, arthrogryposis, neurologic dysfunction of the peroneal nerve, etc.). There is little muscular support in these conditions, so the brace provides the necessary structural support to the child’s foot.

The Wheaton Brace (Figure 7), and other similar devices based on the same construct, can provide some abduction of the foot. A Velcro strap is tightened against the apex of the deformity. The brace comes in two types, with the ankle at 15 degrees plantar flexion and with the angle at 90 degrees dorsiflexion. Because the brace is worn up to the thigh, it contributes not only to some calf muscle atrophy but also to thigh muscle atrophy.

Under the Ponseti method recommendations, the corrected foot should be held in an abducted and dorsiflexed position to prevent relapses. This is the most important criteria to ensure that there is maintenance of the clubfoot correction and is best achieved by using a well-designed Foot Abduction Brace (FAB). A FAB consists of two shoes connected by a bar. If the deformity is unilateral, the external rotation on the affected foot should be set to 60/70° and on the unaffected foot to 30/40°. The bar should be of the length between the child’s shoulders and should be bent to allow for 10-15° of dorsiflexion. Ideally, the bar can be lengthened over time as the child grows. The shoes should be comfortable and straight laced (no curves and can fit both feet). To increase the ease and adherence of use, a brace with shoes that can clip into and out of the bar seems to be preferred by the parents.

Traditionally these bars have been known as the “Denis Browne Split.” The Denis Browne Split utilizes an L-shaped bracket to hold the foot in significant dorsiflexion and is connected to open-toe boots. There is some concern when the child’s feet are still small that it may be difficult to prevent movement in the shoe. The Denis Browne Split is available in many countries and it paved the way for the new style of braces seen today.

Although many modern clubfoot braces are available in the market, their use across the world is uneven given that the cost may be prohibitive for many patients, especially in developing countries. The Steenbeek brace (Figure 8), developed in Uganda by Michiel Steenbeek and David Okello, is made with local tools (leather sewing machine, metal-working equipment, welding tools) and materials (leather, lining, plywood, mild steel rod stock). The cost is under 10 US dollars and matches the recommendations provided by Dr. Ponseti.33

Other locally produced FABs are available, such as in Sweden, Vietnam and Armenia. In Sweden, the brace developed by Dr. Romanus in Gothenburg, uses malleable plastic to mold the shoes that shape to the child’s foot. The shoes are fixed to the bar with screws. In Vietnam, the Prosthetics Outreach Foundation works with Ha Troy OTRC workshop to produce a brace in line with Ponseti recommendations. It must be mentioned that some parents have produced their own home made braces that consist in most cases of a wood or metal bar with shoes attached at the recommended angles. Interestingly, in the patients that these devices have been used there has been a good control of relapses.

FABs are constantly being redesigned to improve comfort and to increase adherence to therapeutic recommendations. Although the functional aspects of most FABs are aligned with the Ponseti method recommendations, different materials are used to attempt an increase in patient utilization and satisfaction. For example, the Kessler Brace (Figure 9) closely follows the angles recommended by the Ponseti method, but the bar has some flexibility to allow the child some ability for plantar flexion during kicking. The bar returns to the original dorsiflexed position once the child stops kicking.18 The Horton Click brace utilizes a shoe that can be easily “clicked” onto the bar. However, this design allows both internal and external rotation of the foot (Figure 10). The Dobb’s Dynamic Clubfoot Brace utilizes a bar that allows the child to move both legs independently and shoes that reduce heel friction, however due to the articulation design, dorsiflexion may be difficult to achieve (Figure 11). The bar component can also be attached to Markell, Mitchell or custom made shoes. The ALFA-Flex shoe is
an FAB produced in Europe that has a large focus on the comfort and fit of the shoe. It uses non-toxic and biocompatible materials (Figure 12). An “intelligent” foam mould for the shoe allows a close, firm fit for the child’s foot and provides proper distribution of pressure in the brace. The foam material has both viscous and elastic components. The shoes are easy to put on due to step-in straps.37

The Mitchell Brace is widely distributed in developed countries; however it is also quite expensive. The brace was designed under the direction of Dr. Ponseti for the treatment of Complex Clubfeet given the difficulty maintaining a good correction with the Markell shoes (Figure 13). Given that the shoes are very comfortable for the child, this brace is in use now for any clubfeet. To note, although many current braces have been described, there is a lack of evidence in the literature regarding biomechanical effects on soft-tissues, functionality, patient adherence, and outcomes (Table 1).

**BRACE WEARING SCHEDULE**

The FAB is used only after the clubfoot has been completely corrected by manipulation, serial casting, and possibly the heel cord tenotomy. All current braces described will provide appropriate maintenance of the clubfoot correction as long as the feet are held in the suggested abducted and dorsiflexed positions and the appropriate bracing schedule is followed. Bracing protocol needs to be tailored to the individual patient based on age, relapse rate associated with that age, and when the correction was finished. For example, bracing hours will be longer for a newborn that was corrected in three weeks as opposed to an older child that is already walking when correction is achieved. Importantly, since the
underlying cause of clubfoot results clinically in a muscle growth and development problem, it is very important that children using a brace maintain a degree of mobility during the day (Table 2).

A brace should be measured and ordered for the child before the last cast is removed due to the high chance of regression leading to discomfort and non-adherence with the brace if the brace is not placed immediately after the cast is removed. If the brace is not ready, a holding cast should be applied to maintain final correction. It is also important not to end treatment early. Based on current information, there is a tendency for relapses up to the age of 4-5 years. Unfortunately, it is not possible using current clinical evaluation to know which patients would have a relapse during this time if the brace is stopped, so it is recommended for the brace to be used for all this period.

### IMPROVING BRACING ADHERENCE

Since adherence to brace wearing protocols is essential for preventing relapses, it is important for health care providers to communicate with patients regarding brace wearing to set proper expectations and ensure accurate use. Table 3 describes current recommendations that can be presented to parents by physicians, nurses, counselors or other health professionals in order to improve adherence with brace wear.

### TABLE 1. Literature Review of Currently Available Clubfoot Braces

<table>
<thead>
<tr>
<th>Brace</th>
<th>Studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheaton Brace</td>
<td>None</td>
</tr>
<tr>
<td>Romanus Brace</td>
<td>None</td>
</tr>
<tr>
<td>Locally Produced - Vietnam</td>
<td>None</td>
</tr>
<tr>
<td>Kessler Brace</td>
<td>Kessler JL. A new flexible brace used in the Ponseti treatment of talipes equinovarus.</td>
</tr>
<tr>
<td>Horton Click</td>
<td>None</td>
</tr>
<tr>
<td>ALFA -Flex Brace</td>
<td>None</td>
</tr>
<tr>
<td>Mitchell Brace</td>
<td>None</td>
</tr>
</tbody>
</table>

### CONCLUSIONS

Although many new brace designs are being proposed and developed, evidence in the literature regarding biomechanical effects, clinical outcomes, functionality and patient adherence is limited. Most braces follow most of the aspects of the Ponseti method recommendations; however, any deviations from this clinical practice and experience should be studied to determine if success rates are similar or improved.

The current research that is available regarding brace design focuses on increasing patient comfort and satisfaction to improve adherence. However, when looking to the future of the Ponseti method and prevention of relapse, brace cost also needs to be assessed. Although the currently available braces are widely distributed in developed countries, access is limited to many parts of the world. This is mostly due to the prohibitive cost of most bracing options (> $300 US dollars). Locally produced orthotics with low cost materials, such as the Steenbeek brace, can provide an option to patients in underprivileged areas and increase adherence and success rate of the treatment.
### TABLE 2. Recommendations for Clubfoot Bracing Schedules (based on current knowledge)

<table>
<thead>
<tr>
<th>a. Final correction in the first few months of life</th>
</tr>
</thead>
<tbody>
<tr>
<td>i. Wear brace 23 hours/day for first three months</td>
</tr>
<tr>
<td>ii. Follow a gradual weaning schedule*: one month 20-22 hours/day, one month 18-20 hours/day, one month 16-18 hours/day, and one month 14-16 hours/day</td>
</tr>
<tr>
<td>iii. Maintain nighttime wearing of the brace (12-14 hours/day) as the child grows and is walking full time for up to age 4-5 years</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>b. Final correction achieved after 8-9 months of age and child is ready to crawl or walk</th>
</tr>
</thead>
<tbody>
<tr>
<td>i. Allow some mobility to help in the development of the weak muscles.</td>
</tr>
<tr>
<td>ii. Begin initial bracing with 18-20 hours/day for 2 months and then 16 hours a day for 3-4 months</td>
</tr>
<tr>
<td>iii. Follow standard maintenance protocol (a. iii.)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>c. Final correction at age 2 to 4 years of age</th>
</tr>
</thead>
<tbody>
<tr>
<td>i. Use the brace at night as per standard protocol (a.iii)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>d. Final Correction after 4 years of age</th>
</tr>
</thead>
<tbody>
<tr>
<td>i. Some patients may still tolerate the brace at night for 1-2 years.</td>
</tr>
<tr>
<td>ii. In some patients, the use of an AFO will be more acceptable.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>e. Children with loose joints (approximately 2-3% of cases)</th>
</tr>
</thead>
<tbody>
<tr>
<td>i. Set the shoe to 30-40% abduction (abduction of 60 to 70 degrees may lead to flat foot, usually presenting when the patient starts walking at 10-16 months of age and after)</td>
</tr>
<tr>
<td>ii. Do not stop using the brace as there is a risk of relapse.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>f. Children with atypical/complex clubfoot</th>
</tr>
</thead>
<tbody>
<tr>
<td>i. Set the shoe for the affected foot at 20-30 degrees.</td>
</tr>
<tr>
<td>ii. Do not bend the bar unless there is 10-15 degrees of dorsiflexion with the last cast.</td>
</tr>
<tr>
<td>iii. Change the angle of the shoe to 40-50 degrees as the foot becomes more normal looking and add the bend in the far to allow 10-15 degrees of dorsiflexion.</td>
</tr>
</tbody>
</table>

*The time in the brace does not need to be consecutive, but it is important for the child to wear the brace while sleeping (e.g., at night, during naps) to encourage mobility during waking hours. If the child attends daycare, consider leaving the brace on in the morning and instructing the daycare as to what time each day that the brace should be removed. If possible, instruct them how to remove and reapply the brace for nap times.

### TABLE 3. Recommendations for Parents (based on current knowledge)

<table>
<thead>
<tr>
<th>a. Expect your child to fuss in the brace for the first 2-3 days.</th>
</tr>
</thead>
<tbody>
<tr>
<td>i. This is not because the brace is painful, but because it is something new and different.</td>
</tr>
<tr>
<td>ii. The child may have skin sensitivity as a result of the casting</td>
</tr>
<tr>
<td>iii. If your child is completely inconsolable and you believe that they are in pain, contact your physician immediately.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>b. Play with your child in the brace. This is a key to getting quickly over the child’s irritability.</th>
</tr>
</thead>
<tbody>
<tr>
<td>i. Since the child is unable to move his/her legs independent of each other in the brace, you must teach your child that he/she can kick and swing the legs simultaneously.</td>
</tr>
<tr>
<td>ii. Gently flex and extend the knees by pushing and pulling on the bar of the brace.</td>
</tr>
<tr>
<td>iii. Try making a game of the motions by singing and/or talking to your child in an encouraging manner.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>c. Make the treatment a routine.</th>
</tr>
</thead>
<tbody>
<tr>
<td>i. Your child is less likely to fuss if you make the use of this brace as a routine, non-negotiable part of their daily activities, just like putting on their pajamas, brushing their teeth, and reading books at night.</td>
</tr>
<tr>
<td>ii. When the child is only wearing the brace while sleeping, put the brace on any time your child goes to the “sleeping spot.”</td>
</tr>
<tr>
<td>iii. Some parents have made a brace for the child’s favorite stuffed animal or doll.</td>
</tr>
<tr>
<td>iv. Some parents call the brace “Nite-Nite shoes” or “Magic Shoes”</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>d. Show your child pictures of other children with clubfoot wearing their brace.</th>
</tr>
</thead>
<tbody>
<tr>
<td>e. Use rewards and incentives to help your child understand the importance of the brace.</td>
</tr>
<tr>
<td>f. For older children, ask your physician to talk to the child at follow up appointments about their brace and how it helps them maintain the correction.</td>
</tr>
<tr>
<td>g. Pad the bar. This will protect your child, yourself, and your furniture from being hit by the bar when the child is wearing the brace.</td>
</tr>
<tr>
<td>i. A bicycle handle bar pad or foam pipe insulation covered with fabric or tape works well.</td>
</tr>
<tr>
<td>ii. Placing a sleep sack on the child at night will also help with padding and keep the baby from pulling at the straps and laces with their hands.</td>
</tr>
<tr>
<td>h. If you notice any bright red spots or blistersing contact your health care provider.</td>
</tr>
<tr>
<td>i. Some mild redness is normal with use.</td>
</tr>
<tr>
<td>ii. Bright red spots or blisters, especially on the back of the heel, usually indicate that the shoe was not worn tightly enough. Make sure that the heel stays down in the shoe.</td>
</tr>
<tr>
<td>iii. Tighten the strap by one more hole or tighten the laces</td>
</tr>
<tr>
<td>iv. Remove the tongue of the shoe. Use of the brace without the tongue will not harm your child.</td>
</tr>
<tr>
<td>v. If the brace shoe has laces, lace the shoes from top to bottom, so the bow is by the toes.</td>
</tr>
<tr>
<td>vi. Check the width of the brace and widen if necessary.</td>
</tr>
<tr>
<td>vii. Never use lotion on any red spots on the skin. Lotion will make the problem worse.</td>
</tr>
<tr>
<td>viii. If persistent and the foot comes out of the shoe, it may be a sign of early relapse.</td>
</tr>
</tbody>
</table>
REFERENCES
IMAGES

Wheaton Brace: http://www.wheatonbrace.com/products/wbrace.html


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Mitchel: http://www.mdorthopaedics.com/home.html
ABSTRACT

Complex clubfeet represent a subset of clubfeet with unique features. Their correction requires a modification of the Ponseti casting technique and good short term results have been reported. However, these clubfeet are very difficult to treat and there is a higher chance for potential complications. We reviewed the database of patients with clubfeet treated from January 2001 to December 2009. There were 837 patients (1376 feet) with 111 (182 feet) (13%) having complex deformity. Of these, 8 patients (10 complex clubfeet) (0.7%) experienced a peroneal nerve dysfunction. Severity of the dysfunction varied from no active dorsiflexion (2 patients) to weakness for active dorsiflexion or foot eversion (6 patients). Deformity correction required an average of 5 casts (range, 1 to 8). Two patients required an Achilles tenotomy and the average ankle dorsiflexion at last follow up was 14 degrees (range: 5 to 25). No surgical releases have been required. Two patients required an ankle foot orthosis to improve gait. There were three relapses (37%) that responded to casting and 1 patient required a tibialis anterior tendon transfer. Only 3 feet have recovered the nerve dysfunction. In conclusion, repeated neurological evaluations and very careful cast placement should be performed during the treatment of complex clubfeet. The modified Ponseti technique, if applied properly, is successful in correcting these feet and avoids extensive surgical releases.

INTRODUCTION

Congenital idiopathic clubfoot is a common foot deformity and most orthopaedic surgeons agree that the initial treatment should be non operative. Treatment with the Ponseti method is very effective in the majority of patients. However, some feet do not respond to the standard casting protocol, and they have been called complex clubfeet. Clinically, complex clubfeet are defined as having rigid equinus, severe plantar flexion of all metatarsals, a transverse crease in the sole of the foot, a deep crease above the heel, and a short and hyperextended first toe. The Achilles’ tendon is exceptionally tight and fibrotic up to the middle of the calf.

Correction of complex clubfoot can be achieved by a modified Ponseti casting technique. However, these feet are very difficult to treat and there is a higher chance for potential complications. In many of these cases, the cast slips very often with the resulting abnormal forces on the foot, heel and possibly the leg that lead to the characteristic deformity. In this report we describe 8 patients (10 feet) with complex clubfeet that had a concomitant peroneal nerve dysfunction. The clinical and practical importance of its early detection before and/or during treatment is discussed as well as treatment recommendations.

PATIENTS AND METHODS

After approval by the Institutional Review Board, we reviewed the records database of 837 patients with clubfoot (1376 clubfeet) consecutively treated at our center from January 2001 to December 2009. Of these, 111 patients (189 feet) (13%) were complex clubfeet.

From the medical records, we evaluated the following variables: age of the patient at first visit to our institution, associated pathology, family history of clubfoot, previous treatment and type of treatment before referral, presence or absence of nerve dysfunction at outside institution, severity of the nerve dysfunction, number of casts required for correction at our institution, physical exam including degree of ankle dorsiflexion and calf muscle atrophy, bracing and compliance, relapses, surgical correction, and recovery from nerve dysfunction.

RESULTS

There were 8 patients (10 clubfeet) that had a peroneal nerve dysfunction associated with the complex clubfoot deformity. Five patients had idiopathic clubfeet, two patients had arthrogryposis and one patient had 47 XYY syndrome without spinal or brain abnormalities.
TABLE 1. Summary of Patients

<table>
<thead>
<tr>
<th>Case</th>
<th>Gender</th>
<th>Age initial visit (mos.)</th>
<th>Side</th>
<th>Associated Pathology</th>
<th>Severity of peripheral nerve palsy</th>
<th>Nerve palsy was found after casting at our hospital</th>
<th>Previous treatment</th>
<th>Treatment of our hospital</th>
<th># Ponseti casts</th>
<th>Relapses at our hospital</th>
<th>Age at Follow-up</th>
<th>Dorsiflexion Latest FU (degrees)</th>
<th>Recovery from nerve palsy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>2</td>
<td>L</td>
<td>Complex</td>
<td>No active dorsiflexion of toes and ankle</td>
<td>No</td>
<td>Cast correction</td>
<td>Cast correction, day AFO and FAB</td>
<td>1</td>
<td>0</td>
<td>2 y</td>
<td>15</td>
<td>no</td>
</tr>
<tr>
<td>2</td>
<td>F</td>
<td>3</td>
<td>B</td>
<td>Complex Arthrogryposis</td>
<td>Bilateral weak toe extensors</td>
<td>No</td>
<td>Cast correction and TAL</td>
<td>Cast correction, FAB, and day AFO</td>
<td>R: 8</td>
<td>L: 8</td>
<td>5 y 11 mo</td>
<td>R: 10 L: 10</td>
<td>Improved</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>4</td>
<td>L</td>
<td>Complex</td>
<td>No active dorsiflexion of toes and ankle</td>
<td>No</td>
<td>Cast correction and tenotomy</td>
<td>Cast correction, tenotomy and FAB</td>
<td>7</td>
<td>0</td>
<td>1 y 2 mo</td>
<td>5</td>
<td>No</td>
</tr>
<tr>
<td>4</td>
<td>F</td>
<td>5</td>
<td>L</td>
<td>Complex</td>
<td>Weak dorsiflexion of ankle</td>
<td>Yes</td>
<td>Cast correction and tenotomy</td>
<td>Cast correction, tenotomy and FAB</td>
<td>3</td>
<td>1</td>
<td>2 y 7 mo</td>
<td>20</td>
<td>Improved</td>
</tr>
<tr>
<td>5</td>
<td>M</td>
<td>13</td>
<td>B</td>
<td>Complex Arthrogryposis</td>
<td>R: weak extensors 4th and 5th toe L: weak toe extensors and peroneal</td>
<td>No</td>
<td>Cast correction, Tenotomy (x2) and AFO</td>
<td>Cast correction and FAB</td>
<td>R: 3</td>
<td>L: 3</td>
<td>4 y 3 mo</td>
<td>R: 20 L: 10</td>
<td>No</td>
</tr>
<tr>
<td>6</td>
<td>M</td>
<td>26</td>
<td>L</td>
<td>Complex 47XYY syndrome</td>
<td>Weak toe extensors, tibialis anterior and peroneal</td>
<td>Yes</td>
<td>Cast correction and tenotomy</td>
<td>Cast correction, TATT, day AFP and FAB</td>
<td>6</td>
<td>1</td>
<td>5 y 6 mo</td>
<td>25</td>
<td>No</td>
</tr>
<tr>
<td>7</td>
<td>M</td>
<td>42</td>
<td>L</td>
<td>Complex</td>
<td>Weak peroneal muscles</td>
<td>No</td>
<td>Cast correction</td>
<td>Cast correction and FAB</td>
<td>7</td>
<td>0</td>
<td>4 y</td>
<td>20</td>
<td>No</td>
</tr>
<tr>
<td>8</td>
<td>F</td>
<td>47</td>
<td>L</td>
<td>Complex</td>
<td>Weak toe extensors and tibialis anterior</td>
<td>Yes</td>
<td>Cast correction, TAL, PMR, TATT and day AFO</td>
<td>Cast correction and FAB</td>
<td>8</td>
<td>0</td>
<td>5 y 2 mo</td>
<td>10</td>
<td>No</td>
</tr>
</tbody>
</table>

F: female; M: male; B: bilateral; L: left; R: right; FAB: Foot Abduction Brace; AFO: Ankle foot orthosis; TAL: Achilles lengthening; PMR: Postero-medial release; TATT: Tibialis anterior tendon transfer.
Five patients were boys and 3 were girls, and 4 had bilateral clubfeet. One patient had family history of clubfoot. Average age at first visit to our center was 17.7 months (range: 2 to 47 months). The average age at last follow up was 3 years 10 months (range, 1 year 2 months to 5 years and 11 months).

Before their initial visit to our center, all patients had plaster-cast treatment (average: 15 casts). Three patients had an Achilles tenotomy and one patient had two times Achilles tenotomy. One patient had an Achilles lengthening. One patient had a postero-medial release, Achilles lengthening and tibialis anterior tendon transfer. Five of the eight patients with initial treatment elsewhere had not been diagnosed with a neurologic deficit by the initial treating physician. One patient has an electromyography (EMG) that showed no abnormality, but the neurologist concluded based on the clinical exam that is was a peroneal nerve dysfunction.

At presentation, the severity of the peripheral nerve dysfunction varied. Two patients had no active dorsiflexion of toes and ankle. The remaining patients had weakness for active dorsiflexion of toes, ankle or foot eversion. Interestingly, there was no record of a hyper-extended first toe which was one of the characteristics of the complex clubfoot.

Two patients were referred to the pediatric neurology department and an MRI of the brain and spine demonstrated no significant abnormalities. Therefore, they were diagnosed as peripheral peroneal nerve dysfunction. Interestingly, three patients treated at our center were found to have a peroneal nerve dysfunction after a series of casting, several months after a tenotomy or a tibialis anterior tendon transfer. However, there was no record of casting problems such as swelling, skin lesions or slippage of cast, or complications of surgery.

Average numbers of casts for full correction were 5 (range: 1 to 8). Two patients required an early Achilles tenotomy followed by casting. No infections, profuse bleeding or skin slough were observed after tenotomy. No surgical releases were required.

At the conclusion of casting, six patients were placed initially in a foot abduction brace full time for 3 months. In one patient, the shoes were “plantar-stop/ AFO” type for more stability. One of these patients was then placed in a hinged AFO that was worn in the daytime and the foot abduction brace was worn at night. Two patients were fit with a solid AFO full time initially. One of these patients was then placed in the foot abduction brace after relapse instead of the AFO. Four patients had formal physical therapy once or twice a week and the others had stretching exercise done by the family. Two patients had transcutaneous electrical nerve stimulation.

Three patients had a relapse (37%) that was treated by additional casting. Two of them were using AFO and the other was using a foot abduction brace with appropriate use. One patient required a tibialis anterior tendon transfer. At the last follow up visit, all feet were well corrected with mean ankle dorsiflexion of 14 degree (range: 5 to 25 degree). All patients had considerable atrophy of the calf muscles. Interestingly, two patients (three clubfeet) recovered a little from the peroneal nerve dysfunction, but the others did not. One of these patients was observed having the nerve dysfunction after treatment so it might be from the pressure of the peroneal nerve (Table 1).

**DISCUSSION**

Peroneal nerve dysfunction is the most frequently encountered mononeuropathy in the lower limbs in adults. Common causes are due to prolonged posture, surgery, weight loss, trauma, bedridden condition, cast positioning and idiopathic. However, peroneal nerve dysfunction is uncommon in childhood. Most occur at the level of the fibular head, where the common peroneal nerve winds around the fibular neck. This segment of the nerve is covered only by subcutaneous tissue and is directly apposed to bone, therefore, making the nerve susceptible to compression injury, which causes most pediatric peroneal nerve dysfunction. Jones et al. reported 17 children with peroneal nerve dysfunction. Causes included compression in 10 (59%), trauma in 3 (18%), entrapment in 3 (18%) and indeterminate in 1 (5%). But most compressive peroneal nerve dysfunction resolved within several months.

Several authors have noted that clubfoot with peroneal nerve dysfunction is very difficult to correct. Gordon et al. reported peroneal nerve dysfunction as a complication of clubfoot treatment in four cases which were resistant and recurrent. The palsies were not observed until late in the course of treatment so the authors concluded that repeated cast pressure at the fibular head might have been the cause of the dysfunction. Because the result of the peroneal nerve dysfunction (drop foot) resembles that of clubfoot, the authors suggested that it would be easy to miss.

Song et al. reported six patients with congenital clubfoot and concomitant peroneal nerve dysfunction. All of the cases were resistant and recurrent. Four of the six patients underwent corrective surgical releases after casting, but with unsatisfactory results. None of the six patients recovered from the nerve dysfunction, therefore the authors suggested that these peroneal nerve palsies should be differentiated from peroneal nerve palsies which are caused by pressure in the cast that will resolve with time.
Edmonds et al. reported nine patients (13 clubfeet) that had no active dorsiflexion of the toes or ankles and no active eversion on the affected sides. The authors used the drop-toe sign, which is done by resting the toes in plantarflexion and observing for active dorsiflexion by plantar stimulation. All of the patients had a drop toe sign before treatment. Two of the nine patients had complex clubfoot. Four of the nine patients had relapses and underwent extensive surgical releases after casting. One of these patients had exploration of the peroneal nerve proximal to the proximal leg fascia with only a thin atrophic nerve distally. Only one patient had maintained a plantigrade foot position without intraarticular surgery. The authors suggested that these cases may need the modified Ponseti method, including earlier-than-usual Achilles tendon lengthening.

Because five of our patients were treated elsewhere with casting or corrective surgery before initial visit, it was not clear whether the peroneal nerve palsies were a complication of prolonged casting or whether the palsies were present before as part of the deformity. Three patients were found as having peripheral nerve dysfunction after series of casting or surgery at our institution. Therefore, these patients might have suffered peripheral nerve dysfunction from complication of prolonged treatment. However, only one of these 3 clubfeet made some recovery from the nerve dysfunction. This may indicate the nerve palsies were not from simple pressure by casting because infant peroneal palsies, which caused mainly by pressure on the fibular head, are reported to have good prognosis.

Feldbrin et al. reported that isolated peroneal nerve damage was seen in 27% of their patients with congenital clubfoot, with 10% having an abnormality of both the peroneal and posterior tibial nerve. Macnicol and Nadeem reported that 9.5% of their clubfoot patients with previous corrective surgery had abnormal responses to motor electrophysiological tests of the peroneal nerve. On the other hand, Bill and Versfeld failed to find abnormal responses of the peroneal nerve in an electromyographic study of patients with idiopathic clubfoot. Electrodiagnostic studies are helpful to determine diagnosis of nerve palsy. However, those studies do not change treatment and prognosis. Repeated neurological evaluations are more important.

Regardless of the underlying cause, it is obvious that these cases are very difficult to treat. Most authors have reported failures of treatment for patients with peroneal nerve dysfunction and the requirement for subsequent corrective surgery. However, corrective surgery frequently brings severe scarring leading to joint stiffness and muscle weakness. The long-term result after corrective surgery was very poor. Although three patients had relapses and most patients needed prolonged casting, all of our patients had excellent deformity correction without surgical releases. However, a longer follow up of the patients is needed since late relapses due to the nerve dysfunction may be possible.

In summary, repeated neurological evaluations and very careful cast placement should be performed during the treatment of complex clubfeet. The modified Ponseti technique, if applied properly, is successful and avoids extensive surgical releases.

REFERENCES


SEPANING THE CHICKEN FROM THE EGG: AN ATTEMPT TO DISCERN BETWEEN CLUBFOOT RECURRENCES AND INCOMPLETE CORRECTIONS


ABSTRACT
Purpose: To better delineate between incomplete clubfoot correction and true clubfoot recurrence based on the time at which the deformity re-appears and the treatment necessary to correct the foot.

Methods: A chart review of all idiopathic clubfoot at a single institution treated by either the Ponseti method or short leg casting and surgery were reviewed for recurrent deformity involving the tibia, ankle, or foot. Comparisons of treatment required to correct deformities were made between those noticed within six months of initial treatment and those noticed after six months. Similar comparisons were made based on the initial treatment of the deformity.

Results: Forty-four of 51 patients showed some clinical deformities after their initial treatment. Over half of these deformities either resolved or did not require operative intervention at a minimum of two years follow-up, while 43% (19/44) were felt to require surgery. Eight patients had deformities re-appear within six months of initial treatment and eleven patients after six months. Six of the eight patients requiring surgery with deformities noticed less than six months after initial treatment required correction of structural deformities (ostotomies and posterior-medial releases), whereas 10/11 patients requiring surgery for deformities noticed after six months required correction for dynamic deformities. These differences were significant (p=0.01). No difference in terms of the number of deformities noticed (22/25 and 22/26) and number requiring surgery (11/22 in the Ponseti group and 8/22 in the surgical group) were found. However, deformities requiring further surgery in the surgical group re-appeared earlier 0.23±0.2 years than those in the Ponseti group 1.7±1 years (p=0.001). These earlier re-appearing deformities required more structural surgery (6/8) than those in the later appearing Ponseti group (1/11; p=0.01).

Conclusions: Nearly half of all re-appearing deformities required surgery. The deformities noticed within six months of initial correction required more structural surgery to correct than those noticed after six months. We propose that the recurrent deformities noticed before six months of age represent incomplete corrections and those after six months true recurrences. Feet initially treated with surgery may be more prone to incomplete correction whereas those treated by the Ponseti method may be more prone to recurrence.

Significance: Not all re-appearing clubfoot deformities are the same. The initial treatment and time at which they first appear may have implications as to the surgery required to correct.

INTRODUCTION
Clubfoot is a common orthopaedic problem in New Zealand. While the entire population of New Zealand is 4 million, 750,000 people claimed Polynesian ethnic background in the 2001 census.1 With an estimated incidence of 6.8 clubfeet per 1000 in Polynesian populations,2 compared with one per 1000 in white European populations, pediatric orthopaedic surgeons in New Zealand encounter an unusually high number of clubfeet. Using this unique population we have previously published the short term results of clubfeet managed by either surgical release or the Ponseti method.3,4 In both treatment groups, we had a higher recurrence rate requiring further surgical intervention than previously described in the literature.5,8 With this relatively high recurrence rate in both prospective cohorts, the authors hoped to retrospectively analyze all patients with recurrent deformities. We attempted to answer four questions. (1) What percentage of feet showing even slight abnormali-
ties after initial correction will require further surgery? (2) Could we discern between incomplete correction and true recurrence based on time after initial treatment that the first signs of deformity resurfaced? (3) Did the surgery required to correct these recurrences differ based on the time the deformities were first noted? (4) Would there be any differences in these factors between initial treatment options (Ponseti versus Surgical). We hypothesized that a relatively high percentage of patients in both groups would show early recurrent deformities, that recurrent deformity within 6 months of initial treatment likely represented incomplete correction and that these patients would require more structural surgery to correct. From our previous review of these patients we felt it likely that the initially treated surgical feet showing a recurrence would require more structural surgery.

**MATERIALS AND METHODS**

In November 2001, after obtaining medical ethical board approval, until January 2005, all patients referred to our institution that were offered the above treatment options for clubfoot treatment were eligible for this study. Only patients with idiopathic clubfeet and a minimum 2 years follow up from their initial casting were included. Fifty-five patients with 86 clubfeet met these inclusion criteria. Twenty-six patients (40 feet) were in the Ponseti group and twenty-nine (46 feet) in the below knee casting and surgery group. Clinical data was collected prospectively at each clinic visit using a templated data sheet as well as dictated notes. At the time of presentation the clubfoot deformities were graded using the validated 6-point scale of Pirani et al. Each group was managed by each treating surgeon and in depth initial treatment protocols can be found in our previously published studies. Briefly, the patients in the Ponseti group were managed with weekly casting, followed by percutaneous Achilles tenotomy, and placement into abduction orthosis. Those in the surgical group were treated with weekly or bi-weekly below knee casts until six months of age when surgical correction, often posterior or posterior-medial release, of the feet was performed.

We then reviewed the available clinical records including the prospective clubfoot worksheet, clinic charts, electronic charts, and operative records of all patients having minimum 2 year follow-up. These were reviewed for any mention of recurrent deformity noted. All abnormalities involving the lower extremities were initially included. These were then selected out for those involving the tibia, ankle, and feet. The date first noticed and the type of deformity noted in the patient’s record was recorded. Once a recurrent deformity had been noted in the chart we followed the natural history of that deformity, recording spontaneous resolution, continued observation, or any treatments planned or employed either surgical or non-surgical. Common clinical findings included rotational deformities of the tibia, equinus of the heel cord, metatarsus adductus, dynamic supination of the forefoot, and overall tightness of the foot. When more than one deformity was noticed, ie tibial torsion and metatarsus adductus, the deformity most pertaining to the foot was included. In some of the patients no distinct mention of the deformity could be found, yet the patient went on to require further treatment. These were felt to be “generalized recurrences.”

Statistical analysis was performed to compare the time from the end of initial treatment that the recurrences were first noticed, the type of recurrence, and the time from initial correction that further treatment was deemed necessary, and the nature of that treatment. The patient rather than the individual foot was used as the unit of analysis. In the Ponseti group the end of initial treatment was defined as the date the child was placed into the Denis Brown bar and boots. For the surgical group, the date the last surgical cast/splint was used for this date. Patients that were unable to finish weekly Ponseti casting were eliminated from this group as were the patients not requiring either an initial posterior or posterior-medial in the surgical group. Comparison between each cohort was then performed for patient’s demonstrating a clinically noticeable deformity. For continuous variables a student T-test was used, for categorical variables 2-tailed Fisher’s Exact test was used. A p-value less than or equal to 0.05 was defined as statistically significant.

**RESULTS**

In the Ponseti group 25/26 met inclusion criteria, whereas 26/29 patients in the surgical group met inclusion criteria. A high percentage of patients in both groups (22/25 and 22/26 respectively) were found to show some clinical deformities. Similarly, 11/22 in the Ponseti group and 8/22 in the surgical group showed early clinical abnormalities and were felt to eventually require surgery. The differences between these groups for the number of recurrent deformities and the number requiring surgery were not statistically different (p=1 and p=0.54). The deformities noticed were similar in both groups with no significant difference found (Table 1). The time elapsed, after initial treatment until these abnormalities were first recognized, however was significantly different. On average, clinically apparent deformities were recognized at 0.7 (+/- 1) years from initial correction in the surgical group and at 1.45 (+/-1) years of age in the Ponseti group (p=0.01). Likewise, the patients eventually requiring surgery in each of these groups showed an even larger difference in time between
Separating the Chicken from the Egg: An Attempt toDiscern between Clubfoot Recurrences and Incomplete Corrections

the end of initial treatment and first detection of recurrent deformity, as the average time in the surgical group was 0.23(+/-0.2) years and those in the Ponseti group 1.7 (+/- 1) years (Figure 1). Three patients in each group underwent re-casting (after initial correction); two out of three in the Ponseti group and all three in the surgical group required operative intervention. A delay between recognition of the early recurrent deformities and the time they were addressed (time from end of initial treatment until surgical decision was made) was seen in both groups and was found not to be significant (2.69+/- 1.3 years in Ponseti group versus 1.84 years in the surgical group, p=0.14). Finally, a statistical difference in the type of surgery required to correct these deformities was found. The authors defined soft tissue procedures such as tibialis anterior transfers, tendo-achilles lengthenings, and even posterior releases to be corrective of dynamic deformities; while full posterior-medial releases with or without pinning and osteotomies to constitute structural deformities. 7/8 of the patients requiring surgery with deformities noticed less than 6 months after initial correction required correction of structural deformities, whereas 10/11 patients requiring surgery for deformities noticed after 6 months of initial correction required cor-

<table>
<thead>
<tr>
<th>Initial Deformity Observed</th>
<th>Initial Ponseti Treatment</th>
<th>Initial Surgical Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Deformities Requiring Surgery</td>
<td>Deformities Resolved/Watched</td>
</tr>
<tr>
<td>Intoeing (tibial torsion/NOS)</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Metatarsus, forefoot adduction</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Equinas</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Tight/Generalized</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Dynamic Supination</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Totals</td>
<td>11</td>
<td>11</td>
</tr>
</tbody>
</table>

**Figure 1.** Graphic comparison between end of initial treatment until deformity noticed in those patients requiring further surgery to correct this recurrent deformity.
reconstruction for dynamic deformities. As the majority (7/8) of surgical patients were recognized earlier than the Ponseti group (1/11); the surgical group required correction of more structural deformities (Figure 1 and Table 2).

**DISCUSSION**

Utilizing a relatively high recurrence rate in both surgically and Ponseti treated clubfeet, in cohorts that had been assembled and followed prospectively, we set out to answer several questions regarding clubfoot recurrences. This is the first study of this type to be found in the literature. Other studies discuss recurrences as treatment failures, surgical options, and in terms of functional results. In this study we begin to answer four unknown questions.

What percentage of feet showing even slight abnormalities after initial correction required further surgery? In our study population between thirty-five to fifty percent of patients noted to have small early recurrent deformities went on to require further surgical treatment. This was seen for both cohorts and was essentially irrespective of age. Both cohorts had a high percentage (84% in the surgical group and 88% in the Ponseti group) of individuals showing some residual signs of the initial deformity. No statistical difference in the deformities noted could be elicited from our data. These deformities were often noted sooner after initial treatment in the surgical cohort and later in the Ponseti group. Fifty percent of these early recurrent deformities (7/8 patients) require much more extensive surgery to correct involving repetitive posterior-medial releases or osteotomies. We feel this type of surgery demonstrates the structural nature of the deformities that were not fully corrected or could not be maintained immediately after the initial procedure. Conversely, the deformities that surfaced later (>6 months); required less invasive surgery often involved a tibialis tendon transfer, tendo-achilles lengthening, or even a posterior release. These we feel demonstrate a true recurrence and thus are dynamic in nature, i.e., the foot was in a corrected position, cartilaginous bones remodel to there new shape and position, and over time a recurrence occurs due to: anterior tibialis over-pull or gradual tendo-achilles contracture which might also lead to posterior capsular tightness. Thus the surgery to re-correct the foot is more soft tissue and dynamic in nature.

Could we discern between incomplete correction and true recurrence based on time after initial treatment that the first signs of deformity resurfaced? We believe that by using 6 months after initial treatment as a cut-off point, we could identify the recurrences that were most likely an incomplete correction or at least an early failure to maintain correction as opposed to a true recurrence (a foot that was corrected and then over time recurs). Sixteen of 44 patients showed recurrent deformities within the first 6 months after treatment (average 0.2 +/- 0.15 years); while 28/44 patients had later recurrences (1.5 +/- 1 years). 50% of the early deformities required surgical intervention and 40% of the later deformities required intervention.

Did the surgery required to correct these recurrences differ based on the time the deformities were first noted? From our data, it appears that those early deformities (<6 month from initial treatment) that do not spontaneously resolve or resolve with re-casting; often (7/8 patients) require much more extensive surgery to correct involving repetitive posterior-medial releases or osteotomies. We feel this type of surgery demonstrates the structural nature of the deformities that were not fully corrected or could not be maintained immediately after the initial procedure. Conversely, the deformities that surfaced later (>6 months); required less invasive surgery often involved a tibialis tendon transfer, tendo-achilles lengthening, or even a posterior release. These we feel demonstrate a true recurrence and thus are dynamic in nature, i.e., the foot was in a corrected position, cartilaginous bones remodel to there new shape and position, and over time a recurrence occurs due to: anterior tibialis over-pull or gradual tendo-achilles contracture which might also lead to posterior capsular tightness. Thus the surgery to re-correct the foot is more soft tissue and dynamic in nature.

Would there be any differences in these factors between initial treatment options (Ponseti versus Surgical)? Eighty-four percent of the surgically treated clubfeet went on to have early recurrent deformities at a statistically earlier time (0.2 versus 1.7 years) than the Ponseti group. Thirty-six percent of these patients required further surgery as opposed to 50% of the Ponseti group. However, 7/8 patients in the surgical group

| TABLE 2. Comparisons between treatment methods, average time recurrent between end of initial treatment and when deformity first noticed, and type of surgery required to correct deformity |
|-------------------------------|-----------------|-------------------|
| Ponseti                        | 10              | 1*                |
| Surgery                        | 2               | 6                 |
|                               |                 | p=0.0062          |
| * Deformity noticed at 0.2 years after boots applied |
| TAL= Tendo-Achilles lengthening |
| TAT= Tibialis Anterior transfer |
| PR= Posterior Release |

Average time after initial treatment that deformity was noted

| Ponseti                        | 1.7 years       |
| Surgery                        | 0.23 years      |

Comparisons between treatment methods, average time recurrent between end of initial treatment and when deformity first noticed, and type of surgery required to correct deformity
required structural surgery to correct these deformities as opposed to the 1/11 in the Ponseti group. We believe these differences to represent a higher incidence of incomplete corrections in surgical group demonstrated by the much earlier noticed deformity (0.2 years after correction) and the type of surgery required to correct the deformity. Whereas the deformities in the Ponseti group were noticed later (average 1.7 years). This makes logical sense as the Ponseti casting has been shown, by Pirani et al through MRI imaging, to mold the pliable cartilaginous bones into their correct position and assume a more normal shape; however this casting in no way alters muscular forces affecting the foot. While surgical release abruptly changes the overall relationships between bones, it does not immediately change their shape. Unless the bones re-model while pinned or the healing scar tissue is strong enough to hold the bones in their new position the correction will be incomplete or will quickly return as the misshapen bones assume a more stable configuration. As this is generally done at a later age than the casting (average 6 months in this cohort); the bones of the foot may be less pliable.

Major limitations of this study need to be pointed out. First while starting out with relatively large prospective cohorts, we chose to look primarily at those patients with recurrences, thus limiting our sample size. We also used a two year minimum follow-up (average follow up of roughly 3.5 years) as inclusion criteria. Additional recurrences may continue to be found as time goes on. Despite the records of these children being recorded prospectively, no standardized objective criteria were initially established to designate an early recurrent deformity. Instead the authors relied on subjective references in the patients chart concerning the first recognition of a recurrent deformity while under the care of different clinicians. Despite these weaknesses, we feel that in general the evaluating clinicians put forth honest evaluations and looking at the overall numbers between cohorts in terms of number of overall patients with clinically noticeable deformities and number of deformities requiring surgical correction the evaluation of these groups appears very similar.

This is the first manuscript to evaluate the differences in the recurrences between surgically managed and Ponseti treated clubfeet. We believe this manuscript gives the clinician some knowledge as to what the natural history of an early recurrent deformity will be after the initial treatment of a clubfoot deformity. Furthermore, it may help to further explain the reported long-term functional differences between surgically corrected clubfoot and Ponseti treated clubfeet. Perhaps the majority of recurrences reported in the literature in surgically treated clubfeet are really incomplete corrections resulting in malformed bones and incongruent joints, thus requiring more structural surgery to further correct and resulting in foot stiffness; whereas the Ponseti recurrences, represent true recurrences do to dynamic forces acting on a corrected clubfoot? By following our large prospective cohort in the future, we hope to be able to answer these questions in the future.

From this study, nearly half of all re-appearing deformities required surgery. The deformities noticed within six months of initial correction required more structural surgery to correct than those noticed after six months. We propose that the recurrent deformities noticed before six months of age represent incomplete corrections and those after six months true recurrences. Feet initially treated with surgery may be more prone to incomplete correction whereas those treated by the Ponseti method may be more prone to recurrence. Thus not all re-appearing clubfoot deformities are the same. The initial treatment and time at which they first appear may have implications as to the surgery required to correct.

REFERENCES


ORTHOPAEDIC SURGEONS AND INDUSTRY: 
THE VALUE PROPOSITION

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ABSTRACT

Although the deferred and non-prosecution agreements entered into by five of the leading orthopaedic implant companies have caused our profession to re-examine the surgeon-industry partnerships that have helped advance the field, the legal and ethical considerations in that relationship have not changed. Moving forward, the surgeon must recognize that a truly valuable exchange must be demonstrated and delivered in that relationship for compensation to be warranted. This paper summarizes the value proposition in the orthopaedic surgeon-industry partnership.

The Deferred Prosecution Agreements entered into by four orthopaedic manufacturing companies and the Non-Prosecution Agreement entered into by an additional orthopaedic company, through the U.S. Attorney's office in New Jersey, has brought into question, “What is the True Value of the Orthopaedic Surgeon’s relationship with Industry?” In this regard there are two definitions of value which warrant exploration: “Value” defined as social principles, goals or standards held or accepted by an individual class or society. It is these two definitions which will be addressed in the context of the relationship of the orthopaedic surgeon with industry.1,3 The discussion will further focus only on the value of the orthopaedic surgeon-industry partnership in regard to product development. The discussion will try to apply context to the requirement for compensation and what constitutes appropriate compensation in this age of increasing accountability for increasingly limited resources of society where healthcare has become a major expenditure of these resources.

The second definition of value which relates to social principles, goals and standards is very germane to this discussion. Medicine in general, and surgery specifically, is considered one of the learned professions. With professionalism comes both privilege and responsibility. The public cedes the learned professions certain privileges because these professional occupations require specialized knowledge, training and experience which provide important and valuable services to the public.2,3 The public is paramount in the value proposition of the surgeon designer-industry relationship. The public in terms of the patient will be discussed later. However, there is another aspect of the public in regard to the value proposition. Industry has a responsibility to its public, the shareholders, to optimize its returns and optimize the use of its resources.4 The surgeon designer must understand that he or she has a responsibility to his or her public, his or her professional field. This includes full disclosure of all potential conflicts of interest which in this day and age includes a complete understanding of the effects these conflicts can have on decision making in the practice of medicine and in the interpretation and reporting of scientific results.5,7

Self regulation is one of those privileges which we as a profession should cherish, respect and promote every day of our professional lives. Self regulation has given our profession relatively exclusive authority to set the standards for the degree of expertise needed for licensure and certification as well as recertification. As surgeons, it has granted us the right to make judgments about the need for surgery and the need to perform operative procedures on our patients which can have unintended consequences including severe complications, even death. In addition to enforcing levels of technical competence, self regulation as well as professionalism require us to enforce certain levels of ethical performance. We are expected to have a dominant commitment to serving others, rather than to personal gain. Privileges ceded to the medical profession require a perception by the public that physicians are truly dedicated to the welfare of their patients over their own self-interest. The basis for “Medicine’s Contract with Society” as articulated by Linda Emanuel is that our ethical responsibility as medical professionals “is primarily about the expert protection of vulnerable people and vulnerable values, in this case patients and the values of health care, respectively.”2,3
It is for these reasons that the orthopaedic surgeon who chooses to partner with industry must understand that because of his or her statute as a medical professional he or she cannot engage in the type of partnerships with industry that other leaders in their fields are able to engage. Eldrick Tont (Tiger) Woods can partner with industry by endorsing products of which he has no involvement in design. Michael William (Coach K) Kryzewski can partner with industry by endorsing a device he has had or procedure he has undergone. The differences between the perceptions and realities of these industry partnerships and between those of a medical professional, including an orthopaedic surgeon and industry, lies in this understanding of the privileges and responsibilities awarded by society to our medical and orthopaedic profession. This differentiation most recently arose in the case of Robert Koffler Jarvik, MD, developer of the Jarvik-7 artificial heart, when he endorsed Lipitor for Pfizer even though he had never completed an internship or residency and had never been licensed to practice medicine. Pfizer eventually withdrew the advertisements after public and congressional outcry questioning the propriety of a medical professional partnering and profiting with industry through endorsements.8-10

It is within this professional and ethical environment that an orthopaedic surgeon who enters into a product development partnership with industry today must function. The principle beneficiary of the partnership between the orthopaedic surgeon and industry should and must be the patient.2,3 The value of the orthopaedic surgeon in the partnerships with industry during the infancy of the orthopaedic surgery discipline was easily defined. Homer Stryker of Kalamazoo, Michigan founded his own company, John Charnley developed his own hip and brought it to Thackery for commercialization and the Association for the Study of Internal Fixation, (AO/ASIF) (Martin Allgower, Maurice Muller, Robert Schneider and Hans Walleneggor) developed a series of implants which they licensed for manufacture to the Straumann Institute, (Waldenburg, Switzerland) and which were widely distributed under the Synthes trademark. These implants were small in scope and were used by relatively few surgeons. Regulation of the commercial manufacture and distribution of orthopaedic implants in the 1950’s and 1960’s were rudimentary. No one would question the value of these partnerships in elevating the quality of care for patients afflicted with musculoskeletal conditions and disorders.11

The maturation of the field of orthopaedic surgery over the last half century has presented both opportunities and more recently threats to the orthopaedic surgeon- industry partnership especially in relationship to orthopaedic implant design and distribution including surgeon education.6,11-13 The vast scope of this endeavor in the competitive capitalistic environment present today in the United States as well as throughout the world (estimates are for a ten billion dollar market for the orthopaedic implants in the United States and a twenty-five billion dollar market worldwide, annually) has created hundreds if not thousands of orthopaedic related companies around the world. Growth in the development and need for orthopaedic surgical procedures requiring implants and specialized techniques to care for the ever increasing numbers of patients who are afflicted with musculoskeletal conditions and diseases, has provided opportunities as well as abuses in the surgeon-industry partnership.4,11 The magnitude of the potential revenues, the large number of orthopaedic surgeons and the potential for large volumes of procedures to be performed allowed for industry to influence the orthopaedic surgeon’s use of implants, including, in some cases, payment for nonexistent or over-valued services which would be considered a violation of anti-kick-back statutes under the False Claims Act.

The actions of the Attorney General’s Office in New Jersey as well as some congressional legislators has called the question “Is there any real value in the surgeon/industry design partnership and if so what constitutes that value and what is it worth?”

It can definitely be argued that the orthopaedic surgeon-industry design development partnership is very different than the physician drug company partnership. Although the professional and ethical considerations are no different, the surgeon actually helps in the development of the device whereas the physician usually is not involved in the development of the drug. In addition the surgeon is intimately involved in providing the instruments and techniques to implant the devices as well as teaching these techniques to other orthopaedic surgeons. This process has an obvious benefit to the patient.

It has been argued “Is there really any value in designing another widget?” As one who has studied hip and knee replacement for over a quarter of a century, a clinic hardly ever goes by where a patient doesn’t ask “Is there anything on the near horizon that might be developed or is in development that will be better?” I respond truthfully that “when I reflect on my career in five year segments there never has been an interval that I had not changed a device or technique because, after careful consideration, I had decided that a technique or device could provide a more durable outcome.” Hence with newer technologies and better understanding of the procedures and long term results, and a more demanding population (obesity and increased activity level in the
joint replacement population), most would agree we still have room for improvement.

If one agrees that new widgets or orthopaedic devices are warranted in orthopaedic surgery, “What contribution of an orthopaedic surgeon in the design and distribution process justifies royalty or consultant fee payments?” The criterion for royalty justification has come under question most recently with the Department of Justice Investigation. All would agree that intellectual property must be transferred between the orthopaedic surgeon and the company in a design project to warrant royalty payment. However, many in the public eye only consider ownership of patents as true intellectual property. In law however, patents, copyrights, trademarks, know how and trade secrets are all considered intellectual property. Only patents (considered true inventions), copyrights, and trademarks are granted exclusive rights protected by law.

Know how is the ability to execute specific tasks or to produce specific products. Know how involves reducing an invention to practice and is essential to the commercial success of many patented inventions. As an orthopaedic implant designer it comes from unique knowledge and insight gained from experience (in many cases twenty or more years) in surgery and from years of analyzing data on what works and what does not. Only surgeons who meet strict criteria to include having critically analyzed their results and demonstrated their ability to understand what works and what doesn’t work warrants involvement in a design. I can’t imagine this can be thoroughly accomplished without extensive publication on the topic. Surgeon volume as a single contribution is a potentially dangerous criteria for design team involvement.

Intellectual property is often times transferred or sold by its inventor through the process of licensing. In the typical license agreement the inventor charges a royalty to the purchaser licensee for the right to utilize the inventor’s intellectual property which often times includes related unprotected know how as well as protected patents. The inventor many times transfers the right for the licensee to pursue patents based on the inventors know how. Most licensees recognize that know how plays at least, if not more, of an important role as conception in the successful commercialization of an invention, and thus include value, and compensate know how contribution in their development programs and licensing agreements. The monitors of the companies involved in the Department of Justice investigation have agreed with this interpretation as well as a fair value amount in terms of percent of product sales (royalty burden) that is appropriate for an orthopaedic implant.

The other important feature of the value proposition in the orthopaedic surgeon industry royalty and consulting partnership is the appropriate documentations of time and effort as well as documentation of personal contribution to that time and effort. The attorney mindset of billing for time spent on a project (which is now required in the surgeon-industry partnership) compared to the medical professional mindset of billing for a completed task, clinic visit or operation, no matter what the time required can be culturally difficult for a medical professional. Many physicians are suspect of the potential for over-billing whether it is related to time or to the potential to justify the time based on over documentation. Unfortunately the old adage that “if it isn’t documented it was not done” is becoming an important standard for the orthopaedic surgeon who consults with industry. This however should be easier for the surgeon to accept as the same practice is being applied to him or her in the clinical setting especially in cases where the government is subsidizing the care through Medicare. Just as in the clinical setting, fair market value for consulting time is being dictated by outside sources. Most recently the monitors, in the case of the Deferred and Non-Prosecution agreements of the Justice Department have dictated what fair market value for consulting time related to design projects should be.

**DISCUSSION**

The Orthopaedic Surgeon and Industry value proposition in regard to design partnerships must follow many of the principles utilized for decades by our legal colleagues. Value can only be assigned when based on time, effort and personal contributions to the project. Fortunately it has now become accepted that know how is as important as patents in regards to intellectual property transfer. It is only with this surgeon know how, with or without patented technology, that engineers of an implant company can produce instruments and products that address clinical problems and can provide predictable outcomes for patients. Especially in the present environment, it is important for implant designers to craft and communicate the message to colleagues, patients and the public, that the value of know how is paramount in developing a device that will provide better, more durable, results for our patients afflicted with musculoskeletal conditions.

The orthopaedic surgeon, as a medical professional, entering into such partnerships must understand that because of the privilege and ethical responsibilities that are attached to that profession, more stringent public oversight and transparency may and probably will be a requirement in that partnership, especially since a large portion of the healthcare dollar expenditure comes from government. We as a profession should help craft the value discussion and this discussion should provide
important information in this regard. In addition, the sensitive issue of compensation has been valued both for hourly compensation and royalty burden payable for a design, and has been defined by one government organization, the Department of Justice.

In addition, transparency in this proposition must be expected in our professional practice to include disclosure to our patients, colleagues, academic institutions and the public. Not only must the surgeon understand and disclose all potential conflicts of interest, but he or she must understand all of the potential ramifications of these conflicts in relationship to the presentation and publication of results related to the devices they design and the techniques they establish.2,3,7,14,16-18 If these principles are followed the orthopaedic surgeon, industry design partnerships should and must continue in this country to keep the United States the world leader in the business of providing the best orthopaedic implant design helping to provide optimal care for patients throughout the world who have been afflicted with musculoskeletal conditions and diseases, while providing an opportunity to contribute to the economic welfare of our and other countries.

DISCLOSURE
Consultant and Royalties for DePuy (JJC)

REFERENCES
ABSTRACT

The purpose of this article is to introduce a novel way of keeping efficient surgical records by creating a sketch of both the pathology and treatment at the time of the surgery. This method of documentation has proven so convenient in the subsequent management of patients in a wide variety of situations that the concept of visual documentation is being presented for consideration. After a brief introduction to the unique history of its origin, a series of cases is offered to emphasize a few of the practical advantages of having a visual source for quick and accurate reference during the patient care process. The article will then conclude with a brief discussion of alternative methods of illustrative record keeping available.

HISTORY:

THE PREDICAMENT AND THE “RESEARCH”

In the early 1990s, I encountered a series of significant problems related to the inaccuracy of orthopaedic residents’ operative dictations, both because of what they had just seen and what they felt were important to document about the surgery. This problem was highlighted by a deposition I gave as an expert witness regarding a patient for whom I had provided revision ACL surgery. There was a particularly awkward moment when an astute attorney noted that my description of the case varied significantly from the dictated note and that the understanding of the diagnosis seemed to have changed over the course of subsequent outpatient clinic notes. I was able to prove that the dictated notes contained obvious errors of both omission and commission that did not even coincide with the pre- or postoperative radiographic findings. This epiphany led me to a personal experiment wherein I decided to sketch what I understood to be the pertinent pathology of a surgical case, as well as what was done to correct it. I also listed the details which were important to recognize about each case.

After accumulating this detail in approximately 55 cases, I compared the residents’ dictated surgery notes to my own “professorial truth” sketches. While the results were never formally published, every Iowa resident since then has heard of the results of this comparison—nearly 50% of the time there was at least one mistake (minor or major) in the operative dictation even though it was dictated immediately after the case. So many of the basics and details were so different from what I had documented in my sketches that one could wonder whether the trainee and I were scrubbed into the same cases that day. Since then, it has been my personal goal to create a brief sketch of each procedure before the patient leaves the operating room. This sketch becomes part of the medical record after it is recorded on the flip side of a brief operative note. More recently, the sketches have been scanned directly into the electronic medical record.

Over time, I have come to rely on these illustrations so heavily that I make it a habit to view them either before a patient visit, or while we are in the exam room, so that both the resident physicians and the patients can learn from seeing the sketch. I often find that without this reference I cannot recall the details that might prove critically important to maximizing the success of the treatment plan.

If my 1990s deposition experience was unnerving, a close look at the fundamental mistakes cropping up in multiple clinic dictations during prolonged treatment and complicated cases is even more impressive. Quickly referring to an illustration allows me to immediately understand exactly what was wrong, what was done about it, and keep on target with what is most important about the postoperative management plan.

ILLUSTRATIVE CASES

Case 1: Articular Surface Lesion Location for Rehabilitation Guidance

A twenty-five year-old woman was referred for revision of an old, failed ACL reconstruction and possible OATS procedure to the medial femoral condyle (MFC). She had a defect which had been documented and microfractured at the time of arthroscopy by her referring physician some 8 weeks previously.

At surgery, the MFC defect displayed encouraging results from the microfracture drilling performed by the referring surgeon. The original technical problem was
an obvious misplacement of the femoral tunnel too far anterior and at 12:00. An accessory medial portal was employed to create a completely new femoral tunnel at the 1:30–2:00 position. The location of the original tibial tunnel was a bit anterior but close enough that posteriorizing that original tunnel was performed. This eliminated the effectiveness of available screw fixation placed within the tibial tunnel. Therefore, a screw and post combined with a spiked staple was used to secure the tibial fixation.

The key to postsurgical management was to be protection of the medial femoral condyle chondral defect (which came into contact with the tibial surface at around 45 degrees of flexion). However, the patient did not do well from the beginning. Her main problem was an impressive lack of motion. Postoperatively, she had not only been noncompliant with non-weight-bearing instructions, she had also not worked on her range of motion and could only demonstrate a range from 10-70 degrees of flexion. The dilemma was, “What can we do about the stiffness, and what are we specifically concerned about regarding the chondral area of concern?”

Postoperative Illustration’s Role

The operative drawing revealed a limited area of concern on the medial femoral condyle which centered around 45 degrees. Compression against the tibial surface in any other general range of motion was not of concern.

Therefore, the patient was sent back to physical therapy with instructions for the therapist to perform active assistive range of motion with the warning to the patient that we would have to manipulate her knee if she did not improve over the next four weeks. While progress was made in physical therapy, we did manipulate her knee at six weeks after the index surgery. Full recovery soon followed with the aid of vigorous therapy and with no problems from the cartilage defect which had been encountered.

Case 2: Pictorial Orientation in Complex Ligament Reconstruction

A patient was seen in the outpatient clinic at six weeks after surgery. They had had a knee dislocation requiring extensive reconstructive surgery. Their current complaint was of severely restricted motion due to the extensive brace they wore. The brace was a long-leg brace complete with a footplate in neutral rotation but with free ankle motion in the sagittal plane. The resident not only reported that the patient was anxious to be free of the brace but also questioned why the brace was used in the first place since he had never seen this type before.
**Postop Role of Illustration**

Reference to the illustration quickly put things into perspective for both the resident and me. A close look at the details showed that the main reason for the extensive brace protection was the original laxity in every direction. However, in the author’s experience, the most concern focused on protecting the knee from varus stress as well as excessive external rotation stress (reverse pivot shift). It was of particular note that the reverse pivot was persistent after the PCL was stabilized intra-operatively and before the posterior lateral sling procedure was performed. The fact that preoperative application of the brace with the footplate brought stability meant that protection of the more vulnerable parts of the surgical reconstruction was effective.

Despite the patient’s request, the brace was continued until healing of the fibular head took place.

**Case 3: Clue to Persistent Pain after Menisectomy**

A 38-year-old entrepreneur mechanic underwent an arthroscopic medial menisectomy as well as a peripheral lateral meniscus repair located at the popliteal foramen six weeks ago. He was restricted to walking with a hinged knee brace locked straight and then actively flexing only to 90 degrees. His goal was to return to work as soon as possible in order to keep his business going. His major concern was that even in the brace, he experienced weight-bearing pain “deep” on the medial side of his knee. Maximum flexion also still produced
posterolateral discomfort when the knee was flexed to 110 degrees.

**Postop Role of Illustration**

Looking at the diagram and seeing chondromalacia on the medial and not the lateral side of his knee was revealing. A specific attempt to load his knee into varus throughout a functional range from 10-50 degrees produced medial discomfort. A similar attempt to load the lateral side brought relief.

A G-II unloader brace was trialed successfully.

The plan was for him to work on gradually increasing his range of motion at the lateral repair site. He was also to wear the unloader brace at his return to work. The remote possibility of his needing an opening wedge proximal tibial osteotomy was mentioned for reference, and to put the long-term use of the brace into proper perspective.

**Cases 4 and 5: Explanation for Delayed Milestones of Postoperative Program vs. Friend**

Two 17-year-old soccer players underwent distal transfer of the patellar tendon and MPFL reconstruction because of recurrent patellar dislocations. They became acquainted during rehabilitation, and both were anxiously competing to return to their sport as soon as possible. At four months post surgery, Case 4 appeared to be progressing quite well with sport-specific drills while Case 5 was progressing very slowly with basic development of quadriceps muscle strength. Routine examination for range of motion and strength revealed no differences between the two patients.

**Role of Illustrations**

Referring to the surgical illustrations pointed to differences in the health of the patella in Case 5. A careful repeat history followed by re-examination for Case 5 revealed: a) anterior knee pain with activity; b) compression of the patella with the knee flexed 40 degrees was uncomfortable; and c) there was fine but audible crepitus present with one-legged squat past 45 degrees.

Plan: Case 4 was allowed to progress as tolerated. Case 5 was made aware of the problem of chondromalacia by pressing on the patella with the knee flexed 40 degrees. They are also warned of possible limitations of activity level in the future.

**Case 6: Explanation for Apparent Failure of Initial Surgery**

A 40-year-old male presented with catching and locking of the lateral aspect of the left knee. Given the acute onset of the symptoms, arthroscopy was performed.

Arthroscopy demonstrated severe articular surface damage to the tibial surface not seen on MRI in addition to a complex medial meniscus tear with severe tibial chondral surface damage beneath it.

**Postop Role of Illustration**

The patient did well for a brief time post surgery but developed increasing general pain when he resumed the demands of his manual labor job. After failed NSAIDs followed by Synvisc injections, an unloader brace trial was successful in the clinic. While the brace proved to be successful for activities of daily living, it was not quite sufficiently successful to allow a return to work. Long-leg standing films demonstrated that the weight-bearing line traversed through the lateral compartment. A closing wedge, proximal tibial osteotomy was performed that brought the alignment barely into the medial compartment.

**Case 7: The Anxious Patient Concerned about Continuing Postoperative Pain**

A 20-year-old woman was operated on six weeks ago and was quite distressed that she was not relieved of all her symptoms. She had originally been seen for a second opinion because of dramatically increased pain after an arthroscopic plica excision and lateral release by an outside surgeon, performed because of chronic anterior knee pain.
Postop Role of Illustration

A quick glance at the illustration reminded the medical team that this was the patient who displayed a grossly palpable plica as well as a medially dislocatable patella at preoperative examination. The presence of the plica played a role in the decision to perform an extensive plicectomy under direct visualization afforded by a limited arthrotomy, in addition to reconstruction of the LPFL with a semitendonosis allograft.

The patient’s concerns were addressed by a) demonstrating the pathology and treatment in the sketch; b) pointing out the newly regained patellar stability; and c) reiterating the lack of the previously palpable plica tissue. She was reassured that great progress had already been made and that because there was no chondromalacia under the patella, a full recovery was anticipated. Full recovery was actually realized by the next visit.

Case 8: The Urgent Telephone Call about a VIP Patient

I was away in New Orleans at a national meeting. My assistant informed me that the mother in a prominent family had just called requesting advice about her 15-year-old son. He had the opportunity to join a traveling soccer club team. However, the sign-up deadline was in the next few days if he did not want to give up his invitation to the next player on the waiting list.

Role of Illustration

At my request, my assistant e-mailed the illustration of the procedure as well as a copy of the last clinic note. While the surgery was complex, sufficient progress had indeed been made to approve of this patient’s return to action. By incorporating The Art of Arthroscopy into my practice, the degree of detail that I habitually included in each illustration allowed me to provide a quick as well as confident response.

Case 9: A Teaching Moment for a Senior Resident

We were in the middle of an extremely busy clinic and were informed that we had fallen behind in the schedule to the point that patients were complaining of waiting time. In an attempt to speed things up, the resident attempted to cut corners on a return patient by merely looking at the last outpatient clinic note. His routine exam failed to reveal any tenderness or limitation of motion and strength seemed adequate. His recommendation was that, at eight weeks after meniscus repair, the patient should be granted her wish to begin conditioning for upcoming volleyball tryouts.
Role of Illustration

A quick glance at the illustration quickly reminded me that this was a patient who was initially seen as a second opinion. She had been told elsewhere that her arthroscopy demonstrated a normal knee except for some mild softening of the lateral tibial plateau. While the chondromalacia was confirmed, it was secondary to the peripheral tear of the lateral meniscus at the popliteal foramen. Armed with this knowledge, the reexamination revealed signs of incomplete healing due to reproduction of posterior lateral pain with flexion to 120 (vs. 140) degrees. This was also accompanied by limited rotation in the end flexion position. Experience has taught me that a safe return to a sport where deep flexion is expected cannot be guaranteed until these parameters have returned to normal.

CONCLUSION

The above cases have been chosen to point out a few of the practical advantages of using some form of artistic documentation of surgical pathology and treatment. The importance of incorporating art into medical practice can be found in one or more of the following paragraphs.

There is clear educational value in providing clear orientation of pathology and treatment at surgery. Sketches or illustrations provide a basis for the rehabilitation plan recommended and demonstrates caregivers are concerned enough about maximizing the outcome of that treatment plan to make sure all pertinent features of the patient's problem at the time of surgery were understood and recorded.

Then too, illustrations provide for excellent resident training. Anyone viewing these sketches gains an immediate and accurate perspective on the post-surgical management in the office setting. Errors can creep into a patient record as the chart becomes voluminous and the original problems become remote (or obscure to the point they are misrepresented, in long or complicated cases). With electronic medical record systems, all images are immediately accessible for conference presentations as well as for immediate patient care.

Surgical illustrations provide rapid and reliable orientation for health care providers when patients call with unexpected complaints or unusual requests. A quick reference to the diagram shows what was actually done.

In complicated cases, in particular, there is value in understanding and orienting to important features brought out by surgical sketches that might affect outcome. I often provide a copy of the surgical illustration to my patients to take to their physical therapy provider so requests for important deviations from standard therapeutic protocols will be clearly understood. Illustrations can also remind examiners about the details of surgery which might not have held any importance unless postoperative problems unfold. A common example is the existence of chondromalacia. A sketch often provides the only documentation of the existence of other pathologies which could explain a patient's new complaint once the more-major symptoms (which led to the surgery) have been addressed.
ALTERNATIVE METHODS OF CREATING ILLUSTRATIONS

Not everyone will have the time for, or be comfortable with, creating a sketch from scratch. However, there are alternative methods of visual documentation available. There are a number of companies and organizations who provide templates for medical documentation. These always contain a drawing of the involved body part (e.g., knee, ankle, shoulder, elbow, hand, spine). While the sketches can be created on plain paper, it may be best to consider permanent storage as part of an electric medical record system via electronic scanning.

Electronic Medical Record Scanning—Conversion of Original Sketch to EMR

The University of Iowa Hospitals and Clinics is currently using Epic as its electronic medical record system. This program has the capacity to accept scanned photographs and graphic illustrations (in color) for inclusion in the patient’s electronic medical record. Particularly in more complicated cases, multiple sketches can be included in the records so health care practitioners may comprehend all of the details involved. Documented below are two sketches from a 350-pound male with a dislocated knee causing peroneal nerve disruption and partial popliteal artery compromise. A second sketch was required to clarify the details of procedures performed for this dislocated and vascularly compromised knee.

Original Sketches via Corel Draw Painter 4

Electronic sketch pads are available for both PC and Mac systems. While Photoshop has the capacity to create a sketch, it is not only complicated to use, it also does not generate the smooth lines available with the Painter program sketches.

I recently began taking a portable computer with a sketch pad into the operating room. The software program I find most helpful has been Corel Draw: Painter Essentials 4, though there are other programs that could be used. The Corel program allows me to accurately create images that are as good as if they were sketched in pencil. In addition, because handwritten notes can be impossible to read, the typed text in Corel Draw is much more attractive, can contain more detail and is more efficient. I have included a selected sketch from one of my early attempts, a crude example of what this method offers.
There is one last illustration method worth mentioning that I am currently trying. This particular electronic medium has an endless library of templates that users can accumulate. These can help document almost every situation providers encounter in their personal practice experience.

The following drawing is of a tibial tubercle transfer procedure with MPFL reconstruction. The transfer was required to eliminate recurrent patellar dislocations and the “J sign,” which was assessed intra-operatively (by femoral nerve stimulation) to be 25 mm. The pertinent details of the case are typed into the text bar to the left. Enlargement of the image is easily achieved to read the printed details of the case.

Use of Templates

ACUTE ARTICULAR FRACTURE SEVERITY AND CHRONIC CARTILAGE STRESS CHALLENGE AS QUANTITATIVE RISK FACTORS FOR POST-TRAUMATIC OSTEOARTHRITIS: ILLUSTRATIVE CASES

Masrouha KZ1, Anderson DD1,2, Thomas TP1,2, Kuhl LL1, Brown TD1,2, Marsh JL1

ABSTRACT

Novel biomechanical methods have been developed to objectively measure acute fracture severity (from inter-fragmentary surface area) and chronic contact stress challenge (from patient-specific finite element analysis) in articular fractures. These new methods help clarify the pathomechanics of the development of post-traumatic osteoarthritis, and can contribute directly to the clinical care of patients. In this manuscript, the value of these two new measures is demonstrated in three illustrative tibial plafond fracture cases, in which both metrics are correlated with cartilage status and with patient outcomes at a minimum of two years after injury. These clinical cases demonstrate the utility of new biomechanical variables to advance clinical research and patient care, by providing a basis to predict outcome and select treatment.

INTRODUCTION

Fractures involving the articular surface of weight-bearing joints often result in post-traumatic osteoarthritis (PTOA), chronic pain, and subsequent poor joint function.1,2 Although the fundamental mechanisms that lead to PTOA are not well understood, studies have shown that the degree of articular fracture severity and of post-fracture joint incongruity both correlate with the development of PTOA.2,7 Unfortunately, elucidating the interactions between these important mechanical factors has been hampered by a lack of methods to objectively measure them. Traditionally, fracture severity and articular malreduction are subjectively assessed on radiographs, using surgeon judgment alone via categorical classifications. Since these methods are known to have poor inter-observer reliability5,8 and to provide inadequate precision for measuring articular surface step-offs,9,10 techniques that are more objective and quantitative are needed to assess the mechanical risk factors for developing PTOA.

Novel objective methods have been recently developed to quantify acute injury severity,3,11,12 post-reduction articular contact stress,3,11,14 and cartilage thickness at two years post-injury.15 These techniques have separately correlated with patient outcomes.3,11,12 However, in addition to independent analysis, these metrics need to be evaluated in concert to better understand factors contributing to cartilage loss and to the development of PTOA.

Between 2001 and 2005, 36 patients with tibial plafond fractures were uniformly treated by the same surgical team, with joint-spanning external fixation and limited approaches to reduce and fix the articular surface with screws. After receiving Institutional Review Board (IRB) approval, 22 of these patients were consented for study, with 11 of them completing all phases of the evaluation. Their acute fracture severity was quantitatively assessed by measuring fracture energy, a pre-reduction CT-based metric that is calculated from inter-fragmentary surface area and bone density information. Their chronic cartilage contact stress was assessed using voxel-based finite element analyses derived from post-reduction CT scans.

The purpose of this manuscript is to present three illustrative cases from this series of patients, linking the relative effect of acute fracture severity and chronically elevated joint contact stress on cartilage thickness with clinical outcome. Three-dimensional cartilage thickness information was obtained with double-contrast multidetector CT (MDCT) scans at greater than two years post-injury. The independent variables were the metrics of fracture severity and of chronic contact stress challenge.

CASE 1

A 26 year old male fell from a height of 16 feet and sustained an open right tibial plafond fracture. Radiographs showed a highly comminuted fracture involving the articular surface and metaphysis, extending into the distal diaphysis, classified as OTA type 43C-3 (Figures 1a, b). The energy of fracture, computed from CT inter-fragmentary area, was 24.4 Joules (Figure 1c). The fracture was initially managed with irrigation and
debride ment, and stabilized with a joint-spanning external fixator. An anteroposterior (AP) radiograph (Figure 2a), and a coronal CT slice (Figure 2b) demonstrate the degree of joint comminution. Four days following injury, the articular surface was reduced through a limited anterolateral approach, and was fixed with four partially threaded cancellous screws. A post-operative AP radiograph (Figure 3a) shows the alignment after this procedure, and a post-operative coronal CT slice (Figure 3b) and volumetric rendering (Figure 3c) reveal residual joint surface incongruity.

At 30 months after injury, radiographs show a healed fracture (Figures 4a, b). The peak contact stress exposure, determined from FEA was 7.3 MPa-s, versus 5.8 MPa-s for the uninjured contralateral ankle (Figure 4c). An anterior osteophyte had developed and there was loss of joint space anteriorly. The Kellgren-Lawrence OA grade was 4, and the Ankle Osteoarthritis Score (AOS) was 63/90 for pain and 65/90 for disability (higher scores indicate more pain and disability). The cartilage loss is better visualized on the double-contrast MDCT scans (Figures 4d, e), which showed cartilage thinning and absence of cartilage over the anterior and posterolateral areas of the ankle joint.

CASE 2

A 41 year old male fell from a height of 10 feet and sustained a left tibial plafond fracture. His radiographs (Figures 5a, b) showed a partial articular fracture of the tibial plafond classified as 43B-2. The fracture energy was 4.8 Joules (Figure 5c). An anterolateral fracture fragment was clearly seen on CT (Figure 5d). The fracture was treated with a joint-spanning external fixator, closed reduction of the anterolateral fragment, and percutaneous screw fixation. Post-operative AP (Figure 6a) and lateral (Figure 6b) radiographs, along with axial CT slice (Figure 6c) and volumetric rendering (Figure 6d), suggest some residual displacement of the anterolateral fragment.

Twenty-seven months after injury, the lateral radiograph shows joint space narrowing anteriorly, with probable osteophyte formation (Figure 7a). The Kellgren-Lawrence grade was 2, and the AOS ankle score was 34/90 for pain and 30/90 for disability. Anterior cartilage loss and subchondral cysts were seen on the double-contrast MDCT scan (Figure 7b). The peak contact stress exposure was 6.5 MPa-s, versus 3.7 MPa-s for the uninjured contralateral ankle (Figure 7c).

CASE 3

A 41 year old female sustained an isolated right tibial plafond fracture in a motor vehicle accident. Initial radiographs revealed an oblique distal tibial fracture with a single intra-articular fracture line, classified as 43C-2 (Figures 8a, b). The CT scan indicated a fracture energy of 9.9 Joules (Figure 8c), and revealed primarily rotational displacement of the main articular fragment (Figure 8d). Two days following the injury, her fracture was treated with a spanning external fixator, and the joint was percutaneously reduced and fixed with partially
Acute Articular Fracture Severity and Chronic Cartilage Stress Challenge

Figure 4. Thirty month follow-up AP and lateral radiographs (a, b) showing joint space narrowing, consistent with the fact that the injured ankle had substantial areas of elevated contact stress exposure compared to the intact contralateral (c). Double-contrast MDCT scans (d,e) better demonstrate anterior osteophyte formation (thick arrow) and loss of anterior joint space (thin arrow).

Figure 5. (left) Radiographs (a, b) show an articular fracture of the tibial plafond that had relatively little liberated surface area (c). The large anterior fragment is better seen on the axial CT slice (d).

Figure 6. (below) Post-operative AP radiograph (a) shows good joint alignment, but a lateral radiograph (b) shows an anterior step-off, not well visualized on an axial CT slice (c) or in this 3D volumetric rendering from the CT (d).
threaded screws. Post-operative radiographs and CT show the reduction and joint alignment achieved during this surgery (Figures 9a-e).

Twenty-four months after injury, AP and lateral radiographs reveal a healed fracture with a well-aligned articular surface and well-preserved joint space (Figures 10a, b). The Kellgren-Lawrence grade was zero, and the AOS ankle score was 22/90 for pain and 24/90 for disability. A double-contrast MDCT scan showed an even distribution of contrast with preserved cartilage thickness on both the bottom of the tibia and the top of the talus (Figures 10c, d). The peak contact stress exposure was 5.1 MPa-s, essentially the same as for the uninjured contralateral ankle (5.6 MPa-s, Figure 10e).

MECHANICAL ASSESSMENTS OF THE FRACTURE CASES

Case 1

With 24.4 Joules of fracture energy, this case had the greatest acute fracture severity among the 22 fractures studied. In Figure 11, the fracture-liberated surface area (mm²) is plotted along the length of the fractured tibia as a solid black line. The inter-fragmentary surface area is high throughout the distal third of the tibia, but it is particularly high directly adjacent to the articular surface. The post-operative CT served as the source material for computational (finite element) analysis of the joint contact stress for this ankle. Compared to the intact ankle, there was significantly elevated contact stress.
Acute Articular Fracture Severity and Chronic Cartilage Stress Challenge

Case 1
Challenge in the fractured ankle (Figure 12). The peak contact stress exposure for this patient was 7.3 MPa-s, among the highest of the 22 fractures studied.

Case 2
Of the 22 cases studied, this was the least severe case, with a fracture energy of only 4.8 Joules. In Figure 11 this patient’s inter-fragmentary surface area is shown as the solid gray line. Finite element analysis based on the post-operative CT scan illustrates the left and right ankle contact stress distributions (Figure 12). Elevated contact stress challenge was seen over the anterior distal tibia on the left side, compared to the intact right ankle. The peak contact stress exposure for this patient was 6.5 MPa-s, which was approximately at the median of the 22 fractures studied.

Case 3
The total energy of this fracture calculated from the pre-reduction CT was 9.9 Joules. The dotted black line in Figure 11 shows the liberated surface area (mm²) along the length of the fractured tibia. Finite element analysis from the post-operative CT illustrates that the chronic cartilage contact stress challenge for the fractured ankle and the intact ankle (Figure 12) was nearly equivalent. The peak contact stress exposure for the injured ankle was 5.1 MPa-s, which was the lowest among the 22 fractures studied.

DISCUSSION
The ability to reliably predict which patients will develop disabling PTOA following intra-articular fractures of weight-bearing joints has long eluded orthopaedic surgeons, since the predisposing mechanical and biological mechanisms are poorly understood and have not been amenable to rigorous quantitative analysis. Over the last several years, we have developed methods which can be used to objectively quantify acute fracture severity, post-reduction chronic joint contact stress...
challenge, and resulting cartilage thickness changes. These quantitative metrics serve as a platform to better understand the relative contribution of mechanical risk factors on cartilage loss, and on the development of PTOA. The three cases presented demonstrate the application of these measurements in individual patients with very different tibial plafond fracture challenges, with a view toward understanding the relative effect of mechanical factors on outcome at a minimum of two years after injury.

Injury severity influences clinical decision-making when treating intra-articular fractures. Injury severity is often assessed on plain radiographs by labeling them as “high” or “low” energy. Since energy is a mechanical unit that can be quantified, those qualitative terms can be objectively measured with CT-based methods. Such techniques have been effective; studies have shown fracture energy to generally correlate with the opinions of experienced clinicians. For articular fractures of the distal tibia, correlating this metric with outcome indicates a threshold for energy of injury, above which PTOA is much more likely to develop. This is illustrated in Case 1: a highly comminuted tibial plafond fracture with a very high energy of injury (24.4 J) distributed along the length of the distal tibia, and particularly concentrated adjacent to the articular surface. Although finite element analysis showed significant residual increased contact stress challenge, the early onset of severe PTOA was almost certainly a direct result of the severity of the initial insult. The blunt impact, shattering the articular surface, likely led to widespread cartilage necrosis that was incompatible with preserving a functioning cartilage surface.

A basic principle of treating articular fractures is that to optimize the chances for a favorable outcome, the articular surface must be reduced to an extent that deleteriously elevated joint contact stress is minimized. Directly quantifying joint contact stress using finite element analysis based upon the post-operative CTs, show differential loading for each fracture case.

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A basic principle of treating articular fractures is that to optimize the chances for a favorable outcome, the articular surface must be reduced to an extent that deleteriously elevated joint contact stress is minimized. Directly quantifying joint contact stress using finite element analysis based upon the post-operative CTs, show differential loading for each fracture case.
articular malreduction led to a loss of articular cartilage in this case. The treatment failed to save a potentially salvageable articular surface.

Unlike the first two cases, which were at the extremes of fracture severity, the energy of injury of Case 3 was at an intermediate level of 9.9 J. At this level of injury it is possible that a perfect articular reduction with minimal increases in chronic joint contact loading was required for the moderately injured joint cartilage to survive. Indeed, post-reduction finite element analysis showed no increased contact stress compared to the opposite side, and a favorable outcome with well-preserved cartilage distribution at 24 months after injury was the result. This fracture had mid-level energy and low post-operative contact stress, and the cartilage was preserved throughout the joint.

These illustrative cases (from a larger series) demonstrate the type of analyses that have become possible through quantitative assessment of critical mechanical variables. More fractures, in larger multi-center series and with long-term follow-up, need to be studied to move the treatment further toward a more objective science, where management decisions are in part guided by quantitative assessment of the disease process, rather than the current practice, where they are based solely on surgeon opinion.

In summary, three illustrative cases have been presented from a larger series of patients with tibial plafond fractures, where injury severity and post-treatment contact stress have been objectively measured and correlated with a minimum two-year outcome. The relative role of each of these mechanical factors is discussed in the context of both acute injury severity and chronic contact stress challenge interacting to influence the development of PTOA. These cases illustrate the potential of measuring important variables to improve clinical research and patient care, in view of thresholds of mechanical challenge that can be used to predict outcome and guide treatment.

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REFERENCES


ABSTRACT
Debate remains regarding whether knee realignment osteotomy should be performed concomitantly with additional major knee reconstruction procedures or if it should be performed in a staged fashion. The purpose of this study is to analyze complications that occur when distal femoral osteotomy or high tibial osteotomy is performed concomitantly with other significant reconstructive procedures. Thirty-five patients with a minimum of one year follow up were identified. These patients underwent either high tibial or distal femoral osteotomy with concomitant significant additional knee reconstruction which included cartilage resurfacing requiring an arthroscopy, ligament reconstruction, meniscal transplantation, or extensor mechanism realignment requiring tibial tubercle osteotomy. Overall, 13/35 (37%) of these patients suffered at least one major or minor complication. Major complications occurred in 20.0% (7/35) and minor complications occurred in 25.7% (9/35). In conclusion, the rate of complication for combined osteotomy and reconstructive knee surgery is similar to that seen in cases of osteotomy done alone and combined surgery is advocated.

INTRODUCTION
High tibial osteotomy (HTO) and distal femoral osteotomy (DFO) are widely accepted treatment options for younger and more active patients with symptomatic medial or lateral compartment gonarthrosis associated with varus or valgus alignment.1-14 Realignment osteotomy procedures are also recommended when lower extremity malalignment is present in patients undergoing reconstructive procedures for ligament laxity, meniscal deficiency, chondral defects or patellar instability.1,4,6-8,12,14,15 Failure to address varus or valgus malalignment may result in premature failure of the associated knee reconstructive procedures to correct these conditions.

The timing of realignment osteotomy and additional reconstructive procedures of the knee is an area of debate.1,4,6-8,14 Concurrent osteotomy and reconstruction decreases total recovery time, eliminates a second surgery, and facilitates early rehabilitation and return of these patients to activities of daily living and sports.1,4,6-8,10,12,14,15 On the other hand, both realignment osteotomies and knee reconstruction procedures have associated post-operative complications and some authors have recommended staging procedures to avoid increased complications.7,8 Major complications from HTO and DFO include extension loss, arthrofibrosis, valgus or varus overcorrection, nonunion, neurovascular injury,2,4,7,11 These problems may be magnified with large corrections, with prolonged operative time, and in non-compliant patients. Additional knee reconstructive procedures may also increase this complication rate by prolonging the operative time and making the rehabilitative process more difficult.

The purpose of this retrospective study was to examine the complications that occurred in patients who underwent knee realignment osteotomy with additional reconstructive procedures of the knee in a single setting.

MATERIAL AND METHODS
After IRB approval, a retrospective review was performed to identify all high tibial osteotomy (HTO) and distal femoral osteotomy (DFO) procedures performed by the senior author from January 2001 to January 2006. Chart review was performed to document demographic data, knee surgeries performed prior and subsequent to the osteotomy, additional procedures done in combination with the osteotomy, and minor and major complications after surgery. Concomitant procedures that were deemed significant included: cartilage resurfacing using an arthroscopy (autologous cartilage implantation and osteochondral allograft transplant), ligament reconstruction, meniscal transplantation, and extensor mechanism realignment requiring tibial tubercle osteotomy.

Complications that were considered minor included hardware pain, superficial infection, anterior knee pain, hematoma, delayed union, and tendinitis. Complications that were considered major included hardware failure,
motion loss requiring intervention, intra-articular fracture, deep venous thrombosis, deep infection, exostosis, neuroma, non-union, and failure of alignment correction.

HTO patients and DFO patients were grouped together and analyzed. Patients were also separated by additional procedure performed with the knee osteotomy for statistical analysis. Complication rates were analyzed for the entire cohort and stratified by group. A group of patients that underwent HTO and DFO without an additional procedure performed with the knee osteotomy during the same time period was also identified. The complications incurred by this group were also recorded for comparison.

### Radiographic Measurements

All patients had pre-operative two-legged standing full length radiographs. A post-operative radiograph was taken at four and eight weeks after surgery and then as required until bone consolidation at the osteotomy site was evident. Post-operative films were also analyzed for timing of bony union. Delayed union was defined as lack of bridging callous and presence of radiolucent areas within the opening wedge defect past a period of three months postoperatively.\(^\text{13}\)

### Operative Techniques and Rehabilitation

Osteotomy is routinely performed concurrently with other significant knee procedures by the senior author. The only exception occurs when a patient requires three or more significant interventions, such as ACL reconstruction, osteotomy and meniscal transplant. In these situations, a portion of the reconstruction is staged. One patient during this study period was selectively staged for this reason and not included in this analysis.

When indicated, arthroscopy for chondroplasty, meniscectomy, microfracture or loose body removal was performed prior to osteotomy. Opening wedge osteotomies were performed in all HTO cases. For HTO cases, an opening wedge osteotomy was performed using a medial proximal tibial approach. Osteotomies were fixed with the Arthrex HTO plate (Arthrex, Inc.; Naples, FL). Both opening and closing wedge techniques where used with DFO. Lateral distal femoral opening wedge osteotomy was performed with fixation using the Arthrex DFO plating system (Arthrex, Inc.; Naples, FL). Medial distal femur closing wedge osteotomy was fixed with a 90 degree fixed angle blade plate (Synthes, Inc; West Chester, PA). Allograft fresh frozen femoral head was fashioned into wedges and morselized for bone grafting the opening wedge osteotomies.

Knees with associated patellofemoral mal-alignment were treated with tubercle realignment as described by Fulkerson\(^\text{16}\) after HTO or DFO was performed. Osteotomy combined with meniscus transplantation was performed as previously described.\(^\text{1}\) For combined ACL reconstruction and osteotomy cases, arthroscopy was performed first for preparation of the notch. Realignment osteotomy was then performed and fixed, followed by drilling of the tibial and femoral tunnels and graft placement and fixation. In knees with posterolateral instability, posterolateral reconstruction was performed subsequent to the realignment osteotomy.

General anesthesia and tourniquet application were routinely applied in all cases. Prophylactic antibiotics and prophylaxis against deep-vein thrombosis were used in all cases. Canister drainage was used in some cases if there was a concern for bleeding. Immediately after surgery, isometric quadriceps and active ankle exercises were instituted. Knee range of motion exercises, patellar mobilization, straight-leg raises, and electrical muscle stimulation began on the first postoperative day, with home exercises supervised by a physical therapist. For the first week, local ice, mild compression, and elevation were used to minimize edema. The patients were instructed to remain at home, except for physical therapy visits, to maximize limb elevation and lessen lower extremity edema. Patients were restricted to non-weight bearing on their leg up to the eighth week postoperatively depending on signs of radiographic osteotomy healing.

### Statistical Analysis

Descriptive statistics were calculated for all variables. Chi-square tests and Fisher’s Exact tests were used to test for differences in proportion. Statistical significance was set at \(P \leq 0.05\). All statistics were calculated using SAS v. 9.1 (SAS Institute, Inc.; Cary, NC).
Complications Associated with Realignment Osteotomy of the Knee

RESULTS

From January 2001 to January 2006, knee realignment osteotomy was performed concurrently with additional reconstructive knee procedures in 35 patients. The patients were followed up at a minimum of twelve months with a mean follow-up of 45 months (range, 12-80 months). The mean age of the cohort was 28.7 years (Range 15-50 years). There were 25 males and 10 females (Table 1).

Additional procedures consisted of 14 allograft osteochondral transplant procedures, 3 autologous chondrocyte implantation procedures, 7 meniscus transplants, 6 tibial tubercle transfers/advancements, 5 ACL reconstructions, and 1 posterolateral reconstruction. Of these 35 patients, 23 patients underwent HTO and 12 patients underwent DFO.

In total, 13 of 35 (37.1%) patients experienced at least one minor or major complication. Major complications occurred in 20.0% (7/35) and minor complications occurred in 25.7% (9/35). 11/23 HTO patients suffered a complication and 2/12 DFO patients suffered a complication. This result was found to be statistically significant (p<0.05). Table 2 presents the details of the minor and major complications that occurred. Two patients suffered joint contracture and this was the most frequent major complication. Six of the 13 minor complications were related to hardware pain.

Hardware failure occurred in 1 patient who underwent HTO with tibial tubercle realignment osteotomy. The distal screw was found to be broken 140 days after surgery. The HTO site was re-operated and chronic inflammation and metallosis without infectious symptoms was found. Re-fixation was achieved and the osteotomy went on to heal without difficulty.

A loss of correction found during the follow-up period was observed in 1 patient who underwent DFO with an OAT procedure. This case was re-operated and corrected without residual deformity. Intra-articular fracture of the lateral tibial plateau was seen intra-operatively in 1 patient during opening of the osteotomy. The correction was not affected and additional fixation was placed. Two patients had loss of range of motion requiring manipulation under anesthesia. Neurora and exostosis were each seen in one patient and both were re-operated. Nonunion and DVT were not seen in any cases. Doppler studies where only performed in patients who had a clinical suspicion for DVT.

Twenty-nine of 35 patients had undergone a prior surgery to the affected knee. A total of 57 prior procedures had been performed on this group, 15 of which were considered major procedures. The breakdown of prior surgery is presented in Table 3. Table 4 presents the procedures that occurred subsequent to the combined osteotomy and knee reconstruction. Nine patients underwent hardware removal, 8 patients underwent arthroscopy and 3 patients had a manipulation under anesthesia.

One patient in our cohort underwent subsequent autologous chondrocyte implantation after lateral opening wedge DFO with osteochondral allograft transplant. After the initial procedures the patient presented 16 months later with increased pain and crepitus after re-injuring

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<th>TABLE 2. Frequencies of complications occurring with isolated osteotomy and osteotomy combined with additional procedures</th>
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<td><strong>Combined</strong></td>
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<td>Procedure N=35</td>
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<tr>
<td><strong>Major Complications</strong></td>
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<td>Intra-articular fracture</td>
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<td>Compartment syndrome</td>
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<td>Deep infection</td>
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<td>Exostosis</td>
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<td>Hardware failure</td>
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<td>Correction failure</td>
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<td>Contracture</td>
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<td>Neurora</td>
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<td><strong>Total</strong></td>
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<td><strong>Minor Complications</strong></td>
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<td>Superficial infection</td>
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<td>Hardware pain</td>
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<td>Delayed union</td>
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<td>Hematoma</td>
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<td>Anterior knee pain</td>
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<td>Pes anserinus pain</td>
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<td><strong>Total</strong></td>
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<th>TABLE 3. Procedures performed on the ipsilateral knee prior to knee osteotomy</th>
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<td><strong>Procedures</strong></td>
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<td>Procedure N=35</td>
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<tr>
<td><strong>Major Procedures</strong></td>
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<tr>
<td>Prior Knee Osteotomy</td>
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<td>Ligament Reconstruction</td>
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<td>Cartilage Resurfacing</td>
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<td>Fulkerson Osteotomy</td>
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<td>Hardware Removal</td>
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<td>Fracture Repair</td>
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<td>Epiphysyal Repair</td>
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<td>Resection of Proximal Tibial Fibula Articulation</td>
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<td><strong>Total</strong></td>
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<td><strong>Minor Procedures</strong></td>
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<tr>
<td>Arthroscopy (Debridement or Diagnostic)</td>
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<td>Meniscectomy/Meniscus Repair</td>
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<td>Marrow Stimulation</td>
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<td>Lateral Release</td>
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<td><strong>Total</strong></td>
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</table>
During the study period there was one patient who underwent ligament reconstruction subsequent to knee osteotomy. This patient presented with varus knee deformity, complete ACL disruption, and posterolateral instability after suffering a non-contact pivot type injury. Opening wedge HTO osteotomy was performed initially. Knee instability persisted and five months later the patient underwent arthroscopic ACL reconstruction and posterolateral corner reconstruction. This patient was not included in the analysis because the case was selectively staged as more than 2 additional procedures were required.

During this same period 43 patients underwent an isolated HTO or DFO without concomitant major surgery. This included 35 HTO and 18 DFO patients. The average age of this group was 39.0 years and there were 28 males and 15 females. This group of patients was significantly older than the combined group (p<0.05) (Table 1). For comparison, this group suffered 10 major complications and 27 minor complications (Table 2). Major complications were experienced by 7/43 patients and minor complications were suffered by 14/43 patients. These rates of complications were not significantly different from the rates of complications for those patients undergoing concomitant reconstructive procedures. 13/43 patients in this group underwent subsequent surgery. This was significantly lower than the group undergoing concomitant additional reconstructive surgery (p<0.05). There were 3 cases of hardware failure in patients who underwent isolated HTO. These failures occurred at 104, 144, and 368 days after surgery.

Table 4: Procedures performed on the ipsilateral knee after realignment osteotomy

<table>
<thead>
<tr>
<th>Procedures Performed Subsequent to Knee Osteotomy</th>
<th>Combined Procedure N=35</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Major Procedures</strong></td>
<td></td>
</tr>
<tr>
<td>Hardware Removal</td>
<td>9</td>
</tr>
<tr>
<td>Ligament Reconstruction</td>
<td>0</td>
</tr>
<tr>
<td>Autologous Chondrocyte Implantation</td>
<td>1</td>
</tr>
<tr>
<td>Exostectomy</td>
<td>1</td>
</tr>
<tr>
<td>I&amp;D</td>
<td>0</td>
</tr>
<tr>
<td>Fulkerson Osteotomy</td>
<td>2</td>
</tr>
<tr>
<td>Bursectomy</td>
<td>1</td>
</tr>
<tr>
<td>Fasciotomy</td>
<td>0</td>
</tr>
<tr>
<td>Total Knee Arthroplasty</td>
<td>1</td>
</tr>
<tr>
<td>Manipulation Under Anesthesia</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>18</strong></td>
</tr>
<tr>
<td><strong>Minor Procedures</strong></td>
<td></td>
</tr>
<tr>
<td>Arthroscopy (Debridement or Diagnostic)</td>
<td>8</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>8</strong></td>
</tr>
</tbody>
</table>

The Iowa Orthopaedic Journal

**DISCUSSION**

Debate exists regarding whether realignment osteotomy around the knee should be done simultaneously with other major knee reconstructive procedures or in a staged fashion. The primary concern with combined surgeries is the possibility of increased risk for complications related to the surgery. Combined surgery results in longer operative times and often includes more extensive exposures and incisions around the knee. However, combined reconstructive surgeries decrease overall recovery times and eliminate a second anesthetic and surgery.

In the current study, major complications were found in 20.0% (7/35) of patients that underwent an additional procedure with a knee osteotomy. Minor complications were found in 25.7% (9/35) of patients in this cohort. The study group consisted of both DFO and HTO procedures done in conjunction with cartilage resurfacing, ligament reconstruction or patellar realignment. Limited information exists regarding combining osteotomy with other reconstructions. The literature available primarily relates to performing ACL reconstruction with HTO. In a series of 27 patients who underwent HTO and ACL reconstruction Boss et al. reported sensory disturbances in 2 patients and 5 patients that required arthroscopies and manipulation for limited motion. Dejour et al. reported on 44 combined HTO and ACL cases with 3 major complications and 16 minor complications. The authors in both of these studies favored the simultaneous approach based on the results of these studies.

In contrast, in a study looking at a population of younger patients with varus malalignment and anterior cruciate ligament deficiency, Noyes et al. recommended correction of varus alignment with HTO first before considering ACL reconstruction. Based on a series of 27 patients Lattermann et al. advised that patients under 40 years old with medial OA and chronic anterior instability should undergo HTO first and then a staged ACL reconstruction can be performed if instability persists. In their series 8 patients that underwent combined ACL and HTO surgery suffered a total of 6 major complications. Two of these complications were subsequent ACL rupture. In this same study 11 patients underwent HTO alone and 8 patients underwent HTO followed by a staged ACL reconstruction. In these groups 4 of 11 and 3 of 8 suffered major complications.

Osteotomy around the knee alone carries an established risk of complication, regardless of technique. Lattermann et al. reported a major complication rate of 33% (10/30) in a cohort of HTO patients. Complications reported in this study included extension defects, marked valgus overcorrection, intra-articular fracture, severe pain over the buttress plate, DVT, and peroneal nerve injury. Dejour et al. reported a minor complication rate of 36.4% (16/44) in a group of patients who
underwent HTO. Minor complications reported included asymptomatic calf thromboses, hematoma and superficial wound infection. At our institution, during the studied time frame, a cohort of 43 patients underwent isolated HTO or DFO by the senior surgeon. In this group major complications occurred in 16.3% (7/43) of patients and minor complications occurred in 32.6% (14/43) of patients.

The most common major complication in our combined reconstruction cohort was contracture seen in 2 patients (2/35, 6%). There was one hardware failure in a patient that underwent tubercle transfer in conjunction with the HTO. Spahn reported implant failure in 16.6% of isolated HTO cases using the Puddu plate. One intra-articular fracture was observed in each of our groups which is relatively low in comparison to other reports in the literature. Spahn reported that intra-articular fracture occurred in 14.6% of patients. This complication seems to be more common in cases with correction angles more than 12.5°. To prevent this complication, the enlargement of the osteotomy must be performed carefully. In addition, we advocate that the osteotomy be made below the guide pins placed for osteotomy alignment, as opposed to above the guide pins. This helps to prevent intra-articular fracture from occurring. Previous series have reported infection rates after HTO of 2.3–54.5%. Spahn reported infection in 4/85 patients undergoing medial opening wedge HTO. In the current study, deep infection did not occur in patients who underwent a combined procedure and in 1 patient who underwent an isolated knee osteotomy (1/43, 2%). This patient was treated by debridement and parenteral antibiotic therapy. Superficial infections occurred in 2 patients (2/35, 6%). There were no cases of nonunion or delayed union in our series. Warden et al. reported that non-union occurred in 1.6% cases, delayed union in 6.6%. Risks also exist for other reconstructive procedures that are often combined with osteotomy. The rate of major complication following ACL reconstruction is relatively small with rates of septic arthritis under 1%, a rate of venous thrombosis of less than 1%, and rates of subsequent surgery for debridement, manipulation or other reason of 14.7%. The risk of rupture of the ACL is approximately 3%. Minimal information exists regarding complications following cartilage resurfacing procedures requiring an arthroscopy although serious adverse events and subsequent surgical procedures have occurred in up to 54% patients.

This study is inherently limited due to its retrospective design. In addition, our cohort undergoing osteotomy and other simultaneous reconstruction is a heterogeneous group that includes both HTO and DFO patients, in addition to several different reconstructions. However, we felt that the data of the group as a whole would provide more information than looking at several very small cohorts of patients undergoing the exact same procedure. It is also difficult to compare our results to studies examining patients only undergoing osteotomy since our cohort was quite young with a mean age of 28.7 years. By contrast, during this same time frame, the average age of patients undergoing isolated osteotomy was 39 years. In addition, since none of the osteotomy patients were undergoing staged procedures we were not able to directly compare overall complication rates for staged versus non-staged groups. Lastly, our study reports complications at a minimum of 12 months follow-up. Longer term follow up may reveal additional information. However, it was felt that the vast majority of complications occur within this time frame.

As a conclusion, we believe that simultaneous osteotomy and knee reconstruction procedures can be valuable, and ultimately safe, if operative planning and technique is done carefully. Combining major knee reconstructive procedures adds significant complexity for which the surgeon must be prepared. In addition, patient compliance and motivation for the rehabilitation program are crucial. This study examines the complications experienced by patients who underwent knee realignment osteotomy with an additional significant procedure. This is a unique patient population because these are patients who are younger and often have complex structural deficits of the knee compared to patients undergoing isolated knee realignment osteotomy. Our data suggests that combined osteotomy and knee reconstruction is safe and results in a risk for complication similar to that seen when osteotomy is done alone.

REFERENCES


STABILIZATION OF DISTAL FEMUR FRACTURES WITH INTRAMEDULLARY NAILS AND LOCKING PLATES: DIFFERENCES IN CALLUS FORMATION

Christopher E. Henderson, MD,' Trevor Lujan, PhD‚‡ Michael Bottlang, PhD,‡
Daniel C. Fitzpatrick, MD,' Steve M. Madey, MD,† J. Lawrence Marsh, MD'

ABSTRACT
Objectives: This study compared callus formation in distal femur fractures stabilized with locking plates and intramedullary nails to test the hypothesis that locking plates induce less fracture callus than IM nails.

Design: Retrospective case matched study.
Setting: Two orthopaedic trauma centers.
Patients: 174 distal femur fracture were reviewed to extract cases treated with retrograde IM nails (NAIL group, n=12). These were then individually matched to cases treated with locking plates (Plate group, n=12).

Intervention: Retrograde IM nailing or locking plate fracture fixation.
Outcome Measures: Periosteal callus was measured on lateral and antero-posterior radiographs taken at 12 weeks after injury using validated software to objectively extract the size of peripheral callus from digital radiographs.

Results: The NAIL group had 2.4 times more callus area per location (231 ± 304 mm²) than the PLATE group (95 ± 109 mm², p=0.028). Compared to the PLATE group, the NAIL group had 3.4 times more callus anteriorly (p=0.31), 2.6 times more callus posteriorly (p=0.25), and 2.3 times more callus medially (p=0.16). At 12 weeks after injury, no or minimal callus for secondary bone healing (<20 mm²) was present in 20% of callus locations in the NAIL group and in 54% of callus locations in the PLATE group.

Conclusion: Significantly less periosteal callus formed in fractures stabilized with locking plates than with IM nails. This result is likely multifactorial and further study of the interaction between construct stiffness and fracture healing in the distal femur is warranted.

INTRODUCTION
Fractures of the distal third of the femur are a treatment challenge despite new fixation options. Fixed angle locking plates have become the most commonly used device for this indication replacing intramedullary nails, blade plates and condylar screws.1 Despite widespread use, there are few studies that directly compare locking plates to more traditional techniques.

Locking plates have been developed in conjunction with a minimally invasive biologically friendly insertion technique which allows the plate to be placed without excessive soft tissue-stripping and with minimal disruption of the bone blood supply.1,2 Similar to intramedullary nails these plates are used to span zones of comminution which then must heal with an external callus. They have been designed to limit fracture gap strain with physiologic loads and have improved fixation in osteoporotic, cancellous, or comminuted bone.3,4,5

One concern with locking plate constructs is that the high stiffness achieved may limit the amount of callus, resulting in delayed healing or nonunion.6,7 For comminuted fractures treated with a bridging technique, peripheral callus is necessary for fracture healing.7,8 To our knowledge there have not been any studies that have directly compared the amount of callus formed with locking plates to that formed with other implants used to treat distal femur fractures such as intramedullary nails. Intramedullary nails have many of the same advantages as locking plates such as percutaneous placement without disruption of blood supply, indirect fracture reduction, success in osteoporotic bone and have been reported to lead to high healing rates in fractures of the distal femur.9,10 There is also evidence that intramedullary nails are less stiff than locking plates.11,12

The purpose of this study was to quantitatively measure callus formation and use it as an outcome assessment to compare two clinical techniques used to stabilize distal femur fractures. We hypothesized that the increased stiffness of locking plate fracture constructs leads to less fracture callus than similar constructs with
intramedullary nails. This hypothesis was tested with a retrospective case matched study design.

**PATIENTS AND METHODS**

Approval from the investigational review board for our institutions was obtained. Patients treated for distal femur fractures between 1998 and 2006 at the University of Iowa and Slocum Center for Orthopaedics were identified by searching the Current Procedural Terminology (CPT) coding records of the hospital for distal femur fracture repair. These diagnoses were confirmed by review of the medical records. One hundred seventy four distal femur fractures were initially identified. Of these forty six were primarily fixed with a femoral retrograde intramedullary nail. Revision cases, periprosthetic fractures below a total hip arthroplasty, patients with incomplete records, missing or poor quality radiographs, or follow up less than 12 weeks were excluded. Fifteen patients met appropriate criteria (NAIL group).

Baseline characteristics of the patient and the fracture were identified from the medical record including age, gender, type of fracture fixation, open vs. closed fracture, periprosthetic fracture (above total knee), and comorbidities such as diabetes and smoking. Injury radiographs were reviewed for OTA fracture classification, postoperative radiographs were reviewed to confirm documented treatment, and 12 week anteroposterior and lateral radiographs were used for callus measurement.

A comparison group of patients treated with locking plates were identified from the original patient cohort (PLATE group). The NAIL group of patients were individually matched to the patients treated with locking plates according to OTA classification, age, gender, open versus closed fracture, periprosthetic fracture, smoking, and diabetes (Table 1). We accepted only exact matches for OTA classification. Three NAIL patients did not have an acceptable PLATE match and were not used. All patients were exact matches for smoking status.

<table>
<thead>
<tr>
<th>Table 1. Demographic and radiologic criteria used for patient matching are reported demonstrating closely matched NAIL and PLATE pairs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Open vs. Closed</strong></td>
</tr>
<tr>
<td>Nail 1 Plate 1</td>
</tr>
<tr>
<td>Nail 2 Plate 2</td>
</tr>
<tr>
<td>Nail 3 Plate 3</td>
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<tr>
<td>Nail 4 Plate 4</td>
</tr>
<tr>
<td>Nail 5 Plate 5</td>
</tr>
<tr>
<td>Nail 6 Plate 6</td>
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<tr>
<td>Nail 7 Plate 7</td>
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<tr>
<td>Nail 8 Plate 8</td>
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<tr>
<td>Nail 9 Plate 9</td>
</tr>
<tr>
<td>Nail 10 Plate 10</td>
</tr>
<tr>
<td>Nail 11 Plate 11</td>
</tr>
<tr>
<td>Nail 12 Plate 12</td>
</tr>
</tbody>
</table>
Eleven of 12 patients were exact matches based on open versus closed fracture; one patient in the NAIL group had a Gustillo type 1 open fracture and was matched to a closed fracture in the PLATE group. Two of 12 patient matches differed in the presence of diabetes. One peri-prosthetic fracture in the NAIL group was matched to a nonperi-prosthetic fracture in the PLATE group. Patient age was matched closely however exact matches were not possible. The average age difference among matched patients was eight years and only three patient matches differed by greater than 10 years. Four patients had all variables matched, five had only a difference in gender, and three had two variables unmatched, no patient pairs had greater than two unmatched variables.

The patient charts and all available radiographs were reviewed for complications including superficial or deep infection, hardware failure or removal, malunion, nonunion, need for revision surgery, and time to weight bearing. Coronal alignment was measured as the angle between a line bisecting the distal femur shaft and a line parallel to the proximal tibial plateau. Normal coronal alignment was considered 5°-7° valgus, and normal sagittal alignment was neutral. Malalignment was defined as greater than a 5° deviation from normal coronal or sagittal alignment. Loss of alignment was defined as greater than a 3° change in angular measurements between postoperative and follow-up radiographs.

The peripheral callus was measured on lateral and antero-posterior radiographs at 12 weeks in all fractures (Figure 1). The callus measurement technique has been previously described and validated. Briefly, custom software extracted the projected area of periosteal callus by using regional pixel intensities and pixel gradients. Callus size was converted from pixels to metric area by using an implant feature of known dimension. The algorithm has less than a 5% error in measuring callus area and the algorithm strongly correlated with orthopaedic surgeons that manually traced the callus outline \((r=0.94)\). In the NAIL group, the projected callus area at the anterior, posterior, and lateral location was measured (41 fracture sites). In the PLATE group, callus at anterior, posterior and medial locations was measured (31 fracture sites). Callus at lateral locations could not be measured since the plate was inserted on the lateral cortex. If multiple fractures could be observed on one cortical location, periosteal callus was measured at all fracture sites and an average was taken.

The amount of callus at each location (anterior, posterior, medial) was compared between the NAIL and PLATE group. Fractures were stratified by OTA classification, open vs. closed, and union vs. nonunion for further comparison. Statistical analysis was performed using Fisher’s exact test and Student’s t test. All comparisons were two-tailed and the significance level was set at 0.05.

**RESULTS**

The results of the chart review and matching process are presented in Table 2. No significant differences were found between the NAIL and PLATE groups baseline characteristics. Ten fractures in each group were treated with a minimally invasive approach with closed reduction of the metaphyseal fracture, two fractures in each group required open reduction of an articular component or irrigation for open fracture. In the NAIL group seven fractures were treated with Trigen retrograde femoral nails (Smith and Nephew; Memphis, TN), four with Stryker T2 retrograde nails (Stryker; Kalamazoo, MI), one with a Synthes Retrograde Femoral Nail (Synthes; Paoli, PA), and one with a GSH (Smith and Nephew; Memphis, TN). All IM nails were crosslocked with a range of one to four cross lock screws distally \((avg = 2.3)\) and zero (one nail) to two cross locks proximally \((avg = 1.2)\). The nail diameters ranged from 11.5 - 13 mm \((avg = 12.6mm)\) and all nails were inserted after overreaming the canal by 0.5 to 1.5 mm \((avg = 1.2)\).

![Figure 1. Periosteal callus measurement in matched plate and nail cases at week 12. A) No periosteal callus on medial cortex. B) Bridging periosteal callus on lateral cortex.](image-url)
Peripheral callus was found to be significantly greater in the NAIL group compared to the PLATE group at 12 weeks postoperatively. The average callus per fracture location in the NAIL group was 233 mm² and in the PLATE group was 95 mm² (p = 0.04) [Figure 2A]. The NAIL group had more callus formation on the anterior, posterior, and medial cortices (p = 0.25, 0.31, 0.16) [Figure 2B]. The NAIL group had 226 ± 236 mm² of callus on the lateral cortex. The largest amount of callus was found at the medial cortex and the smallest amount of callus was found at the anterior cortex in both groups.

In the 12 matched pairs, the NAIL group had a greater average callus amount in eight of the pairs (67%) and the PLATE group had a greater average callus amount in four of the pairs (33%) at week 12 (p = 0.22).

The average amount of callus per femur varied widely in both groups. The NAIL group varied from 37 mm² to 953 mm² (mean=231 mm²) and the PLATE group varied

---

**TABLE 2. Clinical results and complications comparing patients treated with intramedullary nails (NAIL) to locking plates (PLATE)**

<table>
<thead>
<tr>
<th></th>
<th>NAIL (averages)</th>
<th>PLATE (averages)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Follow up</strong></td>
<td>67 weeks (12-144)</td>
<td>57 weeks (16-120)</td>
<td>0.65</td>
</tr>
<tr>
<td><strong>Age</strong></td>
<td>63 yrs (23-87)</td>
<td>65 years (25-96)</td>
<td>0.77</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>89 kg (57-109)</td>
<td>97 kg (57-157)</td>
<td>0.54</td>
</tr>
<tr>
<td><strong>Mechanism of injury</strong></td>
<td>Fall -10</td>
<td>Fall -10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>MVC - 2</td>
<td>MVC -1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Crush – 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Knee ROM</strong></td>
<td>2°-97°</td>
<td>0°-99°</td>
<td></td>
</tr>
<tr>
<td><strong>Time to weight bearing</strong></td>
<td>12 weeks</td>
<td>11 weeks</td>
<td>0.63</td>
</tr>
<tr>
<td><strong>Infection</strong></td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td><strong>5°-10° coronal malalignment</strong></td>
<td>1/12 (8%)</td>
<td>3/12 (25%)</td>
<td>0.59</td>
</tr>
<tr>
<td><strong>Sagittal malalignment</strong></td>
<td>0</td>
<td>1/12 (8%)</td>
<td>1.0</td>
</tr>
<tr>
<td><strong>Δ Alignment &gt;3°</strong></td>
<td>1/12 (8%)</td>
<td>0</td>
<td>1.0</td>
</tr>
<tr>
<td><strong>Nonunion</strong></td>
<td>2/12 (17%)</td>
<td>1/12 (8%)</td>
<td>1.0</td>
</tr>
<tr>
<td><strong>Delayed union</strong></td>
<td>0</td>
<td>1/12 (8%)</td>
<td>1.0</td>
</tr>
<tr>
<td><strong>Secondary surgery</strong></td>
<td>4/12 (33%)</td>
<td>2/12 (17%)</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td>2- nonunion revision</td>
<td>1- nonunion revision</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2- crosslock removal</td>
<td>1- total knee arthroplasty</td>
<td></td>
</tr>
</tbody>
</table>
Stabilization of Distal Femur Fractures with Intramedullary Nails and Locking Plates

from 0 mm$^2$ to 227 mm$^2$ (mean=87 mm$^2$). Several of the fractures in the NAIL group formed a large amount of callus exceeding 500 mm$^2$ at a single anatomic site. No fractures in the PLATE group formed this large amount of callus.

A considerable number of fractures treated with locking plates formed no or very little callus. Ranking periosteal callus by size increments of 20 mm$^2$ demonstrated that 17/31 (55%) fracture sites (ant, post, med on AP and Lateral radiographs) in PLATE cases had between 0-20 mm$^2$ of callus, while only 9/41 (22%) fracture sites (ant, post, med, lat on AP and Lateral radiographs) in NAIL cases had between 0-20 mm$^2$ of callus (p<0.01) [Figure 3A]. There were similar differences between the NAIL and the PLATE groups at all anatomic locations with the largest difference found anteriorly [Figure 3B].

There was no significant difference in peripheral callus formation between open versus closed fractures. Open fractures had an average of 135 mm$^2$ compared to 83 mm$^2$ in closed fractures (p = 0.35). There was no significant difference in callus between cases stratified by the OTA classification. The more comminuted fractures were 33A3 - 103 mm$^2$ and 33C3 - 125 mm$^2$ and the less comminuted 32A2 - 24 mm$^2$ and 33C1 - 89 mm$^2$ (p=0.07). There were no hypertrophic nonunions, in fact the four fractures that went on to nonunion formed very little callus (Nail four: 40 mm$^2$, Nail nine: 187 mm$^2$, Plate seven: 6 mm$^2$, Plate nine: 0 mm$^2$). One nonunion was in an open fracture, two were in patients with diabetes, and none of the nonunion patients were smokers. Two of the nonunions were in a case matched pair. All of the nonunions occurred in the most comminuted classifications, 32A3 or 33A3. Given the small number of nonunions we could not identify other obvious mechanical or biological factors that contributed to this adverse outcome.

**DISCUSSION**

Despite the widespread use of locking plates to fix distal femur fractures, evidence has not emerged demonstrating that these devices are superior to previously established methods. A systematic review comparing traditional plating, intramedullary nails, and locking plates found no observed differences between implants in the rate of nonunion, infection, fixation failure, or revision surgery. However subgroup analyses suggested an increased risk of fixation failure and revision surgery with locking plates compared to conventional plates but a reduced infection rate. Herrera et al. in a systematic review of 29 case series with a total of 415 distal femur fractures found a 1.5% rate of nonunion with intramedullary nailing compared to a 5.3% rate with locked plates.

In a prospective study, intramedullary nails and locking plates were found to have equivalent functional outcome scores. Secondary bone healing requires only relatively stable fixation that results in some interfragmentary movement to stimulate callus formation. There has been recent concern that locking plates may be too stiff suppressing the callus necessary for bridging by secondary healing. In distal femur fractures treated with locked plates, Lujan et al. demonstrated asymmetric callus, with the majority of callus forming medially away from the plate where there is more motion. Less callus was found with stiff stainless steel constructs and those with more holes.
filled compared to less stiff titanium constructs and those with empty holes near the fracture gap. Sanders et al. reported more nonunions in stainless steel plates, 23%, compared to titanium plates, 7% (p=0.05). Locking plate constructs can be several fold stiffer than external fixators and they can be as stiff as traditional plating constructs designed to promote primary bone healing by restricting interfragmentary motion.

Biomechanical studies have evaluated the stiffness and interfragmentary motion of intramedullary nails and locking plate constructs, however there have been no direct comparative studies. Bottlang et al. showed only 0.2 mm of motion with axial loading under body weight with a locked plate construct. A study of gap motion comparing short and long cross locked supracondylar nails showed fracture gap motion ranging from 1.8 mm to 13.6 mm depending on nail length and the number of proximal cross lock screws. These studies indicate that locking plates can be substantially stiffer than intramedullary nails but there have been other biomechanical studies where the differences are less clear. Locking plate constructs appear to have an asymmetric but greater axial displacement than nails with varus loading, however nails have greater total gap motion, especially in response to torsion and shear stress resulting in increased shear strains.

In this case matched study an overall smaller amount of callus was formed by fractures treated with locking plates and there were a greater number of plate cases that formed little or no callus in the absence of identifiable biologic differences. In comparison to intramedullary fixation, a locking plate fracture construct may decrease the amount of callus formation by limiting interfragmentary motion. The fractures that failed to unite formed very little callus indicating that bridging periosteal callus is necessary for fracture healing. We found that the least callus was anterior in our plated fractures and the most callus was medial. The anterolateral position of the locking plate may limit the callus formed anteriorly and laterally by proximity of these cortices to the plate with increased local stiffness relative to the medial cortex which is farther from the plate. The IM nails in this study had an average of 1.2 proximal cross lock screws leading to less stability and more interfragmentary motion than if they had more locking screws. The preparation for and insertion of the nails may also have been factors that stimulated callus in the NAIL group compared to the PLATE group due to extravasation of medullary contents. This offers another plausible reason for the differences in callus seen in this study. Regardless of the reason, the results suggest that in metaphyseal fractures of the distal femur treated without anatomic reduction and compression fixation which require external callus to heal, locking plates produce less callus than IM nails.

One important limitation to the study is that there were an equal number of nonunions in both groups and we acknowledge that fracture union is the critical endpoint. However to the extent that union requires callus, measuring callus could predict subsequent delayed or nonunions, determine the need for secondary intervention, and assess differences in implants and techniques with a smaller number of patients than would be necessary for union as an outcome. The differences in callus between the two groups was also not as clear and distinct as looking at the series wide average would suggest.

Figure 3. Periosteal callus distribution: A) At 12 weeks post surgery, 54% of PLATE cases had no or very little callus (≤20 mm²). B) Percentage of fractures with callus size greater than 20 mm² at each cortical location.
Several nail cases made a large amount of callus resulting in a wide standard deviation. In addition, in four of the matched pairs the plated cases actually had more callus than the nailed cases. This study has several other limitations. It is a retrospective design and a number of patients had to be excluded due to inadequate follow up or poor radiographs resulting in small patient numbers. The majority of our supracondylar femur fractures have been treated with locking plates since 2002, which limited the number of nail cases available for study secondary to a standing hospital policy to destroy radiographs after seven years of storage. Despite our rigorous matching criteria it is possible that patient or biological factors within a matched pair differed enough to effect callus formation to a greater degree than method of fixation. Measuring callus on plain radiographs has limitations including using a two dimensional study to estimate what is a three-dimensional biological process, however radiographs have been shown to effectively approximate callus growth. It is possible that biologic or other mechanical factors not identified in this study contribute to increased callus formation with IM nails. Therefore the results of our study should be interpreted with caution and used as a starting point for further investigation.

In conclusion, in this study locking plates used to bridge fractures of the distal femur led on average to less callus formation than IM nails. Further study of the interaction between construct stiffness and fracture healing in the distal femur is warranted.

REFERENCES
Abstr

ACT

Although there have been a few large case series of giant cell tumor (GCT) in the spine and sacrum, the treatment of these lesions remains controversial. We are reporting 23 additional cases of giant cell tumor in the spine and sacrum gathered from our institution and the personal consultation files of the senior author. Ten lesions occurred in the sacrum with an average age of 31 years (range of 13-49) and 13 occurred in the mobile spine with an average age of 39.1 years (range of 13-64). Most patients presented with pain or neurologic deficit at the site of tumor involvement, and symptoms were usually present for many months prior to diagnosis. Six of the sacral GCT patients were treated with pre-operative arterial embolization and intralesional surgical resection, and two developed a recurrence. Two of the sacral GCT patients had an en bloc resection and neither developed a recurrence. One sacral GCT patient was treated only with serial arterial embolization with good disease control. One sacral GCT patient did not receive any treatment. Eleven spinal GCT patients were treated with en bloc surgical resection and two developed a recurrence, the other two spinal GCT patients were treated with intralesional surgical resection and both developed a recurrence. Giant cell tumors of the spine and sacrum should be managed with en bloc resections whenever possible as this provides the greatest chance for cure. When the risk of post-operative neurologic deficit after en bloc excision is high, as in most of our sacral lesions, conservative therapy involving arterial embolization and intralesional resection offers the best results.

INTRODUCTION

Giant cell tumor (GCT) of bone is a rare neoplasm that accounts for approximately 5% of all primary bone tumors in adults. GCT most frequently occurs at the end of long bones, and the sacrum is the fourth most common site, accounting for between 1.7-8.2% of cases. Giant cell tumor also occurs in the mobile spine, but this location accounts for only 2-4% of cases. In all locations, the neoplasm occurs most commonly between the ages of 20-45 years of age, and it affects males and females with equal frequency. Various treatment methods have been advocated including arterial embolization, curettage, surgical excision, radiation, and cryotherapy. Treatment is very successful in long bone lesions, but the optimal treatment and medical management of GCT in the spine and sacrum has not been well established. We are presenting our experience with the diagnosis and management of 23 cases of giant cell tumors of the spine and sacrum. We discuss the clinical presentation, treatments received, and outcomes of therapy.

MATERIALS AND METHODS

These cases were culled from the IRB approved database maintained by the senior author. A total of 23 cases of giant cell tumor of the spine and sacrum were found. The data collected consisted of clinic notes, operative notes, radiographic images, pathological reports, as well as gross and microscopic imaging.

CASE DESCRIPTIONS

Ten cases occurred in the sacrum (Table 1). Five of these were female and five were male. The mean age was 31 years (range of 13-49 years). All patients had pain for an average duration of 30 months (range of 1 week to 10 years). The pain was most frequently in the lower back and commonly radiated into the thighs. Neurological symptoms were common, occurring in seven of ten (70%) patients. Symptoms included bowel or bladder incontinence, muscle weakness, perineal hypoesthesia, and erectile dysfunction.
TABLE 1. Clinical Data from 10 Patients With Giant Cell Tumor of the Sacrum

<table>
<thead>
<tr>
<th>Patient</th>
<th>Age/sex</th>
<th>LC</th>
<th>Presentation</th>
<th>Tx</th>
<th>Neurologic Deficits at Final F-U</th>
<th>Recurrence</th>
<th>Tx of Recurrence</th>
<th>F-U (mo)</th>
<th>Last Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13/F</td>
<td>S2-S3</td>
<td>2m of pain and weakness</td>
<td>IL, EMB</td>
<td>None</td>
<td>9 months</td>
<td>IL, Chemo, RAD</td>
<td>64</td>
<td>NED</td>
</tr>
<tr>
<td>2</td>
<td>21/F</td>
<td>S1-S2</td>
<td>1w of pain and weakness</td>
<td>IL, EMB, RAD</td>
<td>None</td>
<td>No</td>
<td>7</td>
<td>AWD</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>26/M</td>
<td>S1-S2</td>
<td>1y of pain and neurologic deficit</td>
<td>IL, EMB, RAD</td>
<td>None</td>
<td>No</td>
<td>34</td>
<td>NED</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>29/M</td>
<td>S2-S3</td>
<td>1w of weakness and neurologic deficit</td>
<td>IL, EMB</td>
<td>None</td>
<td>5 months</td>
<td>EMB, RAD</td>
<td>15</td>
<td>AWD</td>
</tr>
<tr>
<td>5</td>
<td>29/M</td>
<td>S1-S2</td>
<td>3y of pain and neurologic deficit</td>
<td>IL, EMB</td>
<td>None</td>
<td>No</td>
<td>0</td>
<td>NED</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>42/M</td>
<td>S1-S5</td>
<td>10y of pain and neurologic deficit</td>
<td>EB, Chemo</td>
<td>Pain, urinary retention</td>
<td>No</td>
<td>14</td>
<td>NED</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>20/M</td>
<td>*</td>
<td>Pain and weakness</td>
<td>ILEMB, RAD</td>
<td>Pain, constipation</td>
<td>No</td>
<td>84</td>
<td>NED</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>35/F</td>
<td>S1-S3</td>
<td>2y of pain and neurologic deficit</td>
<td>EB, RAD</td>
<td>Pain, weakness</td>
<td>No</td>
<td>55</td>
<td>NED</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>35/F</td>
<td>S1-S5</td>
<td>5y of pain and neurologic deficit</td>
<td>EMB</td>
<td>Pain</td>
<td>No</td>
<td>14</td>
<td>AWD</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>49/F</td>
<td>S1-S5</td>
<td>18m of pain and neurologic deficit</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>AWD</td>
<td>AWD</td>
<td></td>
</tr>
</tbody>
</table>

Key: AWD=Alive With Disease; Chemo=Chemotherapy; CT=Computed Tomography Scan; EB=En bloc Surgical Resection; ED=Erectile Dysfunction; EMB=Arterial Embolization; F-U=Follow-Up; Horner’s=Horner's Syndrome; IL=Intralesional Surgical Resection; LC=Location; M=Month; NED=No Evidence of Disease; RAD=Adjuvant Radiation Therapy; Tx=Treatment; W=Week; Y=Year; *=No Records Available.

TABLE 2. Clinical Data from 13 Patients With Giant Cell Tumor of the Spine

<table>
<thead>
<tr>
<th>Patient</th>
<th>Age/sex</th>
<th>LC</th>
<th>Presentation</th>
<th>Tx</th>
<th>Neurologic Deficits at Final F-U</th>
<th>Recurrence</th>
<th>Tx of Recurrence</th>
<th>F-U (mo)</th>
<th>Last Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>58/F</td>
<td>L4-L5</td>
<td>5m of fatigue and pain</td>
<td>EB, EMB</td>
<td>Pain</td>
<td>No</td>
<td>6</td>
<td>NED</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>32/F</td>
<td>C7-T2</td>
<td>Referred after recurrence</td>
<td>EB, RAD</td>
<td>Hypesthesia</td>
<td>8 months</td>
<td>EB</td>
<td>144</td>
<td>NED</td>
</tr>
<tr>
<td>13</td>
<td>62/F</td>
<td>C4</td>
<td>Pain, paralyzed diaphragm</td>
<td>EB</td>
<td>None</td>
<td>40 months</td>
<td>IL, RAD</td>
<td>43</td>
<td>AWD</td>
</tr>
<tr>
<td>14</td>
<td>36/M</td>
<td>C2</td>
<td>Acute C2 Fracture</td>
<td>EB, RAD</td>
<td>None</td>
<td>No</td>
<td>122</td>
<td>NED</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>64/F</td>
<td>T11</td>
<td>Referred after recurrence</td>
<td>EB</td>
<td>None</td>
<td>No</td>
<td>0</td>
<td>NED</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>29/M</td>
<td>T12</td>
<td>3m of pain and neurologic deficit</td>
<td>EB, EMB</td>
<td>Pain</td>
<td>No</td>
<td>10</td>
<td>NED</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>43/M</td>
<td>L5</td>
<td>Long history of pain</td>
<td>EB</td>
<td>Weakness</td>
<td>No</td>
<td>63</td>
<td>NED</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>35/F</td>
<td>L5</td>
<td>1m of pain and neurologic deficit</td>
<td>EB, EMB</td>
<td>None</td>
<td>No</td>
<td>50</td>
<td>NED</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>47/M</td>
<td>L5</td>
<td>Incidental mass on CT</td>
<td>IL, EMB</td>
<td>Pain</td>
<td>27 months</td>
<td>None</td>
<td>29</td>
<td>AWD</td>
</tr>
<tr>
<td>20</td>
<td>30/F</td>
<td>L4</td>
<td>3m of pain</td>
<td>EB</td>
<td>None</td>
<td>None</td>
<td>12</td>
<td>NED</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>31/F</td>
<td>C6</td>
<td>12m of pain and neurologic deficit</td>
<td>EB</td>
<td>None</td>
<td>No</td>
<td>0</td>
<td>NED</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>28/M</td>
<td>L2</td>
<td>1m of pain</td>
<td>EB</td>
<td>Pain, weakness</td>
<td>No</td>
<td>73</td>
<td>NED</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>13/F</td>
<td>C6</td>
<td>3m of pain and weakness</td>
<td>IL</td>
<td>Weakness, Horner’s</td>
<td>Yes, 4 times</td>
<td>EB, RAD, EMB</td>
<td>107</td>
<td>AWD</td>
</tr>
</tbody>
</table>

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Thirteen cases occurred in the spine above the sacrum (Table 2). Eight of these were females and five were males. The mean age was 39.1 years (range of 13-64 years). Patients #12 and #15 were both treated with intralesional surgical resection at an outside institution and referred to our center following recurrence of their disease. Two spinal GCT patients were asymptomatic until the time of their presentation. Patient #19 was diagnosed following an elective total body CT scan, and patient #14 presented acutely with compression fracture.
The other patients presented with back pain. Neurologic symptoms occurred in six of thirteen (46%) patients. Symptoms included arm or leg weakness, parasthesias, diaphragmatic paralysis, and constipation.

**RADIOGRAPHIC FINDINGS**

Radiographs or CT scans were available for all patients except for patient #17. The sacral lesions were large, poorly defined lytic masses arising in the central

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**Figure 1.** Axial CT scan of the sacral giant cell tumor from patient #2. There is a lytic lesion involving both wings of the sacrum.

**Figure 2.** Sagittal CT scan of the sacral lesion of patient #9. There is invasion of the anterior wall of the sacrum and spread into the soft tissues.

**Figure 3.** Axial CT scan of the cervical giant cell tumor of patient #14. The lytic lesion is confined to the body of the vertebrae.

**Figure 4.** Lateral plain film of the spine of patient #22 showing a compression fracture of the L2 body secondary to the giant cell tumor.
part of the sacrum and spreading to involve both wings (Figure 1). Three patients (#6, #7, and #8) also had an associated soft tissue mass (Figure 2). The most frequent location was the upper two segments of the sacrum, although several lesions were so large that they involved the entirety of the sacrum.

The spinal lesions were poorly defined lytic masses confined to the vertebral body (Figure 3). Five patients (#12, #13, #21, #22, and #23) had vertebral compression fractures ranging from mild collapse (Figure 4) to a complete vertebral plana. Patient #23 had extension of her mass into the surrounding soft tissue. Six tumors occurred in the lumbar spine, four occurred in the cervical spine, and two occurred in thoracic spine. One tumor crossed the cervico-thoracic junction to involve two adjacent vertebrae (Figure 5).

**HISTOLOGICAL FINDINGS**

Histologic review was performed on tissue from all cases. A CT guided needle biopsy diagnosis was attempted on six of the ten sacral giant cell tumors and was diagnostic in all six. The remaining four lesions required open biopsy. In the spinal lesions, a CT guided needle biopsy diagnosis was attempted in 7 of the 13 cases. The specimen was diagnostic in all seven cases. The remaining cases were not diagnosed until corpectomy.

Histologic features were typical of giant cell tumor of bone (Figure 6). Lesions in the sacrum occasionally had focal areas of aneurysmal bone cyst transformation. Lesions in the spine were frequently complicated by pathologic fracture. This resulted in considerable reactive bone formation which, on several occasions, led to consideration of an osteoblastic producing neoplasm (Figure 7). Osteoblastoma and aneurysmal bone cyst were not diagnostic considerations in the mobile spine lesions because the posterior elements are usually involved by these processes and our patients only had vertebral body involvement. There was no significant pleomorphism to lead to the consideration of malignancy.

**TREATMENT**

Six out of ten patients with GCT of the sacrum were treated by pre-operative embolization with intralesional surgical resection (Table 1). Three of these patients received adjuvant radiation therapy (patient #2, #3, and #7). The remaining four patients were not treated with intralesional surgical resection. Patient #6 received...
neoadjuvant chemotherapy with doxorubicin and cisplatin followed by en bloc surgical resection. Patient #8 received an en bloc resection with adjuvant radiation therapy. Patient #9 declined to have surgery and instead elected to have serial arterial embolizations.

The most frequent treatment modality for GCT of the mobile spine was en bloc surgical resection, which occurred in eleven of thirteen (85%) of cases (Table 2). Three of these (patients #11, #16, and #18) also received pre-operative arterial embolization. Two others (patients #14 and #12) also received adjuvant radiation therapy. Patient #19 had had extensive disease and opted for pre-operative embolization and intra-lesional surgical resection. Patient #23 had extensive soft tissue involvement of her tumor and was treated with intra-lesional resection only.

**FOLLOW-UP AND OUTCOME**

Average follow-up for the patients with sacral GCT was 31.9 months (range of 0-64 months). Average follow-up for patients with spinal GCT was 50.7 months (range of 0-144 months). No patient in this study died during the follow-up period, and no patients had metastases. In the follow-up period, and no patients had metastases. At final follow-up, five sacral GCT and six spinal GCT patients had a complete neurologic recovery. The remainder of the patients had either chronic pain or residual neurologic deficits (Tables 1 and 2).

**DISCUSSION**

Few studies have presented large case series of GCT in the spine or sacrum. In this study, we have characterized the clinical, histologic, and radiographic presentation of this rare tumor and reported our experience with the treatment and management of 23 cases. Overall, two of nine (22%) sacral GCT and four of 13 (31%) spinal GCT patients who received surgical therapy at our institution developed a recurrence. In contrast, recurrence in long bone giant cell tumor is about 10%. Thus, spinal and sacral GCT carry a much worse prognosis.

Clinically, both spinal and sacral GCT patients in our study had a similar presentation. The most common symptoms were pain and neurologic deficit in the area affected by the tumor, which was present in nearly all patients. All but two patients in this study had pain for months prior to diagnosis, one of which was an incidental finding, while the other presented with an acute compression fracture. Like GCT of long bones, GCT of the spine and sacrum can develop the so-called “benign lung metastasis,” and this event has been reported to occur in up to 13.7% of the spinal lesions. However, none of our patients developed lung metastases.

Radiographically, sacral GCT has been reported to be an expansile lytic lesion involving both sides of the midline, without a sclerotic rim. Lesions in our study were similar, and three patients had adjacent soft tissue masses. Spinal GCT has been reported as an expansile lytic lesion that most often involves the vertebral body, with roughly equal incidence in all parts of the spine. In our study, all patients had lytic masses in the vertebral body, and only one patient had soft tissue involvement. Six lesions (46%) occurred in the lumbar spine, four (31%) occurred in the cervical spine, two (15%) occurred in the thoracic spine, and one (8%) crossed the cervicothoracic junction. While the epiphyseal-metaphyseal location of giant cell tumor in the long bone is a clue to the radiographic diagnosis, these landmarks are not available in the spine and sacrum. As a result, the radiographic changes are less diagnostic in the spine.

Treatment of GCT in the long bones has typically involved curettage, sclerotherapy, and filling of the defect with bone cement. However, therapy of sacral and spinal lesions is less straightforward. Giant cell tumors in these locations frequently do not present until late in the course when the tumor is very large and when wide excision would leave the patient with unacceptable neurologic deficits. Although treatment algorithms have been proposed, the optimal treatment of GCT in the sacrum and spine is not well defined.

In our study, multiple different treatment modalities were applied with varying degrees of success. In the sacrum, two patients had tumors that were small enough to be amenable to complete en bloc surgical excision. Neither patient suffered a recurrence and both were completely disease free at final follow-up. This is consistent with prior studies that have shown en bloc excision to produce excellent rates of local control. Notably, both patients treated with this modality had residual neurologic deficit at final follow-up. This is consistent with prior studies that showed en bloc surgical excision to hold significant risk for permanent neurologic deficit.

In the spine, 11 of our patients were treated with en bloc surgical excision, and two of 11 (18%) developed a local recurrence. The recurrence rate of spinal GCT following en bloc excision has been reported to range from 11-50%. Our results indicate that the true recurrence following en bloc excision is at the lower end of the reported ranges. Six of the 11 patients had no residual neurologic deficit at final follow-up, indicating that en bloc excision produces better results in the spine than it does in the sacrum. Given these results, en bloc surgical excision should be the treatment of choice for patients with spinal GCT unless the operation would result in significant post-operative morbidity.
Six of our sacral GCT patients were treated with pre-operative embolization followed by intralesional surgical resection. Two of these six (33%) had a recurrence of their disease. Previous studies have shown recurrence rates ranging from 20% to 50%. Our results indicate that the true recurrence is at the lower end of these reported ranges. Only one patient treated with pre-operative embolization and intra-lesional resection had any residual neurologic deficits at follow-up. This is consistent with prior studies which have shown intralesional resection of sacral GCT to be associated with lower post-operative morbidity than en-bloc resections. Thus, we have found that this modality produces a reasonably low recurrence rate with excellent preservation of neurologic function. Pre-operative embolization followed by intralesional resection should be the treatment of choice for sacral GCT patients with tumors that are too large for en bloc excision.

Only two of our spinal GCT patients were treated with intralesional resection. In both cases, the patients had extensive disease at the time of their presentation, and both patients developed a local recurrence. The rates of local recurrence following intralesional resection of spinal GCT are poorly established, but are reported to range from 0%-71%. It is likely that this high recurrence rate may be more a reflection of the initial disease burden than the surgical technique itself. For spinal GCT in the mobile spine, this modality should be reserved for patients with extensive disease who cannot be treated with en bloc excision.

A recent study showed no benefit of adjuvant radiation therapy following conservative surgical management of sacral GCT. However, this remains controversial, and some authors still advocate its use following intralesional resections. In our study, none of three sacral GCT patients treated with intralesional resection and adjuvant radiation developed a recurrence; whereas two of three treated with intralesional resection alone developed a recurrence.

In summary, GCT of the spine and sacrum is a rare tumor that most frequently presents with pain and neurologic deficit at the site of involvement. None of our patients developed benign metastases, suggesting that the rates of this complication may be less than previously reported. Whenever possible, en bloc excision should be pursued as the surgical procedure of choice for management of spinal GCT. When en bloc excision is prohibited due to the high risk of post-operative morbidity, as is usually the case with sacral lesions, pre-operative embolization followed by intralesional resection should be the procedure of choice. Serial arterial embolization is an alternative modality that has a lower morbidity, and can be offered as an initial therapy in some patients. In contrast to the most recently published studies, we found an anecdotal benefit of adjuvant radiation therapy for GCT of the sacrum. We also found that CT guided needle biopsy is a valuable tool in establishing a pre-operative diagnosis.

REFERENCES


CLINICAL UTILITY OF CT-GUIDED BIOPSIES IN ORTHOPAEDIC ONCOLOGY

William Lack, MD, Jonathan A. Donigan, MD, Jose Morcuende, MD, Joseph Buckwalter, MD, Georges Y. El-Khoury, MD

ABSTRACT

Background: CT-guided biopsy is a minimally invasive diagnostic method of evaluating musculoskeletal lesions. Other options include incisional and excisional biopsy with the possibility of intraoperative frozen section. The clinician’s decision to order a CT-guided biopsy requires an understanding of the likelihood that this biopsy will affect treatment. This requires an understanding of both diagnostic yield and accuracy. Furthermore, the clinical utility of a biopsy is affected by factors other than the yield and accuracy as the clinical setting may render a technically diagnostic biopsy unhelpful.

Methods: A retrospective review of the electronic record at an orthopedic oncology referral center identified all patients who had undergone CT-guided percutaneous needle biopsy of musculoskeletal lesions after being evaluated by an orthopedic oncologist in clinic over a period of 5 years. 53 CT-guided biopsies of bone lesions and 16 CT-guided biopsies of soft tissue lesions were identified. The diagnostic yield (rate of obtaining tissue from which the pathologist could report a diagnosis) and clinical utility (rate at which biopsy results guided treatment decisions) were calculated and statistically compared.

Results: The overall diagnostic yield of CT-guided bone biopsies was 94% (50 of 53 biopsies) and the clinical utility was 70% (37 of 53 biopsies). In the first 2 years of the study the diagnostic yield was 95% (21 of 22 biopsies) and the clinical utility was 86% (19 of 22 biopsies). In the remaining 3 years the diagnostic yield was 91% (28 of 31 biopsies) and the clinical utility was 58% (18 of 31 biopsies). This decrease in clinical utility over time was statistically significant (p = 0.01). Suspicion of metastasis resulted in a diagnostic yield of 100% (11/11) and a clinical utility of 91% (10/11). Suspicion of primary tumor resulted in a diagnostic yield and clinical utility of 93% (39/42) and 67% (28/42), respectively. This difference in clinical utility was statistically significant (p = 0.02). The diagnostic yield of CT-guided soft tissue biopsies was 75% (12 of 16 biopsies) and the clinical utility was 69% (11 of 16 biopsies). The diagnostic yield was significantly lower for soft tissue biopsy than bone biopsy (p = 0.01). There was no relationship between the rate of diagnostic biopsies and the evaluating pathologist or the location of the lesion within the body.

Conclusions: CT-guided biopsy is useful in the diagnosis of musculoskeletal lesions, however, its clinical utility is substantially lower than its diagnostic accuracy and yield due to a significant rate of diagnostic biopsies that fail to guide treatment, particularly when a primary lesion is suspected. The disparity in clinical utility based on preoperative suspicion of metastasis was even greater in our study than previously shown. CT-guided percutaneous needle biopsy is much more likely to guide treatment in the setting of suspected bone metastasis as opposed to biopsies of suspected primary bone lesions and soft tissue lesions.

INTRODUCTION

CT-guided biopsy is a minimally invasive diagnostic method of evaluating musculoskeletal lesions. Other options include incisional and excisional biopsy with the possibility of intraoperative frozen section. The clinician’s decision to order a CT-guided biopsy requires an understanding of the likelihood that this biopsy will affect treatment. This requires an understanding of both diagnostic yield and accuracy. Furthermore, the clinical utility of a biopsy is affected by factors other than the yield and accuracy as the clinical setting may render a technically diagnostic biopsy unhelpful.

Diagnostic yield, accuracy, and clinical utility have all been studied with respect to CT-guided biopsy. Diagnostic yield is defined as the rate of obtaining adequate tissue at biopsy for pathologic diagnosis and diagnostic accuracy is defined as the rate at which diagnosis at biopsy agrees with the diagnosis following later excisional biopsy. Clinical utility refers to the rate at which biopsies guide treatment decisions, and has been previously described as an important factor in judging the effectiveness of percutaneous biopsy.

It is possible for a technically diagnostic biopsy to be unhelpful in making treatment decisions. A common example would be a CT-guided biopsy of a lesion con-
cerning for a primary malignant bone tumor by history and imaging. If the pathology result of the biopsy is “normal bone fragments and remodeling without tumor cells” the clinician is left with ongoing concern for malignancy despite a technically diagnostic biopsy. Measuring clinical utility accounts for such technically diagnostic yet clinically unhelpful biopsies and is a more accurate assessment of the usefulness of biopsy to the clinician. It was anecdotally noted at our institution that the ability to make treatment decisions based on CT-guided biopsy of musculoskeletal lesions had decreased in recent years. A study was initiated to examine this perceived change and its possible causes.

METHODS

A retrospective review of the electronic record at the University of Iowa Hospitals and Clinics was performed. The study population included both male and female patients of all ages undergoing the chosen procedures. The procedures chosen were CT-guided biopsies ordered by the senior authors between July 1, 2004 and June 30, 2009, excluding fine needle aspirations, ultrasound-guided biopsies and repeat biopsies. 53 CT-guided biopsies of bone lesions and 16 CT-guided biopsies of soft tissue lesions were identified.

The diagnostic yield was calculated by identifying cases for which a definitive pathologic diagnosis was recorded in the electronic medical record. This includes cases in which the pathology report described nonspecific findings such as “normal bone” or “bone remodeling without tumor cells.” The clinical utility was determined by examining the electronic medical record for evidence that the biopsy result had guided treatment decisions. Examples of failure to guide treatment would be a case in which a later incisional biopsy was performed to obtain diagnostic tissue after a nondiagnostic percutaneous biopsy or to confirm a pathologic diagnosis that was contradictory to the patient’s history and imaging. The diagnostic accuracy was not calculated as it requires later excisional biopsy, which was not performed for the majority of lesions in this study.

The data was analyzed for association of diagnostic yield and clinical utility with variables including differential diagnosis, pathologist, patient age and location of the lesion. The significance of the difference between two proportions was calculated for both the diagnostic accuracy and the clinical utility to determine if there were statistically significant differences.

RESULTS

The overall diagnostic yield of CT-guided bone biopsies was 94% (50 of 53 biopsies) and the clinical utility was 70% (37 of 53 biopsies). In the first 2 years of the study the diagnostic yield was 95% (21 of 22 biopsies) and the clinical utility was 86% (19 of 22 biopsies). In the remaining 3 years of the study the diagnostic yield was
91% (29 of 31 biopsies) and the clinical utility was 58% (18 of 31 biopsies). This decrease in clinical utility over time was statistically significant (p = 0.01).

When there was concern for metastasis the diagnostic yield was 100% (11/11) and the clinical utility was 91% (10/11). When there was suspicion of a primary tumor the diagnostic yield and clinical utility were found to be 93% (39/42) and 67% (28/42), respectively. This difference in clinical utility was statistically significant (p = 0.02). In the first two years of the study period 77% (17/22) of biopsies were performed to evaluate suspected primary lesions and in the last 3 years 81% (25/31) were performed for such lesions.

There was a greater variety of pathology results when there was concern for a primary lesion as shown in the table. The majority of lesions concerning for metastasis were found to be metastatic lesions by pathology while lesions concerning for a primary process were broadly distributed by pathology without a dominant result.

The diagnostic yield of CT-guided soft tissue biopsies was 75% (12 of 16 biopsies) and the clinical utility was 69% (11 of 16 biopsies). This was significantly lower than the diagnostic yield for bone biopsy (p = 0.01) while the clinical utility was nearly identical (69% vs 70%). There was a trend toward statistical significance when the clinical utility of soft-tissue biopsy was compared with bone biopsy of suspected metastatic lesions (69% vs 91%, p = 0.09).

There was no relationship between the rate of diagnostic biopsies and the pathologist performing the evaluation or the location of the lesion within the body. Neither was there a relationship between the rate of diagnostic biopsies and the relative frequency with which the pathologist evaluated biopsies from our study population (pathologists evaluating < 1 of these biopsies per year had similar diagnostic rates to those evaluating > 1 biopsy per year). The diagnostic yield was similar across all age groups. There was a suggestion of a lower clinical utility for patients less than 18 years of age (2 of 7 biopsies), however, this was a small subset of patients and the difference did not reach statistical significance.

**TABLE 1**

<table>
<thead>
<tr>
<th>Biopsy Result</th>
<th>Nondiagnostic</th>
<th>Normal</th>
<th>Benign</th>
<th>Metastasis</th>
<th>Primary Malignancy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concern for Metastasis</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>11</td>
<td>11</td>
<td>4</td>
<td>12</td>
<td></td>
</tr>
</tbody>
</table>

**DISCUSSION**

The diagnostic yield of image-guided musculoskeletal biopsy has been reported to be between 80 and 95%. The diagnostic accuracy is well documented with multiple studies reporting accuracy of 97-98% in bone tumors and 93-99% in soft-tissue sarcomas. Clinical utility is much less frequently considered. The clinical utility of percutaneous musculoskeletal biopsy has previously been shown to vary according to the differential diagnosis prior to biopsy, with the clinical utility of biopsy for suspected metastatic lesions (77%) and infection (72%) being significantly higher than that for suspected primary tumors (59%). The results of the present study are consistent with these previous results. Suspicions of metastatic vs primary disease had an even greater effect on the clinical utility of biopsy in this study than previously reported.

The clinical utility of CT-guided biopsy decreased significantly in the later years of the study while diagnostic yield remained high. Given that CT-guided biopsy has a lower clinical utility for suspected primary lesions, it is possible that performing more biopsies for suspected primary disease would lower the clinical utility. However, there was not a significant increase in either the number of biopsies per year or the proportion of biopsies that were performed to investigate suspected primary lesions during the study period. As it was anecdotally noted during the study period that a number of biopsies did not give clinically useful information, this may have directly affected the clinical utility as clinicians interpreted the results with greater skepticism.

CT-guided biopsy is a useful tool in the diagnosis of musculoskeletal lesions, however, its clinical utility is substantially lower than its diagnostic accuracy and yield due to a significant rate of technically diagnostic biopsies that fail to guide treatment. The decision to perform a biopsy and the choice of biopsy technique must be based upon the likelihood that the result will guide treatment while minimizing contamination of surrounding tissues, patient discomfort, and cost.

It may seem counterintuitive that a diagnostic biopsy would fail to guide treatment, but the definition of a successful diagnostic biopsy is simply that a pathologist can
describe the tissue obtained. The clinician must then decide if the tissue obtained is likely to represent the entirety of the lesion in question. When there is concern for a primary lesion, it is difficult to rule out a more concerning lesion when the pathology report describes “fragments of normal bone” or “bone remodeling without tumor cells.”

Our study found a diagnostic yield similar to what has been reported in the literature and found that clinical utility is related to the suspicion of primary vs metastatic disease. The disparity in clinical utility based on preoperative suspicion of metastasis was even greater in our study than previously shown. CT-guided percutaneous needle biopsy is much more likely to guide treatment in the setting of suspected bone metastasis as opposed to biopsies of suspected primary bone lesions and soft tissue lesions.

REFERENCES
THE RISK OF LOCAL RECURRENTNESS ALONG THE CORE-NEEDLE BIOPSY TRACT IN PATIENTS WITH BONE SARCOMAS

Said Saghiieh, MD*; Karim Z. Masrouha, MD*; Khaled M. Musallam, MD**; Rami Mahfouz, MD***; Miguel Abboud, MD†; Nabil J. Khoury, MD††; Rachid Haidar, MD*

ABSTRACT

Introduction: We evaluated the local recurrence rate (LRR) of bone sarcoma along the core-needle biopsy (CNB) tract in patients who underwent Limb Salvage Surgery (LSS) following a diagnostic CNB performed irrespective of the planned surgical incision site and for which surgery did not involve any biopsy tract removal.

Methods: A retrospective review of 10 pediatric patients diagnosed with bone sarcoma using a computed tomography-guided core-needle biopsy, with evaluation of medical records, pathological specimens and radiological films from the date of diagnosis until the most recent follow-up.

Results: None of the patients experienced local recurrence during their follow up, despite the lack of biopsy site resection. CT scans of the involved extremities were negative for any suspicious lesions in all patients up until the most recent follow-up.

Conclusions: Our study and review of the literature suggest that the incidence of tumor seeding the CNB tract in bone sarcoma patients is apparently low, and possibly negligible. CNB should be performed through the most direct approach to the tumor, and LSS can be performed safely through the standard approaches without excision of the biopsy tract.

INTRODUCTION

Bone sarcomas comprise around 1% of all malignancies diagnosed annually in the United States.1 The biopsy method of choice in these sarcomas remains controversial, since randomized controlled trials to compare core-needle biopsies (CNB) with the open biopsy procedure have not been conducted yet.2,3 However, in the era of minimally invasive intervention, several authors have advocated the use of CNB as an index diagnostic measure. This technique has provided accuracy rates ranging from 88% to 96% in bone sarcomas when adequate samples are obtained.4,6

The open biopsy technique has been associated with a significantly increased risk of tumor seeding along the biopsy tract when the scar is not removed en-bloc during surgical resection of the tumor.7 Similar experience with CNB remains limited. Nevertheless, it has been suggested that CNB must be performed along the standard surgical incision site and its tract should be excised during tumor resection. However, the majority of radiologists tend to choose the most optimal approach to the tumor, disregarding the standard incision site. This is to avoid multiple biopsy attempts and to attain the highest possible yield. Moreover, surgeons often cannot localize the needle site during definitive surgery which is usually scheduled following 12 weeks of neo-adjuvant chemotherapy.

We herein evaluate the local recurrence rate (LRR) of bone sarcoma along the CNB tract in patients who underwent Limb Salvage Surgery (LSS) following a diagnostic CNB performed irrespective of the planned surgical incision site and for which surgery did not involve any biopsy tract removal.

PATIENTS AND METHODS

This is a retrospective review of bone sarcoma cases in pediatric patients (≤ 21 years) diagnosed at the American University of Beirut Medical Center (AUBMC) between January 2001 and December 2005. After receiv-
The Risk of Local Recurrence along the Core-Needle Biopsy Tract in Patients with Bone Sarcomas

ing approval for our study from the Institutional Review Board (IRB), we identified 22 patients, 10 of whom were diagnosed by CNB and underwent subsequent LSS for bone sarcoma of the extremities. These ten patients were included in this study. Medical records, pathological specimens and radiological films of these patients were reviewed from the date of diagnosis until the most recent follow-up.

The mean age of the patients at diagnosis was 12.5 years (range: 7 to 18 years) with a male to female ratio of 1:1 (see Table 1). All patients had stage IIB tumors at diagnosis.

Biopsy

All biopsies were performed under computed tomography (CT)-guidance using a 12-gauge coaxial cutting needle (Ackermann Bone Biopsy Needle Set, William Cook Europe). Biopsies were performed under local anesthesia by an experienced interventional radiologist without the presence of an orthopaedic surgeon. The most direct approach to the soft tissue mass was selected and used for CNB. The site of biopsy was recorded for each patient. After confirmation of the diagnosis, patients were started on neoadjuvant chemotherapy as per the St. Jude-Children’s Research Hospital (Memphis, TN) protocols.

Surgery

Surgical resection was performed through a medial standard incision in nine patients with knee tumors and through an anterior approach in one patient with tumor of the humerus, without any attempt at excision of the CNB tract. The surgical margins in all patients were either normal or had no viable tumor.

Follow-up

Postoperatively, patients were followed-up clinically and radiographically every three months for two years and then every six months up until the most recent follow-up. The average time for follow-up was four years (range, two to six years). The involved extremity was examined by the surgeon looking for any suspicious nodule or mass. A CT scan of the involved extremity was also performed. CT images were evaluated for any suspicious lesions suggestive of local recurrence in the bone or surrounding soft tissue. Metastatic workup was completed by a technetium bone scan for local and distant metastases and a CT scan of the chest for distant metastases. All patients were compliant to follow-up schedules.

RESULTS

Of the 10 patients reviewed, none experienced local recurrence during their follow-up, despite the lack of biopsy site resection. CT scans of the involved extremities were negative for any suspicious lesions in all patients up until the most recent follow-up. Two patients experienced distant relapse seen on CT scans of the chest during follow-up, not associated with any evidence of local recurrence. One (patient #3) had a lesion in the left upper lobe and underwent radical resection of the lobe. The other (patient #8) also had a lesion in the left upper lobe. This patient also had a relapse of the tumor in his spine seen on bone scans. He died on treatment for his metastatic disease. No other patients showed evidence of local or distant metastasis on bone scan up until the most recent follow-up.

Of the 10 cases, final biopsies were performed from an anteromedial approach in five cases, one from an ant-

<table>
<thead>
<tr>
<th>Patient number</th>
<th>Age (yrs)</th>
<th>Gender</th>
<th>Follow-up (yrs)</th>
<th>Tumor site</th>
<th>CNB approach</th>
<th>Local recurrence</th>
<th>Distant relapse</th>
<th>Tumor necrosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12</td>
<td>F</td>
<td>6</td>
<td>Tibia</td>
<td>Anteromedial</td>
<td>None</td>
<td>No</td>
<td>91%</td>
</tr>
<tr>
<td>2</td>
<td>11</td>
<td>F</td>
<td>6</td>
<td>Tibia</td>
<td>Anteromedial</td>
<td>None</td>
<td>No</td>
<td>20%</td>
</tr>
<tr>
<td>3</td>
<td>12</td>
<td>M</td>
<td>5.5</td>
<td>Femur</td>
<td>Anteromedial</td>
<td>None</td>
<td>Yes</td>
<td>80%</td>
</tr>
<tr>
<td>4</td>
<td>17</td>
<td>M</td>
<td>5</td>
<td>Shoulder</td>
<td>Anterior</td>
<td>None</td>
<td>No</td>
<td>100%</td>
</tr>
<tr>
<td>5</td>
<td>14</td>
<td>F</td>
<td>3.5</td>
<td>Tibia</td>
<td>Anteromedial</td>
<td>None</td>
<td>No</td>
<td>100%</td>
</tr>
<tr>
<td>6</td>
<td>18</td>
<td>F</td>
<td>3.5</td>
<td>Femur</td>
<td>Lateral</td>
<td>None</td>
<td>No</td>
<td>100%</td>
</tr>
<tr>
<td>7</td>
<td>13</td>
<td>M</td>
<td>3.1</td>
<td>Femur</td>
<td>Anteromedial</td>
<td>None</td>
<td>No</td>
<td>100%</td>
</tr>
<tr>
<td>8</td>
<td>11</td>
<td>M</td>
<td>3</td>
<td>Femur</td>
<td>Anteromedial</td>
<td>None</td>
<td>Yes</td>
<td>50%</td>
</tr>
<tr>
<td>9</td>
<td>7</td>
<td>F</td>
<td>2</td>
<td>Femur</td>
<td>Anteromedial</td>
<td>None</td>
<td>No</td>
<td>100%</td>
</tr>
<tr>
<td>10</td>
<td>8</td>
<td>M</td>
<td>6</td>
<td>Femur</td>
<td>Lateral</td>
<td>None</td>
<td>No</td>
<td>80%</td>
</tr>
</tbody>
</table>

CNB = core-needle biopsy
The en-bloc. gone open biopsies without removal of the biopsy tract increases from 7% to 38% in patients who have undergone open biopsies. Without removal of the biopsy tract may not be high enough to warrant excision of the biopsy tract in bone sarcoma patients diagnosed by CT-guided biopsies. The question was raised as to whether surgeons should identify and excise the needle tract of CNBs at the time of the definitive surgery to avoid possible seeding of the tumor. This is important since local recurrence has been shown to negatively impact the survival of patients with operable bone sarcoma.

A recent publication recommended that the CNB approach be made along the plane of the standard surgical incision. This would make the job of the surgeon much easier, yet this biopsy approach may not always yield the most appropriate sample for accurate diagnosis especially when the tumor bulk is arising from the far cortex. This was observed in two of our patients where an anteromedial approach retrieved an inconclusive sample, but an accurate diagnosis was made from an anterolateral approach in one and a lateral approach in the other. This is important because an early, accurate diagnosis can greatly improve the patient’s prognosis and multiple biopsy attempts would delay the definitive diagnosis and treatment. Of note, both techniques did not affect retrieval of tissue specimens for additional testing, especially for molecular diagnosis of solid tumors, mainly Ewing’s and synovial sarcoma.

Davies et al. (1993) were the first to describe a case in which there was recurrence of the osteosarcoma along the needle biopsy tract. Most studies of bone sarcomas have not identified any reports of recurrence along the needle biopsy tract. As mentioned in a recent review of the literature, there has not been any quantification of the risk of recurrence in patients undergoing CNB without en-bloc resection of the tract. Additionally, in breast carcinoma, where there is an abundance of experience with CNB, studies have failed to show that the possibility of needle tract seeding is of any clinical significance. However, there is a general consensus that the biopsy must be performed in coordination between the interventional radiologist and the orthopaedic surgical oncologist so that the tract may be removed during the definitive surgery. Our study and review of the literature suggest that the incidence of tumor seeding the biopsy tract in bone sarcoma patients diagnosed by CNB and after follow-up of LSS without excision of the biopsy tract may not be high enough to warrant excision of the entire tract. In fact, we have found not any patient in our center that has experienced local recurrence of tumor at the biopsy tract after several years of follow-up.

Our study has several drawbacks, including the small number of patients, the inclusion of two histological types of bone sarcoma (Ewing sarcoma and osteosarcoma), and the multiple tumor sites, but all patients were treated along a well-established protocol, operated on by the same surgical team, and followed strict follow-up protocols. Given the rarity of bone sarcomas, conducting large, multi-center studies with long-term follow-up in order to fully quantify the risk of tumors seeding the biopsy tract would be quite a difficult, albeit unlikely,
undertaking. Yet, any significant change in current practice would only be brought about by such studies. However, from our small study it seems that the rate of recurrence in these patients is apparently low, and possibly negligible.

REFERENCES
MATERIAL PROPERTIES OF COMMON SUTURE MATERIALS IN ORTHOPAEDIC SURGERY

S. Najibi,*† R. Banglmeier,† J.M. Matta,* M. Tannast*†

ABSTRACT

Suture materials in orthopaedic surgery are used for closure of wounds, repair of fascia, muscles, tendons, ligaments, joint capsules, and cerclage or tension band of certain fractures. The purpose of this study was to compare the biomechanical properties of eleven commonly used suture materials in orthopaedic surgery. Three types of braided non-absorbable and one type of braided absorbable suture material with different calibers (n=77) underwent biomechanical testing for maximum load to failure, strain, and stiffness. All samples were tied by one surgeon with a single SMC (Seoul Medical Center) knot and three square knots. The maximum load to failure and strain were highest for #5 FiberWire and lowest for #0 Ethibond Excel (p<0.001). The stiffness was highest for #5 FiberWire and lowest for #2-0 Vicryl (p<0.001). In all samples, the failure of the suture material occurred at the knot. There was no slippage of the knot in any of the samples tested. This data will assist the orthopaedic surgeon in selection and application of appropriate suture materials and calibers to specific tasks.

INTRODUCTION

Suture materials have multiple applications in orthopaedic surgery ranging from closure of surgical wounds, repair of fascia, muscles, tendons, ligaments, joint capsules, and cerclage or tension band of certain fractures. The quality of tissue repair is dependent on multiple variables including tissue characteristics, material properties of the suture, and surgical technique. The choice of suture material has important implications in tissue repair. Adverse surgical outcomes can be avoided by selection of the suitable suture materials for appropriate indication.4,9,11,12,15,16,19,20,21

Surgical complications associated with failure of tissue repair include wound dehiscence, re-rupture of muscle, tendon and ligaments, incisional hernia, failure of repair of capsulolabral structures, and loss of reduction of fractures.4,9,11,12,15,16,19,20,21 Different knots and anchor materials have been studied extensively.2,3 However, manufacturer-independent information on the biomechanical properties of commonly used suture materials with varying calibers in orthopaedic surgery is not available.

We raised the following four questions: what is (1) the maximum load to failure, (2) the strain, (3) the stiffness, and (4) the location of material failure for each of the selected suture types?

MATERIALS AND METHODS

An experimental, comparative study of commonly used suture materials in orthopaedic surgery was performed. Three types of braided non-absorbable and one type of braided absorbable suture material with various calibers were tested. The braided non-absorbable suture materials included Numbers 2 and 5 FiberWire (Arthrex, Naples, FL); Numbers 0, 1, 2, and 5 Ethibond Excel (Ethicon, Somerville, NJ); and Numbers 2 and 5 TiCron (Sherwood-Davis & Geck, St. Louis, MI). The braided absorbable suture material included Numbers 2-0, 0, and 1 Vicryl (Ethicon, Somerville, NJ). This yielded a total of eleven suture materials for testing.

FiberWire is made with a core of several small individual strands of biocompatible polyethylene covered with braided polyester suture material. Ethibond suture is made from braided polyester and coated with polybutyrate for easier tying. TiCron is made of braided polyethylene coated with silicone. Vicryl is a braided suture material made by copolymerization of lactide and glycolide.

A pilot study was performed on a set of four randomly selected suture types from the aforementioned eleven varieties. This was done in order to have a manufacturer-independent data for a power analysis and calculation of the adequate sample sizes. With an alpha level of 0.05 and a test power of 0.8, the calculated sample size (i.e., the minimum number of samples of each suture type.
tested) was 4 for each suture. An n of 7 of each group was selected to minimize alpha and beta errors.

The diameter of all suture samples were measured and recorded with a digital caliper (E-Base Measuring Tools Co., Taiwan, Table 1) prior to biomechanical testing. The suture samples were looped over two stainless steel hooks which were placed at a distance of 50mm from one another. The free ends of the sutures were tied with a single SMC (Seoul Medical Center) knot with three half-hitches over reversed posts.13 The SMC knot was chosen because of its superior characteristics in regards to strength and slippage.1,8,18 Three half-hitches could be shown to be optimal for the knot-holding capacity.14 All the knots were tied by one experienced surgeon (SN). This was done in a nonaqueous environment under direct visualization. The free ends of the sutures were secured with a surgical clamp 5mm distal to the knot. This was performed to assess any knot slippage. The suture material was marked at the knot to detect any slippage. The completed suture loops were loaded onto a model 8501M Instron servo hydraulic machine (Instron, Canton, MA), pre-tensioned to 10 N and loaded to failure at 1mm per second.

The following variables were recorded for each suture sample (n=77): (1) the load to failure, (2) the strain at maximum load to failure, (3) the stiffness as the ratio of load to displacement on the linear portion of the stress strain curve, and (4) the location of material failure. The experimental reproducibility of the first three variables was detected with the intraclass correlation coefficient (ICC). A very good reproducibility was found for all three continuous variables with an ICC of 0.99 (95% confidence interval 0.99 – 0.99) for load to failure, 0.88 (0.73 – 0.96) for strain, and 0.97 (0.95 – 0.99) for stiffness, respectively. The Kappa coefficient was used for assessment of the reproducibility of the location of material failure. A Kappa of 1.0 was found for failure at the knot.

We used the Kolmogorov-Smirnov test to assess the normal distribution for load of failure, strain, and stiffness. We used one-way ANOVA to assess differences among the eleven different suture materials for these three key variables. When a difference between groups was identified with ANOVA, we compared group means using an unpaired Student’s t-test. The level of significance was set at 0.05.

**RESULTS**

There was a statistically significant difference for the average maximum load to failure among the eleven different suture types (p < 0.001, Table 2). The highest load of failure was found in Number 5 FiberWire followed by Number 2 FiberWire. The lowest load to failure was found in Number 0 Ethibond Excel.

There was a statistically significant difference for the average strain among the eleven different suture types (p < 0.001, Table 2). The highest strain occurred in Number 5 FiberWire followed by Number 5 TiCron. The lowest occurred in Number 0 Ethibond Excel.

There was a statistically significant difference for the average stiffness among the eleven different suture types (p < 0.001, Table 2). The highest stiffness was calculated for Number 5 FiberWire followed by Number 2 FiberWire. The lowest stiffness occurred in 2-0 Vicryl.

Of the 77 tested suture samples, all the failures occurred at the knot where the suture broke. There was no knot slippage in any of the samples.

---

**TABLE 1. Overview on analyzed braided suture materials and calibers**

<table>
<thead>
<tr>
<th>Type of suture</th>
<th>Bioabsorbability</th>
<th>Material</th>
<th>Cross-section area [mm²]</th>
<th>Diameter [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number 5 FiberWire</td>
<td>Non-absorbable</td>
<td>polyethylene covered with braided polyester</td>
<td>0.75</td>
<td>0.98</td>
</tr>
<tr>
<td>Number 2 FiberWire</td>
<td>Non-absorbable</td>
<td>polyethylene covered with braided polyester</td>
<td>0.37</td>
<td>0.69</td>
</tr>
<tr>
<td>Number 5 Ethibond Excel</td>
<td>Non-absorbable</td>
<td>braided polyester and coated with polybutylate</td>
<td>0.61</td>
<td>0.88</td>
</tr>
<tr>
<td>Number 2 Ethibond Excel</td>
<td>Non-absorbable</td>
<td>braided polyester and coated with polybutylate</td>
<td>0.27</td>
<td>0.58</td>
</tr>
<tr>
<td>Number 1 Ethibond Excel</td>
<td>Non-absorbable</td>
<td>braided polyester and coated with polybutylate</td>
<td>0.23</td>
<td>0.54</td>
</tr>
<tr>
<td>Number 0 Ethibond Excel</td>
<td>Non-absorbable</td>
<td>braided polyester and coated with polybutylate</td>
<td>0.16</td>
<td>0.44</td>
</tr>
<tr>
<td>Number 5 TiCron</td>
<td>Non-absorbable</td>
<td>braided polyethylene coated with silicone</td>
<td>0.5</td>
<td>0.79</td>
</tr>
<tr>
<td>Number 2 TiCron</td>
<td>Non-absorbable</td>
<td>braided polyethylene coated with silicone</td>
<td>0.25</td>
<td>0.56</td>
</tr>
<tr>
<td>Number 1 Vicryl</td>
<td>Absorbable</td>
<td>braided copolymerized lactide and glycolide</td>
<td>0.21</td>
<td>0.51</td>
</tr>
<tr>
<td>Number 0 Vicryl</td>
<td>Absorbable</td>
<td>braided copolymerized lactide and glycolide</td>
<td>0.14</td>
<td>0.42</td>
</tr>
<tr>
<td>Number 2-0 Vicryl</td>
<td>Absorbable</td>
<td>braided copolymerized lactide and glycolide</td>
<td>0.09</td>
<td>0.33</td>
</tr>
</tbody>
</table>
The choice of suture material for tissue repair in orthopaedics is influenced by multiple factors. These include the caliber of the suture, material properties of the specific tissues being repaired (fascia, tendon, or bone), balance between rigid and elastic fixation (e.g., fracture fixation versus tendon repair), location of the repair (superficial versus deep), and bioabsorbability. The purpose of this study was to assess the material properties of the most common suture materials of various calibers used in orthopaedics. This data will assist the orthopaedic surgeon in selection and application of appropriate suture materials and calibers to specific tasks.

One limitation of this study was in vitro testing of the materials. FiberWire, Ethibond and TiCron are not bioabsorbable and the material properties do not change in vivo. Vicryl, however, is bioabsorbable and the in vitro data is representation of the initial suture strength. Another limitation of the study was that only a single load to failure as opposed to cyclic loading was performed. It is possible that the suture materials may undergo dynamic creep with cyclic loading. However, in order for the results to be applicable to a clinical worst-case scenario, a single load to failure test was performed. This was to assess the tolerance and material properties of the suture materials at their yield point.

Clinical application of different suture materials is influenced by multiple factors. These factors include the material properties of the suture and the tissues being repaired, the desired stiffness of the construct, and the potential for bioabsorbability. For example, in the case of the four-part proximal humerus fracture where the greater and lesser tuberosities need to be repaired but rigid fixation with screws is not possible, non-absorbable suture materials with a high-load to failure and caliber are ideal (i.e., Number 5 FiberWire in conjunction with Number 5 Ethibond).

Other examples are repair of subcutaneous fascia layers and tendons such as reattachment of the abdominal muscles to the iliac crest, repair of fascia lata, or repair of the Achilles tendon. In these applications, an absorbable suture material is more desirable compared to a non-absorbable suture material of equivalent strength and stiffness. The non-absorbable suture materials and knots can be palpable, irritating, and a nidus for infection. An unexpected finding of this study was that Number 1 Vicryl has equivalent strength to Number 2 Ethibond and Number 2 TiCron. The bioabsorbability of Vicryl is an advantage in the aforementioned applications. Moreover, selection of appropriate suture material and caliber is important in avoiding potential complications. In one study, abdominal hernias were reported after reattachment of the abdominal muscles to the iliac crest with 2-0 Vicryl. This could potentially be avoided with utilization of Number 1 Vicryl for this task.

In comparison of Number 5 caliber FiberWire, Ethibond and TiCron, the highest load to failure and stiffness were recorded in Number 5 FiberWire. In comparison to 18 gauge stainless steel wire (load to failure 910 N, stiffness of 320 N/mm), single loop Number 5

<table>
<thead>
<tr>
<th>Type of suture (n=77)</th>
<th>Max. load to failure [N]</th>
<th>Strain [%]</th>
<th>Stiffness [N/mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number 5 FiberWire</td>
<td>620 ± 29</td>
<td>23 ± 7</td>
<td>62 ± 18</td>
</tr>
<tr>
<td>Number 2 FiberWire</td>
<td>282 ± 30</td>
<td>16 ± 3</td>
<td>35 ± 6</td>
</tr>
<tr>
<td>Number 5 Ethibond Excel</td>
<td>247 ± 10</td>
<td>18 ± 2</td>
<td>25 ± 2</td>
</tr>
<tr>
<td>Number 2 Ethibond Excel</td>
<td>134 ± 9</td>
<td>18 ± 2</td>
<td>13 ± 2</td>
</tr>
<tr>
<td>Number 1 Ethibond Excel</td>
<td>118 ± 7</td>
<td>15 ± 1</td>
<td>12 ± 1</td>
</tr>
<tr>
<td>Number 0 Ethibond Excel</td>
<td>73 ± 5</td>
<td>13 ± 1</td>
<td>12 ± 1</td>
</tr>
<tr>
<td>Number 5 TiCron</td>
<td>226 ± 12</td>
<td>22 ± 4</td>
<td>19 ± 5</td>
</tr>
<tr>
<td>Number 2 TiCron</td>
<td>136 ± 3</td>
<td>16 ± 1</td>
<td>14 ± 1</td>
</tr>
<tr>
<td>Number 1 Vicryl</td>
<td>130 ± 9</td>
<td>16 ± 1</td>
<td>15 ± 1</td>
</tr>
<tr>
<td>Number 0 Vicryl</td>
<td>105 ± 6</td>
<td>16 ± 1</td>
<td>12 ± 1</td>
</tr>
<tr>
<td>Number 2-0 Vicryl</td>
<td>76 ± 3</td>
<td>15 ± 1</td>
<td>10 ± 1</td>
</tr>
</tbody>
</table>

**DISCUSSION**

*The Iowa Orthopaedic Journal*
FiberWire is the suture material which has the closest material properties. It can be utilized for tension band fixation of subcutaneous fractures such as olecranon or patellar fracture without the need for future hardware removal. In addition, Number 5 FiberWire has the advantage of being less irritating to subcutaneous tissues than stainless steel wire.

There are several studies in the literature which assess the biomechanical properties of sutures. Most of these studies assess material properties of specific suture knots, pull out strength of anchors or comparison of one type of suture versus stainless steel wire. Some of the data in these studies is comparable and supportive of our data (Table 3). However, none of these studies assesses the material properties of the various calibers of most common suture materials.

In summary, the choice for application of suture material is guided by matching the material properties of the tissues being repaired to that of the suture material.

**REFERENCES**


TRACE METAL ANALYSIS FOLLOWING LOCKED VOLAR PLATING FOR UNSTABLE FRACTURES OF THE DISTAL RADIUS

Lucas S. Rylander, M.D., Joseph C. Milbrandt, Ph.D., Evan Armington, M.D., Marty Wilson, B.S., David J. Olysav, M.D.*

ABSTRACT
An increase in the utilization of metallic devices for orthopaedic interventions from joint replacement to fracture fixation has raised concern over local metal ion release and possible systemic sequelae due to dissemination of these ions. Our purpose was to determine whether serum titanium concentrations were elevated in patients who had previously received a locked volar distal radius plate. Our hypothesis was that the simple presence of titanium alone in a relatively fixed implant was not enough to raise serum titanium levels. Twenty-two potential subjects who had received a volar locked distal radius plate were identified through review of a single surgeon’s operative logs. Eleven met inclusion criteria. Serum titanium levels were measured in these subjects and compared to both current and historical control groups. We found no difference between controls and our study group. We conclude that a locking titanium volar distal radius plate does not raise serum titanium levels in this population.

INTRODUCTION
A dramatic increase in the utilization of metallic devices for orthopaedic interventions from joint replacement to fracture fixation has raised concern over local metal ion release and the possible development of systemic sequelae due to dissemination of these ions. Several deleterious effects have been associated with increased metal ion levels including bone loss, prosthetic loosening, local tissue toxicity, hypersensitivity reactions, and even malignant cellular transformation. Considerable research supports elevated metal ion levels in the serum and urine of patients with metal-on-metal hip implants as well as in modular femoral stems and spinal instrumentation. Few studies, however, have examined whether fixed metallic implants, such as a locked volar distal radius plate, can also result in an increase in systemic metal ion levels.

All metal implants in vivo may undergo corrosion and wear which will result in the production of metal ions and surface degradation products. With fracture fixation devices such as intramedullary nails or volar plates, this phenomenon may be facilitated by micromotion of the implant, galvanic corrosion between materials of differing composition in close proximity, and fretting corrosion between the nail-screw or plate-screw interface. Most studies reporting on serum ion levels in patients have been in the context of a joint replacement device. With fracture fixation devices, which are used regularly in far younger patients than those commonly undergoing a total joint arthroplasty, there is the potential for significantly prolonged exposure to metal ions produced by that implant.

The shedding of metal ions greatly increases the total surface area in contact with the body. Locally, metal ions enter the cells and may alter the intracellular processes. Systemically, they undergo wider dissemination as both free ions and ingested particles that are transported to sites remote from the implant, including the spleen, regional lymph nodes, and the lungs, all of which may be adversely affected. Studies into possible carcinogenic effects have shown a correlation between chromosomal damage and elevations in degradation products and metal ions. This correlation appears to be dose-dependent and specific to the type of metal. Also, several studies have noted moderate elevations in hematopoietic malignancies in patients with hip arthroplasties. Since fracture fixation devices are generally amenable to removal, should elevations in local or systemic ions be discovered in association with fixed implants, patients may benefit from earlier removal of implants following fracture union.

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We wished to determine whether serum titanium (Ti) concentrations in patients who had previously undergone open reduction and internal fixation of distal radius fractures using locked volar plates were elevated in comparison to control groups. We hypothesized that the mere presence of a titanium implant was not sufficient to significantly elevate serum titanium levels, but that device motion also is required for serum titanium to reach detectable levels.

MATERIALS AND METHODS

Study Design

This is a retrospective, non-randomized study comparing postoperative serum titanium concentrations in patients with a previously implanted unilateral volar distal radius locked plate.

Implant Type

The implant used in the current study was a DVR (distal volar radius) plate manufactured by Hand Innovations. It consists of a titanium plate with two distal rows of locked titanium screws and a variable length for the radial shaft where screws are of non-locking variety. In our study, we used exclusively three-hole plates with screws placed in all three proximal holes on the radial shaft. Motion of this device, theoretically, should be limited to only the three proximal non-locked screws which are stabilized by friction fit at the screw-plate-bone interface.

Patient Selection

Potential subjects were identified through review of a single surgeon's operative logs and hospital billing codes. Patients deemed eligible for the study had previously undergone open reduction and internal fixation of a unilateral distal radius fracture with the previously described hardware construct. The patient's medical records were reviewed to ensure they had no other artho-implants which might otherwise elevate titanium levels above that from the volar plate alone. Only patients with three-hole plates and all three proximal screw holes filled were included in our study. Subjects were contacted, consented to participate, and asked to provide a venous blood sample for trace metal analysis. Trace metal analysis was performed by a contract laboratory. Patient data was then compared to a control group previously established from prior ion studies within our department as well as to a current control group of volunteers free of any implanted metallic devices. The current control group was sent for evaluation with the same batch of samples from our study group in order to eliminate differences in laboratory analysis.

Serum Collection and Ti Analysis

Venous blood samples were collected and processed from each subject. Venipuncture was performed with needles and syringes verified to be free of trace metal contamination. Blood samples were collected in SARSTEDT Monvetter (neutral) blood collection tubes via a Vacutainer Brand Safety-Lok 21G3/4 butterfly blood collection set with a Multi-Adapter (SARSTEDT 0197). A total of 30 ml was collected from each subject. To further limit possible contamination, the first 10 ml collected served as an apparatus washout and was discarded. Collected blood samples were allowed to clot for 30 minutes and then were centrifuged. The serum aliquots were collected and frozen at -80°C until processed for trace metal analysis.

Serum samples from implanted and control subjects were sent for Ti analysis to a single contract laboratory which utilized high resolution inductively coupled plasma-mass spectrometry (ICP-SFMS) (SGAB Analytica, Luleå, Sweden). Serum samples were analyzed for Ti (isotopes 47 and 49) after 20-fold dilution (0.14M supra-pure HNO3 in DDIW) using ICP-SFMS operated in medium resolution mode. Instrumental drift was corrected using internal standardization (In) and quantification was done by external standardization. Quality control/assurance procedures included analysis of blank samples and serum control materials (SERO AS, Norway) were processed along with study samples. The detection limit reported was 0.25 mg/L (ppm). Additional details on operating conditions and measured parameters were reported by Rodushkin et al., 2001.

Statistical Analysis

Subgroup comparisons were made using analysis of variance (ANOVA) and student's t-test. A p-value of <0.05 was considered to be significant.

RESULTS

A total of 22 subjects were identified for potential inclusion in the study. Of the 22, one declined to participate and 10 were unable to be contacted or reached. A total of 11 subjects (8 females, 3 males) with a mean age of 63 years agreed to participate. Demographic data for our patients is listed in Table 1 including age, sex, height, weight, and time since surgery.

Trace metal analysis revealed that only one subject had a serum titanium concentration (0.58 µg/L) above the minimum detectable level (0.25 µg/L). All controls also had levels below the detection limit except for a positive control that sustained daily titanium exposure due to welding and had a titanium level of 2.86 µg/L (Figure 1). Titanium levels in both historical and current controls as well as those individuals with volar plates...
were lower than those reported for two separate hip prostheses (one non-modular, one modular) as well as for those individuals with spinal instrumentation (Figures 2, 3). No evidence of any implant loosening was found on postoperative imaging review.

**DISCUSSION**

Previous studies within our department have found increased serum titanium levels with both spinal instrumentation as well as modular and non-modular femoral total hip stems. Multiple studies have found increased cobalt (Co) and chromium (Cr) levels with metal-on-metal total hip bearings. Concern over the effect of these ions both in the form of local tissue reactions as well as systemically have led to numerous investigations into their effect with no conclusive results to date.

In our review of the literature, we were unable to find a study to show that a fixed titanium implant in the body does not result in elevated serum titanium levels. We felt it was important to determine whether the presence of a static titanium implant was significant enough to raise systemic titanium levels, or if other factors were required to generate significant increases in systemic titanium levels. Should evidence continue to mount regarding deleterious effects of increased local or systemic metal ion concentrations, this study would allow us to better stratify device safety protocols and develop guidelines for removal of fracture fixation devices if indicated.

The Hand Innovations DVR plate is a commonly implemented orthopedic implant used to treat fractures of the distal radius. Because it is a mostly fixed angle device made of titanium with motion only occurring at the non-locked radial shaft screw-plate interface, it is ideally suited to demonstrate that fixed titanium implants alone are not sufficient to cause serum ion elevations. While micromotion is possible at the plate-screw-bone interface, the friction fit at this site evidently is enough to disallow systemic ion elevations based on our results. Whether ions are produced at all or if production takes place but renal clearance occurs rapidly enough to prevent detection is not known based on our study. Regardless, it appears that titanium ion levels are essentially undetectable with the three-hole DVR model.

Several questions remain to be answered. Our study was able to evaluate systemic ion levels but we are unable to comment on whether local soft tissue concentrations are increased, and what, if any, effect this may have. In

### TABLE 1

<table>
<thead>
<tr>
<th>Study Population</th>
<th>Volar-plated subjects</th>
<th>Study Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Subjects</td>
<td>11</td>
<td>4</td>
</tr>
<tr>
<td>Gender (M/F)</td>
<td>3/8</td>
<td>1/3</td>
</tr>
<tr>
<td>Age (years)</td>
<td>63 ± 15 (36 to 83)</td>
<td>56.3 ± 5</td>
</tr>
<tr>
<td>Height (inches)</td>
<td>66.6 ± 2.7 (63.5 to 72)</td>
<td>66.5 ± 4.5</td>
</tr>
<tr>
<td>Weight (pounds)</td>
<td>171.8 ± 36.8 (129 to 240)</td>
<td>221 ± 42.8</td>
</tr>
<tr>
<td>Time since surgery (months)</td>
<td>26.8 ± 9.0 (14 to 39.5)</td>
<td>N/A</td>
</tr>
</tbody>
</table>

**Figure 1.** Serum Titanium Concentration in Control vs. Study Groups. Concentrations in subjects with volar plates were not elevated when compared to controls. An employed welder served as a positive control for the analysis.

**Figure 2.** Serum Ti concentrations of study and historical controls vs. volar plating, modular and non-modular Ti hip prostheses, and Ti spinal instrumentation. No differences in control concentrations were observed in our study versus historical controls. Serum titanium concentrations in patients with modular and non-modular total hip prosthesis (1 year post-implant) and titanium spinal implants (2 years post-implant) are shown for reference (mean ± SD).
addition, because our data is specific to titanium, we are unable to stratify our results to other metal ions such as cobalt or chromium. These two ions are very important in the current controversy over metal-on-metal implants as they form the bearing surfaces for those prostheses. Unfortunately, there are currently no commonly used cobalt-chromium fixed implants that are free of motion for us to evaluate and establish as a control group for these metals like there is with the currently studied titanium plates. Finally, we are unsure if continued long term exposure of the studied device will eventually cause increased serum titanium levels. We would hypothesize that once fracture union occurs no further device motion would take place and therefore no further increase in titanium levels would result. Further studies are needed to verify this theory.

It is important to address several limitations of our study. First, it is retrospective in nature and we lack preoperative serum ion levels for comparison. Secondly, only one size of implant with a fixed amount of titanium was evaluated. A larger implant exposing the body to a higher amount of titanium could conceivably result in elevated ion levels. Further, we don’t have a similar device exposed to movement to show that motion of the current implant could increase serum titanium levels. However, we feel that previous studies focusing on hip and spine implants showing increased titanium levels support this conclusion. Despite these limitations, we feel that our study demonstrates that the presence of a relatively fixed angle titanium device alone is not enough to cause detectable increases of systemic ion levels. This increases the applicability and confidence we will be able to place in future studies of titanium devices which do allow implant motion.

CONCLUSIONS

Our findings suggest that fixed titanium DVR plates do not result in a detectable increase in systemic exposure to trace metal ions. The absence of titanium elevations in this study population leads us to conclude that micro-motion at plate-screw-bone interfaces is not sufficient to yield a detectable increase in systemic titanium levels. These data establish that the presence of bodily titanium alone is not enough to generate detectable increases in serum titanium levels in contrast to data previously found in modular and non-modular femoral stems and spinal instrumentation. We propose that device motion may be necessary for increased serum titanium levels to occur.

REFERENCES


ABSTRACT
Background: Compound limb fractures due to high-velocity missiles are complex and usually associated with multiple other injuries. These can occur in both military and civilian settings. High-velocity missiles are presently used by terrorists worldwide. Early surgical debridement and skeletal fixation are the gold standards in managing these injuries, but data supporting these recommendations are lacking.

Aim of the study: Our aim was to determine the relationship between time (the time of injury to the time of surgical treatment) and the rate of deep infection in patients treated in Medical City, Baghdad, Iraq due to terrorist activity from 2004-2008.

Design: This is a retrospective review of a series of open limb fractures.

Patients and method: A total of 102 civilian patients with 114 limb fractures due to high-velocity missile injuries were selected for this study from Medical City records. Patients were followed in the outpatient department in Medical City Teaching Complex both clinically and radiologically.

Results: Surgical treatment was accomplished in less than six hours from time of injury in group A (55 fractures, 48.4%) and more than six hours in group B (59 fractures, 51.7%). The infection rate for group A was 30.9% and group B was 23.7%.

Conclusion: A very high infection rate was noted for these injuries, and there was no increase in the rate of deep infection in patients treated more than six hours after the injury.

INTRODUCTION
Open fractures due to high-velocity missile injuries (bullets and shells) are very extensive injuries; there has been an increase in the number of these injuries in civilian sectors due to terrorism. The injuries concomitant with the open fractures have long been considered surgical emergencies.

Most texts recommend surgical debridement within six to eight hours of injury for any open fracture. The American College of Surgeons Committee on Trauma, in its Resources for Optimal Care of Injured Patients, indicates six hours is the benchmark time from injury to debridement of open fractures in trauma centers.

Missiles used in Iraq may be solid, such as those from pistol or rifle bullets, but they may also be fragments of shells, land mines or grenades. Missiles can be high-, medium-, or low-velocity. Medium- and high-velocity missiles produce almost the same pattern of injury: damage to the body by laceration, crushing, shock waves and cavitation. Low-velocity missiles damage by laceration and crushing only. In land mine injuries the damages are produced primarily by a blast effect, secondarily by fragments entering the body, and thirdly by whole-body propulsion and burns. In addition to all of these pathophysiologic effects, psychological trauma must be considered.

Management of open limb fractures involves patient resuscitation, wound and limb assessment, fracture classification, intravenous antibiotics and administration of tetanus toxiod. Best practices suggest urgent debridement of the wound and stabilization of the fracture using a range of techniques. Others have said that a delay in surgical management of open fractures does not significantly increase infection rates.

There are many complications with missile injuries such as infection, nonunion and malunion in addition to social, economic and psychological factors. Most of these injuries require long-term treatment protocols and care from many medical specialties to allow the patient return to a normal or near-normal life.

There is a lot of literature showing that six hours is the gold standard for management of open fractures from multiple causes (including injuries from missiles).
Early or Delayed Surgical Treatment in Compound Limb Fractures Due to High Velocity Missile Injuries

However, most of these authors collected data from patients with open fractures due to causes other than missile injuries.

A large number of injuries occur in Iraq from both high- and low-velocity missiles, and many patients arrive in Medical City and at other medical facilities more than six hours post injury. Our medical staff has performed many operations on patients who presented many days after their injuries. However, all of them received antibiotic prophylaxis, and we collected data from them for follow-up so we might discover the effects of delayed surgical management of missile injuries on the rate of infection.

**PATIENTS AND METHODS**

We collected data from patients who were victims of high-velocity missile injuries in Baghdad and who were treated in Medical City (a tertiary center) for the time period between 2004 and 2008. We selected 102 patients with 114 open limb fractures (Table 1) and they were followed in the outpatient department in Medical City for a minimum of one year after treatment. We depended on Medical City data and direct patient questionnaires in addition to medical and radiological follow-ups. Patient selection depended on what surgery was done. We excluded patients with head injuries and patients with extensive limb injuries that required amputation. All our patients were victims of high-velocity missile injuries only (61 blast injuries and 53 bullet injuries).

Initially, we categorized our patients into four groups; those treated within six hours, those treated within seven to 12 hours, those treated within 13 to 24 hours and those treated after more than 24 hours. All patients were treated at the Medical City Emergency Depart-

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**TABLE 1. Surgical management delay by site of injury**

<table>
<thead>
<tr>
<th></th>
<th>Treated more than 24 hours after injury</th>
<th>Treated 13-24 hours after injury</th>
<th>Treated 7-12 hours after injury</th>
<th>Treated less than 6 hours after injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper limb Injuries (19)</td>
<td>8</td>
<td>1</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Lower limb Injuries (19)</td>
<td>16</td>
<td>15</td>
<td>15</td>
<td>49</td>
</tr>
<tr>
<td>Total number of Injuries (114)</td>
<td>24</td>
<td>16</td>
<td>19</td>
<td>55</td>
</tr>
</tbody>
</table>

**TABLE 2. Number of injuries by time of surgical treatment**

<table>
<thead>
<tr>
<th></th>
<th>Group (1) more than 6 hours</th>
<th>Group (2) less than 6 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of open fractures</td>
<td>59</td>
<td>55</td>
</tr>
</tbody>
</table>

---

ment, resuscitated and transferred to the operating room for definitive care including generous surgical wound debridement and skeletal fixation of their fractures. For all patients, we use external fixators (AO type and Hoffman III) to stabilize the fractures.

All patients received triple antibiotics and a few received anti-tetanus injections based on availability (because of the shortage of medication in Iraq).

Superficial infection was defined as the presence of cellulitis or pus involving the soft tissues at the traumatic wound in the absence of clinical or radiological features of osteomyelitis (requiring antibiotic treatment or surgical intervention). Deep infection was defined as the development of osteomyelitis diagnosed clinically (development of chronic discharging sinus) or radiologically, that required surgical debridement of bone. A microbiological culture was not considered essential for the diagnosis of superficial or deep infection, but could be used in the treatment of infection.

Finally, we divided the injuries into two groups as in Table 2.

Missile injuries were classified by the following grading system:

*Minor:* Only soft tissue involvement with no bony, vascular or nerve injury, with or without retained metal (shrapnel or gunshot fragments).

*Moderate:* Soft tissue involvement, nondisplaced or drill fracture, no vascular or nerve injury, with or without retention of metal.

*Severe:* Soft tissue injury with severely displaced, comminuted fracture, usually with retained single or multiple metallic fragments, with vascular or nerve injury or both.

*Ablative:* Extensive soft tissue damage, bone loss associated vascular or nerve injury.
Thus, the elements that define severity of injury are:  
1- The degree of soft tissue damage.  
2- Bony defect or severe comminution.  
3- Vascular or neural injury.  
Injuries were moderate (84) and severe (30).

RESULTS
102 patients with 114 open fractures sustained between 2004 and 2008 were followed for a minimum of one year. Their ages ranged between 12 and 65 years, they were treated in the Medical City Orthopaedic department. Patients were divided in to two groups based on the time from injury to surgical treatment (less than and more than 6 hours). The deep infection rate for Group 1 was 30.9% and for group 2 was 23.7% (table3)

In this group with 114 fractures, there were 31 infections (22 with moderate injuries and 9 with severe injuries), so the severity of injury was not a significant factor in our patient’s infection rate, but this is not a significant conclusion because of the small number of patients. Because there was no increase in the infection rate with increasing time to treatment, a statistical analysis was not carried out.

DISCUSSION
Open fractures are a management challenge in orthopaedic surgery for the following reasons:
1. Variability in mechanism of injury (traffic accidents, blunt trauma, blast injuries, bullet injuries, among others).
2. The degree of contamination present.
3. The delay in transfer of some patients to suitable medical facilities, though urgency of debridement within six to eight hours of injury seems nearly universally accepted.
4. The different types of shock sometimes associated with these injuries. Shock management plays a major role in treatment of compound fractures.
5. The policy for treating these injuries within six hours may not be in the patient’s best interests in all cases. Emergent treatment can result in complex cases being performed during off-hours by relatively inexperienced surgeons, anesthetists and operating theatre staff, with the potential for less favorable outcomes.  
6. Medical co-morbidities.

The primary goal in management of open fractures is the prevention of devastating infection of bone and soft tissues. To achieve this, the most widely accepted treatment protocols include emergent surgical irrigation and debridement of open fracture wounds, administration of broad-spectrum antibiotics, and stabilization of the fracture.  

Thus, the elements that define severity of injury are:

<table>
<thead>
<tr>
<th>Time from injury to operating room</th>
<th>More than 6 hours</th>
<th>Less than 6 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of injuries</td>
<td>59</td>
<td>55</td>
</tr>
<tr>
<td>Number of infections</td>
<td>14</td>
<td>17</td>
</tr>
<tr>
<td>Infection rate</td>
<td>23.7%</td>
<td>30.9%</td>
</tr>
</tbody>
</table>
Early or Delayed Surgical Treatment in Compound Limb Fractures Due to High Velocity Missile Injuries

department. No significant difference was found in the rate of infection between injuries treated in less than six hours versus those treated after seven hours.

Open fractures may require emergent surgical treatment for reasons other than the prevention of infection, such as the preservation of soft tissue viability and vascular status. The findings of Skaggs et al. suggest that, in children who received early antibiotic therapy following an open fracture, surgical debridement within six hours after the injury offered little benefit over debridement within 24 hours after the injury with regard to the prevention of acute infection.

Khatod et al. in a retrospective review of 191 open fractures concluded that the Gustilo grading system of open fractures is a significant prognostic indicator for infectious complications. They found no significant difference between early (less than six hours) and late treatment but they continued to support the emergent treatment of open tibia fractures.

We have noticed that the Gustilo classification for open fractures poorly describes injuries due to missiles. Bullet- and shell-mechanism injuries are totally different from those of blunt trauma since the small skin wounds of the former usually cover extensive damage to underlying soft tissues. We consider all high-velocity missile injuries as grade III Gustilo.

Spencer et al. conducted a prospective audit of 142 open long-bone fractures over the five years between 1996 and 2001 at The Princess Margaret Hospital in Swindon, Great Britain. The authors could not demonstrate a significant increase in infection rates (10.1% for early wound debridement versus 10.8% for late wound debridement) and all their patients received intravenous antibiotics within four hours of injury.

Harley et al. in a retrospective review of 241 open fractures at the University of Alberta Hospital, Edmonton, Alberta, Canada, concluded that the risk of developing an adverse outcome was not increased by aggressive debridement/lavage and definitive fixation up to 13 hours from the time of injury, when early prophylactic antibiotics administration and open fracture first aid were instituted.

Charalambous et al. (UK) in a retrospective study reviewed 383 open tibia fractures and concluded there was no difference between early and delayed treatment groups with respect to overall infections.

Sungaran et al. (Australia) in a retrospective review of 161 open tibia fractures found no increase in infection rate, as five infections occurred in the zero-to-six-hours treatment group and no infections in occurred when treatment was delayed by more than 12 hours. They found that infection correlates with the grade of open injury.

Yassir B. AlArabi et al. (UK) studied 248 open long-bone fractures and showed an infection rate of 7.8%/9.6% for less than six hours/more than six hours injuries respectively.

Time from injury to debridement did not predict infection in bivariable or multivariable analysis, suggesting that something occurring on admission to the definitive treatment center was associated with decreased infection risk. Postulated factors included antibiotic administration and aggressive resuscitation. These two factors need to be investigated further to define the exact cause. Gosselin et al. analyzed data from 913 participants in seven studies, and concluded that the use of antibiotics had a protective effect against early infection compared with no antibiotics or placebo.

Patzakis et al. found that the most important factor contributing to infection in gunshot wounds was the type of missile used. Three of four infections recognized in this study of open fractures were in close-range shotgun wounds, and there was no significant difference between the infection rate of the group receiving no antibiotics and the group receiving antibiotics. They concluded that two cardinal factors influenced the infection rate in 333 open fractures:

1. The presence or absence of pathogenic organisms in wounds when no antibiotic was given.
2. The presence of resistant organisms in wounds when either penicillin/streptomycin combination or cephalothin was given.

There is a large gap between the conclusions of Fried-rich in 1898 that debridement of traumatic wounds is only effective if carried out within six hours of injury using experimental contamination in guinea pigs, and what we have today—highly developed modalities of resuscitation and antibiotics.

CONCLUSION

We have concluded that there is no difference in infection rates based on time (less than or more than six hours from injury to debridement) of open fractures from high-velocity missiles. We do not support delaying surgical treatment of open fractures from missile injuries. We do insist on optimal medical facilities and experienced trauma surgeons for these procedures, which may delay surgery to prevent potential harm from inexperienced surgeons, poor medical facilities or suboptimal surgical decisions for skeletal fixations. Early antibiotic administration and good resuscitation as early as possible are vital.

We experienced a high percentage of infections of 27.1% (31 patients) and this figure needs to be investigated further to determine whether this type of open injury has a high infection rate or if there were defects in injury management in Medical City.
REFERENCES
UPPER EXTREMITY FRACTURES IN PEDESTRIAN VERSUS MOTOR VEHICLE ACCIDENTS: AN UNDERAPPRECIATED CONCERN

David C. Landy,* M.P.H., Robert A. Norton,** M.D., Jodie A. Barkin,* Stephen Henriques,** Patrick Owens,** M.D., Roberto A. Miki,** M.D.

ABSTRACT

Background: Though pedestrian versus motor vehicle (PVMV) accidents are a common cause of trauma admission and subsequent orthopaedic consult, the prevalence of upper extremity fracture (UEF) in such events and its association with lower extremity injury (LEI) is unknown. We sought to describe UEF in PVMV accident patients at the time of orthopaedic consult.

Methods: A retrospective chart review was conducted for all pedestrian hit by motor vehicle cases for which an orthopaedic consult was performed at Jackson Memorial Hospital between July 2006 and January 2008. Fractures were recorded by location along with relevant clinical information. Logistic regression was used to calculate odds ratios (O.R.) and 95% confidence intervals (C.I.) for variables associated with UEF.

Results: 336 cases were identified and reviewed. LEI was the most frequent injury type (67% of cases). UEF was also common, found in 25% of cases (humerus 11%, ulna 7%, radius 6%, hand 4%, and wrist 2%). Tibia or fibula fracture, femur fracture, and spine fracture were negatively associated with UEF in univariate analyses and after controlling for other associated factors.

Conclusions: In PVMV accident populations, UEF is a frequent injury often seen in the absence of any LEI. These findings emphasize the importance of carefully screening all PVMV accident patients for UEF and may call into question the usefulness of currently discussed injury pattern.

INTRODUCTION

Pedestrian versus motor vehicle (PVMV) accidents are a common cause of mortality and morbidity world-wide. In 2007 alone, 70,000 pedestrians were injured and another 4,654 killed in PVMV accidents in the United States. Despite these staggering numbers, PVMV accidents are an even larger problem in the developing world with mortality rates as high as 40 per 100,000 persons per year in some countries.

Clinically the diagnosis of both orthopaedic and non-orthopaedic injuries is often complicated in PVMV cases by a loss of consciousness, the presence of multiple injuries, and high injury severity. The administration of pain medications, lack of symptoms from immobility, lack of associated lab abnormalities and reduced access to imaging can further complicate the diagnosis of orthopaedic injuries. For these reasons, clinical research efforts have employed biodynamic constructions and epidemiological review to identify predictors of orthopaedic injury following PVMV accidents.

Biodynamic constructions describe the relationships between physical objects in an event. These models of PVMV accidents most often assume lower extremity vehicle contact is the initiating event and predict an injury sequence consisting of a lower extremity injury followed by injury to the body, head and upper extremities. Fitting with these predictions, epidemiological reviews of PVMV accidents have shown lower extremity injury to be the most prevalent injury type; however, there is little evidence to support the clinical utility of other injury associations. One examination of the existence of such a pattern found the triad of head, pelvis, and knee in only 10 of 115 patients.

Epidemiological review of PVMV accidents is complicated by the heterogeneity and uniqueness of many such cases as well as variations in referral patterns. Despite these challenges, the discovery of orthopaedic injury predictors could lead to improved patient care and resource utilization. This is especially true for injuries such as upper extremity fractures (UEF) which can be difficult to diagnose, are traditionally underappreciated in PVMV accidents, and are associated with increasing morbidity such as impaired function, pain, and deformity. We, therefore, sought to describe the relative frequency
and clinical associations of UEF in PVMV accident at the time of orthopaedic consults through a retrospective review of over 300 such cases.

**MATERIALS AND METHODS**

A retrospective chart review was conducted for all PVMV accident cases for which the pedestrian was brought to Jackson Memorial Hospital, a level I trauma center with multiple emergency rooms, and for which an orthopaedic consult was performed between July 2006 and January 2008 (Figure 1). A team of medical students, an orthopaedic resident and an orthopaedic attending reviewed medical records. All fractures were recorded by location along with relevant clinical information including age, gender, length of hospital stay, chest injuries, abdominal injuries, and neurological injuries. Patients less than 15 years of age were excluded and those involved in a foot run over by vehicle incident (Figure 1). A database was constructed to allow for the grouping of variables and statistical analysis using STATA 9.0. IRB approval for this project was obtained from the University of Miami’s IRB.

Humerus, ulna, radius, wrist, and hand fractures were grouped together as UEF. Femur, tibia, fibula, ankle, and foot fractures were grouped with knee fractures and ligament tears as lower extremity injuries (LEI).

**STATISTICAL METHODS**

A series of Fisher’s Exact tests were performed to identify if any of the recorded injuries or groups of injuries was associated with a UEF. Variables associated with UEF at a two sided alpha of less than 0.05 on univariate analysis were used in a logistic regression model. Odds ratios (O.R.) and 95% confidence intervals (C.I.) are reported for all variables associated with UEF at alpha less than 0.05 with logistic regression. Due to the frequency
of both femur and tibia-fibula fractures, Fisher’s exact test was performed to examine the statistical significance of the relationship with P value reported.

RESULTS

393 PVMV accident cases were initially identified and reviewed. Forty-three cases were excluded because the patient was less than 15 years of age and 14 more were excluded as foot run over by vehicle cases leaving a total sample of 336 PVMV accident cases (Figure 1). Of 336 cases, 225 (67%) were male, 265 (79%) were less than 65 years of age, and 115 (34%) spent over 10 days in the hospital (Table 1). Death occurred in only 9 cases (3%).

UEF’s were found in 85 cases (25%) and were distributed throughout the extremity: humerus 38 (11%), ulna 24(7%), radius 20 (6%), hand 14 (4%), and wrist 7 (2%) (Table 2). Of the 85 cases with an UEF, 15 (18%) had multiple UEF’s: 7 cases of both ulna and radius fractures, 1 cases of both ulna and radius plus wrist fractures, 3 cases of either an ulna or radius fracture and hand or wrist fracture, 2 cases of humerus and forearm fractures, 2 cases of humerus and either hand or wrist fractures. For a description of the frequency of all injuries please see Appendix.

Univariate analysis found tibia or fibula fracture, femur fracture, and spine fracture to all be negatively associated with UEF (Appendix 1). All were still negatively associated with UEF on logistic regression: tibia or fibula fracture (O.R. = 0.46, 95%C.I. = 0.27-0.78), femur fracture (O.R. = 0.30, 95%C.I. = 0.11-0.80), and spine fracture (O.R. = 0.42, 95%C.I. = 0.19-0.90). Odds ratios and adjusted odds ratios are presented in Table 3.

LeI’s were the most common injury, encountered in 226 cases (67%). Amongst LEI’s tibia and/or fibula fractures were the most common injury occurring in 148 cases (44%). Fractures of the femur were also common occurring in 43 cases (13%) and negatively related to the tibia-fibula fractures. Femur fracture occurred in just 8% of cases without a tibia-fibula fracture as compared to 16% of cases without, p = 0.03, LEI were negatively associated with UEF (O.R. = 0.33, 95%C.I. = 0.20-0.55).

DISCUSSION

In a review of 336 PVMV accident cases for which an orthopedic consult was called, UEF was found in 25% of cases, suggesting this is a common injury following such events. Consistent with previous epidemiological reviews and biodynamic models, LEI was the most common injury overall. Though we found no positive clinical associations with UEF, negative associations existed between UEF and both LEI and spinal fractures. These finding highlight the heterogeneity of PVMV accident cases and the need for careful screening of patients involved in such events. The results also demonstrate that many PVMV accidents likely do not involve lower extremity contact as the initiating event. These findings should be viewed in relation to other previously described samples of PVMV accidents. Peng et al. examined a sample in which a lower extremity fracture was found in just 24% of adult cases fitting with their case identification from 13 different trauma centers (5 level I, 7 level II) throughout Los Angeles County. In this mix of cases which may have included increased numbers of less severe cases, only 8% of adult patients had an UEF. Brainard et al. examined cases brought to a single level I trauma facility in Arizona. Their sample had a mortality rate of 22% and tibia-fibula fractures in 39% of cases. In this group of more severe cases, 30% of patients had an UEF. In contrast to our findings, however, they reported a statistically significant positive relation-

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**TABLE 1. Patient Characteristics of 336 Adult PVMV Accident Orthopaedic Consult Cases**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>N (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>225 (67)</td>
</tr>
<tr>
<td>Female</td>
<td>111 (33)</td>
</tr>
<tr>
<td>Age by Trauma Groups</td>
<td></td>
</tr>
<tr>
<td>15-65 Years</td>
<td>265 (79)</td>
</tr>
<tr>
<td>&gt;65 Years</td>
<td>67 (20)</td>
</tr>
<tr>
<td>Missing</td>
<td>4 (1)</td>
</tr>
<tr>
<td>Hospital Stay</td>
<td></td>
</tr>
<tr>
<td>&lt;1 Day</td>
<td>53 (16)</td>
</tr>
<tr>
<td>1-3 Days</td>
<td>92 (27)</td>
</tr>
<tr>
<td>4-10 Days</td>
<td>76 (23)</td>
</tr>
<tr>
<td>11-30 Days</td>
<td>70 (21)</td>
</tr>
<tr>
<td>&gt;30 Days</td>
<td>45 (13)</td>
</tr>
</tbody>
</table>

**TABLE 2. Prevalence of UEF in 336 PVMV Accident Orthopaedic Consult Cases**

<table>
<thead>
<tr>
<th>Injury</th>
<th>N (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Extremity</td>
<td></td>
</tr>
<tr>
<td>Humerus Fracture</td>
<td>38 (11)</td>
</tr>
<tr>
<td>Ulna Fracture</td>
<td>24 (7)</td>
</tr>
<tr>
<td>Radius Fracture</td>
<td>20 (6)</td>
</tr>
<tr>
<td>Hand Fracture</td>
<td>14 (4)</td>
</tr>
<tr>
<td>Wrist Fracture</td>
<td>7 (2)</td>
</tr>
</tbody>
</table>

* 15 cases had multiple UEF’s

**TABLE 3. UEF Associated Injuries with Adjustments for 336 PVMV Accident Orthopaedic Consult Cases**

<table>
<thead>
<tr>
<th>Absence of Injury</th>
<th>O.R. (95%C.I.)</th>
<th>Adjusted O.R. (95%C.I.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tibia or Fibula Fracture</td>
<td>0.54 (0.32-0.90)</td>
<td>0.46 (0.27-0.78)</td>
</tr>
<tr>
<td>Spine Fracture</td>
<td>0.46 (0.22-0.99)</td>
<td>0.42 (0.19-0.90)</td>
</tr>
<tr>
<td>Femur Fracture</td>
<td>0.35 (0.13-0.92)</td>
<td>0.30 (0.11-0.80)</td>
</tr>
</tbody>
</table>

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ship between upper extremity fracture and an ipsilateral lower extremity fracture, the “Ipsilateral dyad”.

The frequency of UEF and negative relationship between UEF and both LEI and spine fractures should be interpreted with caution as our selection strategy may have underrepresented the least and most severe cases. As Jackson Memorial Hospital is home to the region’s only level one trauma center, it is likely a greater proportion of more severe cases were brought in. It is also possible that for some of the less severe cases that were brought in, no orthopedic consult was ordered. At the same time, the most severe cases may have been missed as death may have preempted the orthopaedic consult. Figure 1 provides a representation of the logistic challenges in identifying and defining cases from PVMV accidents. A second limitation to this study is the retrospective design and subsequent lack of systematic protocol for the identification of injuries including orthopaedic injuries. Finally, with only 336 cases used in the analysis and the low frequency of certain injuries, it is possible the statistical comparisons could have been underpowered.

In conclusion, there are likely many PVMV accident cases that do not resemble the currently proposed biodynamic models. This accident heterogeneity likely explains the difficulty researchers have in finding clinically useful predictors of PVMV accidents from epidemiological reviews. The large number of UEF cases we found and the negative relationship between UEF and LEI suggest not only that the initiating event in many PVMV accidents may not involve the lower extremity but also that UEF may be a more frequent consequence of PVMV accidents than previously appreciated. Physicians responsible for PVMV accident cases should be careful to consider the possibility of UEF in all patients regardless of LEI status.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

REFERENCES

### APPENDIX

**List of Injury Variables for 336 PVMV Accident Orthopaedic Consult Cases**

<table>
<thead>
<tr>
<th>Injury Site and Type</th>
<th>UEF Positive (%)</th>
<th>n=85</th>
<th>UEF Negative (%)</th>
<th>n=251</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Extremity*</td>
<td>41 (48)</td>
<td></td>
<td>185 (74)</td>
<td></td>
</tr>
<tr>
<td>Foot Fracture</td>
<td>3 (4)</td>
<td></td>
<td>12 (5)</td>
<td></td>
</tr>
<tr>
<td>Ankle Fracture</td>
<td>8 (9)</td>
<td></td>
<td>37 (15)</td>
<td></td>
</tr>
<tr>
<td>Tibia and Fibula Fracture*</td>
<td>28 (33)</td>
<td></td>
<td>120 (48)</td>
<td></td>
</tr>
<tr>
<td>Knee Injury</td>
<td>13 (15)</td>
<td></td>
<td>51 (20)</td>
<td></td>
</tr>
<tr>
<td>Knee Fracture</td>
<td>10 (12)</td>
<td></td>
<td>43 (17)</td>
<td></td>
</tr>
<tr>
<td>Knee Ligament Tear</td>
<td>4 (5)</td>
<td></td>
<td>11 (4)</td>
<td></td>
</tr>
<tr>
<td>Femur Fracture*</td>
<td>5 (6)</td>
<td></td>
<td>38 (15)</td>
<td></td>
</tr>
<tr>
<td>Body</td>
<td>37 (44)</td>
<td></td>
<td>115 (46)</td>
<td></td>
</tr>
<tr>
<td>Clavicle Fracture</td>
<td>4 (5)</td>
<td></td>
<td>16 (6)</td>
<td></td>
</tr>
<tr>
<td>Scapula Fracture</td>
<td>5 (6)</td>
<td></td>
<td>13 (5)</td>
<td></td>
</tr>
<tr>
<td>Sternum Fracture</td>
<td>0 (0)</td>
<td></td>
<td>1 (&lt;1)</td>
<td></td>
</tr>
<tr>
<td>Rib Fracture</td>
<td>11 (13)</td>
<td></td>
<td>45 (18)</td>
<td></td>
</tr>
<tr>
<td>Lung Contusion</td>
<td>13 (15)</td>
<td></td>
<td>32 (13)</td>
<td></td>
</tr>
<tr>
<td>Pleural Injury</td>
<td>7 (8)</td>
<td></td>
<td>30 (12)</td>
<td></td>
</tr>
<tr>
<td>Pneumothorax</td>
<td>7 (8)</td>
<td></td>
<td>28 (11)</td>
<td></td>
</tr>
<tr>
<td>Hemothorax</td>
<td>0 (0)</td>
<td></td>
<td>10 (4)</td>
<td></td>
</tr>
<tr>
<td>Spine Fractures*</td>
<td>9 (11)</td>
<td></td>
<td>51 (20)</td>
<td></td>
</tr>
<tr>
<td>C Spine Fracture</td>
<td>2 (2)</td>
<td></td>
<td>14 (6)</td>
<td></td>
</tr>
<tr>
<td>T Spine Fracture</td>
<td>1 (1)</td>
<td></td>
<td>12 (5)</td>
<td></td>
</tr>
<tr>
<td>L Spine Fracture</td>
<td>6 (7)</td>
<td></td>
<td>33 (13)</td>
<td></td>
</tr>
<tr>
<td>Sacrum Fracture</td>
<td>11 (13)</td>
<td></td>
<td>29 (12)</td>
<td></td>
</tr>
<tr>
<td>Pelvic Fracture</td>
<td>14 (16)</td>
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<td>54 (22)</td>
<td></td>
</tr>
<tr>
<td>Abdominal Injury</td>
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<td>30 (12)</td>
<td></td>
</tr>
<tr>
<td>Splenic Laceration</td>
<td>2 (2)</td>
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<td>13 (5)</td>
<td></td>
</tr>
<tr>
<td>Liver Laceration</td>
<td>6 (7)</td>
<td></td>
<td>14 (6)</td>
<td></td>
</tr>
<tr>
<td>Other Abdominal</td>
<td>6 (7)</td>
<td></td>
<td>14 (6)</td>
<td></td>
</tr>
<tr>
<td>Head</td>
<td>22 (26)</td>
<td></td>
<td>66 (26)</td>
<td></td>
</tr>
<tr>
<td>Cerebral Event</td>
<td>12 (14)</td>
<td></td>
<td>39 (16)</td>
<td></td>
</tr>
<tr>
<td>Epidural Hematoma</td>
<td>1 (1)</td>
<td></td>
<td>5 (2)</td>
<td></td>
</tr>
<tr>
<td>Subdural Hematoma</td>
<td>7 (8)</td>
<td></td>
<td>16 (6)</td>
<td></td>
</tr>
<tr>
<td>Subarachnoid Hematoma</td>
<td>9 (11)</td>
<td></td>
<td>31 (12)</td>
<td></td>
</tr>
<tr>
<td>Other Intracranial Event**</td>
<td>1 (1)</td>
<td></td>
<td>7 (3)</td>
<td></td>
</tr>
<tr>
<td>Facial Fracture</td>
<td>8 (9)</td>
<td></td>
<td>25 (10)</td>
<td></td>
</tr>
<tr>
<td>Nasal Fracture</td>
<td>11 (13)</td>
<td></td>
<td>15 (6)</td>
<td></td>
</tr>
<tr>
<td>Skull Fracture</td>
<td>2 (2)</td>
<td></td>
<td>14 (6)</td>
<td></td>
</tr>
</tbody>
</table>

* Significant relation with UEF at the P<.05

** Only includes patients not recorded as having another type of hematoma
ABSTRACT

Background: Dynamic intraoperative assessment of patella tracking utilizes femoral nerve stimulation to contract the quadriceps muscles in assessing the proper distance to transfer the tibial tubercle during distal realignment procedures for patellofemoral instability.

Purpose: We describe the effects of tourniquet inflation and catheter placement on intraoperative femoral nerve stimulation for assessment of patellar tracking.

Methods: Percutaneous electromyographic (EMG) needles were placed into the quadriceps and sartorius muscles to monitor muscle activity and changes in amplitude threshold (mA) required for femoral nerve stimulation with increasing tourniquet inflation times. Eleven patients used ultrasound for catheter placement and ten were manually placed based upon body landmarks.

Results: Tourniquet application time correlated positively with the change in amplitude threshold required to generate muscle contraction. Patients had an average four-fold increase in required stimulus amplitude from the baseline thresholds (pre-tourniquet inflation) to final thresholds (tourniquet inflated) with a two-hour tourniquet inflation time. The use of ultrasound for catheter placement significantly decreased the baseline amplitude required in comparison with catheters placed without ultrasound, (p = 0.0330).

Conclusions: Increased tourniquet inflation times require greater stimulus amplitude to generate quadriceps muscle contraction. Ultrasound guidance for catheter placement can provide femoral nerve stimulation at low amplitudes.

INTRODUCTION

The senior author has utilized peripheral nerve stimulation in an attempt to provide a dynamic assessment during patellar realignment procedures. The purpose of this study was to evaluate the influence of the use of a tourniquet on intraoperative femoral nerve stimulation and the resultant muscle contraction/activity. The study objective is to evaluate the threshold required to stimulate the femoral nerve with increased tourniquet time. A second objective is to compare the accuracy of catheter placement for nerve stimulation with and without ultrasound-guided assistance.

Brief History of Realignment and Rationale

There have been over a hundred procedures described to treat PFI. A key question in all procedures, is just how far does one need to transfer the tendon? The senior author has focused on the use of quadriceps muscle contraction intraoperatively to assess the kinematic tracking of the patella for determining the proper transfer distance of the tendon for proper patellofemoral alignment.

Peripheral nerve stimulation is being used to add further dynamic evaluation of the patellar realignment procedures. This current study is to evaluate effects of the tourniquet use on this dynamic assessment and provide guidelines for its use. This dynamic evaluation technique allows the surgeon to assess how the patella tracks within the trochlea when the quadriceps mechanism is stimulated in the absence of other soft tissue constraints. Thus, we are hypothesizing that this dynamic tracking provides a more realistic picture of what can be expected post-operatively.

Lavery et al. described an innovative approach known as dynamic intraoperative assessment utilizing a “stimulating” femoral catheter to directly activate the quadriceps muscle to assess patellar tracking and accomplish proper placement for the tibial tubercle osteotomy. Ebinger et al. also published preliminary results of the procedure. These two publications made it evident that the tourniquet plays a pivotal role in femoral nerve stimulation, not only regarding the duration of tourniquet inflation but also in the accurate placement of the catheter for initial stimulation. In this study, we
explore the effects of the pneumatic tourniquet on direct femoral nerve stimulation used to perform dynamic intraoperative assessment for patella tracking. Tourniquet application is hypothesized to increase the amplitude required to generate muscle contraction during EMG intraoperative assessment.

In this study, EMG activity was used to evaluate the intraoperative tourniquet effects by measuring the changes in amplitude threshold (mA) required to produce a palpable muscle contraction of the extensor mechanism via femoral nerve stimulation. A second focus of the study was to determine whether there was a difference in the baseline threshold required with femoral catheters placed with the aid of ultrasound guidance in comparison to catheter placement by free-hand method, utilizing only anatomical body landmarks.

**METHODS**

Twenty-one patients participated in the study (11 males and 10 females). Patients were included in the study if they were to have a lower extremity surgery and receive a femoral block to relieve post-operative knee pain. The procedures performed were not restricted to Fulkerson\(^5\)/medial patellofemoral ligament (MPFL) reconstructions; the majority of patients were being treated for anterior cruciate ligament (ACL) reconstructions. Patients receiving operations that did not allow for sufficient use of the tourniquet to observe its effects on femoral nerve stimulation were excluded from participation in the study. With the patient lying in the supine position, a “stimulating” femoral catheter was placed anteriorly in the patient’s operative leg by an anesthesiologist. The “stimulating” catheter was connected to an EMG monitoring system, NIM-Eclipse Spinal System (Medtronic, Minneapolis, MN) that provided direct stimulation to the femoral catheter in a pulsating frequency of 50 Hz. A more detailed description of catheter placement can be found in the primary paper describing the procedure.\(^6\)

Because of an observed variation in the placement of the catheters early in the study, ultrasound was also utilized for proper placement of the femoral catheters in one group (eleven patients) and free-hand placement was used in the other group (ten patients). A standard sized cuff pneumatic tourniquet was set at 100mmHg above the patient’s systolic blood pressure during its application. The tourniquet was applied in a standard manner for a time period of at least one hour, but not exceeding two hours. Percutaneous EMG needles were placed distal to the tourniquet in four muscle bellies receiving their innervations from the femoral nerve: the vastus lateralis, rectus femoris, vastus medialis, and the sartorius muscle (Figure 1). The needles were spaced approximately 4.0 cm apart and covered with Tegaderm.

Muscle activity was monitored by the EMG monitoring system and by palpation of the muscle contractions in the sterile field. This provided confirmation that the EMG activity being recorded was produced by the muscle contractions generated because of the femoral nerve stimulation.

The protocol for evaluating the effects of the tourniquet on femoral nerve stimulation were as follows: 1) An initial stimulation was performed before tourniquet inflation to establish the patient’s baseline amplitude threshold (mA) required to produce contraction of the quadriceps and sartorius muscles; 2) At 30-minute intervals, while the tourniquet was inflated, the femoral nerve was stimulated to observe the threshold of stimulus required to produce muscle contraction; and 3) When the tourniquet was deflated, femoral nerve stimulation was performed every 1 to 2 minutes to observe the length of time required for the threshold of required stimulus to return to that of the patient’s initial baseline. For patients having a distal realignment procedure to treat PFI, the EMG evaluation included the aforementioned protocol and stimulations with the NIM-Eclipse Spinal System (Medtronic, Minneapolis, MN) before and after tetanus stimulations for dynamic intraoperative assessment. This was used to assess whether muscle fatigue occurred over the course of dynamic intraoperative assessment for patellar tracking. The research study was given full approval by the Institutional Review Board.

**RESULTS**

Thirty patients were recruited to the study and 21 participants completed the study (Table 1). There were 14 ACL reconstructive operations, four Fulkerson\(^5\)/MPFL reconstructions, two isolated MPFL reconstructions, and one posterior cruciate ligament (PCL) reconstruction. Nine patients were lost to the study for the following reasons; the catheter accidentally being dosed with lo-
cal anesthetic (three patients), intubation of patient with long-acting muscle relaxant (one patient), patient opting out of the study prior to surgery (four patients), and equipment malfunction (one patient). The participants in the study had a positive correlation between the tourniquet application time and the magnitude of stimulus threshold (mA) required to generate contraction of the quadriceps and sartorius muscles. The patients demonstrated an average of a four-fold increase in the magnitude of required stimulus amplitude (mA) change from their baseline response (tourniquet not inflated) as compared to that of the final stimulation (tourniquet inflated) after a period of 90 to 120 minutes duration (Figures 2A, 2B). Baseline stimulations ranged from as low as 0.5 mA to as high as 11.0 mA. Final stimulations with the tourniquet applied ranged from 1.3 mA to 30.0 mA. There was a wide range of baseline stimulus thresholds in the patients. We hypothesized that the precision of the catheter placement nearest the nerve might play a role in achieving muscle contraction at lower thresholds via femoral nerve stimulation. To evaluate whether a more precise placement of the catheter in closer proximity to the femoral nerve would result in lower baseline thresholds, ultrasound was utilized to guide the placement of the catheters (eleven patients) had an average baseline threshold of 1.782 mA (SD = 1.266; SEM = 0.382; Range = 0.5 mA to 4.5 mA; Mdn = 1.0mA; Mode = 1.0mA). In the free-hand catheter placement group (ten patients) there was an average baseline threshold of 4.240 mA (SD = 3.295; SEM = 1.042 Range = 0.5 mA to 11.0 mA; Mdn = 4.0 mA; Mode = 4.0 mA). The difference between the average baseline stimulation of both groups was statistically significant (p = 0.0330) (Figure 3). The final stimulation (tourniquet inflated) threshold for the group using ultrasound had an average of 8.909 mA (SD = 8.807; SEM = 2.785; Range=1.3 mA to 30 mA; Mdn = 10.5mA; Mode = 15.0mA) and not statistically significant (p = 0.6612). During the distal realignment procedures, the tetanus stimulations did not appear to have a significant influence upon the magnitude of change in thresholds observed throughout the application of the tourniquet. Thresholds appeared to follow a similar increase that was observed in patients who were not receiving multiple tetanic stimulations. Follow-
ing tourniquet deflation, an average of six minutes was required for each patient’s stimulus threshold to return to baseline (Figure 4).

**DISCUSSION**

Tourniquet application has an appreciable effect on femoral nerve stimulation and the performance of dynamic intraoperative assessment. Ischemic conditions and compression of the soft tissues that occur during tourniquet application have been shown to decrease the amount of muscle contraction force generated post tourniquet application. This study evaluated the electrophysiological changes of nerve conduction during tourniquet application. The longer the tourniquet application time, the greater the threshold of stimulus required to produce an unequivocal muscle contraction. Understanding the effects of the tourniquet on femoral nerve stimulation is essential for physicians who will implement dynamic intraoperative assessment into their treatment of PFI with distal realignment procedures. Precise placement of the femoral catheter in close proximity of the femoral nerve can allow the physician to establish lower baseline thresholds to produce quadriceps muscle contraction and observe the tracking of the patella. There was a significant difference in the baseline thresholds established in patients with the ultrasound-guided catheter placement in comparison to those with catheters placed with free-hand technique. There was not a significant difference in the final thresholds between the two groups; however, through a close examination of the data it is evident that patients who had higher baseline thresholds were more likely to have higher final thresholds. In the ultrasound group (eleven patients) there were only three cases (11 mA, 12 mA, 30 mA) resulting in a final threshold stimulation of 10 mA or greater, whereas the free-hand group (ten patients) had six cases of greater than 10 mA (10 mA, 11 mA, 14 mA, 15 mA, 15 mA, 30 mA).

Patients were not randomly assigned to one group or the other for the purposes of this study, nor were the anesthesiologists placing the catheters. Therefore, it is unknown whether a novice placing the ultrasound catheter would equate to, or be superior to an expert performing free-hand catheter placement. The use of ultrasound guidance is not essential to carry out dynamic intraoperative assessment, it merely serves as an aid to provide closer placement of the catheter to the femoral nerve. We believe that ultrasound may allow for lower amplitudes of stimulus for dynamic intraoperative assessment. When higher amplitudes are required to contract the extensor mechanism as a result of the catheter being placed further away from the femoral nerve, it could be the result of direct stimulation of muscle in conjunction with the stimulation of the femoral nerve. In the three cases where we observed baseline thresholds above 5 mA, we hypothesize that there was a field effect in which the stimulation was not isolated to the femoral nerve and may have resulted in the direct stimulation of the muscles as well. Lower baseline thresholds of 3 mA or less were achieved in both groups; however, these low thresholds were more frequently established in the ultrasound group with ten cases (0.5 mA, 1 mA, 1 mA, 1 mA, 1 mA, 1.1 mA, 2.5 mA, 3 mA, 3 mA) in comparison to only four cases in the free-hand group (0.5 mA, 1.4 mA, 1.5 mA, 2 mA). For this reason, ultrasound placement can be helpful for those who are familiar with ultrasound imaging.

Implementing dynamic intraoperative assessment into the operating room will not require any major changes in the manner in which a surgeon operates and assesses the transfer distance of the tibial tubercle. Consequently, the senior author has not experienced any significant difference in the length of surgery time in comparison to his performing distal realignment procedures in patients with PFI prior to his use of dynamic intraoperative assessment. In conducting this study, collaboration between the surgeon and anesthesiologist was important. At our institution, regional blocks for surgery on the lower extremities are very commonly employed to provide localized post-operative pain relief. If a surgeon wants to perform dynamic intraoperative assessment, it is imperative that the femoral catheter is not dosed until
after dynamic intraoperative assessment is completed. Some patients who were consented to the study were unable to participate because their catheters had been dosed prior to entering the operating room. In this event, one would have to resort to passive assessment for patellar tracking. We have found this situation to be easily avoided by notifying the anesthesia department of our protocol and adding a clinical note in the patient’s records for the treating anesthesiologist. If the surgeon plans to perform dynamic intraoperative assessment early on in an operation, endotracheal intubations of the patient for general anesthesia should also not include any long-acting muscle relaxants that can impede contraction of the extensor mechanism. We recommend using succinylcholine when the surgeon requires earlier assessment as in isometry testing of a semitendinosis graft in an isolated MPFL reconstruction. Through our experimentation we have noted that should an operation require extended use of the tourniquet over two hours, or in the event of a patient’s threshold increases to such a point beyond the amplitude that is producible by the nerve stimulator, dynamic intraoperative assessment can continue to be performed by releasing the tourniquet and stimulating the femoral nerve at the patient’s baseline threshold within approximately six minutes after deflation of the tourniquet cuff.

CONCLUSION
The use of a pneumatic tourniquet has an effect on femoral nerve stimulation that should be taken into consideration when performing dynamic intraoperative assessment. The longer the tourniquet is applied, the greater the threshold of required stimulus to generate sufficient contraction of the extensor mechanism to observe patellar tracking. The use of ultrasound for placement of the femoral catheter can provide proficient localization of the femoral nerve and allow for use of lower amplitudes of stimulus to perform dynamic intraoperative assessment for patellar tracking. The use of ultrasound is not required for performing dynamic intraoperative assessment. Lower baseline thresholds of 3mA or less were also achieved with free-hand placement of the catheter; however, they were more frequently observed in the ultrasound group.

ACKNOWLEDGMENT
We gratefully acknowledge Medtronic’s loan of EMG equipment.

The authors express their appreciation and thanks to Diana Johannes for her assistance in the preparation of this article.

REFERENCES
PRIMARY HIP AND KNEE REPLACEMENT: “ARE WE ALL OPERATING ON THE SAME PATIENTS, EVEN AT THE SAME INSTITUTION?”

Paul K. Herickhoff, MD,* John J. Callaghan, MD,** Richard Johnston, MD,**
J. Lawrence Marsh, MD,** Charles R. Clark, MD,** and Nicolas Noiseux, MD**

ABSTRACT

Background: Survey studies have concluded that a lack of consensus exists between orthopaedic surgeons on indications for total hip and knee arthroplasty. Geographic variation in the rates of these operations has raised concerns that some surgeons inappropriately indicate healthier patients for surgery than others. The objective of this study was to compare primary hip and knee arthroplasty patients’ pre-operative validated outcome scores between four orthopaedic surgeons operating at a single academic institution from 2003 to 2007.

Methods: A retrospective chart review was performed using CPT-4 codes to identify patients who underwent primary total hip or knee arthroplasty at our institution between June 2003 and June 2007. Pre-operative SF-36 and WOMAC scores were recorded for each patient. Patient demographics including age, gender, body mass index (BMI), number of co-morbidities, life orientation score (a measure of patient optimism), smoking and alcohol use, education level, and occupation were also recorded. Statistical analysis using unbalanced analysis of variance (ANOVA) and Chi-Square test were used to compare data between the surgeons, with statistical significance set at P < 0.05.

Results: There was no statistically significant difference in SF-36 or WOMAC stiffness and function scores between the surgeons. There was a small difference in WOMAC pain scores between the surgeons’ total knee patients, but not total hip patients. The number of primary hip and total knee replacements performed by each surgeon ranged from 151 to 955, with a total of 1896 primary joint replacements by the four surgeons during the study period.

Conclusions: Patients undergoing primary total joint arthroplasty at our institution were equally disabled between four surgeons, despite the surgeons performing variable numbers of the procedures. Further comparative effectiveness research using validated outcome measures is warranted.

INTRODUCTION

542,000 total knee replacements and 231,000 total hip replacements were performed in the United States in 2006.1-2 Despite these numbers and an increasing prevalence of these operations over recent years,3 at least three survey studies have demonstrated disagreement among orthopaedic surgeons on the indications for total hip and knee arthroplasty.4-6 Although orthopaedic surgeons may differ in their survey responses regarding the indications for these surgeries, no study has demonstrated a difference in patient-based measures of disability between different total joint arthroplasty surgeons. Variation in the rates of total hip and knee arthroplasty (and other common surgical procedures) between geographic regions is well documented in the literature, and has been one area of focus in the debate over Health Care Reform in the United States.7-8 An important question to inform this debate is: “Are surgeons who perform more of these operations indicating healthier patients for surgery than surgeons who do them less frequently?” The literature provides no clear answer to this question at present. The purpose of this study was to investigate this question at our institution by comparing pre-operative patient-based measures of disability between four total joint surgeons operating at a single university hospital over a four year period.

METHODS

After obtaining IRB approval, a retrospective chart review was performed using CPT-4 codes to identify patients who underwent primary total hip or knee arthroplasty at our institution between June 2003 and June 2007. All diagnosis categories were included. The

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** University of Iowa Hospitals and Clinics
Department of Orthopaedics and Rehabilitation
John Pappajohn Pavilion, Lower Level
200 Hawkins Drive
Iowa City, IA 52242
surgeons were arbitrarily designated Surgeon A, B, C, or D. Surgeons A and D are primarily total hip and knee arthroplasty surgeons, while Surgeons B and C devote significant portions of their practice to other orthopaedic procedures.

Pre-operative SF-36 and WOMAC scores were recorded for each patient. Patient demographics including age, gender, body mass index (BMI), number of co-morbidities, life orientation score (a measure of patient optimism), smoking and alcohol use, education level, and occupation were also recorded. Education level was classified into one of three groups: some high school or less, high school graduate, or any post-graduate work. Occupation was also classified into three groups: homemaker/retired/unemployed, skilled labor, and professional/managerial/sales/clerical/student.

Separate analyses were undertaken for total hip patients and total knee patients. Unbalanced analysis of variance (ANOVA) and Chi-Square test were used to compare data between the surgeons. Fisher’s exact test substituted Chi-Square test in case that some cell has an expected value fewer than 5. For all analyses, a P value less than 0.05 was considered statistically significant. Data were analyzed using SAS software (version 9.1.3; SAS Institute, Cary, NC).

Finally, we compared the age and gender data of our patient cohort with 2006 National Data available from the American Academy of Orthopaedic Surgeons website to see if any differences exist between our institution and the national average.

**RESULTS**

From 2003 to 2007, Surgeons A, B, C, and D performed a total of 646, 579, 151 and 955 total joint replacements, respectively. Of these, 82, 81, 78 and 82 percent were primary procedures (see Table 1). Pre-operative SF-36 scores were available for 65% of patients, while WOMAC scores were available for 44% of patients.

Among total knee arthroplasty patients, there was no statistically significant difference between the surgeons in SF-36 scores (PCS and MCS components), or WOMAC stiffness and function scores. Surgeon C had significantly higher WOMAC pain scores than Surgeons D and B. In terms of patient demographics, no statistically significant difference was found between the surgeons in male to female ratio, education, occupation, smoking and number of musculoskeletal comorbidities. Life orientation scores were higher for Surgeon A than Surgeons C and D, and Surgeon B scores were higher than Surgeon C. Surgeon B had higher age, lower BMI, and higher rate of alcohol use compared to the other surgeons (Table 2).

Among total hip arthroplasty patients, there were no statistically significant differences between the surgeons in SF-36 scores (PCS and MCS) or WOMAC pain, stiffness, and function scores. In terms of patient demographics, no statistically significant difference was found between the surgeons in male-to-female ratio, education, smoking, alcohol use, life orientation scores, and musculoskeletal co-morbidities. Surgeon C operated on a significantly higher proportion of homemaker/retired/unemployed patients than the other surgeons, and also had a higher number of systemic comorbidities. Surgeon C also had a higher BMI than Surgeons A and B. Surgeon B’s patients were significantly older than Surgeon D (Table 2).

Finally, surgeons at our institution operated on a greater percentage of males and younger patients compared to the 2006 national average1,2 (Table 2).

<table>
<thead>
<tr>
<th>TABLE 1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Surgeon A</strong></td>
</tr>
<tr>
<td>Primary Total Knees</td>
</tr>
<tr>
<td>Primary Unicompartment Knees</td>
</tr>
<tr>
<td>Revision Total Knees</td>
</tr>
<tr>
<td>Primary Total Hips</td>
</tr>
<tr>
<td>Revision Total Hips</td>
</tr>
<tr>
<td><strong>Total Number of Joint Replacements</strong></td>
</tr>
<tr>
<td>Total Number of Primary Joint Replacements</td>
</tr>
<tr>
<td>Percent Primary Joint Replacements</td>
</tr>
</tbody>
</table>
**TABLE 2**

**VALIDATED OUTCOME SCORES**

<table>
<thead>
<tr>
<th></th>
<th>Surgeon A</th>
<th>Surgeon B</th>
<th>Surgeon C</th>
<th>Surgeon D</th>
<th>TOTAL KNEES</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCS</td>
<td>29.6</td>
<td>30.92</td>
<td>29.23</td>
<td>30.21</td>
<td>30.08</td>
</tr>
<tr>
<td>MCS</td>
<td>47.02</td>
<td>46.68</td>
<td>45.15</td>
<td>45.96</td>
<td>46.15</td>
</tr>
</tbody>
</table>

* No statistically significant difference between surgeons

**WOMAC Score**

<table>
<thead>
<tr>
<th></th>
<th>Surgeon A</th>
<th>Surgeon B</th>
<th>Surgeon C</th>
<th>Surgeon D</th>
<th>TOTAL KNEES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pain</td>
<td>41.41</td>
<td>46.91</td>
<td>28</td>
<td>44.31</td>
<td>46.32</td>
</tr>
<tr>
<td>Stiffness</td>
<td>41.29</td>
<td>43.45</td>
<td>42.5</td>
<td>42.12</td>
<td>42.50</td>
</tr>
<tr>
<td>Function</td>
<td>43.27</td>
<td>49.32</td>
<td>42.96</td>
<td>47.74</td>
<td>45.06</td>
</tr>
</tbody>
</table>

* Surgeon B patients higher pain scores than Surgeons A and C (p = .013, .029)

**PATIENT DEMOGRAPHICS**

**Mean Age (years)**

<table>
<thead>
<tr>
<th></th>
<th>Surgeon A</th>
<th>Surgeon B</th>
<th>Surgeon C</th>
<th>Surgeon D</th>
<th>National Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>62.04</td>
<td>66.39</td>
<td>63.18</td>
<td>62.84</td>
<td>67</td>
</tr>
</tbody>
</table>

* Surgeon B patients older than Surgeon A and D (p < 0.0001, < 0.0001)

<table>
<thead>
<tr>
<th>Gender</th>
<th>Surgeon A</th>
<th>Surgeon B</th>
<th>Surgeon C</th>
<th>Surgeon D</th>
<th>National Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>56.5</td>
<td>64.52</td>
<td>53.66</td>
<td>59.2</td>
<td>63</td>
</tr>
<tr>
<td>Male</td>
<td>43.5</td>
<td>35.48</td>
<td>46.34</td>
<td>40.8</td>
<td>37</td>
</tr>
</tbody>
</table>

* Data given in percent

* No statistically significant difference between surgeons

<table>
<thead>
<tr>
<th>BMI</th>
<th>Surgeon A</th>
<th>Surgeon B</th>
<th>Surgeon C</th>
<th>Surgeon D</th>
<th>National Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>34.82</td>
<td>31.91</td>
<td>35.08</td>
<td>34.35</td>
<td></td>
</tr>
</tbody>
</table>

* Surgeon B patients lower BMI than Surgeons A, C, and D (p < 0.001, 0.0159, < 0.001)

**Number of Comorbidities**

<table>
<thead>
<tr>
<th></th>
<th>Surgeon A</th>
<th>Surgeon B</th>
<th>Surgeon C</th>
<th>Surgeon D</th>
<th>National Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Musculoskeletal</td>
<td>2.76</td>
<td>2.69</td>
<td>2.82</td>
<td>2.61</td>
<td></td>
</tr>
<tr>
<td>Systemic</td>
<td>3.57</td>
<td>3.18</td>
<td>3.42</td>
<td>3.47</td>
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</tr>
</tbody>
</table>

* No statistically significant difference between surgeons

**Education**

<table>
<thead>
<tr>
<th></th>
<th>Surgeon A</th>
<th>Surgeon B</th>
<th>Surgeon C</th>
<th>Surgeon D</th>
<th>National Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Any college or greater</td>
<td>51.96</td>
<td>47.46</td>
<td>48.15</td>
<td>50</td>
<td></td>
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<tr>
<td>High school graduate</td>
<td>37.43</td>
<td>36.02</td>
<td>40.74</td>
<td>39.08</td>
<td></td>
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<tr>
<td>Some high school or less</td>
<td>10.61</td>
<td>10.53</td>
<td>11.11</td>
<td>10.92</td>
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</tr>
</tbody>
</table>

* Data given in percent

* No statistically significant difference between surgeons

**Occupation**

<table>
<thead>
<tr>
<th></th>
<th>Surgeon A</th>
<th>Surgeon B</th>
<th>Surgeon C</th>
<th>Surgeon D</th>
<th>National Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Professional/office/student</td>
<td>29.38</td>
<td>23.71</td>
<td>30.77</td>
<td>26.35</td>
<td></td>
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<tr>
<td>Labor</td>
<td>16.38</td>
<td>14.66</td>
<td>7.89</td>
<td>16.25</td>
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<tr>
<td>Retired/Unemployed/Homemaker</td>
<td>54.25</td>
<td>61.64</td>
<td>61.54</td>
<td>57.4</td>
<td></td>
</tr>
</tbody>
</table>

* Data given in percent

* No statistically significant difference between surgeons

**Smoking**

<table>
<thead>
<tr>
<th></th>
<th>Surgeon A</th>
<th>Surgeon B</th>
<th>Surgeon C</th>
<th>Surgeon D</th>
<th>National Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>12.43</td>
<td>10.04</td>
<td>11.54</td>
<td>10.8</td>
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<tr>
<td>No</td>
<td>87.57</td>
<td>89.96</td>
<td>88.46</td>
<td>89.2</td>
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</tbody>
</table>

* Data given in percent

* No statistically significant difference between surgeons

**Alcohol**

<table>
<thead>
<tr>
<th></th>
<th>Surgeon A</th>
<th>Surgeon B</th>
<th>Surgeon C</th>
<th>Surgeon D</th>
<th>National Average</th>
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</thead>
<tbody>
<tr>
<td>Yes</td>
<td>43.96</td>
<td>56.6</td>
<td>38.46</td>
<td>47.04</td>
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<tr>
<td>No</td>
<td>56.04</td>
<td>43.4</td>
<td>61.54</td>
<td>52.96</td>
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* Data given in percent

* Surgeon B patients more likely to drink alcohol (p = 0.031)

**Life Orientation Score**

<table>
<thead>
<tr>
<th></th>
<th>Surgeon A</th>
<th>Surgeon B</th>
<th>Surgeon C</th>
<th>Surgeon D</th>
<th>National Average</th>
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<tbody>
<tr>
<td></td>
<td>16.16</td>
<td>15.42</td>
<td>11.6</td>
<td>14.65</td>
<td></td>
</tr>
</tbody>
</table>

* Surgeon A higher Life Orientation Score than Surgeon C and D (p = 0.011, 0.009)

* Surgeon B higher Life Orientation Score than Surgeon C (p = 0.034)
### TABLE 2 (continued)

#### VALIDATED OUTCOME SCORES

<table>
<thead>
<tr>
<th>Score</th>
<th>Surgeon A</th>
<th>Surgeon B</th>
<th>Surgeon C</th>
<th>Surgeon D</th>
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<tbody>
<tr>
<td>SF - 36</td>
<td>28.13</td>
<td>28.24</td>
<td>28.51</td>
<td>28.9</td>
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<tr>
<td>PCS</td>
<td>43.71</td>
<td>44.48</td>
<td>47.42</td>
<td>44.44</td>
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</tbody>
</table>

* No statistically significant difference between surgeons

#### WOMAC Score

<table>
<thead>
<tr>
<th>Component</th>
<th>Surgeon A</th>
<th>Surgeon B</th>
<th>Surgeon C</th>
<th>Surgeon D</th>
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<tbody>
<tr>
<td>Pain</td>
<td>42.33</td>
<td>46.9</td>
<td>46.35</td>
<td>44.19</td>
</tr>
<tr>
<td>Stiffness</td>
<td>40.39</td>
<td>45.21</td>
<td>47.84</td>
<td>43.44</td>
</tr>
<tr>
<td>Function</td>
<td>41.82</td>
<td>43.84</td>
<td>45.87</td>
<td>43.46</td>
</tr>
</tbody>
</table>

* No statistically significant difference between surgeons

#### PATIENT DEMOGRAPHICS

<table>
<thead>
<tr>
<th>Demographic</th>
<th>Surgeon A</th>
<th>Surgeon B</th>
<th>Surgeon C</th>
<th>Surgeon D</th>
<th>National Average</th>
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<tbody>
<tr>
<td>Mean Age (years)</td>
<td>59.75</td>
<td>62.1</td>
<td>58.67</td>
<td>58.15</td>
<td>65</td>
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</table>

* Surgeon B patients older than Surgeon D (p = 0.005)

<table>
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<th>Gender</th>
<th>National Average</th>
</tr>
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<tbody>
<tr>
<td>Female</td>
<td>50.57</td>
</tr>
<tr>
<td>Male</td>
<td>49.43</td>
</tr>
</tbody>
</table>

* Data given in percent

<table>
<thead>
<tr>
<th>Data given in percent</th>
<th>Surgeon B</th>
<th>Surgeon C</th>
<th>Surgeon D</th>
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</thead>
<tbody>
<tr>
<td>BMI</td>
<td>31.36</td>
<td>30</td>
<td>32.38</td>
</tr>
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</table>

* No statistically significant difference between surgeons

<table>
<thead>
<tr>
<th>Number of Comorbidities</th>
<th>Surgeon A</th>
<th>Surgeon B</th>
<th>Surgeon C</th>
<th>Surgeon D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Musculoskeletal</td>
<td>2.38</td>
<td>2.62</td>
<td>2.13</td>
<td>2.24</td>
</tr>
<tr>
<td>Systemic</td>
<td>2.89</td>
<td>3.07</td>
<td>3.7</td>
<td>2.82</td>
</tr>
</tbody>
</table>

* Surgeon C more systemic comorbidities than Surgeon A and D (p = 0.025, 0.013)

<table>
<thead>
<tr>
<th>Education</th>
<th>Surgeon A</th>
<th>Surgeon B</th>
<th>Surgeon C</th>
<th>Surgeon D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Any college or greater</td>
<td>48.33</td>
<td>57.26</td>
<td>55.56</td>
<td>59.16</td>
</tr>
<tr>
<td>High school graduate</td>
<td>37.92</td>
<td>33.33</td>
<td>40</td>
<td>32.43</td>
</tr>
<tr>
<td>Some high school or less</td>
<td>13.75</td>
<td>9.4</td>
<td>4.44</td>
<td>8.41</td>
</tr>
</tbody>
</table>

* Data given in percent

<table>
<thead>
<tr>
<th>Occupation</th>
<th>Surgeon A</th>
<th>Surgeon B</th>
<th>Surgeon C</th>
<th>Surgeon D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Professional/office/student</td>
<td>33.06</td>
<td>22.61</td>
<td>15.91</td>
<td>37.04</td>
</tr>
<tr>
<td>Labor</td>
<td>17.36</td>
<td>20.87</td>
<td>18.18</td>
<td>15.12</td>
</tr>
<tr>
<td>Retired/Unemployed/Homemaker</td>
<td>49.59</td>
<td>56.52</td>
<td>65.91</td>
<td>47.84</td>
</tr>
</tbody>
</table>

* Data given in percent

<table>
<thead>
<tr>
<th>Occupation</th>
<th>Surgeon A</th>
<th>Surgeon B</th>
<th>Surgeon C</th>
<th>Surgeon D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Professional/office/student</td>
<td>33.06</td>
<td>22.61</td>
<td>15.91</td>
<td>37.04</td>
</tr>
<tr>
<td>Labor</td>
<td>17.36</td>
<td>20.87</td>
<td>18.18</td>
<td>15.12</td>
</tr>
<tr>
<td>Retired/Unemployed/Homemaker</td>
<td>49.59</td>
<td>56.52</td>
<td>65.91</td>
<td>47.84</td>
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</table>

* Data given in percent

<table>
<thead>
<tr>
<th>Smoking</th>
<th>Surgeon A</th>
<th>Surgeon B</th>
<th>Surgeon C</th>
<th>Surgeon D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>21.67</td>
<td>16.67</td>
<td>10.87</td>
<td>18.26</td>
</tr>
<tr>
<td>No</td>
<td>78.33</td>
<td>83.33</td>
<td>89.13</td>
<td>81.74</td>
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* Data given in percent

<table>
<thead>
<tr>
<th>Alcohol</th>
<th>Surgeon A</th>
<th>Surgeon B</th>
<th>Surgeon C</th>
<th>Surgeon D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>57.14</td>
<td>51.69</td>
<td>45.65</td>
<td>58.18</td>
</tr>
<tr>
<td>No</td>
<td>42.86</td>
<td>48.31</td>
<td>54.35</td>
<td>41.82</td>
</tr>
</tbody>
</table>

* Data given in percent

<table>
<thead>
<tr>
<th>Life Orientation Score</th>
<th>Surgeon A</th>
<th>Surgeon B</th>
<th>Surgeon C</th>
<th>Surgeon D</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.92</td>
<td>14.28</td>
<td>15.46</td>
<td>15.02</td>
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</table>

* No statistically significant difference between surgeons
DISCUSSION

Consensus statements on indications for total hip and knee arthroplasty have been developed and published by the National Institute of Health. In spite of these efforts, several studies have shown that disagreement exists between orthopaedic surgeons on indications for total hip and knee arthroplasty. In a survey of orthopaedists in the New York City area, Mancuso showed moderate agreement (greater than 50%) was noted on 5 of 9 variables for total hip arthroplasty, and 6 of 10 variables for total knee arthroplasty. Wright et al. surveyed 234 orthopaedic surgeons in Ontario, and found the respondents to disagree on how 20 of 34 patient characteristics affected their decision to perform knee replacement surgery. Tierney et al. showed strong agreement (>95%) on 7 of 33 surgical indications among 220 orthopaedic surgeons surveyed in the State of Indiana. Cross et al. performed a systematic review of the literature on indications for total knee arthroplasty and found that “pain not responsive to drug therapy” was the only patient factor of over 27 reviewed on which there was greater than 90 percent consensus.

Wennberg and others have argued that, “in the absence of professional consensus based on outcomes, individual physicians can hold onto idiosyncratic clinical rules of thumb defining who needs surgery.” This “surgical signature” phenomenon has been postulated to explain dramatic variation in the rates of common surgical procedures, including total hip and knee arthroplasty between neighboring geographic regions. The assumption has been made that orthopaedic surgeons in regions with high rates of total hip and knee arthroplasty may be inappropriately indicating patients for surgery. This assumption has never been proven in the literature. In a retrospective chart review of elective primary hip and knee replacement patients from low-rate and high rate regions of Ontario, Canada, an expert panel of four orthopaedic surgeons, two rheumatologists, two family physicians, an internist, epidemiologist and a physiotherapist concluded that inappropriate use of these surgeries does not account for the high rate of total joint replacement in these regions. Interestingly, Hawker and others demonstrated that both the “potential need” for total joint arthroplasty and “patient willingness” to undergo surgery were greater in a region with a high rate of these surgeries when compared to a low rate region. Multiple authors have argued that total joint arthroplasty is, in fact, an underutilized procedure, since: a) there is a significant unmet need for total joint arthroplasty among those who might benefit, b) the surgeries carry a low risk of morbidity and mortality, c) over 90% of patients experience substantial pain relief and improvements in quality of life, and d) these procedures have been demonstrated to be cost-effective.

An important question which, heretofore, has not been addressed in the literature, is: “Are total joint surgeons operating on the same patients?” Put another way, does disagreement in orthopaedic surgeons’ survey responses about indications for total joint arthroplasty, or differences in the number of patients they indicate for these procedures mean that some surgeons are indicating ‘healthier’ patients for surgery than others? At several hospitals, including our own, valid, reliable patient-based measures of overall health and condition-specific disability such as the SF-36 and WOMAC are included in the medical record. These data provide a reasonable gauge for comparison of patients indicated for surgery by different orthopaedic surgeons.

At our institution, we found patients’ pre-operative general health (SF-36) and hip and knee arthritis specific outcome measures (WOMAC scores) to be essentially the same between the four total joint surgeons. While the retrospective nature of this study prevents us from knowing which patient factors each surgeon used to indicate patients for total joint arthroplasty during the study period, or the relative importance of those factors to the surgeon, this study shows that the patients indicated for total joint arthroplasty by different surgeons at our institution were equally disabled.

There are several limitations to our study. First, this comparison was performed at a single academic institution; therefore, these results cannot be generalized to other institutions, nor have we compared surgeons operating in different institutions. Second, this study was a retrospective chart review, and a power analysis was not undertaken to determine the number of patients needed to detect clinical significance. Third, we had incomplete data on some patients in our study population, which may have biased our results. Finally, this study does not correct for any referral bias that may have existed between the surgeons.

Despite these limitations, this study is important for several reasons. First, this study demonstrates that orthopaedic surgeons who perform more total joint arthroplasty operations than their colleagues do not necessarily operate on healthier patients. Second, this study highlights the need for, and the research possibilities opened by, the creation of a National Total Joint Arthroplasty Registry. Finally, in the context of $1.1 billion dollars recently allocated for Comparative Effectiveness Research by the passage of the American Recovery and Reinvestment Act of 2009[18], this study serves as a model for designing and funding future studies comparing patient-based measures of disability between healthcare providers.
ACKNOWLEDGMENTS

This project was supported by the Bierbaum Research Fund.

The authors would like to thank Yubo Gao, PhD, for performing the statistical analysis for this project, and Alison Klaassen and Joyce Woody for their assistance in data collection.

REFERENCES

ABSTRACT
OBJECTIVE: The purposes of this study were (a) to evaluate the distribution by primary payer (public vs. private) of U.S. pediatric patients aged 5–18 years who were hospitalized with a sports-related lower extremity fracture and (b) to discern the adjusted mean hospital length of stay and mean charge per day by payer type.

METHODS: Children who were aged 5 to 18 years and had diagnoses of lower extremity fracture and sports-related injury in the 2006 Healthcare Cost and Utilization Project Kids’ Inpatient Database were included. Lower extremity fractures are defined as International Classification of Diseases, 9th Revision, Clinical Modification codes 820–829 under Section “Injury and Poisoning (800-999),” while sports-related external cause of injury codes (E-codes) are E886.0, E917.0, and E917.5. Differences in hospital length of stay and cost per day by payer type were assessed via adjusted least square mean analysis.

RESULTS: The adjusted mean hospital length of stay was 20% higher for patients with a public payer (2.50 days) versus a private payer (2.08 days). The adjusted mean charge per day differed about 10% by payer type (public, US$7,900; private, US$8,794).

CONCLUSIONS: Further research is required to identify factors that are associated with different length of stay and mean charge per day by payer type, and explore whether observed differences in hospital length of stay are the result of private payers enhancing patient care, thereby discharging patients in a more efficient manner.

INTRODUCTION
School-aged youth sports injuries pose a serious threat to the health and well-being of young people. At least 4.3 million sports and recreational injury episodes occur each year to school-aged children in the United States. Lower extremity fracture (LEF) is the most frequent traumatic orthopaedic injury, and the most common principal diagnosis of all hospitalizations for sports-related injuries.

These LEF injuries can have profound negative consequences for young people in terms of their physical, mental, and emotional health. They can also place a tremendous burden on the patient’s family, the health care system, and society as a whole.

Much of the previous research on sports-related injuries in children focused on injuries that were treated in emergency departments (ED) or outpatient clinics because most of these injuries do not require hospitalization. Though a recent paper described the characteristics of pediatric sports injuries that resulted in hospitalization, it dealt with all hospitalizations resulting from sports injury and did not study payer-based hospital length of stay (LOS) and hospital charges. There is no published literature using national data to describe the LOS and hospital charges by payer type resulting from sports-related LEF injuries in the pediatric population.

The purposes of this retrospective study were (a) to evaluate the distribution by primary payer (public vs. private) of U.S. pediatric patients aged 5–18 years who were hospitalized with a Sports-Related LEF and (b) to discern the adjusted mean hospital length of stay and mean charge per day for this group of patients by payer type.

METHODS
Data Source
This study used sample data from the Healthcare Cost and Utilization Project (HCUP) Kids’ Inpatient Database (KID), which is the only national dataset on hospital use, outcomes, and charges designed to study children’s use of hospital services in the United States. The 2006 KID contains approximately 3.1 million pediatric discharges from 3,739 community, non-rehabilitation hospitals in 38 states representing all 4 geographic census regions (northeast, midwest, west, and south). This KID database includes a sampling of all hospital discharges where the patient was age 20 or less at admission during the year 2006. The sample is weighted by design to be representative of all community hospitals in the American Hospital Association annual survey of hospitals, thus allowing for extrapolation to a national estimation of
Injury and Poisoning

9.1.3.11 Descriptive statistics including means, standard deviations/error and percentages were used to characterize the study population in total and by primary payer type. Proportional comparisons were conducted via χ² tests. Patient demographic variables include age at time of admission, sex, race, and median household income quartiles based on the ZIP code of the family’s residence. Hospitalization variables include admission month and source, diagnostic and procedure codes, duration of stay, total charges, expected payer, and discharge disposition. Hospitals included in this database are divided into strata using 6 characteristics: ownership/control, bed size, teaching status, rural/urban location, US region, and hospital type (pediatric vs. other). Bed capacity is categorized into small, medium, or large, and varied in specific bed capacity depending on whether the hospital was located in a rural area or was an urban non-teaching or urban teaching hospital.

Sample of Patients

All patients in the KID in 2006 who were aged 5 to 18 years and had a diagnosis of a sports-related injury and LEF were selected. Three International Classification of Diseases, 9th Revision, Clinical Modification,¹⁰ external cause of injury codes (E-codes) that were used for the sports patient selection were as follows: E886.0, tackles in sports that cause fall on same level from collision, pushing, or shoving, by or with other person; E917.0, striking against or struck accidentally by objects or persons in sports without subsequent fall; and E917.5, striking against or struck accidentally by objects or persons in sports with subsequent fall. Although other injuries may have been sports related, only these 3 E-codes were used specifically to identify sports injuries in this study. The LEF codes¹⁰ are 820–829 under Section “Injury and Poisoning (800-999).” Having applied the above entry criteria to the KID database, we got 2,039 discharges records. After applying sampling weights for hospital length of stay and hospital charge variables. Instead, the least square mean analysis in SAS procedure GLM was used to assess the dependent variables length of stay and charge per day by primary payer type, adjusting for continuous variables like age, number of diagnoses, number of procedures, and number of comorbidities, and categorical variables like sex, hospital setting (rural, urban non teaching, urban teaching), hospital bed size (small, medium, large), and region of the country (northeast, midwest, south, west). The variable mean charge per day was derived as the ratio of total charges to length of stay. The level of significance for all statistical tests was set at P<.05.

RESULTS

In 2006, there were 3,345 children hospitalized with sports-related LEF injuries nationwide, representing 6.93% of pediatric LEF patients and accounting for 0.04% of the weighted patients in the database.

Table 1 shows the characteristics of 3,345 national hospital discharges for sports-related LEF in pediatric patients with a mean age of 13.8 years old (not shown). Among those discharges, nineteen percent (=633/3345) reported a public payer as the primary source of insurance coverage, while 81% (=2712/3345) reported having a private primary payer. Patients with a public payer were younger; with 38% aged 5–12 years and 26% aged 16-18 years, as compared to 30% and 35% of those with a private payer. It is clear that patients were predominantly male (87%), while in public payer patients 93% were male. Admission rates among seasons was stable between payer types, summer is the highest rate season, followed by fall, spring, and winter. Fifty-seven percent of private payer patients chose urban teaching hospitals for treatment, and sixty-seven percent of public payer patients did so. Patients from the southern region outnumbered every other regions patients in terms of payer types. It also showed that children with sports injuries were more likely to be admitted to large (60%), urban, teaching hospitals (55%).

Table 2 presents the adjusted least square (LS) means for hospital length of stay and means for charge per hospital day by primary payer. Here, we only showed the relevant least square means since the calculated standard error and P value were not correct due to the complex design in KID.²¹ The adjusted LS mean hospital length of stay among patients with a public payer (2.50 days) was about 20% longer than the LOS among patients with a private payer (2.08 days). The adjusted mean charge per day by private payer ($8,794) is about 11.3% higher than that by public payer ($7,900).
In this study, we analyzed the KID data and found, nationwide, an estimated 3,345 LEF hospitalizations for sports-related injuries among children who were aged 5 to 18 years in 2006, resulting in annual charges of about $61 million. These will have a major impact on the health and well-being of injured children and their families. These injuries also constitute a substantial economic burden to the health care system as well. To our knowledge, this is the first study to describe the characteristics of pediatric sports injuries that result in LEF hospitalization nationwide by payer type.

The present study showed a clear gender disparity in which males were generally more likely to sustain LEF injuries than females, which is consistent with previous findings that boys were more likely to sustain sports related injuries.14–16 Our findings showed that children with sports injuries were more likely to be admitted to large, urban, teaching hospitals. Also, there were more patients from the southern region than any other region, likely reflecting climate variation.

After adjusting for potentially confounding factors, we revealed that public payer patients were hospitalized about 20% longer than those patients for whom the primary source of health insurance coverage was a private payer. Also, there exists an approximately 11.3% difference in the adjusted mean charge per hospital day by payer type. It is unclear due to the limitations of the present database analysis whether the observed differences in LOS and charge per day are the result of enhancement of care by private payers leading to a more efficient and timely hospital discharge.

There are several limitations here. The cost information provided by the KID is based on hospital charges,

### TABLE 1

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Total (N=3,345)</th>
<th>Public payer (n=633)</th>
<th>Private payer (n=2,712)</th>
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<tr>
<td></td>
<td>n</td>
<td>% (95% CI)</td>
<td>n</td>
</tr>
<tr>
<td></td>
<td>n</td>
<td>% (95% CI)</td>
<td>n</td>
</tr>
<tr>
<td><strong>Ages (years)</strong></td>
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<td></td>
<td></td>
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<tr>
<td>5-12</td>
<td>1042</td>
<td>31 (29,33)</td>
<td>238</td>
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<tr>
<td>13-15</td>
<td>1190</td>
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<tr>
<td>16-18</td>
<td>1113</td>
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<tr>
<td><strong>Gender</strong></td>
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<tr>
<td>Female</td>
<td>390</td>
<td>12 (10,13)</td>
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<tr>
<td>Male</td>
<td>2878</td>
<td>88 (87,90)</td>
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<td><strong>Admission season</strong></td>
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<td>Spring</td>
<td>551</td>
<td>18 (16,20)</td>
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<tr>
<td>Summer</td>
<td>1131</td>
<td>37 (35,39)</td>
<td>212</td>
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<tr>
<td>Fall</td>
<td>942</td>
<td>31 (28,33)</td>
<td>179</td>
</tr>
<tr>
<td>Winter</td>
<td>454</td>
<td>15 (13,16)</td>
<td>91</td>
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<td><strong>Hospital setting</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Rural</td>
<td>373</td>
<td>11 (10,13)</td>
<td>66</td>
</tr>
<tr>
<td>Urban, nonteaching</td>
<td>1025</td>
<td>31 (29,33)</td>
<td>134</td>
</tr>
<tr>
<td>Urban, teaching</td>
<td>1876</td>
<td>57 (55,60)</td>
<td>412</td>
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<tr>
<td><strong>Hospital bed size</strong></td>
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<tr>
<td>Small</td>
<td>455</td>
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<tr>
<td>Medium</td>
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<tr>
<td>Large</td>
<td>1937</td>
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<td><strong>Region of country</strong></td>
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<tr>
<td>Northeast</td>
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<td>Midwest</td>
<td>765</td>
<td>23 (21,25)</td>
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<tr>
<td>South</td>
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<td>34 (31,36)</td>
<td>265</td>
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<tr>
<td>West</td>
<td>608</td>
<td>18 (16,20)</td>
<td>136</td>
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aThe sum in one group is probably not equal to the sum in another group due to varied missing values. All cross-tabulation proportions are statistically different with P values<0.05.

### TABLE 2

<table>
<thead>
<tr>
<th>Payer</th>
<th>Mean days of hospital stay b</th>
<th>Mean charge per day b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public</td>
<td>2.50</td>
<td>$7,900</td>
</tr>
<tr>
<td>Private</td>
<td>2.08</td>
<td>$8,794</td>
</tr>
</tbody>
</table>

badjusted for age, sex, hospital setting, hospital bed size, region, number of diagnoses, number of procedures, and number of comorbidities.
not actual costs. In general, they are not the same. Therefore, our estimation of total hospital charges may not reflect fully the financial impact on the patients and their families. There is an underestimation of the total number of hospitalizations because only 3 E-codes that are very specific to sports injuries were used; many other sports injuries may have codes that do not specify the injury as being sports related. In addition, not all hospitals in the United States were included in the KID.

CONCLUSIONS
This study analyzed characteristics of sports-related LEF injuries that resulted in hospitalization in children by primary insurance payer type. The physical damage and financial burden that resulted from such an injury could have a lifelong impact on the children and their families. Because children are eager to participate in sports activities and research has demonstrated that most of these injuries are preventable, orthopaedists and pediatricians can be instrumental in preventing pediatric sports injuries by participating in patient education, research, and programs that promote safe play. More research is needed to identify factors that are associated with different length of stay and mean charge per day by payer type.

REFERENCES
ABSTRACT

Total ankle replacement (TAR) was first attempted in the 1970s, but poor results led to its being considered inferior to ankle fusion until the late 1980s and early 1990s. By that time, newer designs which more closely replicated the natural anatomy of the ankle, showed improved clinical outcomes. Currently, even though controversy still exists about the effectiveness of TAR compared to ankle fusion, TAR has shown promising mid-term results and should no longer be considered an experimental procedure. Factors related to improved TAR outcomes include: 1) better patient selection, 2) more precise knowledge and replication of ankle biomechanics, 3) the introduction of less-constrained designs with reduced bone resection and no need for cementation, and 4) greater awareness of soft-tissue balance and component alignment. When TAR is performed, a thorough knowledge of ankle anatomy, pathologic anatomy and biomechanics is needed along with a careful pre-operative plan. These are fundamental in obtaining durable and predictable outcomes. The aim of this paper is to outline these aspects through a literature review.

ANKLE BIOMECHANICS

Ankle biomechanics should be evaluated when planning TAR. Some important factors to consider include: 1) limb and ankle alignment; 2) bony and ligamentous anatomy of the ankle joint; 3) ankle motion which occurs in the sagittal, coronal, and transverse planes; and 4) both talocrural and subtalar joint contributions to motion in these three planes.

The ankle joint is composed of three articulations: the tibiotalar, fibulotalar, and tibiobibular joints. The talus has been described as the frustum of a cone with its apex oriented medially. When viewed from the top, the dome appears shaped like a wedge narrowed posteriorly/medially and wider anteriorly/laterally. The tibial plafond has a mirror shape compared to the talus, but with a longer radius of curvature. Thus, when the talus is plantarflexed, its narrowest portion sits in the ankle mortise and allows rotation between the talus and mortise. When the talus is maximally dorsiflexed, the tibiobibular syndesmosis accommodates the talus, and the wider portion of the talar articular surface locks into the ankle mortise, allowing little or no rotation between the talus and the mortise.

The facets of both the medial and lateral malleoli are parallel to corresponding facets of the talus. There is articular contact at these facets from extreme plantarflexion through complete dorsiflexion. Different radii of curvature have been found between the talus and the mortise as well as between the talus and the mortise facets. The ankle joint was formerly thought to function as a simple hinge whose primary axis was transverse and perpendicular to the sagittal plane. It has been shown, however, that the primary axis is correlated with the transmalleolar plane and externally rotated an average of 23 degrees. Recent studies have demonstrated that the axis of rotation is not fixed but rather changes direction and position throughout ankle motion. The position and orientation of these axes account for coupled ankle motion. As the ankle is dorsiflexed, it rotates externally and everts. Conversely, as the ankle is plantar flexed, it rotates internally and inverts.

The role of the medial and lateral ankle ligaments is fundamental when describing ankle biomechanics. Leardini et al. formulated a two-dimensional four-bar linkage model of the ankle joint to describe dorsi/plantar flexion in unloaded conditions (Figure 1). The experiments demonstrated that the human ankle joint complex behaves as a single-degree-of-freedom system during passive motion, with a moving axis of rotation. The four-bar-linkage model showed that the talus/calcaneus complex and tibia/fibula complex rotate about each other on approximately inextensible line segments, represented by the calcaneofibular and tibiocalcaneal ligaments. In this model, the four bars described are: 1) the calcaneofibular ligament; 2) the tibiocalcaneal...
The authors also described different radii of curvature of the calcaneofibular and tibiocalcaneal ligaments; and 4) the line connecting the distal insertions of the calcaneofibular and tibiocalcaneal ligaments (Figure 1). It was deduced that the ankle is a single-degree-of-freedom mechanism where mobility is allowed by the sliding of the articular surfaces upon each other and the isometric rotation of two ligaments about their origins and insertions, without tissue deformation.

The authors also described different radii of curvature of the posterior 75% of the talar articular surface and the anterior 25%. The posterior 75% showed a longer radius of curvature. This explains why, during dorsiflexion, the articular contact area is shifted anteriorly, with posterior joint distraction and, conversely, during plantarflexion the articular contact area is shifted posteriorly, with an anterior joint distraction. Furthermore, this model explains how, in a tibial reference frame, the instantaneous center of rotation moves from a posteroinferior to an anterosuperior position during a complete cycle from maximal plantarflexion to maximal dorsiflexion.

The authors also showed that the calcaneofibular and tibiocalcaneal ligaments, which are approximately isometric during the whole range of motion, control and guide passive motion and are therefore responsible for correct joint mobility. On the other hand, the tension and length of the other ankle ligaments changes according to joint position. The other ligaments are therefore responsible for joint stability.

The human ankle joint has unique articular characteristics. When loaded, the ankle joint has a smaller area of contact between the opposing articular surfaces compared to the knee and hip. At 500N of load, the contact area of the ankle joint averages 350mm², compared with 1120 mm² for the knee and 1100 mm² for the hip. Therefore, the smaller contact area makes the normal peak contact stress higher in the ankle than in the knee or hip. In addition, ankle joint articular cartilage differs from that of the knee and hip in thickness and tensile properties. The thickness of ankle articular cartilage ranges from <1 mm to slightly <2 mm.

Ankle motion occurs in the sagittal, coronal, and transverse planes. Sagittal plane motion, which consists of plantarflexion and dorsiflexion, constitutes the greatest amount of motion in the healthy ankle. The range of sagittal plane motion has been reported to be 13° to 33° of dorsiflexion and 23° to 56° of plantarflexion. Most studies indicate that the range of motion required for normal walking is around 12° of dorsiflexion and 15° of plantarflexion. Transverse-plane motion is coupled with sagittal plane motion. Michelson and Helgemo reported that dorsiflexion resulted in an average of 7.2° ± 3.8° of external rotation of the foot relative to the leg and 1.9° ± 4.12° degrees of internal rotation with plantarflexion. Coronal motion is described as varus or valgus rotation. Michelson et al. observed that both maximal dorsiflexion and plantarflexion of the ankle were associated with inversion of the ankle. They attributed coronal plane motion to the position of the deltoid ligament.

It has been debated in the literature as to how much the talocrural and subtalar joints contribute to each motion. It has been shown that the talocrural joint has a greater contribution to dorsiflexion/plantarflexion and that the subtalar joint has a greater contribution to inversion/eversion. Axial rotation is thought to take place in approximately equal proportions at both joints. Furthermore, the key role of the talonavicular joint in

Figure 1. Two-dimensional four-bar linkage model of the ankle joint to describe dors/plantar flexion in unloaded conditions. The talus/calcaneus complex and tibia/fibula complex rotate about each other on approximately inextensible line segments, represented by the calcaneofibular (AC) and tibiocalcaneal (BD) ligaments. The other two bars in this four-bar linkage model are formed by: 1) the bony segment connecting the proximal insertions of calcaneofibular and tibiocalcaneal ligaments (AB, red dashed line); and 2) the bony segment connecting the distal insertions of calcaneofibular and tibiocalcaneal ligaments (CD, red dashed line). Redrawn from Learndini et al. J Biomech. 1999 Jun;32(6):585-91.
BRIEF HISTORY

The first generation of TARs were formed by two components, a concave polyethylene tibial component and a convex metal (usually cobalt-chrome alloy) talar component. In some designs the materials were inverted for tibial and talar components. Constrained or unconstrained TAR designs were introduced, but poor results and high failure rates were recorded with both types. With constrained implants, the inability to dissipate the rotational forces produced by the continuous variation of rotational axis resulted in loosening as the main cause of failure.1 On the other hand, with unconstrained designs, instability occurred due to the excessive strain placed on surrounding soft tissues.1 First-generation implants required large bone resection to allow cement fixation and component positioning. This has been shown to be another drawback and possible cause of loosening of these devices for two main reasons: 1) cementing techniques used in the 1970s would currently be considered inadequate, and 2) bony strength of the both tibia and talus rapidly decreases incremental to bone resection.14 It has been shown, as well, that bone strength was significantly higher in the talus (40% on average) than in the tibia, explaining the higher rate of loosening for the tibial component. In summary, first-generation implants were abandoned because of the high failure rates, most commonly due to cement fixation, over-constraint, lack of constraint, wound healing, component loosening and pain.

The second phase of implants began in the 1980s with the introduction of modern TARs, like the Buechel-Pappas Total Ankle Replacement (Endotec, South Orange, NJ) in the USA and the Scandinavian Total Ankle Replacement (STAR; Waldemar Link, Hamburg, Germany) in Europe. In 1992, the Agility Total Ankle System prosthesis (DePuy, Warsaw, IN), designed by Dr. Frank Alvine, was the first ankle implant to receive FDA approval.2 At the end of this phase, almost all TARs were semi-constrained, cementless (with minimal bone resection required), and using porous coatings to encourage bone ingrowth.3 Tibial metal-backed, polyethylene inserts and large contact areas on the tibia and talus became common features as well.

The last phase started in the late 1990s with the introduction of a few new implants, including the Salto (Tornier SA, Saint Ismier, France), HINTEGRA (Newdeal SA, Lyon), Mobility (DePuy, Warsaw, IN), TNK (Kyocera Corporation, Japan), and BOX (Finsbury Orthopaedics, Leatherhead, Surrey, UK). All these designs (with the exception of the TNK which is a ceramic implant) use the three-part mobile bearing system.1

INDICATIONS

Although patient selection appears to be critical to successful and predictable outcomes, indications for TAR are still being defined. The optimal patient is older (>50 years old) with end-stage ankle arthrosis, non-obese and with low physical demands.15,16 Patients with post-traumatic ankle arthrosis, especially younger patients, seem to have worse outcomes and are more likely to undergo revision than patients with other causes of arthrosis.17 However, some authors18 reported similar outcomes in patients less than and more than 50 years of age, and others19 have stated that TAR may have a role in less active, young (<50 years old) patients with post-traumatic arthrosis. Nevertheless, in general, weight and activity level should guide indications; less active and non-obese patients are less likely to place excessive demands on the TAR and undergo early failure and revision.

Another factor that needs to be taken into account is the presence of degenerative changes in other joints, such as the subtalar, midtarsal, knee, hip, and the contralateral ankle. These patients seem to benefit more from TAR than from arthrodesis because ankle arthrodesis shifts abnormal loads onto the neighboring joints and thus accelerates degenerative changes.15 In fact, it has been shown that at an average of eight years after ankle fusion, approximately 50% of the patients have clinically significant hindfoot arthritis20 and after an average of 22 years, virtually all patients develop hindfoot arthritis.21

In patients with combined subtalar and tibiotalar arthrosis, advocates of ankle fusion would perform a tibiocalcaneal fusion with retrograde nailing to take care of every cause of pain. Ankle arthroplasty has a role in these cases as well. If subtalar arthrosis is at an early stage and the patient’s symptoms are mainly referable to the ankle joint, TAR-only can be performed. This allows better motion of the ankle and less stress across the subtalar joint. If the patient will become symptomatic because of subtalar degeneration, a subtalar fusion may be performed subsequently. If the patient has subtalar symptoms or severe arthrosis at first evaluation, subtalar fusion combined with TAR can be performed. The two procedures can be performed concurrently, or the TAR can be performed 45-60 days after the subtalar fusion.

Patients amenable to triple arthrodesis or with previous triple arthrodesis, may benefit more from TAR than from a pantalar arthrodesis.19 As previously described, TAR and triple arthrodesis can be performed concurrently or with a two-stage procedure.22
Rheumatoid arthritis with multiple joint involvement is not a contraindication for TAR. Similar outcomes have been reported with TARs in osteoarthritis and rheumatoid arthritis in comparative studies. Furthermore, Cracchiolo et al. performed ankle fusion in 14 patients with rheumatoid arthritis and a history of previous hip and knee surgeries; they reported functional improvement in only one patient. On the other hand, some authors suggest that higher subsidence rates occur in patients with rheumatoid arthritis.

It has to be mentioned here that, in very select patients, TAR can be indicated to treat painful ankle fusion. Few cases have been reported in the English literature and we refer readers to specific writings regarding this topic.

Absolute contraindications to TAR include: 1) active infection, 2) peripheral vascular disease, 3) inadequate soft-tissue envelope, and 4) Charcot neuroarthropathy. Relative contraindications include: 1) young, active patients, 2) previous infection, 3) severe lower extremity malalignment, 4) marked ankle instability, 5) marked osteoporosis, and 6) osteonecrosis of the talus. Malalignment and instability are controversial factors and will be described in detail in the pre-operative planning section. In case of focal or superficial bone necrosis, designs that remove more talar bone can be indicated.

**WORK-UP AND PRE-OPERATIVE PLANNING**

Weight bearing antero-posterior, lateral and mortise views of both ankles are required. The rearfoot alignment (Cobey/Saltzman view) is essential to evaluate the ankle joint and identify any calcaneal-tibial deformities. This view is obtained with the patient standing on an elevated platform, a cassette positioned 15° anteriorly inclined from vertical and the x-ray beam oriented perpendicular to the film, aimed at the ankle. In case of diaphyseal deformities, antero-posterior and lateral views of the leg are required (Figure 2B).

In the sagittal plane, the anterior distal tibial angle (ADTA) should be measured. The ADTA is formed by the mechanical axis of the tibia and the joint orientation line of the ankle in the sagittal plane and measures 80° ± 3° in the normal lower extremity (Figure 3B). An increased ADTA represents a recurvatum deformity.

In the coronal plane, the lateral distal tibial angle (LDTA), the tibial-talar angle and the calcaneal tibial alignment should be measured. The LDTA (Figure 3A) is formed by the distal tibial articular surface and the anatomical axis of the tibia and measures 89° ± 3°. A decreased LDTA represents a varus deformity. The tibial-talar angle (Figure 3C) is defined by the tibial and talar articular surfaces in the ankle joint. When the tibial-talar angle is >10° the joint is defined as incongruent (unstable). The calcaneal-tibial alignment (measured on the Cobey/Saltzman view) is useful to confirm any varus or valgus deformities as well as to assess every talar compensation (inversion and eversion) to an abnormal LDTA. The subtalar joint can compensate 15° of eversion and 30° of inversion. Evaluation of subtalar joint compensation and range of motion is important because tibial realignment (with osteotomy or TAR) may unmask a subtalar deformity. If this distal (rearfoot) deformity is not addressed, further symptoms may develop.

If an abnormal ADTA or LDTA is present (sagittal or coronal deformity), the center of rotation of angulation (CORA) is measured. The CORA is the intersection of the mid-diaphyseal line and the line starting from the middle of the joint and perpendicular to the abnormal ADTA or LDTA (Figure 4). The CORA can be located at the joint line level (usually due to anatomical joint line malalignment or to ankle degeneration) or proximally (usually due to tibial deformities/fractures).

Malalignment and instability should be thoroughly evaluated in pre-operative planning. Both can lead to edge-loading of the implant, polyethylene wear, progressive deformity and high early failure rates. Malalign-
Figure 3. Pre-operative measurement. A) The lateral distal tibial angle (LDTA) is formed by the distal tibial articular surface and the anatomical axis of the tibia (normal values 89° ± 3°). B) The anterior distal tibial angle (ADTA) is formed by the mechanical axis of the tibia and the joint orientation line of the ankle in the sagittal plane (normal values 80° ± 3°). C) The tibial-talar angle (α) is defined by the tibial and talar articular surfaces in the ankle joint; if it measures > 10°, the joint is defined as incongruent.

Figure 4. The center of rotation of angulation (CORA) is the intersection of the mid-diaphyseal line and the line starting from the middle of the joint and perpendicular to the abnormal ADTA or LDTA (LDTA in this figure). The CORA can be located proximally at the tibia (A) or at the joint line level (B).
ment can be due to: 1) previous tibial fractures which result in diaphyseal or metaphyseal tibial malalignment (Figure 4A), either in the coronal or sagittal plane; 2) multi-articular degeneration of the hindfoot involving the subtalar and midtarsal joints (i.e., rheumatoid patients) which can result in varus or valgus malalignment; and 3) Ankle joint pathologies that include distal tibial articular surface malalignment, talar tilt due to ligamentous instability, or both (Table 1).

1) In diaphyseal or metaphyseal tibial malalignment, a varus/valgus or procurvatum/recurvatum deformity or both are present. In coronal malalignment, the LDTA is abnormal and the CORA is located in the tibial diaphysis or metaphysis. Diaphyseal or metaphyseal tibial malalignment usually needs to be addressed with osteotomy before considering TAR. Only in cases of minimal ADTA or LDTA changes (<10°), can realignment be performed with the TAR tibial cut (Figure 5B). In this case, the choice of implant is very important. TAR instruments that allow distal tibial slope changes are required in cases of abnormal ADTA.

2) In varus or valgus hindfoot malalignment, ADTA and LD TA are normal, but calcaneal-to-tibial malalignment is present. Varus/valgus hindfoot malalignment is due to multi-articular degeneration, and subtalar or triple arthrodesis is usually sufficient to correct the deformity;

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### TABLE 1.

<table>
<thead>
<tr>
<th>Deformity type</th>
<th>Abnormal angles</th>
<th>Scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td>Varus tibial deformity-congruent joint</td>
<td>Decreased LDTA, CORA at the level of tibial articular surface, normal tibial-talar angle</td>
<td></td>
</tr>
<tr>
<td>Valgus tibial deformity-congruent joint</td>
<td>Increased LDTA, CORA at the level of tibial articular surface, normal tibial-talar angle</td>
<td></td>
</tr>
<tr>
<td>Varus tibial deformity-incongruent joint</td>
<td>Decreased LDTA, CORA at the level of tibial articular surface, tibial-talar angle &gt; 10°</td>
<td></td>
</tr>
<tr>
<td>Valgus tibial deformity-incongruent joint</td>
<td>Increased LDTA, CORA at the level of tibial articular surface, tibial-talar angle &gt; 10°</td>
<td></td>
</tr>
<tr>
<td>Incongruent joint</td>
<td>Normal LDTA, tibial-talar angle &gt; 10°</td>
<td></td>
</tr>
</tbody>
</table>
otherwise calcaneal osteotomies can be combined. As previously mentioned, in these cases one-stage or two-stage procedures can be performed.

3) When the malalignment is in the ankle joint, it can be due to: a) tibial joint line deformity or progressive degeneration, b) an incongruent (unstable) joint, or c) both. These deformities are usually in the coronal plane and the surgeon can therefore encounter five different scenarios, summarized in Table 1.

The most common scenario in ankle osteoarthritis is a varus hindfoot alignment due to talar tilt. Valgus alignment is rare and often associated with rheumatoid arthritis.

Some authors report that pre-operative varus or valgus deformity did have a significant effect on TAR survivorship, with the likelihood of revision being directly proportional to the size of the angular deformity. They report that TAR should be undertaken with extreme caution in the presence of marked malalignment. Some authors have shown that patients with preoperative incongruent joints were 10 times more likely to develop progressive edge-loading than patients with congruent joints. Conversely, Hobson et al. compared TAR results from a group of patients with coronal deformity up to 10° with a second group with 11° to 30° of deformity. They did not find significant differences between the two groups and stated that TAR can be safely performed in patients with a hindfoot deformity of up to 30°. They highlighted as well the importance of adequate correction of alignment and instability. Similarly, Kim et al. compared the results of TAR in neutral and in varus ankles (>10°) and concluded that results are similar in the two groups when appropriate additional procedures to correct deformity are carried out simultaneously with the TAR. The importance of ligamentous stability has also been stated by some biomechanical studies.

For minimal distal tibial deformities (<10°), realignment can be performed with the tibial cut. For more severe deformities, a dome or wedge osteotomy is required prior to considering TAR. In pre-operative planning, a greater medial tibial resection must be planned in cases of valgus tibial deformity, while a greater lateral resection is needed for varus tibial deformity.

In incongruent joints, it is important to plan additional soft-tissue procedures based on the type of instability and to choose the correct implant. Indeed, it can be helpful in cases of severe deformity to use instruments that allow independent tibial and talar cuts (see surgical technique section).

As previously mentioned, talar avascular necrosis is a contraindication for TAR. However, in cases of focal or superficial bone necrosis, TAR can be performed. In
these cases, designs that remove more talar bone are recommended.15

Once alignment planning has been performed, sizing of the tibial and talar components is evaluated with the specific phantom templates of the chosen implant.

**SURGICAL TECHNIQUE**

The patient is positioned supine, with a bump under the hip and a tourniquet on the proximal thigh. A midline 10 cm incision is made centered on the joint line. The superficial peroneal nerve is identified and protected throughout the procedure. The joint is approached through the bed of the tibialis anterior tendon (or the extensor hallucis longus). The goal is to achieve correct soft tissue balance and tibiotalar alignment, in order to position the tibial and talar components perpendicular to the plumb line of the body, i.e., parallel to the floor when the patient is standing. Therefore, careful debridement of osteophytes, synovial tissue and excessive capsule is carried out (Figure 5A). The medial and lateral gutters need to be debrided as well.

In **congruent varus** (or **valgus**) ankles, the tibial cut is then performed to neutralize the lateral distal tibial angle and to have a reference for talar tilt reduction (Figure 5B). In varus tibial deformity, more bone should be removed laterally compared to medially (Figure 5B), and **vice versa** in valgus tibial malalignment. Talar tilt is then reduced by sub-periosteal deltoid ligament release with a Cobb elevator (Figure 6A). If this is not sufficient, the tibialis posterior tendon is released as well.

In **incongruent varus** (or **valgus**) ankles, the lateral distal tibial angle is normal and no neutralizing cuts are necessary. Talar tilt is reduced with intra-articular and extra-articular soft tissue procedures, as described above.

In cases of **severe varus or valgus deformity** (i.e. **rheumatoid patients**) tibial and talar bone cuts are necessary to re-align the joint, with a “sculpturing technique.”31 When performing tibial cuts with the talus still tilted, it is important to have TAR instruments that allow a talar cut independent of the tibial one. Then, soft tissue procedures can be performed to achieve a rectangular space between the tibial and talar cuts.

At this point, bone cuts are completed and trial components positioned, according to the surgical technique of the implant selected. With the trial components, range of motion and stability should be checked. If dorsiflexion is limited and this is not due to component malpositioning, a percutaneous Achilles tendon lengthening is performed (Figure 6B). If stability of the implant is not satisfactory due to varus tilt, reconstruction of the lateral ligaments may be necessary after definitive component positioning (Figures 6C, 7). Generally, if the implants are placed in anatomic alignment, with an appropriate polyethylene spacer, instability is uncommon. If ligamentous stabilization is required, this can be performed as for ankle instability, with anatomic repair (Broström36 or Broström-Gould37) with or without auto/allograft augmentation, or with non-anatomic reconstruction tenodeses (i.e., Watson-Jones,38 Evans,39 Chrisman-Snook40 procedures).
Occasionally, despite these measures, hindfoot malalignment persists and requires correction with a separate hindfoot procedure (calcaneal osteotomy, subtalar fusion), that can be performed concomitantly or as staged procedure, depending on the complexity of the index operation.

The post-operative regimen is dictated by the combined bony procedures (arthrodesis or osteotomy). If only TAR and soft tissue procedures were performed, the patient is immobilized in a walking plaster cast for 4-6 weeks. Weight bearing is usually allowed with crutches, unless markedly poor bone quality is identified. Then, the plaster is removed, free range of motion and weight bearing as tolerated are allowed.

RESULTS

Results with first-generation ankle replacements were found to be poor and it was recommended their use be discontinued for the Mayo, Conaxial (Beck-Steele), Bath and Wessex, Newton, Waugh, Smith and Oregon implants.

With newer designs, encouraging results have been reported. Studies on long-term prosthetic survival rates (>10 years follow-up) of TAR have mainly been reported by inventors of the different prostheses. In fact, Buechel et al. reported a 12-year survival rate of 92% for 75 Beuchel-Pappas prostheses. Kofoed reported the results of 33 cemented STAR and of 25 uncemented STAR implants with a 70% survival rate (confidence limit, 60.3-78.5) for the cemented group and 95.4% survival rate (confidence limit, 91.0-99.9) for the uncemented group. Knecht et al. found a 10-year survival of 85% with 132 Agility prostheses.

Henricson et al. reported on survivorship of 531 different TARs implanted in Sweden from 1993 to 2005 and recorded in the Swedish Ankle Arthroplasty Register. The estimated overall five-year survival rate was 0.78 (95% CI: 0.74–0.82) and the 10-year survival rate was 0.62 (0.52–0.72). Gender and rheumatoid arthritis were not correlated with higher failure rates. Conversely, lower age at the index surgery implied an increased risk of revision (p = 0.002, RR 0.98, CI: 0.96–0.99). For the three
surgeons who had implanted the majority of the STAR ankles, survival rates became significantly higher after the first 30 cases, increasing at five years from 0.70 (0.57–0.77) to 0.86 (0.80–0.93).57

Fevang et al.51 reported on survivorship of 257 TARs recorded in the Norwegian Arthroplasty Register and implanted between 1994 and 2005. The overall five-year and 10-year survival were 89% and 76%, respectively. The authors found no significant influence from age, sex, type of implant, diagnosis, or cementation on the risk of revision.51

A recent systematic review was conducted to compare the outcomes of different TARs available on the market.52 Thirteen Level IV studies reporting on 1105 total ankle arthroplasties (234 AgilityTM, 344 STAR, 153 Buechel-PappasTM, 152 HINTEGRA®, 98 SaltoTM, 70 TNK, 54 MobilityTM) were included. Residual pain was common (range, 27%–60%), superficial wound complications occurred in 0% to 14.7%, deep infections occurred in 0% to 4.6% of ankles, and ankle function improved after total ankle arthroplasty. The overall failure rate was approximately 10% at five years with a wide range (range, 0%–32%) between different centers. The authors concluded that superiority of an implant design over another could not be supported by the available data.52

SooHoo et al.53 compared the reoperation rates following ankle arthrodesis and TAR. Patients with TAR had an increased risk of device-related infection and of having a major revision procedure. The rates of major revision surgery after ankle replacement were 9% at one year and 23% at five years compared with 5% and 11% following ankle arthrodesis. Patients treated with ankle arthrodesis had a higher rate of subtalar fusion at five years postoperatively (2.8%) than did those treated with ankle replacement (0.7%).53 Conversely, similar rates of revision for TAR and ankle fusion have been reported by Haddad et al. in their systematic review.54

Saltzman et al.55 wrote a preliminary report (24 months follow-up) of a prospective controlled trial of STAR versus ankle fusion. The authors found that major complications and need for secondary surgical intervention were more common in the TAR group than in the ankle fusion group. However, ankles treated with STAR ankle replacement had better function and equivalent pain relief compared to ankles treated with fusion.

CONCLUSIONS

Even though many aspects are still being defined (indications, long-term outcomes of the newer designs, etc.), TAR should no longer be considered inferior to ankle fusion or as an experimental procedure. However, surgeons should remember that TAR is not for every patient and that the appropriate indication, based on the evidence available, is fundamental to obtaining durable and predictable outcomes. Ankle fusion is still a valid alternative for patients who are not amenable to TAR. A thorough knowledge of ankle anatomy, pathologic anatomy and biomechanics together with a careful pre-operative planning are mandatory to successful technical performance of total ankle replacement surgery.

REFERENCES


HIGH TIBIAL OSTEOTOMY VERSUS UNICOMPARTMENTAL KNEE ARTHROPLASTY FOR MEDIAL COMPARTMENT ARTHROSIS OF THE KNEE: A REVIEW OF THE LITERATURE

Federico Dettoni, MD,* Davide Edoardo Bonasia, MD,* Filippo Castoldi, MD,* Matteo Bruzzone, MD,* Davide Blonna, MD,* Roberto Rossi, MD*

ABSTRACT
This review examined the literature regarding high tibial osteotomy (HTO) and unicompartmental knee arthroplasty (UKA), focusing on indications, survivorship and functional outcomes of the two procedures, as well as revision to total knee arthroplasty (TKA) after failed HTO or UKA. HTO and UKA share the same indications in selected cases of medial unicompartmental knee arthrosis. These indications include patients who are: 1) 55 to 65 years old; 2) moderately active; 3) non-obese; 4) have mild varus malalignment; 5) no joint instability; 6) good range of motion; and 7) moderate unicompartmental arthrosis. With the correct indications, both treatments produce durable and predictable outcomes in the treatment of medial unicompartmental arthrosis of the knee. There is no evidence of superior results of one treatment over the other.

INTRODUCTION
High tibial osteotomy and unicompartmental knee arthroplasty represent a “strange couple” in the treatment of medial compartment arthrosis of the knee. Even though they are very different procedures with different philosophies, in some cases they share the same indications. Therefore, some authors describe them as alternative options, while others deny any overlaps of indication. HTO has long been considered a successful and widely performed procedure to address malalignment and subsequent unicompartmental arthrosis of the knee. UKA has gained popularity in the management of unicompartmental arthrosis, when total knee arthroplasty and HTO are the only alternative treatments available.

The aim of this review is to identify the correct indications for HTO and UKA, analyze the results from both treatments, and report on the comparison studies in the literature.

INDICATIONS FOR HTO AND UKA

Indications for HTO
The original intent of HTO is correction of a knee angular deformity or metaphyseal tibial malalignment, which determines a medial symptomatic overload or initial arthrosis. The ideal candidate for an HTO is a young (less than 60 years old), active patient affected by symptomatic mild-to-moderate varus knee (5 to 15 degrees) with mild medial compartment involvement (less than grade III, Ahlbach classification), intact lateral and patellofemoral compartments, good knee range of motion (knee flexion >120 degrees), and no joint laxity or instability. However, the indications for HTO have been recently expanded to include posterolateral laxity and varus hyperextension thrust, anterior cruciate ligation (ACL) deficiency and varus thrust or alignment, and combined ligamentous laxity with varus or postero-lateral thrust. A better understanding regarding the importance of tibial slope in knee stability and modern surgical techniques, which allow multiplanar correction of alignment, led to this expansion in terms of indication. The body mass index (BMI) of the patient is a controversial factor. In fact, whether obesity significantly affects the outcome of HTO has not yet been proven.

In the last few decades, HTO has been associated with other procedures in order to improve the outcomes in younger patients, and these mainly include: 1) cartilage resurfacing procedures; 2) meniscal transplantation; and 3) ligament reconstruction.

The degree of osteoarthritis affecting the medial compartment is a key factor in determining the outcome of HTO. Even though cartilage repair procedures have

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been associated with HTO for the treatment of focal chondral defects in malaligned knees, severe degenerative involvement of the medial compartment still remains a contraindication for HTO.\textsuperscript{5}

Arthritic involvement of the lateral and patellofemoral compartments is another contraindication to HTO. It has been shown that when HTO for medial compartment arthrosis is performed in an otherwise healthy knee, no degenerative changes occur in the lateral or patellofemoral compartments.\textsuperscript{9} On the other hand, HTO does not manage symptoms related to bi- or tri-compartmental arthrosis of the knee.

Another key factor in the selection of patients amenable to HTO is age: the risk of failure increases 7.6\% per year of age, and in patients over 65 years the relative risk is 1.5 times that of younger patients. Therefore, HTO is not recommended in patients older than 65 years.\textsuperscript{7}

### Indications for UKA

UKA is the partial surface replacement of the knee joint. Its increasing popularity is due to: 1) the possibility of replacing a severely damaged compartment; 2) the preservation of bone stock; together with 3) a faster recovery time and minimal invasiveness compared to TKA. With recent technical improvements, UKA is consistently less invasive, and newer designs with arthroscopic techniques will soon be introduced into the marketplace.\textsuperscript{8}

The ideal indications for UKA include: 1) unicompartamental osteoarthritis or femoral condyle avascular necrosis, with intact lateral and patellofemoral compartments; 2) age over 60 years; 3) low demands; 4) no obesity; 5) minimal pain at rest; 6) range of motion (ROM) arc over 90 degrees with less than 5 degrees flexion contracture; and 7) within 10 degrees of axial malalignment, which can be passively corrected almost to neutral.\textsuperscript{9,10}

Anterior cruciate ligament (ACL) deficiency has been considered a contraindication for UKA because of increased stresses across the components with subsequent polyethylene wear and early failure.\textsuperscript{11} Nevertheless, some authors have reported UKA can be done safely in ACL-deficient knees when the tibial component slope does not exceed 7 degrees. In UKA as well as in HTO, the importance of tibial slope for anterior/posterior stability of the knee has been proven, but there is no evidence yet about the reliability of UKA in ACL-deficient knees.\textsuperscript{12,13}

### Indications for both HTO and UKA

Despite the differences in indications between the two procedures, a small population of patients can be considered amenable to either HTO or UKA. The current indications for both treatments are summarized in Table 1.

### OUTCOMES OF HTO AND UKA

Many papers in the literature described the outcomes of HTO and UKA. These mainly focused on survivorship analyses, technical features (such as closed versus open HTO, or all polyethylene versus metal-backed tibial UKA), complications and adverse effects of the procedures, as well as outcomes of revisions to TKA. Only a few papers reported a direct comparison of the two procedures.

### Results of HTO

Survivorship analyses have reported increasing survival rates for HTO, with correct patient selection and precise surgical technique. As the authors gained knowledge and experience over a period of years, the 10-year survivorship increased from around 50\% to 80\% (Naudie, 1999;\textsuperscript{14} Papachristou, 2006;\textsuperscript{15} Gstöttner, 2008), then to 90\% (Sprenger, 2003\textsuperscript{17}), 95.1\% (Koshino, 2004\textsuperscript{18}), and up to 97.6\% (Akizuki, 2008\textsuperscript{19}). The same authors reported a survivorship at 15 years increasing from 65.5\%,\textsuperscript{16} 66\%,\textsuperscript{15} 86.9\%,\textsuperscript{18} to 90.4\%,\textsuperscript{19} Fletcher et al. in 2006\textsuperscript{20}

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### Table 1. Ideal indications for UKA, HTO and overlaps between the two treatments

<table>
<thead>
<tr>
<th></th>
<th>UKA</th>
<th>HTO or UKA</th>
<th>HTO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>&gt; 55 years</td>
<td>55 – 65 years</td>
<td>&lt; 65 years</td>
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<tr>
<td>Activity level</td>
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<td>Active</td>
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<td>Weight (BMI)</td>
<td>&lt; 30 &lt; 30</td>
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<tr>
<td>Alignment</td>
<td>0 - 5°</td>
<td>5 – 10°</td>
<td>5 – 15°</td>
</tr>
<tr>
<td>AP Instability</td>
<td>No to grade I</td>
<td>No to grade I</td>
<td>Any</td>
</tr>
<tr>
<td>ML Instability</td>
<td>No to grade I</td>
<td>No to grade I</td>
<td>No to grade II</td>
</tr>
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<td>ROM</td>
<td>Arc 90° and &lt; 5° flexion contracture</td>
<td>Arc 100° and &lt; 5° flexion contracture</td>
<td>Arc 120° and &lt; 5° flex contracture</td>
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<tr>
<td>Arthrosis severity</td>
<td>Any</td>
<td>Aklback II</td>
<td>Aklback I - II</td>
</tr>
</tbody>
</table>

UKA = medial unicompartmental knee arthroplasty; HTO = high tibial valgus osteotomy; BMI = body mass index; AP Instability = antero-posterior instability; ML Instability = medio-lateral instability; instability grading: according to the American Medical Association (grade I = 0-5 mm, grade II = 5-10 mm, grade III = >10 mm, no hard stop); Arthrosis severity = medial compartment arthrosis according to Ahlback classification, assuming that lateral and patellofemoral compartments are intact.
reported an 85% survivorship at 20 years of follow-up. Patient satisfaction and clinical results were reported to be good as well, with 50 to 80% achieving good to excellent results at five-to-seven years follow-up, and 30 to 60% good to excellent results at 10-to-15 years follow-up. Advanced age, over- or under-correction, instability and severe arthrosis were reported as unfavorable factors. The goal to be achieved in alignment assessment is a slight valgus overcorrection (2 to 5 degrees).

Controversies still exist regarding these topics and how to be preferred when comparing between closing wedge, opening wedge, or dome-like, as none has shown significantly better outcome over the others. Interestingly, all papers reporting long-term outcomes and all studies comparing HTO and UKA considered only closing wedge osteotomies, and this lack of the literature regarding the newer opening wedge technique requires further investigation.

Before the introduction of internal fixation and early motion in HTO, when cast immobilization was part of the postoperative treatment, authors recorded a risk between 7.6% and 8.8% of patients having patella baja following a lateral closing wedge osteotomy. This complication was probably due to contracture of the patellar tendon during cast immobilization. A more recent study showed that closing wedge osteotomy increases patellar height, whereas opening wedge osteotomy lowers patellar height. The clinical implications of patellar height changes on outcomes and following TKA are still controversial.

Lateral closing wedge HTO has for many years been considered the gold standard in treating medial knee osteoarthritis. However, this technique entails fibular osteotomy or proximal tibiofibular joint disruption, peroneal nerve dissection, more demanding subsequent TKA, loss of bone stock, and more difficulty controlling tibial slope (with a tendency to decrease it). For all these reasons, the opening wedge HTO gained popularity and became a widely used alternative. This technique however is not itself free from drawbacks including the necessity for bone grafting and possible collapse or loss of correction.

Results of UKA

UKA was introduced in the 1970s but did not gain wide acceptance due to poor early results, high failure rates, and high technical demands as reported by Insall et al. in 1980. In the last few decades, opinion has completely changed and the latest reports in the literature showed highly satisfactory survival rates and considerable patient satisfaction.

In a study on the Finnish Arthroplasty Register, Koskinen reported a 10-year survival rate ranging from 53% to 81%, depending on the prosthetic model implanted. In single-center studies, 10-year survivorship was reported to be up to 93%, while O'Rourke et al. reported an 85% survival rate at 15 years and 72% at 25 years. Patient satisfaction mirrors these excellent survivorship results, particularly in activities requiring complete knee ROM, such as going down stairs and kneeling.

Aspects which most likely affect the outcome of UKA are prosthetic design, alignment, and stability.

Koskinen et al. reported a remarkable difference in terms of 10-year survivorship for four different UKA designs (81%, 79%, 78% and 53%). Furthermore, Borus et al. in their review of the literature, reported overall inconclusive results regarding the use of fixed versus mobile-bearing components and metal-backed versus all polyethylene tibial components.

Robertsson et al. stated that surgeons' confidence with this technically demanding procedure markedly influenced the outcome. They showed that hospitals performing less than 23 UKAs per year reported a revision rate 1.6 times higher compared to that of departments performing a higher volume of UKAs. These authors also concluded that implant design influenced the outcome of UKA.

The importance of tibial slope for the antero-posterior stability of the knee has been proven in UKA, but there is no evidence yet about the reliability of the procedure in ACL deficient knees.

Comparisons between HTO and UKA

Only a few studies have compared groups of patients treated with HTO and UKA (Table 2), and only two of these studies were randomized controlled trials (RCT).

Karpman and Volz performed a retrospective study, reviewing the records of patients treated with HTO and UKA with 20- to 40-month follow-up. HTO obtained a 100% survival rate at two years follow-up, while UKA showed a 91% survival rate at three years. Good-to-excellent results were achieved in 57% of the HTO group, and in 91% of the UKA group. The authors concluded that UKA is a valid alternative to HTO, and performed better.

Broughton et al. reported a retrospective study comparing 49 HTO and 42 UKA procedures at a mean follow-up of 7.8 years and 5.8 years respectively. The matching of groups was made post-hoc, by comparing the pre-operative findings. HTO was performed with
lateral closing-wedge technique and either excision of the fibular head or release of the fibulotibial joint. No internal fixation was performed. Postoperatively, plaster casts were used for six weeks. The UKA implanted was a St. Georg Sledge (Waldemar Link), cemented in all cases. Both medial and lateral compartment procedures were included. Patients were assessed by interview, examination and radiographs when possible, using the Baily knee score, an adaptation of the Hospital for Special Surgery score. UKA showed significantly better results compared to HTO in terms of Baily score (76% and 43% good results, respectively), revision rates (7% and 20% respectively), pain (87% and 23% with mild or no pain), and early complications (including wound problems, deep venous thrombosis and infection). The main cause of unsatisfactory results in the HTO group was inadequate correction of the deformity. Although the authors concluded that UKA performed better than HTO, concerns were raised about the differences in follow-up time, accuracy of the osteotomies, patient selection criteria, and the inclusion of lateral compartment procedures.

Weale and Newman37 reassessed the same cohort at 12 to 17 years follow-up in 1991. Only 21 osteotomies and 15 UKAs were available at this end-of-study follow-up. Good results were found in seven HTOs (21%) and eight UKAs (42%). The revision rate was 34% in the osteotomy group, and 12% in the UKA group. The surviving HTOs and UKAs showed a similar Baily knee score of 31 and 34 respectively. Interestingly, the same patients had significantly different Baily knee scores six years before: 35 and 42 respectively. A total of 43% of the HTOs had mild or no pain, compared to 80% of the UKAs. The authors concluded that the superior results of UKA compared with HTO were maintained even at long-term follow-up.

Ivarsson and Gillquist38 prospectively evaluated the rehabilitation programs of ten patients undergoing a closing wedge HTO (12-month rehabilitation program) matched to ten patients undergoing a UKA (4 Oxford-Biomet, 6 PCA-Howmedica, 6-month rehabilitation program). The mean age of the patients was 63 years (range 53-72 years). Lysholm knee function score, a six-step activity grading scale, the torque of the thigh muscle, VAS pain score, and gait analysis were performed. Muscle strength at six months was better in UKA than in HTO, but it was comparable in the two groups at 12 months. The UKA group tended to reach a higher Lysholm postoperative score, but the difference was significant only with a statistical p of 10%. Pre- and post-operative gait analysis showed an increase in the maximal gait velocity and duration of single-leg support in the UKA group, while no differences were observed in the HTO group. Based on their data, the authors recommended UKA in older patients.

Borjesson et al.39 performed a similar study on 18 HTO and 22 UKA patients, evaluating British Orthopaedic Association (BOA) score, time–distance variables of gait, range of motion, patient satisfaction, and physical activity level achieved. The design of this study was prospective and randomized: Patients (from 55 to 70

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**TABLE 2. Summary of studies that compared groups of patients treated with HTO and UKA**

<table>
<thead>
<tr>
<th>author</th>
<th>year</th>
<th>type of study</th>
<th>number</th>
<th>HTO type/UKA model</th>
<th>Follow-up</th>
<th>survivorship</th>
<th>Outcome</th>
<th>pain</th>
<th>ROM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Karpman et al.</td>
<td>1982</td>
<td>retrospective</td>
<td>23</td>
<td>CWHTO</td>
<td>2 y</td>
<td>100%</td>
<td>57% good/excellent</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Broughton et al.</td>
<td>1986</td>
<td>retrospective</td>
<td>49</td>
<td>CWHTO</td>
<td>7.8 y</td>
<td>80%</td>
<td>43% good/excellent (Baily)</td>
<td>59%</td>
<td>no/mild</td>
</tr>
<tr>
<td>Weale et al.</td>
<td>1994</td>
<td>retrospective</td>
<td>42</td>
<td>CWHTO</td>
<td>5.8 y</td>
<td>93%</td>
<td>76% good/excellent (Baily)</td>
<td>87%</td>
<td>no/mild</td>
</tr>
<tr>
<td>Ivarsson et al.</td>
<td>1991</td>
<td>prospective matched</td>
<td>10</td>
<td>CWHTO</td>
<td>12 mo</td>
<td>100%</td>
<td>0% good/excellent (Lysholm)</td>
<td>6.5</td>
<td>100</td>
</tr>
<tr>
<td>Stukenborgh-Colman et al.</td>
<td>2001</td>
<td>prospective randomized</td>
<td>32</td>
<td>CWHTO</td>
<td>7-10 y</td>
<td>60%</td>
<td>71% good/excellent (KSS)</td>
<td>-</td>
<td>117</td>
</tr>
<tr>
<td>Borjesson et al.</td>
<td>2005</td>
<td>prospective randomized</td>
<td>18</td>
<td>CWHTO</td>
<td>5 y</td>
<td>100%</td>
<td>BOA score median 37 (max=39) 100% no/mild</td>
<td>123</td>
<td></td>
</tr>
<tr>
<td>Dettoni et al.</td>
<td>2008</td>
<td>prospective</td>
<td>54</td>
<td>OWHTO (Puddu)</td>
<td>2.4 y</td>
<td>100%</td>
<td>BOA score median 37 (max=39) 100% no/mild</td>
<td>123</td>
<td></td>
</tr>
<tr>
<td>W-Dahl et al.</td>
<td>2010</td>
<td>national</td>
<td>450</td>
<td>Hemicallotasis</td>
<td>10 y</td>
<td>83%</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Newman</td>
<td>2011</td>
<td>registry review</td>
<td>4799</td>
<td>Accuris</td>
<td>2-4 mo</td>
<td>100%</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Year = year of publication; HTO = high tibial osteotomy; UKA = unicompartmental knee arthroplasty; CWHTO = closing wedge high tibial osteotomy; OWHTO = opening wedge high tibial osteotomy; y = years; mo = months; Baily = Baily Knee Score; Lysholm = Lysholm Knee Score; KSS = Knee Society Score; BOA score = British Orthopaedic Association Score.
years of age) with moderate medial knee arthrosis (Ahlback’s grades I–III) were randomly assigned to one of the two surgical procedures by drawing lots, and were examined before surgery as well as at three months, 1 year and 5 years after surgery. HTO was performed as first described by Coventry (closing wedge osteotomy, postoperatively immobilized in a whole-leg plaster cast for six weeks) and the UKA used was Brigham (Depuy). No differences were detected between the two groups regarding BOA score, range of motion, and patient satisfaction. Time-distance variables of gait showed clinically significant differences in favor of the UKA group at three-months after surgery, but these became insignificant at one-year and five-year follow-up.

Stukenborg-Colisman et al. published a prospective randomized trial, comparing the clinical outcomes of 32 patients treated with HTO and 28 patients treated with UKA. Patients were computer randomized. The osteotomies were performed according to the technique described by Coventry: closing wedge osteotomy, fixation with a two-thirds tubular plate and a cortical screw. The UKA used was the Tubingen unicompartmental knee sliding prosthesis (Aesculap). Postoperatively, full weight bearing in the UKA and partial weight bearing for six weeks in the HTO was allowed. Patients were assessed at an average of 2.5, 4.5, and 7.5 years after surgery using the Knee Society scoring system. At the latest follow-up, the surviving HTOs obtained an average knee score of 76, while UKAs scored 74. The mean functional score was 71 for HTO and 59 for UKA. Average range of motion was 117 degrees in the HTO group and 103 degrees in the UKA group. HTOs showed more postoperative complications. Kaplan-Meier analysis predicted a survivorship of 82% at five years and 77% at 10 years for UKA, compared to 78% and 60% for HTO. None of the differences reported in this study were statistically significant.

The authors concluded that there was insufficient evidence to prefer one method over another with regard to results and longevity. Stukenborg-Colisman et al. published a prospective randomized trial, comparing the clinical outcomes of 32 patients treated with HTO and 28 patients treated with UKA. Patients were computer randomized. The osteotomies were performed according to the technique described by Coventry: closing wedge osteotomy, fixation with a two-thirds tubular plate and a cortical screw. The UKA used was the Tubingen unicompartmental knee sliding prosthesis (Aesculap). Postoperatively, full weight bearing in the UKA and partial weight bearing for six weeks in the HTO was allowed. Patients were assessed at an average of 2.5, 4.5, and 7.5 years after surgery using the Knee Society scoring system. At the latest follow-up, the surviving HTOs obtained an average knee score of 76, while UKAs scored 74. The mean functional score was 71 for HTO and 59 for UKA. Average range of motion was 117 degrees in the HTO group and 103 degrees in the UKA group. HTOs showed more postoperative complications. Kaplan-Meier analysis predicted a survivorship of 82% at five years and 77% at 10 years for UKA, compared to 78% and 60% for HTO. None of the differences reported in this study were statistically significant.

The authors concluded that there was insufficient evidence to prefer one method over another with regard to results and longevity. W-Dahl et al. reported the outcomes of all UKAs, TKAs and HTOs performed in Sweden from 1998 to 2007. In this study, 8793 UKA and 65661 TKA were included. For HTOs, a single institutional series of 450 patients, age 30–64 years, was used to calculate the revision rate and to compare to UKAs (n = 4,799; age 30–64 years). The 10-year cumulative revision rate (CRR) for HTO was 17%. Comparable CRR was observed in UKAs, but the risk of revision for the HTOs appeared to be somewhat lower for the first years of follow-up.

Some papers performed a review of literature regarding HTO and UKA, with inconclusive results due to difficulties in pulling data from nonhomogeneous studies. Griffin et al. reported that, despite the poor-to-average quality of studies in the literature, HTO seemed to have a higher complication rate, lower survivorship and similar functional results compared to UKA. Chang et al. determined that UKA provided improved range of motion, decreased rehabilitation time, and immediate weight bearing, while the advantages of HTO over UKA were the ability to maintain a higher level of activity without potential wear of arthroplasty components. The authors concluded that there was insufficient evidence to prefer one method over another with regard to results and longevity.

Brower et al. concluded in their meta-analysis (Cochrane Database Systematic Review, 2007) that there is silver-level evidence that HTO causes more complications than UKA, and that there is silver-level evidence for no significant difference in pain, function and gait analysis after HTO compared to UKA.

Richmond reported that for younger, more active patients who have abnormal alignment, HTO seems to be a better choice than UKA. For the older, more sedentary patient, UKA is supported by the literature as a more reliable operation.

**REVISION TO TKA**

Whether revision HTO or UKA to TKA performs worse than primary TKA is also still controversial. Given that TKA represents the endpoint of every failed HTO or UKA, this aspect is particularly important, and can drive a surgeon’s preference for one treatment over another.
Revision HTO to TKA

Windsor et al. analyzed the outcomes of 45 TKAs implanted after failed HTO, and compared them to data from other TKAs retrieved from other studies at the same institution. The incidence of poor results (by HSS score) was higher in the group of TKA after HTO than in other TKAs, implanted as primary or as revision after failed TKA. Fixation of the tibial component did not appear to be compromised, but an alteration of patellofemoral mechanics (patella infera) was observed. The authors concluded that patients treated with HTO should be informed that the results of TKA after a failed HTO may not be as good as TKA without previous osteotomy.

Karabatsos et al. performed a retrospective matched cohort study at a mean follow-up of five years, comparing 20 patients who underwent TKA after HTO and 20 matched patients who received a primary TKA. Surgical difficulties were more frequently encountered in the TKA-after-HTO group, with longer operative times, more difficult exposure, and an increased number of lateral releases. There were differences in pain and function according to WOMAC and SF-36 scores, but these were not statistically significant. The authors concluded that TKA after HTO is a more challenging procedure, technically, than primary TKA and that functional outcomes after TKA after previous HTO tended to be inferior, even though differences were not significant.

Van Raaij et al. performed a systematic review of the literature on TKA after prior HTO. The authors reported prolonged surgical time, extra operative procedures and less postoperative knee ROM, but no increase in revision surgeries for patients receiving TKA after prior HTO compared to patients receiving primary TKA. Improvements in pain and physical function scores were detected within the first three-to-six months after TKA implants in patients receiving primary TKA compared to patients receiving TKAs after prior HTO. But at mid-term and long-term follow-up, no significant differences in knee clinical scores were found between the two populations. In patients receiving TKA after prior HTO, tibial component fixation was reported to be at risk due to the loss of metaphyseal bone stock and modification of proximal tibial anatomy. A revision tibial component with a long stem can increase primary stability, but may prevent accurate placement of the component due to an asymmetric medullary canal subsequent to HTO. Nevertheless, no differences in revision rates at minimum five years of follow-up were found between patients receiving TKA after previous osteotomy compared to primary TKA. The authors concluded that osteotomy does not compromise subsequent TKA.

Similar conclusions were drawn by Amendola et al. and Kazakos et al.

Revision UKA to TKA

Revision of a failed UKA to TKA is thought to raise problems related to bone stock management and inferior clinical outcomes.

Barrett and Scott reported on 29 failed first-generation UKAs that were converted to TKA. The mechanism of failure was loosening in 55% of the cases and progression of degenerative disease in the opposite compartment in 31% of cases. The average time to revision was 47 months (range 4–113 months). In 66% of the failures, the authors identified technical errors at the time of initial UKA or poor patient selection.

McAuley et al. reported on a series of 39 consecutive UKA revisions to TKA, and observed that bone deficiencies were not challenging. The failed UKAs were easily managed using standard primary modular components and local autograft to treat bony defects. Good-to-excellent results were obtained in all patients at 24–120 months of follow-up, with an average range of motion (ROM) of 111 degrees and a mean knee society score and function score of 89 and 81 points respectively.

Becker et al. performed a matched-pair comparative study on 28 patients treated with TKA following failed UKA and 28 patients with primary TKA at a mean follow-up of 40-70 months. The authors found that revision of a UKA to a TKA showed inferior functional results in comparison to primary TKA, with significant differences in knee society scores, WOMAC and ROM. Patients were satisfied after revision UKA to TKA, but not as much as patients who received a primary TKA. In addition, the authors reported technical difficulties associated with UKA revisions to TKA, mainly about bone loss on the tibial side. TKA after UKA required significantly thicker polyethylene inlays in comparison with primary TKA.

Oduwole et al. reported on the mode of failure of a series of 106 Oxford phase III (Biomet) UKAs. The authors observed a 13.2% failure rate at one-to-four years of follow-up and concluded that long-term results of TKA after failed UKA were inferior compared to primary TKA in terms of pain and functional outcome (WOMAC, SF-36, ROM) and that revision could be complex.

Robertsson et al. evaluated the satisfaction of 27,372 patients operated upon between 1981 and 1995 in Sweden (Swedish Knee Arthroplasty Register-SKAR), with a simple four-point questionnaire. Patients who received a TKA after a failed UKA were less satisfied than patients who received a primary TKA.

Springer et al. reported the outcomes of 22 consecutive failed UKAs that underwent conversion to TKA. In 27% of the patients, defects requiring bone graft were found on the femoral condyle. No femoral stems or metal augmentations were required. On the tibial side, 45% of the patients had defects requiring bone graft.
wedge augmentation was required in 23% of the knees and stems were used in 9% of the cases. According to the knee society clinical rating system, the results of TKA after failed UKA were similar to both primary TKA and revision TKA. The authors concluded that patients should be informed that surgical results may not be as successful as a primary TKA, and surgeons should be aware that not all failed UKAs are easily converted to TKA.

Comparison between Revision HTO and Revision UKA

Gill et al.58 compared a group of 30 revision HTOs-to-TKAs with a group of 30 revision UKAs-to-TKAs, matched by age, gender, type of TKA, primary disease and length of follow-up. The study investigated technical difficulties at revision, complications, and outcomes using the knee society rating system. The most frequent technical difficulties in the revision HTO group were: 1) obtaining an acceptable exposure, and 2) achieving correct tibial component positioning. In the revision UKA group, the major technical difficulty was managing bony defects, on both the tibial and femoral sides. Significantly more osseous reconstructions were required in the UKA group (77%) compared to the HTO group (20%). The HTO group required more procedures to improve exposure: seven V-Y quadricepsplasties, 11 lateral retinacular releases, 3 PCL releases and 1 PCL sacrifices were performed. Nevertheless, these associated procedures did not affect the outcome of TKA at final follow-up. In the UKA group, two quadricepsplasties, 11 medial or lateral compartment releases, 1 PCL resection and 1 tibial tubercle osteotomy were performed. Post-revision ROM did not differ in the two groups. The HTO group scored significantly better in both Knee Society Knee score (87.3 points compared to 78.3 in the UKA group) and function score (88.6 compared to 67.7 in the UKA group). The authors concluded that the results of revision UKA-to-TKA approached but did not equal those obtained with revision HTO-to-TKA, which remains superior.

CONCLUSIONS

Although both HTO and UKA are effective for managing medial compartment knee arthrosis, they should not be considered equivalent treatment options. The literature review showed that correct patient selection is fundamental to obtaining durable and predictable results with both techniques. In addition, the indications seem to be very different for the two procedures. Nevertheless, a small population can be amenable to either HTO or UKA, and this includes patients: 1) from 60 to 65 years old; 2) who are moderately active; 3) who are non-obese; 4) with mild varus malalignment (from 5 to 10 degrees); 5) without joint instability; 6) with a good range of motion; and 7) with moderate unicompartmental arthritis.

Both HTO and UKA showed satisfactory results and survival rates at mid- and long-term follow-up. A few papers attempted to make comparisons between the two procedures and generally showed slightly better results for UKA in terms of survivorship and functional outcome. However, the differences were not remarkable and the quality of these studies is insufficient to draw any definitive conclusion. Furthermore, as shown in the present review, UKA and HTO are different procedures with different indications and a comparison between them is meaningful only in the small population of patients amenable to both treatments.

Whether revision HTO or UKA to TKA performs worse than primary TKA is a debatable issue. Given that TKA represents the endpoint of every failed HTO or UKA, this is particularly important, and was considered in the present paper. Both revision HTO and revision UKA to TKA are technically more challenging than primary TKA: 1) HTO in terms of surgical exposure and tibial component positioning, and 2) UKA in terms of bone stock loss and the need for bone grafting both on the femoral and the tibial sides. While HTO does not seem to affect the results of subsequent TKA, revision UKA to TKA apparently performs worse than primary TKA. It must be mentioned here that all the studies in the English literature reported the results of TKA after closing wedge HTO and no data are available about TKA after opening wedge HTO. This is an important issue because, theoretically, TKA is easier after opening wedge HTO than after closing wedge HTO. Indeed, with opening wedge HTO, there is no risk of patella alta, bone stock is maintained and the risk of impingement between the tibial stem and the anterior tibial cortex is decreased.

In conclusion, further investigation is required to determine the most reliable management choice for those patients that can currently be treated with either HTO or UKA.
REFERENCES


ABSTRACT

Surgical treatment and reconstruction of a pediatric patient with a bone malignancy should consider many patient and tumor specific factors. Surgical treatment should be geared first and foremost towards obtaining wide margins. To that end the options can include amputation, rotationplasty and prosthetic reconstruction. Advances in adjuvant chemotherapy for musculoskeletal malignancy in pediatric patients has increased acceptance of limb-salvage procedures as a viable option for treatment, whereas limb ablation was formerly the only acceptable means for attaining disease eradication. The advent of the expandable prosthesis has gained significant interest due to the appeal of improved cosmesis and potential for equal limb length at skeletal maturity. The latest generation implants allow for non-invasive lengthening with an outpatient procedure and are generally very well-tolerated by the patient. Review of current literature demonstrates that this procedure has generally good patient reported outcomes but has a high complication rate. Aseptic loosening and mechanical dysfunction are common modes of failure and often necessitate one or more large revision surgeries. Further improvement in implant design and biomaterials may decrease the incidence of these complications and promising work in these areas is ongoing. When discussing this specific option, patients and family should be counseled regarding the likelihood of future surgeries to manage the expected complications.

INTRODUCTION

Primary bone malignancy, although an uncommon form of cancer, is most often encountered in the pediatric population. The most common forms encountered are osteosarcoma and Ewing’s sarcoma. Adequate treatment of these malignancies relies on a multidisciplinary approach; with the surgeon’s goal to obtain a wide resection of the tumor. Advances in diagnostics and chemotherapeutic treatment regimens have led to improved survival. In addition, they offer improved local control which has made limb salvage surgery an option for most patients.

These bone tumors are frequently found at the physes of long bones, with the knee being the most common location. Therefore, the surgeon must consider that any surgical resection, especially limb salvage techniques, will cause a limb length discrepancy from phsyseal resection. This discrepancy must somehow be reconciled with surgical techniques to approximate equal leg lengths at skeletal maturity. This historically has been done with a combination of acute lengthening and contralateral epiphysiodesis. Currently there are several manufacturers who now offer options for prosthetic reconstruction with an expandable implant. This option offers the patient good function with hope for an equal leg length at maturity. In this paper we will review the indications for expanding endoprosthesis and alternative modes of treatment. We also will review the principles of surgical technique and available outcome data pertinent to the expanding endoprosthesis in the treatment of pediatric musculoskeletal malignancy.

INDICATIONS AND ALTERNATIVES

When evaluating the pediatric patient with a primary bone malignancy the primary goal of the treating surgeon is wide resection of the lesion. This may be accomplished with several surgical options: limb ablation, rotationplasty and reconstruction.

Limb Ablation

Limb ablation, amputation or disarticulation, was once considered the only acceptable method for eradication of malignancy in the lower extremity. Multimodal therapy, especially improved chemotherapeutic regimens, has largely made limb salvage techniques the standard of care for the large majority of tumors. A recent study comparing surgical techniques in patients with osteosarcoma and Ewing’s sarcoma has noted improved
Musculoskeletal Tumor Society (MSTS) scores in patients undergoing limb salvage compared with amputation. However, depending on specific patient and tumor circumstances, limb ablation remains a good option. Simon et al. concluded in their analysis of 22 patients that those treated with amputation were least worried about damaging their limb, but had more difficulties with navigating uneven terrain. Tumor-specific relative indications for amputation would include those lesions which could not be resected without destruction of neurovascular structures, infection in the surgical field, significant muscle or soft-tissue involvement and poor response to pre-operative chemotherapy.

Rotationplasty

Van Nes rotationplasty is another option in the patient requiring a large resection of the distal femur. This procedure can also be performed when there is a required resection of the proximal tibia. The benefit of this procedure is that one can resect a large portion of distal femur or proximal tibia and still reconstruct a viable below “knee” amputation. One analysis of 30 rotationplasty procedures noted that there were 96.5% good and excellent results with a minimum follow-up of three years. Hanlon reported on 14 patients treated with rotationplasty for osteosarcoma followed for a mean of 8 years. All patients had good or excellent results according to the Enneking functional evaluation and all but one had no pain, with the other having only intermittent pain controlled by non-narcotic means. Thirteen of the fourteen patients had excellent emotional acceptance of the procedure, with the other having good acceptance. All patients reported that they would choose to have the procedure again.

The reported complication rate with this procedure is relatively low when considering the patient population and surgical alternatives. Hanlon reported that three of 14 patients in his series required reoperations for surgical complications. However, a larger series noted that 30 of 70 patients had some type of early or late complication. In this series 16 of the early complications required operative intervention to manage their complication. The main complications described were vascular occlusions, nerve complications, non-union, infection and development of thigh length inequality.

Despite the excellent results reported in the literature, the primary disadvantage of this technique is thought to be the cosmetic and potential psychological implications of this operation. The psychological disturbance often cited as a potential deterrent to this procedure has largely been discounted by the literature. In properly selected patients it is well-tolerated and has good results with relatively low incidence of immediate and long-term complications. Furthermore, although the ankle is subject to altered loading patterns the development of ankle arthrosis has not been shown in long-term radiographic or clinical follow-up.

Reconstruction

Along with improved treatment regimens, in recent years there has been an increasing focus on improving quality of life and function for the larger number of patients surviving their disease. Results of comparative studies differ with regard to whether amputation, rotationplasty or reconstruction offers the superior outcome. However, with improved device manufacturing and biomaterials there is an ever-gaining interest in limb-salvage by endoprosthetic reconstruction. In addition, there is a belief that limb salvage by prosthetic may offer psychological advantage due to an essentially normal outward appearing limb. Although it has been noted that most patients who survive this life-threatening disease adjust well to any necessary surgical treatment.

Reconstructive options for salvage of the limb are many in the skeletally immature patient. They include allograft reconstruction, endoprosthetic reconstruction, and allograft-prosthetic composites. When accounting for the future growth potential of the pediatric patient, however, the options are more limited. Prosthetic reconstruction of the limb can be done with essentially two different modalities: modular prosthetic components and growing or expandable components. Modular components are thought to offer the advantage of increased prosthetic construct strength at maximal lengthening. The disadvantages are that each lengthening requires an operation that involves a rather large exposure. In the patient requiring multiple lengthenings this results in excessive scar formation and higher risk of infection. This option has never gained great favor in the young patient due to difficulties with participation in rehabilitation and the accompanying poorer results.

Expandable components offer the advantage of either minimally invasive or non-invasive expansion procedures. The disadvantages of these devices, however, are the potential for failure of the expansion mechanism and failure of the prosthesis at maximal lengthening. The modular component may be more desirable in a patient where lengthening requirements will be minimal, whereas the expandable component may be desirable in a patient who will require multiple lengthening procedures.

In 1986 Lewis reported on six patients safely and successfully treated with implantation of an expandable and adjustable prosthesis. The expandable endoprosthesis is an option that offers the potential of limb salvage with equalized leg lengths at maturity. This can be ac-
Expanding Endoprostheses for Pediatric Musculoskeletal Malignancy

accomplished through an expanding drive mechanism which can be accessed through a minimal approach or with newer prosthesis that are capable of non-invasive expansion in-situ. The advantages of limb salvage include potential for improved functional outcome. Rougrieff and colleagues showed in their comparative series of 227 patients who underwent either limb salvage, above-the-knee amputation, or hip disarticulation that those undergoing limb salvage had significantly higher MSTS and Knee Society scores.34

The remainder of this article will focus on review of the expandable endoprosthesis for limb salvage of the pediatric malignancy.

PRINCIPLES

When considering implantation of an expandable endoprosthesis wide excision should be the goal.9 Pre-operative planning will give an indication to the extent of the tumor and size of resection required.22 The amount of bone resected will limit the lengthening capability of the prosthesis; as the telescoping portion can be only as long as the prosthetic implanted.

An additional consideration is the acute lengthening. The benefits of acute lengthening are allowing for a longer rehabilitation period of the limb prior to undergoing the first lengthening procedure as well as possibly diminishing the number of future lengthening procedures needed. The amount of acute lengthening, however, must be conservative to avoid neurovascular complications. In general, it is recommended that this number not exceed 1-2 centimeters.36

DEVICE OPTIONS

Virtually all U.S. orthopaedic manufacturers offer modular knee systems which can be considered for the child at or near skeletal maturity. Decision regarding which device should be placed is based on surgeon preference as there is no data to guide selection of one particular manufacturer.

There are several manufacturers worldwide that produce expandable prostheses, they are mentioned in the following sections. In the United States, the only manufacturer that we are aware of is Wright Medical (Arlington, TN) who produces the Repiphysis system. We have had experience with this device at our institution.

PREOPERATIVE PLANNING

When considering implanting an expanding endoprosthesis it is important to calculate estimated remaining growth.10 A child at or near skeletal maturity does not need an expandable device. Depending on their remaining growth the surgeon can consider an acute lengthening with implantation of a conventional endoprosthesis with or without a contralateral epiphysiodesis. Calculation of remaining growth is instructive when counseling the patient and family members on surgical options and approximate number of lengthening procedures required.

Growth estimates are typically done utilizing data compiled by Anderson and Green.2 Using this data, any number of calculation schemes can be used to estimate growth anticipated in the contralateral limb and expected growth loss from resection of an involved physis or physis. One such option for a quick calculation is the Menelaus, or “arithmetic,” method.29 Using the assumption that on average the femoral physis grows 0.9 centimeters per year, and the tibial physis grows an average 0.6 centimeters, this allows the surgeon an estimate of anticipated discrepancy. It is important to note that chemotherapeutic and radiation treatment protocols have been shown to affect physeal growth, which further complicate these calculations.15,16

Dominikus and colleagues have evaluated the accuracy of growth prediction in children undergoing limb-sparing surgery for treatment of bone sarcomas.10 In their study they analyzed a series of fifteen patients with regard to their predicted discrepancy pre-operatively, and compared this to the amount of lengthening that was required by the time they reached skeletal maturity. They found that overall the elongation of the surgically treated limb exceeded the predicted growth by 24%.10 However, all patients in this study had limb lengths within 1 cm at skeletal maturity, which was due to the adaptability of the extendable device.

With use of the expandable prosthesis, pre-operative planning is paramount. Magnetic resonance imaging (MRI) can best define the extent of the tumor (Figure

![Figure 1. Pre-operative coronal STIR MRI demonstrating a Ewing's sarcoma of the distal femur.](image-url)
These should be done both prior to, and following neoadjuvant chemotherapy sessions. Planned resection and imaging data must be communicated to the manufacturer as these devices are custom made for each patient. Furthermore, careful examination of imaging studies will advise as to the proximity of the tumor to neurovascular structures. A prerequisite for limb salvage is the ability to maintain the neurovascular bundle without compromising local control of the malignancy. In addition, careful study of the tumor can advise toward the surgical approach made.

**SURGICAL TECHNIQUE**

Exposure of the tumor is done through an extensile approach as dictated by the pathoanatomy of the tumor. In general for tumors of the distal femur we prefer an anterior approach with a medial parapatellar arthrotomy. Biopsy tracts are incorporated into the incision and ellipsed out. The procedure begins with the resection of the tumor in the distal femur. Careful dissection is used to fully expose the tumor and any soft tissue extension (Figure 2). The collateral and cruciate ligaments are dissected off the tibia. The bone segment is measured and resected as planned based on pre-operative imaging. It is sent to pathology for confirmation of margins. After confirming margins the instruments are exchanged for clean tools and the surgical team applies new sterile gowns and gloves. The femoral osteotomy is then planned and the canal reamed to the predetermined diameter. Both cemented and press-fit options are available.

The tibial cut is then made to resect the tibial spines and articular cartilage only. This tissue is sent for pathologic examination. The tibial canal is then reamed perpendicular to the physis to minimize trauma to the physisc. A small cohort of patients having this device implanted has demonstrated that growth arrest does not occur following drilling and placement of a smooth press-fit stem across the tibial physis.

Trial implants are then inserted and range of motion and stability in extension and flexion are tested. Once satisfied the final tibial component is placed. The femoral canal is then prepared with thorough irrigation. The femoral component is then placed with or without cement (Figure 3). Typically 1-2 cm of acute lengthening with the implant has been advocated to reduce the number of future lengthening procedures required. The hinge portion of the device is then assembled and the wound irrigated and closed. Post-operative radiographs are obtained to evaluate for implant and host bone complications (Figure 4).

![Figure 2. Intraoperative photograph demonstrating careful dissec tion of the distal femur in preparation for en bloc resection of the malignancy.](image1)

![Figure 3. Gross specimen of Ewing sarcoma of the distal femur. Resection was carefully measured and planned based on pre-operative imaging and implant has be custom made to match resection.](image2)

![Figure 4. Post-operative anteroposterior and lateral views of the knee demonstrating the implanted Repiphysis prosthesis.](image3)
LENGTHENINGS

The patient is seen at routine follow-up intervals. At each visit radiographs of the prosthesis are obtained to evaluate for complications. Orthoradioentgenograms are regularly obtained to assess the limb length discrepancy. When a discrepancy exists of one to two centimeters, lengthening is undertaken.

The lengthening procedure is done under radiographic guidance, typically in the fluoroscopy suite. Anesthesia is generally not required, and light intravenous sedation and/or analgesia are optional. In addition to negotiating the risk of the anesthetic to the patient, and additional advantage of performing awake lengthening is the ability to monitor pain and neurovascular examination.

The locking mechanism of the prosthesis is located under fluoroscopy and the skin is marked overlying this. The electromagnetic coil is then applied around the leg at the location of the skin marking. The device is activated in 20 second intervals to achieve the desired lengthening. Images are examined after each lengthening interval.

Following the procedure the patient may require oral analgesics and assistive devices for a short period; however, this is quite variable between patients.

CONVERSION

Due to the diminished strength of the expanded endoprosthesis, it has been recommended by some authors that children undergo conversion to a conventional fully-constrained hinge prosthesis at reaching skeletal maturity. However, there is no consensus on this point as some investigators feel that a fully expanded implant is strong enough to withstand stresses at full lengthening. In general there is increased concern for failure with full expansion of a telescoping prosthesis compared with a modular lengthened prosthesis.

OUTCOMES

Kenan reported on 54 children with osteosarcoma or Ewing’s sarcoma who were treated with the Lewis Expandable Adjustable Prosthesis (LEAP). The LEAP prosthesis requires a small surgical approach to the chuck device for each lengthening. The authors noted that occasionally a fibrous membrane was found encasing the prosthesis which needed to be divided prior to lengthening. Of the 34 patients available for two to twelve-year follow-up, 24 patients had required revision procedures at some point, with all revisions successful. Twelve patients reached skeletal maturity without leg length discrepancy.

Schiller published on a group of six patients followed through skeletal maturity. His patients were treated with the Pafford-Lewis prosthesis and the Kotz Modular Femur Tibia Reconstruction system. Similar to the LEAP, this prosthesis expands telescopically requiring a small surgical approach to the site of the screw mechanism. These six patients had complications requiring a total seven revision procedures. On average each patient underwent 7.8 lengthening procedures for an average expansion length of 13.2 cm. Limb lengths at maturity were not reported in this series.

In 1993 Eckardt published a series of 12 patients treated with combination of different expandable prostheses. They primarily used the LEAP in these patients, except for two patients who had Techmedica expandable prostheses. Ten were in the lower extremity, and two in the humerus. This series showed a high rate of failure of the implanted component, with seven of the 12 having a failure of the expansion mechanism. They largely converted to modular lengthening procedures in these patients. A second series was published by Eckardt in 2000 reporting on 32 patients treated with four different prosthetic styles. Twenty-two patients had a LEAP implanted, four Wright Medical modular prostheses, four Howmedica (Stryker/Howmedica/Osteonics; Rutherford, NJ) modular prostheses and two Techmedica prosthesis. In this series they continued to demonstrate a disappointing rate of device failure of 25%. However, the failures were largely salvageable and of the 19 surviving patients, limb salvage was successful in 16. Additionally, of the nine patients who reached skeletal maturity at the time of the report, six had equal leg lengths.

Schindler and colleagues evaluated their use of the Stanmore Mark II and Mark III ‘growing prosthesis’ (Stanmore Implants Worldwide, Stanmore, UK) in 18 children. This particular prosthesis was initially designed with ball-bearings (Mark II) and then with modular C-clips (Mark III) which could be implanted with subsequent surgeries to lengthen the prosthesis in a modular fashion. The next generation, the Mark IV, utilized the telescopic worm-wheel screw mechanism allowing for less invasive expansion procedures; however, these were not used in this particular cohort. Their series noted that at ten years there was a 100% failure rate of their prosthesis with amputation (two patients) or revision (ten patients) as the endpoint. Despite this, however, 84% of patients reported good or excellent results based on the MSTS scores. Further, function was estimated at 77% of expected normal function based on these scores. Patients had an average leg length discrepancy of 1.5 centimeters at skeletal maturity.

The Phenix (Phenix-medical, Paris, France) endoprosthesis was implanted in 15 patients as reported by Neel and colleagues. They noted patients had good early results with average Musculoskeletal Tumor Society (MSTS) scores of 90% at an average of 18 months. Of
the three patients at skeletal maturity at the time of the report all had leg lengths within one centimeter. This is a custom manufactured device that utilizes stored energy in the form of a compressed spring for future lengthening. The energy is then selectively released in a closed fashion by subjecting the limb to an electromagnetic field which heats the polymer casing allowing for controlled expansion. The advantage of this technology is that lengthening is performed closed and, except for unusual circumstances, without general anesthesia. The Phenix is now manufactured as Repiphysis (Wright Medical Technology, Arlington, TN).

The only study, to our knowledge, examining the outcome of the Repiphysis prosthesis was reported by Gitelis et al.14 The fourteen patients in this series were reported at greater than two years follow-up. There was a 100% limb-salvage rate in this series, although there were five necessary revision surgeries all related to failure or fracture of the implanted components. Patients had an average MSTS score of 83.5% at the time of most recent follow-up.

A summary of the available literature is compiled in Table 1.

### COMPLICATIONS

#### Aseptic Loosening

Aseptic loosening is the most frequently encountered complication in this particular limb-salvage procedure. This is largely due to the long lever arm created at the bone-implant interface which is necessitated by the extensive resection. Schindler noted that in their series the patients who developed aseptic loosening had an average of 57.8% of their femur length resected, compared with 46.2% in those who did not develop this complication. This was consistent with a finding reported by Cannon, who described a resection of greater than 60% increasing the likelihood of aseptic loosening.8

#### Mechanical Failure

Mechanical failure is another frequently reported complication in the literature on this topic. This most frequently involved failure of the expansion mechanism, but there are also reports regarding fatigue fracture of the prosthesis.12,14,22 As experience with different expansion mechanisms has increased, this mode of failure seems to be reported with less frequency in the literature.

#### Infection

The series reviewed here indicate a variable incidence of deep infection. Kenan et al. reported four of 34 patients (11%) whereas many other series report no or only one of their cohort having an infection.22 These numbers are difficult to interpret given the inherent small numbers included in these studies. Deep infection with this procedure is a disastrous complication and many reports describe necessary treatment with limb ablation depending on the severity of the infection.

#### Other

Less frequently reported complications include fracture, neurologic compromise and post-operative stiffness. These were infrequently and variably reported. A summary of reported complications is compiled in Table 1.

### TABLE 1. Summary of outcome data available of expanding endoprostheses for treatment of pediatric malignancy

<table>
<thead>
<tr>
<th>Series</th>
<th>N</th>
<th>Avg F/U (yrs)</th>
<th># lengthen/pt</th>
<th>cm length/exp</th>
<th>AMP</th>
<th>REV</th>
<th>AL</th>
<th>INF</th>
<th>FX</th>
<th>HW</th>
<th>NV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kenan 1999</td>
<td>34</td>
<td>2 to 12</td>
<td>4.0</td>
<td>1.5</td>
<td>5</td>
<td>24</td>
<td>16</td>
<td>4</td>
<td>NA</td>
<td>3</td>
<td>NA</td>
</tr>
<tr>
<td>Schiller 1995*</td>
<td>6</td>
<td>6.3</td>
<td>7.8</td>
<td>0.6</td>
<td>0</td>
<td>7</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>NA</td>
<td>2</td>
</tr>
<tr>
<td>Neel 2003</td>
<td>14</td>
<td>1.8</td>
<td>4.3</td>
<td>0.9</td>
<td>1</td>
<td>8</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Eckardt 1993</td>
<td>7</td>
<td>3.1</td>
<td>1.6</td>
<td>1.7</td>
<td>1</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>Eckardt 2000</td>
<td>19</td>
<td>8.8</td>
<td>2.0</td>
<td>1.0</td>
<td>0</td>
<td>3</td>
<td>NA</td>
<td>5</td>
<td>0</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Schindler 1997**</td>
<td>14</td>
<td>8.7</td>
<td>4.3</td>
<td>1.2</td>
<td>2</td>
<td>10</td>
<td>6</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Gitelis 2003</td>
<td>14</td>
<td>2.1</td>
<td>4.1</td>
<td>0.9</td>
<td>0</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>

N = number of patients, AMP = amputations, REV = revisions, AL = aseptic loosening, INF = infections, FX = fractures, HW = hardware failures, NV = neurovascular complications

*only included survivors who reached skeletal maturity

**excluded amputations from final analysis

NA = data not available from review of manuscript
FUTURE DIRECTIONS

At this point the majority of the experience with expanding prostheses is represented in the distal femur and proximal tibia. This technology has been applied for the proximal femur,\textsuperscript{27} total femur\textsuperscript{27,37} and proximal humerus;\textsuperscript{12} but with even less experience. Further development and research is necessary to evaluate the utility of implants in these locations as well as others.

A common finding at time of lengthening or revision procedures reported in multiple publications was a pseudocapsule surrounding the prosthesis which was stained black/gray by metallic wear debris.\textsuperscript{27,36} Schindler’s group noted that this tissue had very low elasticity and required division to allow for lengthening. Improvements in implant design and biomaterials will improve wear characteristics and decrease complications related to lengthening and aseptic loosening.

An exciting new development in this field has been the creation of a “bioexpandable” endoprosthesis to address the issue of the increasing leverage between endoprosthetic/bone segments with subsequent lengthening.\textsuperscript{6,7} Baumgart and colleagues have reported on the MUTARS BioXpand device (Implantcast, Buxtehude) which employs the technique of callous distraction to lengthen the host bone segment. This device accomplishes this by use of the fully implantable motorized nail, the “Fitbone,” rather than external fixation devices as classically described by Ilizarov. There are, as of yet, no long term studies that we are aware of evaluating the outcomes and complications of this particular procedure.

SUMMARY

The pediatric patient with a malignant bone tumor of the extremity is a challenging clinical scenario. Advances in adjuvant therapy have made limb-salvage procedures a realistic option without compromising survival or local recurrence. Surgical options to be discussed with the family include amputation, rotationplasty and prosthetic reconstruction. The advent of the expandable prosthesis has gained significant interest due to the appeal of limb salvage with a good cosmetic result and potential for equal limb length at skeletal maturity. Devices now exist which allow for non-invasive lengthening on an outpatient basis. Review of the literature demonstrates that this procedure has generally good patient reported outcomes but has a high complication rate, with aseptic loosening being the most common mode of failure. Further improvement in implant design and biomaterials may decrease these complications and work in these areas is underway. Currently, patients choosing this option should be counseled regarding the likelihood of future surgeries to manage the expected complications.

REFERENCES


TOTAL KNEE REPLACEMENT IN PATIENTS WITH BELOW-KNEE AMPUTATION

Matthew D. Karam, MD,* Michael Willey, MD,* Donald G. Shurr, CPO, PT**

ABSTRACT

Total knee replacement (TKR) is reserved for patients with severe and disabling arthritis that is non-responsive to conservative measures. Based on existing data, total knee replacement is a safe and cost-effective treatment for alleviating pain and improving physical function in patients who do not respond to conservative therapy. Despite the large variation in health status of patients and types of prosthesis implanted, total knee replacement has proven to be a relatively low risk and successful operation. Each year in the United States surgeons perform approximately 300,000 TKR.1 Likewise, lower extremity amputation is commonly performed in the United States with an annual incidence of 110,000 per year.2 Nearly 70% of all lower extremity amputations are performed as the result of chronic vascular disease, followed by trauma (22%), congenital etiology and tumor (4% each).3 Approximately 50% of all lower extremity amputations are performed secondary to complications from Diabetes Mellitus.

Norvell et al. demonstrated that patients who have previously undergone transtibial amputation and ambulate with a prosthesis are more likely to develop degenerative joint disease in the contralateral extremity than the ipsilateral extremity.4 Further, radiographic changes consistent with osteoporosis have been demonstrated in up to 88% of limbs that have undergone transtibial amputation.8 To our knowledge, there have been only three reported cases of total knee replacement in patients with ipsilateral transtibial amputation.5-7 The purpose of the present study is to review the existing data on total knee replacement in patients who have undergone transtibial amputation. Further we present a patient with a transtibial amputation who underwent contralateral total knee replacement.

LITERATURE REVIEW

A review of the current literature identified three case reports of total knee replacement in patients with ipsilateral below-knee amputation.5-7 Each report described a patient who developed degenerative osteoarthritis that was unresponsive to conservative therapy and were indicated for TKR. The studies differed in their approach to alignment of the tibial cut, rehabilitation after the procedure, and timing of the contralateral TKR. Pasquina et al. reported a case of a seventy-six year old man who underwent BKA for chronic osteomyelitis.6 He developed OA in the ipsilateral knee and after failing conservative treatment underwent TKR. Prior to the procedure he was fitted for prosthesis with a larger socket to accommodate for post-operative swelling. He began physical therapy on post-operative day one and by post-operative day four was advanced to weight bearing as tolerated in the modified prosthesis. They reported an excellent surgical outcome (Table 1). The patient subsequently underwent TKR of the contralateral extremity.

Crawford et al. reported an eight month follow-up of bilateral total knee replacements in a seventy-five year old woman with a right BKA. They initially performed TKR of the contralateral limb followed by the ipsilateral limb four years later. Intra-operatively, when performing TKR on the ipsilateral limb, the knee was maintained in full flexion with the assistance of a sterile polystyrene packaging box. Despite limited insertion, an intramedullary guide rod was utilized to align the tibial cut. The patient remained non-weight bearing for three weeks post operatively to allow for wound healing. They also reported an excellent functional outcome (Table 1).

Konstantokos et al.5 reported a man in his early 40s who was indicated for a TKR who had previously undergone ipsilateral BKA for a non-united open tibia fracture. Pre-operatively a modified prosthesis for his BKA was created to stabilize the tibia during the procedure. Intra-operatively an extramedullary jig was aligned with the prosthesis for the tibial cut. The patient underwent standard physical therapy and remained NWB for three weeks post operatively to allow for wound healing. They also reported an excellent functional outcome (Table 1).
TABLE 1. Summary of Case Reports of TKR Performed in Patients with Ipsilateral BKA

<table>
<thead>
<tr>
<th>Authors</th>
<th>Demographics</th>
<th>Residual Tibia</th>
<th>Surgical Technique</th>
<th>Rehabilitation</th>
<th>Functional Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pasquina et al. 1999</td>
<td>76 year old male</td>
<td>17cm</td>
<td>Cemented TKR without discussion of maintaining tibial alignment</td>
<td>Weight bearing as tolerated on post-operative day 4 in modified prosthesis</td>
<td>• Independent ambulator&lt;br&gt;• 0-105° flexion arc</td>
</tr>
<tr>
<td>Crawford et al. 2003</td>
<td>75 year old female</td>
<td>12.5cm</td>
<td>Cemented cruciate-retaining TKR using sterile box to maintain flexion and tibial</td>
<td>Non-weight bearing for 6 weeks</td>
<td>• Independent ambulator&lt;br&gt;• with crutches to 100 yds&lt;br&gt;• 10-115° flexion arc&lt;br&gt;• Knee Society score 53 to 85&lt;br&gt;• Function Score 0 to 40</td>
</tr>
<tr>
<td>Konstantokos et al. 2008</td>
<td>male in early 40s</td>
<td>17cm</td>
<td>Posterior stabilized cemented TKR using a sterile customized prosthesis to support the tibia and maintain alignment</td>
<td>Non-weight bearing for 3 weeks</td>
<td>• 0-120° flexion arc&lt;br&gt;• Knee Society score 44 to 80&lt;br&gt;• Function Score 10 to 40</td>
</tr>
</tbody>
</table>

**CASE REPORT**

A sixty-seven year old man presented to our institution in 2006 with severe posterior and medial knee pain of approximately one year duration. The patient had previously undergone a contralateral total ankle replacement which became infected and required a below knee amputation in 1999. At baseline he ambulated with the assistance of a cane. Radiographs at the time of presentation demonstrated Grade 4 osteoarthritis. Initial conservative therapy including activity modification, heel wedge, multiple Synvisc injections, non-steroidal anti-inflammatory drugs (NSAIDs), Ketorolc, and quadricep strengthening exercises provided only transient relief.

Given his ongoing pain and disability he was indicated for and underwent a posterior-stabilized total knee replacement. The procedure was uncomplicated. Postoperatively he underwent standard physical therapy without limitation due to his contralateral BKA. At his latest follow-up (6 weeks) his range of motion was 5-115 degrees he reported improved function and was ambulating without assistive devices.

**DISCUSSION**

Patients who present with symptomatic knee osteoarthritis after previously undergoing below knee amputation offer a unique challenge for orthopaedic surgeons. The aforementioned cases demonstrate that despite varying approaches this procedure can be performed safely and effectively. Two reports discussed the challenge of achieving adequate alignment of the tibial component. Crawford et al. reported the use of a sterile polystyrene box to maintain flexion with the use of an intermedullary alignment guide. The length of residual tibia limits the utility of this method. Konstanakos et al. utilized a custom prosthesis intra-operatively to maintain tibial alignment. They argued that this provided a greater fulcrum to measure alignment, which may be particularly useful for patients with less residual tibia. Regardless of technique, it has been shown by Ritter et. al. that post operative tibial malalignment leads to an increased failure rate in TKR and demands careful consideration.

The reports also differ in their post-operative protocol, specifically the time to full weight bearing. Pasquina et al. advanced their patient to full weight bearing on post-operative day four with use of a temporary prosthesis, while the other patients remained non-weight bearing for three and six weeks post-operatively. Restrictions on return to full weight bearing were related to concerns regarding soft-tissue healing. No reports of wound complications were noted.

Another interesting difference was the timing of TKR in patients with BKA. Norvell et al. demonstrated in a large group of veteran traumatic amputees that the prevalence ratio of symptomatic knee arthritis in the intact limb was 1.4 as compared to only 0.1 for the knee of the amputated limb. They argued that compensatory gait alterations shifted loads away from the amputated limb increasing cumulative stresses seen across the intact limb. Crawford et al. in a patient with bilateral disease elected to perform a staged TKR beginning with the contralateral limb, followed by TKR of the ipsilateral knee. They felt that this enabled more comfortable weight bearing on that leg when attempting to mobilize following the second knee replacement. Another potential advantage cited by the authors was that an overall improvement in function following the first knee replacement may deter the patient from undergoing a further, more difficult joint replacement on the amputated leg. We described a patient with degenerative osteoarthritis in the contralateral extremity that failed conservative modalities and underwent successful TKR. Despite conflicting reports in the literature concerning the sequence of TKR in patients with BKA it should be noted that good outcomes where achieved regardless.
CONCLUSION

Total knee replacement has proven to be successful in alleviating pain and improving physical function in patients with debilitating arthritis. Given the incidence with which below knee amputations are performed, orthopedic surgeons are likely to encounter this unique situation with increasing frequency. We reviewed three cases that offer different approaches to determining optimal tibial alignment, post-operative rehabilitation, and management of symptomatic arthritis in patients with a BKA. We further reviewed our own experience of a patient who underwent a TKR opposite the side of a BKA. These cases demonstrate that TKR should be considered a practical treatment alternative for patients with debilitating arthritis following BKA who have exhausted conservative modalities.

REFERENCES

SEA URCHIN INJURIES TO THE HAND: A CASE REPORT AND REVIEW OF THE LITERATURE

William J. Dahl, M.D., * Peter Jebson, M.D., ** Dean S. Louis, M.D.†

ABSTRACT

Sea urchin injuries to the hand are uncommon. A variety of home remedies can be found on the Internet and other sources for dealing with this problem in the acute setting. Many long term complications such as granulomas, arthritis, and tenosynovitis can result from a neglected sea urchin injury. We report an unusual case of a patient with a remote sea urchin injury who presented with ulnar digital nerve paresthesias. A traumatic neuroma was found on surgical exploration. We review the literature on injuries to the hand caused by sea urchins and their management. Management of sea urchin injuries to the hand with retained spines requires surgical debridement in order to prevent significant long term complications including stiffness, tenosynovitis, granulomas, and arthritis.

INTRODUCTION

Sea urchin injuries to the hand are more commonly seen in coastal regions of the world where humans may come into contact with the animals either accidentally or intentionally. Sea urchins are animals belonging to the class Echinoidea. They are found in salt water habitats throughout the world. There are over 600 unique species of which 80 are toxic to humans. The most common species around the western coast of the United States are Strongylocentrotus purpuratus and Strongylocentrotus franciscanus. Their spines are made of calcium carbonate and are not in themselves poisonous. The spines can contain poisons including histamine, serotonin, glycosides, steroids, cholinergic substances, and bradykinin-like substances. Hands unfortunately are often the point of contact between sea urchins and humans.

The initial injury results in pain, erythema, burning, edema, and inflammation at the site of injury. Spines are brittle and can often fragment and break off in the hand. Complete removal of the offending spines typically terminates this reaction. Retained spines can result in a variety of complications including granulomas, arthritis, and synovitis. We report an unusual case of a digital nerve neuroma secondary to a retained sea urchin spine. We also review the English language literature on sea urchin injuries to the hand following a Pubmed search using the terms “sea urchin hand.”

CASE REPORT

A 55 year old right hand dominant woman was on vacation in Hawaii. She and her husband were snorkeling when a large wave pushed her up on the rocky shore. While attempting to brace herself, her right hand landed on a sea urchin. She noted the immediate onset of pain and saw several purple pigmented puncture wounds at the base of her right ring finger (Figure 1). She went to an urgent care clinic where she had some of the spines removed followed by application of a dry dressing. Over the next few months, she continued to be bothered by a foreign body sensation as well as stiffness of the ring finger and paresthesias in the ulnar digital nerve distribution.

The patient presented to our clinic ten weeks after her initial injury with a chief complaint of a foreign body sensation at the base of the right ring finger. Several scars from puncture wounds were visible at the base of the right ring finger. She noted the immediate onset of pain and saw several purple pigmented puncture wounds at the base of her right ring finger (Figure 1). She went to an urgent care clinic where she had some of the spines removed followed by application of a dry dressing. Over the next few months, she continued to be bothered by a foreign body sensation as well as stiffness of the ring finger and paresthesias in the ulnar digital nerve distribution.

The patient presented to our clinic ten weeks after her initial injury with a chief complaint of a foreign body sensation at the base of the right ring finger. Several scars from puncture wounds were visible at the base of the ring finger. There was a palpable mass along the ulnar border of the ring finger at the level of the midproximal phalanx. The patient demonstrated significant stiffness with a pulp to palm distance of approximately one centimeter. She had diminished sensation to light touch along the ulnar aspect of her ring finger. There was no Tinel’s sign present. MRI demonstrated a possible foreign body as well as extensive flexor tenosynovitis (Figure 2).

The patient was taken to the operative theater for surgical exploration. A Bruner type surgical incision was made on the volar aspect of the ring finger.
Multiple small fragments of what appeared to be sea urchin spines were embedded in the subcutaneous tissues, flexor tendon sheath, and flexor digitorum superficialis tendon. There were also multiple small fragments of foreign material embedded in a bulbous expansion of the ulnar digital nerve (Figure 3). All of the fragments were carefully removed from the tissues and an extensive flexor tenosynovectomy was carried out. The exploration was extended into the palm in order to fully release the adherent flexor digitorum profundus and superficialis tendons. Postoperatively, the patient was placed into an early motion therapy protocol.

**DISCUSSION**

Immediately following a sea urchin injury, patients typically will complain of significant pain at the site of injury. Systemic symptoms including hypotension, paresthesias, and weakness can result from a bolus of toxin. The flower sea urchin *Toxopneustes pileolus* contains a dangerous neurotoxin which can produce numbness, muscle paralysis, respiratory distress and death.15 Examination of the affected hand will often reveal puncture wounds and purplish tattoo-like coloration at the site of spine entry. A variety of “home remedies” for sea urchin injuries can easily be found on the internet. These include removal of visible spines, hot water soaks, vinegar soaks, and ammonia soaks among others. There is little in the medical literature on the acute management of these injuries. It has been reported that the complete removal of the spines will cause the local reaction to subside.3 A reasonable approach dictates the removal of easily accessible spines and a careful physical examination for possible joint involvement.7,16 A low threshold for surgical exploration should be present if there is concern for a traumatic arthrotomy. The majority of patients, at least initially after a sea urchin injury, will unfortunately not be seen by a hand surgeon.
If the patient is evaluated by a hand surgeon, it is imperative that a complete workup is carried out. The surgeon should first be certain that the patient has received a tetanus booster if needed. An accurate history documenting the date of the injury as well as any treatment rendered should be obtained. A thorough physical examination should follow documenting any visible scars, joint deformity, range of motion deficits, and neurovascular status. Plain radiography should be performed as the calcium in spines should render them radiopaque. However, a report by Wada noted that no spines were visible on plain radiography in their series of five patients. Ultrasonography is an affordable next step in the diagnostic imaging work-up of sea urchin injuries. A report by Groleau et al. describes the use of ultrasound to identify several spines and tenosynovitis in the case of sea urchin injury to the hand. As in our case, MRI can also identify pathology associated with the sea urchin injury such as spine location and any associated bone and soft tissue changes.

Surgical options should be dictated by the patient’s clinical presentation and the results of the workup. If a patient presents early with only a minimally debilitating foreign body sensation, simple removal of the offending spine versus observation may be chosen. The surgeon should also be aware of the potential for septic arthritis and infectious flexor tenosynovitis. If, as in our case, the patient presents with stiffness and a foreign body sensation, the surgeon should be prepared for exploration including careful inspection of the flexor tendon sheath. Intra-operative aerobic, anaerobic, mycobacterial and fungal cultures should be routinely obtained. Surprisingly, reports in the literature cite no evidence for active infection in chronic sea urchin injuries.

Complications of untreated sea urchin injuries to the hand include arthritis, granuloma formation, flexor tenosynovitis, and persistent dorsal edema. Arthritis from sea urchin injuries has been described in the literature. The arthritis seen in association with sea urchin granulomas demonstrates joint space narrowing, osteolysis, subchondral sclerosis, and periosteal reaction on plain radiographs. The progression of arthritis is often slow when compared to that associated with the septic arthritides. If neglected, this arthritis can progress to total joint destruction. Wada et al reported on 5 patients with sea urchin spine arthritis. They recommended a thorough synovectomy and joint debridement for patients with chronic irritation. Cooper and Wakefield reported a patient with granulomatous synovitis and arthritis that ultimately required an amputation due to loss of motion. It is thought that the arthritis seen in sea urchin injuries is a result of synovitis and granuloma formation. Granuloma formation after sea urchin injury was first reported by Gâte in 1936.

Inflammatory or infectious tenosynovitis is another known complication of sea urchin injuries. Infectious tenosynovitis appears shortly after the initial injury. A patient presenting with the classic Kanavel signs should undergo emergent operative debridement and culture-guided antibiotic therapy though cultures are often negative. A more indolent course is associated with inflammatory tenosynovitis. This patient may recover from the initial insult and have a period of minimal to no symptomatology. Then they typically notice a gradual increase in swelling and diminished range of motion in the affected finger or fingers. As noted in our case, and those presented by Lamir and Groleau, MRI or ultrasound can reveal the soft tissue swelling and tenosynovitis associated with chronic inflammation. These patients benefit from a thorough tenosynovectomy and removal of any offending foreign material. Antibiotics and anti-inflammatory agents are not useful in these cases.

Our case is unusual in that our patient had a neuroma secondary to sea urchin spine penetration of the ulnar digital nerve. Our case highlights the appropriate measures that need to be taken in order to successfully address a chronic injury resulting from a sea urchin injury. These include a thorough pre-operative workup including history and physical examination and the use of appropriate imaging modalities including plain radiographs, ultrasound, and MRI if needed. Surgical exploration can then be undertaken including spine removal, tenosynovectomy and, if indicated, appropriate sampling for cultures and pathology. This should be followed by early motion therapy protocol postoperatively. If these steps are followed, successful return of function is possible even for patients with chronic hand injuries from sea urchins provided that irreversible changes such as arthritis or bone loss have not occurred.

REFERENCES

A NOVEL TENDINOUS INTERCONNECTION RELEASE TECHNIQUE FOR CLAW-TOE DEFORMITY

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ABSTRACT

Claw-toe deformity is a common and potentially debilitating condition that requires appropriate diagnosis and management. Operative treatments for claw-toe deformity depend on the severity and flexibility. In a subset of patients, causation for flexible clawed lesser toes can be related to the force transferred through the tendinous interconnection from the flexor hallucis longus tendon to the flexor digitorum longus tendon.

The authors present a surgical technique for claw-toe deformity correction by releasing the tendinous interconnection from the flexor hallucis longus tendon to the flexor digitorum longus tendon in the midfoot area combined with toe manipulation. This technique can theoretically prevent the lack of toe grasp function associated with a flexor tenotomy as well as excessive stiffness associated with a flexor tendon transfer. Meticulous soft tissue dissection and protection of the medial plantar nerve are required to prevent complications.

INTRODUCTION

Claw-toe deformity is defined as an anatomical deformity of the lesser toes with hyperextension at the metatarsophalangeal (MTP) joint while the proximal interphalangeal (PIP) joint is flexed and the distal interphalangeal joint is either flexed or extended. Numerous surgical techniques for claw-toe correction have been described depending on the flexibility of the toes including long flexor tendon tenotomy, flexor tendon transfer, proximal phalangectomy, PIP joint resection, and PIP joint arthrodesis. However, sacrifice of the long flexor tendon and/or the PIP joints of the toes has been shown to have suboptimal effects including recurrence of toe deformity, persistent edema, residual pain, cock-up deformity, callosities beneath the metatarsal heads, and excessive stiffness.

We describe a technique in which the tendinous interconnection from the flexor hallucis longus (FHL) tendon to the flexor digitorum longus (FDL) tendon (TIFF) is released to correct the deformity of claw toes. This technique is indicated when flexible claw lesser toes are due to extrinsic force from the FHL tendon. Clinical diagnosis is made when the claw deformity in the lesser toes, mostly the 2nd and 3rd, is accentuated with isolated active plantar flexion of the hallux interphalangeal joint against resistance. This is confirmed by lack of active hallux interphalangeal joint flexion when the lesser toes are held in full extension. The benefits of this procedure include preservation of the FDL tendon and the PIP joint function of the lesser toes while eliminating the deforming force transferred from the FHL tendon.

SURGICAL TECHNIQUE

A patient with claw-toe deformity (Figure 1) was placed in the supine position with a thigh tourniquet. A bump was placed beneath the contralateral hip to improve accessibility to the medial aspect of the operative foot.

A four-centimeter longitudinal incision was made in the sole of the foot just medial to the palpable medial band of the plantar fascia (Figure 2A). The aponeurotic tissue between the plantar fascia and the abductor hallucis was sharply released. The FHL and FDL tendons were identified by palpating and observing motion with manipulation of the toes. The TIFF was then completely released. Isolated flexion of the hallux was demonstrated after traction was applied to the proximal aspect of the FHL tendon causing a synchronous flexion of the great, second and third toes. The TIFF was then completely released. Isolated flexion of the hallux was demonstrated after traction was applied to the proximal aspect of the FHL tendon. The second and third toes were manipulated to full range of motion (Figure 3). The tourniquet was deflated and skin closure was performed. The second and third toes were taped in extension (Figure 4).
Figure 1. Claw-toe deformity in the 2nd and 3rd toes is observed in standing. The deformity is increased with ankle dorsiflexion.

Figure 2. The medial longitudinal skin incision (A) and intra-operative finding of the flexor hallucis longus (FHL) tendon, the flexor digitorum longus (FDL) tendon, and the tendinous interconnection from the FHL tendon to the FDL tendon (TIFF) (B).

Figure 3. Decreased deformity of the 2nd and 3rd toes immediately after release of the tendinous interconnection from the FHL tendon to the FDL tendon (TIFF).
A Novel Tendinous Interconnection Release Technique for Claw-Toe Deformity

Immediate full weight-bearing as tolerated was allowed. Toe taping was maintained for four weeks followed by progressive rehabilitation in regular shoes. The patient was pain-free at five months post-op, and returned for care for their contralateral symptoms (Figure 5).

POSTOPERATIVE CARE

Claw-toe deformity treatment goals are pain relief, reduced deformity, improved function, reduced morbidity and prevention of progression of the existing deformity.13 Although various surgical techniques have shown clinical success, a percentage of patients may not be completely satisfied with the results.7,13 In general, types of operative treatment for claw-toe deformity depend on the severity and flexibility. When the deformity is rigid, a combination of bony correction and soft tissue release as well as a flexor tendon transfer may be required. For patients with flexible deformities, flexor tendon releases or transfers have been recommended.3

We have observed a subset of patients whose flexible claw lesser toes are related to the force transferred through the TIFF. Positive physical findings are dem-
onstrated when the claw deformity in the lesser toes, mostly the 2nd and 3rd, are accentuated with isolated active plantar flexion of the hallux interphalangeal joint against resistance. This can also be seen where there is relative shortening of the first ray. Arthrodesis of the hallux MTP joint using bone graft can restore length. In these situations, FHL tendon forces can bypass the main insertion at the base of the hallux distal phalanx through the tendinous interconnection toward the FDL tendon. Anatomic studies have shown that the tendinous slip from the FHL tendon to the FDL tendon of the 2nd toe is constant while the slip to the 3rd to 5th toes exists in decreasing frequency. Extreme force from the FHL tendon, as high as six times that of the FDL tendon, can explain potential detrimental effects on the lesser toes, especially in variations where the tendinous slips insert on only one or two toes.

Releasing the TIFF was mentioned by Gauthier in 1987. This procedure was used to prevent a “harness syndrome” which occurred with shortening of the first metatarsal. We propose a similar surgical procedure in correction of select flexible claw toe deformities. This procedure theoretically can prevent the lack of toe grasping function associated with a flexor tenotomy as well as excessive stiffness associated with a flexor tendon transfer. Meticulous soft tissue dissection and protection of the medial plantar nerve are required to prevent complications.

REFERENCES


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ABSTRACT
The treatment of displaced calcaneal fractures remains controversial. Early surgical management to restore articular congruence and the structural function of the calcaneus is widely accepted as the best way to avoid the negative consequences of malunion. Concerns remain however regarding the best approach for reducing and maintaining reduction of these complex fractures, while minimizing the risk of surgical complications. The potential for serious wound complications is a major concern, particularly breakdown of the lateral calcaneal skin flap with the extensile lateral approach. Various approaches have been developed to try and balance the need for direct reduction of the articular surface while minimizing the potential for wound complications. Palmer originally described a laterally based approach through the sinus tarsi for direct visualization of the articular surface for reduction. He and others have found this approach to be useful and reasonably safe. At times, however, it may be necessary to extend the limits of a small incision over the sinus tarsi to treat adjacent fractures or to aid reduction in more complex fractures. In addition, a limited sinus tarsi incision without elevation of the lateral calcaneal skin flap does not allow for plate fixation, a notable advantage of the extensile lateral approach, particularly in gaining reduction of the body of the calcaneus. The authors have used an extended sinus tarsi approach to include placement of plate percutaneously beneath the lateral calcaneal skin flap through a sinus tarsi approach, and to treat adjacent fractures and soft tissue injuries. A clinical series of 13 patients (including 7 chronic smokers and 1 with diabetes and vascular disease) with closed displaced intra-articular calcaneal fractures (Sanders types II and III) were treated by open reduction and internal fixation via this approach. Adjacent fractures were treated through the same incision. Two patients developed wound complications. No wound complications occurred in smokers.

The vascular anatomy of the lateral calcaneal artery related to this approach was also studied with 16 cadaver legs. The lateral calcaneal artery (LCA) passed within 2 mm of the superior border of the Superior Peroneal Retinaculum (SPR) at the midline of the peroneal sheath.

By avoiding dissection through the deep portion of the SPR, the lateral calcaneal artery can be protected, thus preserving the blood supply to the lateral calcaneal skin flap.

INTRODUCTION
Calcaneal fractures have long been recognized as a source of significant disability and remain one of the most difficult articular fractures to treat. There has historically been debate over the best approach for treating these fractures. The goal of operative treatment of calcaneal fractures is to obtain the best possible reduction of the articular surfaces and restoration of the architecture of the non-articular portions of the bone, and to hold this reduction with stable internal fixation. These goals must be balanced with the need to minimize the operative risks, especially the risk of wound healing complications. Operative and non-operative management have both been suggested for the acute treatment of calcaneal fractures, however it is generally accepted that in most cases operative treatment of displaced calcaneal fractures is warranted in order to avoid the negative consequences of malunion. Operative management can consist of reduction through an extensile open incision.
sion, limited incision or percutaneous techniques. Both lateral and medial approaches have been described, but the lateral approach allows direct exposure of the articular surface, while the medial approach is limited to reduction of the body. Various internal fixation techniques have been described, but a laterally based plate is commonly accepted to give the most rigid fixation. Since displaced calcaneus fractures present with various degrees of comminution and soft tissue trauma, it is advantageous for the calcaneus fracture surgeon to have a variety of methods of treatment to balance minimizing risks of wound complications against obtaining the best reduction possible.

The widely used lateral approach to the calcaneus, described by Letournel and popularized by Zwipp, has been termed, the extensile lateral approach. This approach provides excellent direct exposure of the calcaneal body as with the medial approach while also providing direct exposure of the articular surface. The wide exposure allows the surgeon to place a lateral plate which gives rigid control of the body reduction with lag screw fixation through the plate into the medial sustentacular fragment. This provides for reduction of the body fragment medially, even when extensive comminution of the lateral wall is present. This exposure relies on developing a lateral calcaneal flap that is supplied by the LCA which is the terminal branch of the peroneal artery. One drawback of this approach is the potentially catastrophic wound complications that can result in the need for a soft tissue flap, or rarely below-the-knee amputation. Gupta et al. reported a series of patients who underwent open reduction and internal fixation of the calcaneus with a modification of the Palmer incision. This modified incision differed from the one that Palmer described by being placed more dorsally and oriented more longitudinally like a typical approach to the sinus tarsi. This provided good exposure of the posterior facet, and unlike Palmer who used structural bone graft to support the articular reduction, they used internal fixation, consisting of interfragmentary compression screws. The authors obtained satisfactory reductions and minimal wound complications.

We describe an extensile sinus tarsi based approach, for open reduction of displaced calcaneal fractures that the senior author (J.F.) began using in 1999 based on the technique described by Gupta et al. for higher risk patients or those with concomitant fractures that could be addressed simultaneously. It affords placement of a lateral plate subcutaneously by using retrograde subperiosteal elevation of the lateral calcaneal skin flap. Screw fixation into the body of the calcaneus is gained by percutaneous screw placement posteriorly. In this way, direct reduction and rigid plate fixation is achieved as with the typical extensile lateral approach. The advantage of this approach is that it can be easily and safely extended to address other injuries. Proximally, the approach can be extended to include a directly lateral approach to the distal tibia, fibula and syndesmosis, which we have previously described. Distally the talus, calcaneocuboid joint and cuboid are easily accessed, without undue risk to the sural or superficial peroneal nerve. The protection of the lateral calcaneal artery is important to the success of the approach, as with the extensile lateral incision, and we also present a cadaver study to highlight the anatomy of the LCA relative to this surgical approach.

**CLINICAL CASE SERIES**

We retrospectively reviewed thirteen patients who had undergone open reduction and lateral plate fixation without bone graft of closed displaced intraarticular calcaneus fractures using an extensile sinus tarsi approach. This approach was chosen at the discretion of the senior author (J.F.) in cases of patients at higher risk for wound complications such as smokers or those with concomitant injuries that could be treated from a lateral approach. The surgeries were all performed by the senior author (J.F.) between February 1999 and June 2002. During the same time period, the senior author used the extensile lateral approach for isolated calcaneal fractures in other patients not deemed as high risk for wound complications.

Preoperative computed tomography scans were obtained in all patients. Fractures were classified according to the classification system described by Sanders. Six patients had type II-A fractures, three patients had type II-B fractures, three patients had type III-AB fractures, one patient had a type III-AC fracture.

There were 12 males and one female with an average age of 45.1 years (range from 26-71 years). The mechanism of injury was a fall from a height in eight patients, motor vehicle accidents in three patients and snowmobile accidents in two patients. Seven patients were chronic smokers (average 1.5 packs per day). All were counseled to stop smoking. One patient had diabetes and vascular disease, with lateral calcaneal fracture dislocation impacted into the lateral ankle gutter.

Fixation was obtained using the following plates with screws: An Ace/Depuy titanium calcaneal perimeter plate in six patients, a Synthes calcaneal or cervical H-plate in five patients, and a Synthes 2.7 mm reconstruction plate in one patient. One patient had a calcaneal anterior process fracture with calcaneal-cuboid subluxation fused with a large staple.
Operative Technique

For exposure of an isolated calcaneal fracture, the patient is positioned either in full lateral or semi-lateral position with a hip bump. A skin incision is made longitudinally beginning 3cm above the tip of the lateral malleolus along the posterior border of the distal fibula. At the tip of the fibula, the incision is directed toward the base of the fourth metatarsal. This is carried distally to the level of the calcaneal-cuboid joint. The incision lies in a plane between the superficial peroneal nerve and the sural nerve. In this manner, both nerves can be left untouched within the subcutaneous fat. The dorsal communicating branch of the sural nerve may cross the field distally but is usually small in size and easily retracted. In some circumstances, the branch might be more proximal in the field and if necessary, it can be sharply transected near the point at which it branched from the sural nerve. The incision is deepened by mobilizing the sinus tarsi fat pad dorsally. The intermediate root of the inferior extensor retinaculum (IER) can be released too to gain better exposure of the fracture line passing obliquely through the angle of Gissane. The extensor digitorum brevis (EDB) muscle is sharply elevated off of the anterior process with the lateral root of the IER, and reflected dorsally and distally.

The peroneal tendons are retracted laterally between the superior peroneal retinaculum and IPR and the inferior peroneal retinaculum is released off of the bone to expose the lateral calcaneal wall down to the anterior process. The subcutaneous tissues overlying the peroneal tendons are left untouched which also preserves the sural nerve. With the anterior calcaneus and sinus tarsi exposed, the peroneal tendons below the SPR are retracted with a freer elevator placed along the lateral wall of the calcaneus and sharp dissection is used to perform retrograde subperiosteal elevation of the soft tissues off of the lateral calcaneus and proceeding to the tuberosity. Insertion of a broad elevator can enhance the retraction by placing the soft tissues under tension and thus facilitating sharp elevation off of the lateral wall of the calcaneus. Care is taken to make sure that the elevator is not placed into the fracture, but lateral to the lateral wall fragment. The CFL can be transected initially when oriented more vertically. When the calcaneal insertion is elevated with the entire lateral calcaneal soft tissue flap, it remains in its anatomic relationship to the surrounding soft tissues and later reduces back to the calcaneus. It can later be re-approximated with a single stitch if desired. We have not done this uniformly. The SPR is opened if it requires repair or if inspection of the peroneal tendons warrants this. An anatomic repair can be performed. Care is taken to avoid any dissection of the floor of the SPR. Our cadaveric study shows that this inherently protects the LCA, which passes deep to and just along the proximal border of the SPR.

At this point, excellent direct visualization of the articular surface of the posterior facet is possible. Tilting the bed into Trendelenberg position and allowing the foot to invert over a cloth bump aids in visualizing the subtalar joint. The interosseous talo-calcaneal ligament (ITCL) could be transected, which allows the medial articular fragment to be better visualized by tipping into varus. This can aid visualization of the articular surface, but we avoid this in most cases because of the importance of this ligament as a primary stabilizer of the subtalar joint. It is possible that joint instability may result and could add to the chance of post-traumatic arthritis. A 4.5mm Shantz pin or a half ring with crossed tensioned olive wires can be used for traction and control of the tuberosity. The fracture is mobilized, comminution and interposed soft tissues are debrided and provisional reduction of the articular surface and body is held with K-wires. The fracture is typically reduced from anterior to posterior. The anterior process is reduced to the sustentaculum fragment, the lateral articular fragment(s) are reduced and pinned and the tuberosity is loosely reduced and provisionally pinned from posteriorly with pins into the sustentaculum or anterior process. An initial lag screw is placed across the posterior facet fracture lagging the joint fragments. Satisfactory articular reduction is gained and confirmed clinically and fluoroscopically with lateral, axial heel and Broden’s views. Next a lateral plate is placed beneath the internally elevated soft tissue flap, and directly fixed to the anterior calcaneus and the articular fragments. The plate is not contoured and the lateral wall fragment typically reduces into the body of the calcaneus with lagging of the plate to the stable medial fragment. This creates a smooth lateral surface which is less likely to create impingement on the peroneal tendons. The screws for fixation to the tuberosity are placed percutaneously. Fluoroscopy can be utilized, but a small right angle hemostat can also be used to localize the holes for the percutaneous screws by visualizing the holes in the plate directly with retraction of the lateral soft tissues. Once the fixation is complete and final fluoroscopic or x-ray images obtained, the wound is thoroughly irrigated and the EDB and sinus tarsi fat pad reduced and sutured with absorbable sutures. The CFL can be repaired if desired. The skin is closed in two layers with 3-0 or 4-0 absorbable sutures and the skin with Nurolon. A gauze dressing is placed with a bolster, and a dressing of ABD pads is placed over the foot and ankle with an A-O style splint(s) using modest molding over the lateral wall to augment compression. The heel portion of the foot plate is left long to suspend the heel.
After the second case in the series, which was complicated by a wound hematoma, a small closed suction drain was placed into the wound and brought out distally. The drain in our series was removed 24-48 hours postoperatively and wounds were examined on the second postoperative day. We currently do not suture the drains and we remove them at 24 hours through the dressing. Exposure and reductions are performed under tourniquet control.

All patients begin motion once the incision is well healed and the sutures are removed, which is usually 2 ½ - 3 weeks postoperatively. They remain non-weight bearing for 10-12 weeks.

RESULTS

Clinical case series

Four patients underwent ORIF with concurrent primary subtalar arthrodesis. Three were smokers and had fractures types III-AB, III-AC. In these cases, the articular surface damage was deemed to be too severe to warrant ORIF alone. Six patients underwent concurrent peroneal sheath and/or tendon reconstruction, six patients underwent concomitant lateral ankle ligament reconstruction, two patients underwent concurrent open reduction and internal fixation (ORIF) of a talar neck and head fracture respectively, and two patients underwent concurrent ORIF of fibular fractures.

The average length of follow-up time was 19 (range from 2-41) months, excluding one patient who underwent subsequent below-knee amputation six weeks post-operatively. Of those patients who did not undergo primary subtalar arthrodesis, postoperative radiographs with Broden’s views revealed articular reduction within two millimeters. Postoperative measurement of Bohler’s angle averaged 29 (range 25-36) degrees and Gissane’s angle averaged 131 (range 122-150) degrees (Figure 1). These angles were in the ranges of normal population.17,18

Eleven patients healed their soft tissues uneventfully by three weeks. One patient had peripheral vascular disease and diabetes with a severely displaced lateral calcaneal fracture-dislocation into the lateral gutter of the ankle joint with significant fibular comminution. The patient had normal pain sensation and was given the option of surgery due to the severe injury to both the ankle and subtalar joints. This patient’s postoperative course was complicated by wound dehiscence and infection, which was salvaged with a below-knee amputation. One patient sustained a lateral wound dehiscence due to a hematoma. It healed uneventfully after surgical debridement, closure and subsequent local care. After this episode, a medium hemovac drain was placed intraoperatively in all remaining patients with no subsequent wound healing complications.
The Limits of Proximal Extension Based upon the Vascular Anatomy of the Lateral Calcaneal Artery

Sixteen lower extremity cadaver specimens were obtained through the University of Michigan Medical School Anatomic Donations program. The popliteal artery was cannulated with intravenous tubing and the arterial system was manually injected with silicone-based dye solution after cleansing with saline solution. Specimens were frozen overnight after allowing the dye to disseminate and consolidate.

After allowing the specimens to thaw, the extensile sinus tarsi approach was performed. The superficial portion of the SPR was divided, but the deep portion was preserved. The anterior flap was mobilized to the ankle to facilitate the photographic demonstration of the anatomy. After transection and removal of the peroneal tendons within the tendon sheath, the superior border of the deep fibers of the superior peroneal retinaculum was identified (Figure 2). The floor of the peroneal tendon sheath above the superficial peroneal retinaculum was transected longitudinally and the underlying posterior peroneal artery branch, or lateral calcaneal artery (LCA) was identified (Figure 3).

Three measurements were made to define the location and orientation of the LCA relative to the superior border of the deep portion of the SPR. The first was the distance from the superior margin of the floor of the SPR, at the fibular attachment, to the point where the LCA emerged from the posterior margin of the fibula. The second measurement was made at the midline of the floor of the SPR. The third measurement was taken where the LCA crossed the posterolateral margin of the SPR.

The LCA was seen to consistently emerge from the posterior lateral edge of the fibula proximally and course distally behind the deep portion of the peroneal tendon...
sheath superior to the SPR. Three orientations of the LCA were noted as it passed distally: vertical, oblique and horizontal.

The LCA was found to emerge from the posterior fibular border an average of 10.6 (range from 2 to 23) millimeters proximal to the superior border of the deep fibers of the SPR. At the midline of the peroneal sheath, the average distance from the LCA to the SPR was 2.0 (range from 0 to 4) millimeters. In all specimens, the LCA traversed directly posterior to the lateral border of the deep portion of the SPR.

**DISCUSSION**

Various other open approaches have been described in treating calcaneus fractures. They include the extensile lateral approach, medial approach, combined lateral and medial approach, sinus tarsi approach and limited posterolateral approach. Palmer in 1948 initially described his lateral sinus tarsi approach with structural bone grafting beneath the depressed articular fragment. Essex-Lopresti in 1952 used a small sinus tarsi incision to elevate depressed joint fragments with Steinman pin fixation. These authors highlighted the value of direct access to the articular fracture for reduction.

The essential principles of reduction have endured. The goal of treatment is to achieve anatomic reduction of the articular surface of the subtalar joint and reduction of the tuberosity. With improvements in implants over time, rigid fixation with plates and screws has replaced bone grafting and percutaneous pinning as the usual method of maintaining reduction, with many authors favoring a lateral plate fixation.

Good to excellent clinical results have been published in patients undergoing open reduction and internal fixation with the extensile lateral approach, however high wound complication rates are reported. They include superficial epithelial necrosis, full-thickness skin sloughing, deep purulent infections and osteomyelitis. In a retrospective study by Abidi and Conti et al., risk factors included single layered closure, high body mass index, extended time between injury and surgery, and smoking. Folk et al. found that smoking, diabetes, and open fractures all increase the risk of significant wound complications and are cumulative.

Past anatomic studies supported the conclusion that division of the LCA can lead to ischemia of the lateral calcaneal skin flap. It extended distally curving around the lateral malleolus and anteriorly supplying the posterior and inferior portions of the fasciocutaneous flap of the extensile lateral approach. Freeman et al. described in a study that the LCA passed at a mean of 31 mm posterior to the lateral malleolus on a line from it to the insertion of the calcaneal tendon, at an average of 15 mm anterior to the tendon. Borrelli et al. studied the vascularity of the lateral calcaneal flap and concluded that the lateral calcaneal artery was found to be responsible for the majority of the blood supply to the corner of the flap. They found that it emerged from the deep fascia of the leg 15 mm proximal to the tip of the lateral malleolus and 33 mm posterior to the posterior edge of the fibula and 11.5 mm anterior to the anterior edge of the Achilles tendon. They stated that the posterior vertical portion of the typical extensile lateral incision placed the LCA at risk to injury, which could lead to possible wound complications.

In a similar fashion we found the LCA to be at risk with this extended sinus tarsi approach if at the proximal edge of the floor of the SPR. The description of the relationship of the LCA to the SPR provides an identifiable landmark for this extended sinus tarsi approach. By avoiding dissection through the deep portion of the SPR, the LCA can be protected, thus preserving the blood supply to the lateral calcaneal skin flap. We have found that it is not clinically necessary to extend the deep dissection this far proximally as the exposure of the posterior subtalar articular surface is excellent with division of the CFL alone. It could be tempting, however, to carry the deep dissection farther proximally as it would provide even wider access to this area.

In conclusion, the extended sinus tarsi approach provides good exposure to the calcaneus for reduction and fixation and also provides exposure for concomitant treatment of injuries to the lateral ankle and talus. The incision can be extended to allow access to the distal tibia and fibula, talus and the lateral column of the foot.

**ACKNOWLEDGMENT**

The senior author (J.F.) would like to thank his fellowship director and mentor, Elly Trepman M.D. for introducing him to the modified Palmer approach, which formed the basis of this extended technique. Dr. Trepman is the senior author on the paper by Gupta et al.
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DISTAL RADIUS HEMIARTROPROPLASTY COMBINED WITH PROXIMAL ROW CARPECTOMY: CASE REPORT

Jeffrey S. Boyer, MD* and Brian Adams, MD*

ABSTRACT

Severe wrist arthritis is most commonly treated by complete wrist arthrodesis,1-3 which provides predictable pain relief but the loss of motion may reduce ease of function.4 In selected patients, motion preserving surgical options, including limited intercarpal fusion, proximal row carpectomy (PRC), and total wrist arthroplasty (TWA) are considered. However, limited fusion and PRC are typically possible only in less severe cases in which there are some articular surfaces showing minimal degeneration that can be retained.5

TWA is an option for patients who have lower activity demands and specific needs or desires to maintain some wrist motion.1,3 Recent utility and decision analysis studies6,7 demonstrate that arthroplasty is associated with higher quality adjusted life year (QALY) than arthrodesis in patients with rheumatoid arthritis. Despite these positive aspects of TWA, the procedure is not as widely accepted as hip, knee, or shoulder arthroplasty. Early implants had problems related to both materials and design, with breakage, loosening and joint imbalance being common complications.8 Newer generation implants are improved with more predictable early function, less joint imbalance, and rare breakage, but distal component loosening remains a substantial problem. Thus, patients with poor bone stock and those with high activity demands are typically not candidates for TWA, and all patients are advised to restrict activities to reduce the risk of implant loosening.9,10

A new motion preserving procedure has recently been used at our institution in selected patients with severe arthritis who do not qualify for TWA but request an alternative to complete wrist fusion. In this procedure, a distal radius implant arthroplasty is combined with a PRC. The distal radius component of a Universal 2 (UNI 2) total wrist arthroplasty system (Integra Life Sciences, Plainsboro, NJ) is used. To our knowledge, there have been no previous publications on this technique. We report our first two cases which have shown a satisfactory early outcome for pain relief and functional wrist motion.

CASE 1

KW is a 36-year-old female with a 15 year history of rheumatoid disease who presented with bilateral wrist arthritis causing pain and deformity. The left wrist was more painful than the right. She is currently taking Azathioprine and daily prednisone, which has stabilized her arthritis. She had undergone a previous right wrist extensor tenosynovectomy and a left long finger boutonnière reconstruction. Despite trials of splinting and intra-articular steroid injections, she continued to have pain in her wrists.

Examination of the two wrists was nearly equivalent showing bilateral volar wrist subluxation and ulnar deviation. Range of motion of the more painful left wrist was 50° of flexion and 45° of extension with full pronosupination. Her resting posture showed approximately 20° of ulnar deviation. She could radially deviate to neutral but was unable to achieve additional ulnar deviation. The distal ulna was severely subluxated dorsally. Preoperative radiographs in Figures 1A and 1B show severe arthritis with volar subluxation of the carpus and dorsal subluxation of the ulna but the capitate head appeared to be preserved.

Surgical options of complete wrist arthrodesis, total wrist arthroplasty, and distal radius implant arthroplasty with proximal row carpectomy were discussed with the patient. Due to her young age and relatively active lifestyle she was not a good candidate for total wrist replacement. She was quite concerned that her function would be substantially limited by bilateral wrist fusions based on her experience using wrist splints. Thus she chose to proceed with distal radius implant arthroplasty combined with proximal row carpectomy.

The operation was performed under regional anesthesia and tourniquet. A dorsal longitudinal incision was made. The extensor retinaculum was raised as a radially based flap and a tenosynovectomy was performed. The extensor tendons were mobilized both radially and ulnarily. The dorsal wrist capsule was raised as a distally based flap. The proximal carpal row was severely malaligned and arthritic but the capitate head cartilage

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Figure 1. Preoperative PA (A) and lateral (B) radiographs of left wrist in a 36-year-old female with rheumatoid arthritis. Intraoperative photo (C) showing the distal radius arthroplasty with proximal row carpectomy procedure. Postoperative two-year follow-up PA (D) and lateral (E) views following distal radius arthroplasty with proximal row carpectomy.
was in good condition. The lunate fossa showed arthritis with erosions. The distal radioulnar joint was arthritic and subluxated and the decision was made to perform a Darrach resection of the distal ulna. A distal radius component of the Universal 2 total wrist replacement system (Integra Life Sciences, Plainsboro, NJ) was implanted as described previously. An intraoperative photo is shown in Figure 1C. The capsule and retinaculum were reapproximated. The skin was closed over a subcutaneous suction drain. A fluff dressing and wrist splint was applied. Her drain was removed, and she was discharged on the second post-operative day.

Her post-operative course was uneventful. She continued on prednisone and other rheumatoid medication without interruption. The wound had some slight superficial dehiscence at the two-week post-operative follow up and thus the sutures were retained for an additional week. She was transitioned to a removable splint and started on gentle wrist motion. At three weeks, the wound was healed and her pain was minimal. At four months she was pain free in her left wrist and back to her preoperative activity level including gardening. Wrist range of motion was 50° flexion, 30° extension, 5° radial deviation, and 15° ulnar deviation. At one year follow up the motion was unchanged.

At the time of this report, she is two years out from the procedure. The follow up radiographs are in Figures 1D and 1E. Wrist range of motion had remained fairly stable with small gains in radial and ulnar deviation. Because of the good response to the procedure on the left wrist, she elected to have the same procedure on the right wrist. She is pleased with the early results of the right wrist.

**CASE 2**

LD is a 52-year-old right hand dominant male who presented with over a year and a half of right wrist pain. Initially his pain was aggravated by repetitive and stressful activities such as shoveling and heavy lifting but gradually the pain escalated despite anti-inflammatory medications, splinting, and a change in life style. He began to have pain with activities of daily living (ADL), such as note-taking during classes that he was taking to pursue a less physically strenuous new career.

In 2000, he had a left partial wrist arthrodesis for osteoarthritis that provided good pain relief but very
limited motion. He has osteoarthritis of both knees and smokes about one pack per day. His medical history is otherwise unremarkable. Physical examination showed 30° flexion, 40° extension, 5° radial deviation, 25° ulnar deviation, 60° supination, and 80° pronation. Radiographs (Figures 2A, 2B) demonstrated severe radiocarpal arthritis.

He sought relief for pain in the right wrist but wished to retain as much motion as possible in this dominant wrist, in particular because of the minimal motion he had in the left wrist. We had a discussion about the surgical options similar to the first patient (KW). The plan was to perform an intra-operative assessment after completing a proximal row carpectomy to determine the condition of the capitate head and the lunate fossa. If these surfaces showed substantial degeneration then a distal radius implant would be inserted.

Surgical exposure was performed using the same technique as described for the first case. Intra-operative findings showed substantial arthritis involving the lunate fossa and mild degeneration of the capitate head. The decision was made to insert a distal radius implant. Passive motion in the operating room was 35° each of flexion and extension after closure.

He was placed in a splint and discharged from the hospital after an overnight stay. Sutures were removed at two weeks and a removable splint was applied. He was instructed in gentle range of motion exercises. At six weeks after surgery, he had complete relief of wrist pain and had progressed to using this wrist for all activities of daily living. At three months after surgery active wrist range of motion was 30° flexion, 39° extension, 31° ulnar deviation, 5° radial deviation, 90° pronation, and 80° supination. He was bearing weight on the wrist.

Figures 2C, D. One-year follow-up PA (C) and lateral (D) views show stable position of the component and wrist. Some erosion of the hamate has occurred which is likely due to impingement on the implant.
intermittently during crutch walking due to knee pain at that time. At one year follow up he has no wrist pain and the motion was maintained. The one-year post-operative radiographs are shown in Figure 2C and 2D. Some erosion of the hamate has occurred which is likely due to impingement from the implant in ulnar deviation.

**DISCUSSION**

Treatment options for severe wrist arthritis are limited, particularly in physically active patients. Traditional motion preserving procedures are best suited for patients in whom the degeneration spares the lunate fossa because this optimizes the potential outcome following a proximal row carpectomy or scaphoid excision with intercarpal fusion. Total wrist arthroplasty can be considered but the risk of distal component loosening precludes this option in younger or active patients.

When selecting a procedure the expected range of motion should be sufficient to make it more beneficial than total wrist arthrodesis, which usually provides a predictable result for pain relief and durability. Functional wrist range of motion can be defined in three different ways: full normal motion, the motion used by individuals with normal wrists during routine activities, or the minimum range needed to perform activities. Normal wrist range of motion as defined in the American Medical Association Guidelines to the Evaluation of Permanent Impairment is 60° flexion, 60° extension, 30° ulnar deviation, 20° radial deviation, 80° pronation, and 80° supination. Although several studies have tried to define what constitutes functional wrist motion by measuring the ranges used by normal volunteers to perform activities of daily living, there is no consensus of opinion. Another study used standardized tests and volunteers to perform tasks at different motion-restricted states. Subjects were able to perform the tasks regardless of the degree of wrist motion limitation. However, performance was significantly worse for the motion-restricted state.

A recent article reviewed the results of several published studies on total wrist arthroplasty and arthrodesis in rheumatoid patients. The authors chose to use the definition of functional as reported by Palmer et al. of 5° flexion, 30° extension, 10° radial deviation, and 15° ulnar deviation. The authors claimed that three of the eighteen studies on total wrist arthroplasty reported motion in the functional range following wrist replacement. Our patients achieved functional range of motion and were equal to or better than total wrist patients.

PRC has been used to treat non-inflammatory arthritis of the wrist for many years. Recent 10 year follow up studies of PRC show high satisfaction rates for pain relief and most patients obtain functional motion. In nearly all of these patients there was radiographic evidence of radiocapitate arthrosis at follow up but its presence did not correlate with greater clinical symptoms. However, the lunate fossa and capitate head were not degenerated at the index operation in these patients. Other reports found poor outcomes after PRC in patients with degenerative changes of the lunate fossa or capitate head. A 41 month follow up study of eight patients with degeneration of the lunate fossa and or capitate head who were treated by PRC with capsular interposition showed good pain reduction, functional motion, and unchanged grip strength. Both of our patients had substantial degeneration of the lunate fossa, one had early degenerative changes of the capitate head, and the other had radiocarpal subluxation and thus we believe they were not good candidates for PRC alone.

Our patients have complete pain relief at one year. Their wrist range of motion is functional and very acceptable to them. This novel technique was successful in the treatment of both osteoarthritis and inflammatory arthritis however both patients had good bone stock and soft tissue quality. Similar to traditional PRC, some degeneration of the capitate head is likely to occur but it may well remain asymptomatic as seen in our second patient. Based on these early results, we believe distal radius implant arthroplasty combined with PRC is an option for carefully selected patients who would otherwise only be eligible for complete wrist arthrodesis.

**ACKNOWLEDGMENT**

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Distal Radius Hemiarthroplasty Combined with Proximal Row Carpectomy: Case Report


MARJOLIN’S ULCER: INCIDENTAL DIAGNOSIS OF SQUAMOUS CELL CARCINOMA ON HEMIPELVECTOMY FOR RECALCITRANT PELVIC OSTEOMYELITIS

William Lack, MD, Todd McKinley, MD

ABSTRACT
Hemipelvectomy is a radical surgical procedure reserved for particularly devastating pathology including recalcitrant pelvic osteomyelitis. We describe the incidental diagnosis of a metastatic squamous cell carcinoma by pathology after hemipelvectomy for pelvic osteomyelitis. This tumor was located deep within the chronic wound and deemed to be a Marjolin’s ulcer (malignant transformation within a chronic wound). There are multiple reports and case series describing hemipelvectomy for tumor or infection, as well as one case report of a tumor arising years after successful surgical treatment of a chronic decubitus ulcer, but we were unable to find any describing the diagnosis of a Marjolin’s ulcer at pathology following hemipelvectomy for osteomyelitis. This case demonstrates the diagnostic dilemma of malignant transformation within a chronic wound and is an opportunity to highlight the interventions necessary to prevent such progression.

CASE REPORT
A 66-year-old woman presented for treatment of a draining right decubitus ulcer in June of 2008. She had a history of T12 paraplegia following a motor vehicle accident in 1966. She was immunocompetent and without other contributing major comorbidities. She reported a 10 to 12 year history of ulcerations in this region with conservative management at her care facility. She was admitted to an outside hospital 4 weeks prior to her presentation for treatment of sepsis, presumably secondary to her decubitus wound. Physical exam demonstrated an 8 x 10cm foul-smelling wound in the right gluteal region that tracked down to ischium. She had two smaller and more superficial lesions in the left gluteal region. Examination of her lower extremities was also notable for ulcers of the bilateral heels. She had no motor or sensory function of her lower extremities bilaterally.

She was initially treated with surgical debridement of her right ischial wound including resection of the proximal femur and partial excision of the ischium. She also underwent a diverting colostomy. The excised ischial bone was sent for pathology and reported to be consistent with the diagnosis of osteomyelitis.

Pathology (6/2008):
Sections of bone show bony fragments and trabeculae with marrow filled with fibrinopurulent debris. There are abundant neutrophils seen eroding into bony trabeculae.

Wound cultures taken during the initial debridement grew Serratia marasacens and Prevotella. The Infectious Disease team was consulted during her first admission and all subsequent admissions. She was treated with broad spectrum antibiotics for an initial six week course. She was treated with negative pressure wound therapy as an outpatient. Her wound was healing well until June, 2009 at which time she presented with increasing drainage. She underwent irrigation and debridement with a rotational gluteus medius flap to her right decubitus ulcer. She presented again one month later with fevers and increasing drainage and was treated with repeat irrigation and debridement, followed by a similar presentation in September 2009 with another irrigation and debridement. She grew MRSA and Pseudomonas in cultures from these surgeries.

Given the recalcitrant nature of her pelvic osteomyelitis we discussed the possibility of hemipelvectomy. She elected to proceed with hemipelvectomy which was performed on 10/20/09 with the use of an anterior flap for coverage of her posterior ulcer. The procedure was complicated by a tear in the internal iliac vein during final amputation. This was repaired primarily. Two enlarged lymph nodes were encountered during the pelvic dissection near the bifurcation of the right internal and external iliac vessels. These nodes and the complete amputation specimen were sent for pathology.

The patient recovered remarkably well considering the magnitude of the operation. Her wound sealed in the first postoperative week. However, her pathology report determined she had a malignancy.
Pathology (10/2009):
A. Lymph node, pelvic, biopsy: Metastatic squamous cell carcinoma (1/1).
B. Bone, pelvis, excision: Benign bone without significant inflammation or metastatic tumor.
C. Leg and pelvis, right hindquarter amputation: Squamous cell carcinoma, well differentiated, 14 cm, arising from a large ulcer in the posterior gluteal soft tissue with extension into underlying bone of pelvis and femur, anterior / medial soft tissue margin focally involved, bony margins not involved.
D. Lymph node, site not specified, biopsy: Metastatic squamous cell carcinoma (1/1).

The diagnosis was discussed with the patient and the oncology team was consulted to discuss therapeutic options. A chest/abdomen/pelvis CT, ordered to stage the cancer, showed residual bilateral pelvic and inguinal lymphadenopathy as well as bilateral 1.2cm lung masses. A palliative approach was recommended by oncology. She was discharged 1 month following her hemipelvectomy but was subsequently readmitted 2 months postoperatively for bowel obstruction. Exploratory laparotomy by general surgery revealed an incarcerated hernia of her colostomy with significant adhesions and metastatic disease. She had a prolonged intensive care unit stay for postoperative urosepsis. Attempts at weaning mechanical ventilation were unsuccessful. Her family chose to proceed with comfort measures only in accordance with her wishes and she passed away.

DISCUSSION

Recalcitrant pelvic osteomyelitis is a potentially lethal disease that often requires aggressive measures to achieve a cure.1,2 The indications for hemipelvectomy in patients with pelvic osteomyelitis include sepsis and an intolerable state (i.e., foul-smelling wound intolerable to patient). In addition to the cardiopulmonary risks of any prolonged surgical intervention, hemipelvectomy carries with it the risks of intra-pelvic dissection including massive hemorrhage or bowel/bladder injury.1,2 The possibility of a Marjolin’s ulcer should be considered prior to hemipelvectomy for recalcitrant pelvic osteomyelitis. The presence of such a tumor affects the predicted life expectancy of the patient as well as the goals of surgery.

The term Marjolin’s ulcer was coined by Da Costa in his description of malignant degeneration of a chronic wound and referred to the initial description of this process by the French physician of the same name in 1828.3 These initial reports were both regarding tumors arising in vascular lesions without bony involvement and malignant transformation associated with osteomyelitis was not described until 1963.4 A recent literature review of Marjolin’s ulcer reported that 76.5 percent of the cases included in the review occurred in burn scars, but that the types and locations of wounds varied greatly and included venous stasis ulcers, traumatic wounds, pressure sores, and osteomyelitis.5 Another recent review focused on Marjolin’s ulcers specifically associated with osteomyelitis, quoting an incidence of cancerous transformation of 0.2% to 1.7% of chronic osteomyelitis cases.6 The vast majority of these tumors are squamous cell carcinomas, but fibrosarcoma, myeloma, lymphoma, plasmacytoma, angiosarcoma, rhabdomyosarcoma, and malignant fibrous histiocytoma have also been reported.7

Regardless of the nature of the wound in which they arise, these tumors are frequently aggressive and
associated with metastasis at the time of diagnosis. They are most likely to present after a chronic wound has been present for greater than 10 years and frequently for more than 40 years. Measures including proper positioning and skin care, early ulcer treatment, and frequent biopsy of chronic ulcers (> 10 years duration) remain the mainstays of preventing the long term sequelae of decubitus ulcers including both pelvic osteomyelitis and Marjolin’s ulcer. 11, 12 Although there have been case reports of hemipelvectomy for eradication of Marjolin’s ulcer, this surgical indication is rare given the aggressive nature of these tumors, likelihood of metastasis at diagnosis, and frequency of multiple comorbidities in these patients.13 Further highlighting the advantages of prevention over treatment, there has been a case report of Marjolin’s ulcer developing at the site of a previously surgically treated and healed chronic decubitus ulcer.14

To our knowledge we have reported the first case of the incidental finding of squamous cell carcinoma on hemipelvectomy for pelvic osteomyelitis. It is likely that the recalcitrant nature of this patient’s ulcer was secondary to the tumor. However, differentiating between recalcitrant osteomyelitis and Marjolin’s ulcer is difficult given their similar and often simultaneous clinical presentations. The pathology results from the initial debridement confirmed pelvic osteomyelitis, at which time this tumor was likely present based on its size and metastasis at final pathology and the natural history of Marjolin’s ulcer.

The clinical dilemma is not whether the diagnosis in such presentations is pelvic osteomyelitis or Marjolin’s ulcer, but rather is the diagnosis pelvic osteomyelitis and Marjolin’s ulcer. In hindsight, we recommend that excised soft tissue should be sent for pathology in addition to bone to evaluate for malignancy. A malignant transformation must always remain on the differential for an orthopedist treating a chronic, nonhealing wound, particularly in the setting of osteomyelitis.

REFERENCES
LIPOMA ARBORESCENS OF THE SUBDELTOID BURSA: A CASE REPORT

Matthew Teusink M.D., Georges El-Khoury M.D., and Joseph Buckwalter M.D.

ABSTRACT

Lipoma arborescens is a benign, diffuse villous proliferation of the synovium characterized by replacement of the subsynovial tissue by mature adipocytes. Its etiology is unknown and fewer than 100 cases have been reported. It resembles other collections of subsynovial fat, the only difference being its large size and villous macroscopic appearance. It typically presents in patients in their fifth through seventh decades of life. It is most commonly monoarticular and most frequently affects the suprapatellar pouch of the knee. There have been reports of involvement of the hip, shoulder, wrist, elbow, ankle, and associated bursae. To our knowledge there have been only three previous cases of lipoma arborescens of the subdeltoid bursa in the literature.

We report on a case of unilateral lipoma arborescens of the subdeltoid bursa in an elderly patient presenting as a shoulder mass.

CASE REPORT

An 80-year-old male patient presented for evaluation of a left upper extremity mass at his shoulder. He had noticed the mass for the previous six weeks. He only had modest pain in the shoulder. The pain was mild in nature and was intermittent. He was able to continue all of his activities of daily living without any restrictions. It was in his nondominant upper extremity. He presented for the sole reason of work up of the mass and not any associated symptoms such as pain or weakness. He had previously seen an outside physician who attempted an aspiration of the mass, which had only revealed blood.

His medical history was significant for a pulmonary embolism for which he was taking warfarin.

Physical examination revealed a soft, palpable, “racketball sized” lesion anterior to his left shoulder. It was nontender. He had full active range of motion of his left shoulder. He was able to put his hand behind his back and reach the top of his head. He did not have any pain with range of motion.

The plain x-rays of his shoulder showed no evidence of fracture, dislocation, nor mass lesion. There were degenerative changes of the acromioclavicular joint noted.

MRI of his left shoulder was performed to further evaluate the mass. The MRI showed a large amount of fluid within the subacromial-subdeltoid bursa. The mass measured 1.2 cm x 3.1 cm and demonstrated a frond-like excrescent appearance. It was hyperintense to muscle and isointense to fat on T1, intermediate signal intensity on T2, and suppresses on the T2 fat-sat images. It was read by our musculoskeletal radiologists as being consistent with lipoma arborescens.

He was also noted to have tendinosis of the supraspinatus tendon with bursal and articular surface partial tearing involving less than 50% of the tendon without evidence of complete tear.

The diagnosis of lipoma arborescens was discussed with the patient. The option of arthroscopic biopsy and synovectomy was discussed. Given that the patient was asymptomatic he preferred to continue on a course of observation of the mass.

He returned to clinic two months later. He continued to have no pain and no change in the size of the mass.
A repeat MRI was performed which showed stable appearance of the mass and was again read as being consistent with lipoma arborescens. Given that the mass was stable and the patient had very minor symptoms in his shoulder he again did not wish to undergo any surgical procedures and wished to continue further conservative treatment. He was scheduled for follow-up in approximately one year.

DISCUSSION

The etiology of lipoma arborescens is unknown. It has previously been described with degenerative joint disease and chronic rheumatoid arthritis. Clinically it usually presents as joint swelling, pain, limitations in range of motion, and recurrent effusions.

This case is unique in that the patient’s chief complaint was an anterior shoulder mass and not pain or restriction of motion.

The MRI characteristics of lipoma arborescens have previously been described by Vilanova et al. There is a morphologic pattern of intra-articular fat deposits with a villous proliferation of the synovial membrane. Subsynovial components have high signal intensity similar to subcutaneous fat on T1 and T2-weighted images and low signal on fat-suppressed images. It does not enhance with gadolinium. In their series all cases of lipoma arborescens of the shoulder had an associated rotator cuff tear. Our patient was also found to have a partial thickness tear of the supraspinatus.

Histologic findings of lipoma arborescens show finger-like villi infiltrated by mature fat tissue, chronic inflammatory cells, and vessels, and lined by synovium. The differential diagnosis of lipoma arborescens includes other benign synovial disorders. Other disorders included in the differential diagnosis with lipoma arborescens are pigmented villonodular synovitis (PVNS), synovial hemangiomas, synovial lipoma, and synovial chondromatosis. These other diagnoses can usually be excluded based on MRI findings. A synovial lipoma is a discrete round or oval mass isointense with fat on all sequences, whereas lipoma arborescens has a villous appearance. PVNS is low intensity on T1 and T2-weighted images and enhances with gadolinium. Synovial hemangioma is low signal on T1-weighted images and high signal on T2-weighted images and characteristic hypointense linear fibrous septa. Synovial chondromatosis is associated with loose body formation.

Treatment of lipoma arborescens is open or arthroscopic synovectomy. Recurrence of the lesions following synovectomy is uncommon. In our case given the patient’s age and lack of symptoms he elected to continue observation of the lesion. If it does become more painful, our recommendation would be arthroscopic synovectomy with excision of the lesion.

REFERENCES

BILATERAL OLECRANON EPiphySAL Fracture Non-unION IN A COnPETITIVE ATHLETE

Randy R. Clark, MD, and Todd O. McKinley, MD

ABSTRACT

Olecranon epiphyseal stress fractures and epiphyseal non-unions have been described in throwing athletes, weight lifters and gymnasts. We present a case in which bilateral olecranon epiphyseal fractures were diagnosed in a competitive NCAA Division One wrestler who presented with chronic elbow pain. Given the rigors and physical demands of collegiate wrestling, we present a novel technique for open reduction internal fixation, grafting and supplementation with BMP for accelerated healing and return to competition.

INTRODUCTION

Stress fractures through the olecranon epiphyseal plate have been described in throwing athletes, weight lifters, gymnasts and have even been reported in a wrestler.1-8 These injuries are thought to occur due to valgus extension overload across the ulnohumeral joint, repetitive abutment of the olecranon into the olecranon fossa, the deceleration phase of throwing and impact of the medial olecranon onto the medial wall of the olecranon fossa.9

The olecranon ossific nucleus typically presents around the age of 8 and 11 years and fuses by the age of 15 and 17 years.10 It is during this time period that the elbow is susceptible to these injuries.

Repetitive overload and shear forces presumably cause abnormal stress across the growth plate, creating a Salter Harris Type One fracture. If the forces continue, a non-union occurs through the growth plate. Biopsy of the these lesions show dense, poorly organized, cellular collagenous connective tissue separating two areas of reactive new-bone, consistent with a non-union. Furthermore, the epiphyseal plate is absent, indicating that this is not just failure of fusion of the epiphys.5,11,12

These injuries have been treated with a variety of methods. Conservative management combines elbow immobilization, rest and subsequent rehabilitation. Rehabilitation focuses on eccentric strengthening of the elbow flexors, improving throwing mechanics, modification of technique in order to decrease the forces across the elbow joint and gradual return to training activities when all symptoms have resolved and radiographs demonstrate fracture healing. Conservative management may require several months of restricted activities. Electrical and ultrasound bone stimulators can be employed to promote healing. However, conservative measures have a high failure rate.13

Given the prolonged time period and uncertain outcome associated with conservative treatment, most athletes pursue operative intervention. Operative techniques include various forms of open reduction and internal fixation, bone grafting and post-operative immobilization followed by rehabilitation. The literature reports that most athletes are able to return to a pre-injury level within their sport after surgery and a period of recovery and rehabilitation.4,6,13,14

While olecranon epiphyseal fracture occurrence and their treatment have been widely described in throwing athletes, we present an interesting case in a competitive collegiate wrestler.

CASE

A 19-year-old Division One NCAA competitive wrestler, with a history of a stress fracture in his left elbow, presented to clinic days after falling on his right elbow during competition. Radiographs demonstrated a displaced olecranon fragment with sclerotic appearing fracture lines consistent with an olecranon non-union. Further history revealed that the athlete’s elbow had been painful for several months. The patient elected to have his non-union surgically stabilized with grafting. Surgery revealed an established non-union, which was stabilized with a 1/3 tubular plate and screws, supplemented with bone morphogenic protein and allograft cancellous bone.

After his operation the patient revealed that his opposite, left elbow had substantial pain. Furthermore, this elbow was painful in his previous three wrestling seasons. Further history revealed that in each of the three previous seasons, his left elbow pain progressively worsened as the season progressed. Therefore, x-rays

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were obtained which were remarkable for an olecranon epiphyseal non-union. The patient had an identical procedure performed two days after his first operation on his left elbow.

The patient was allowed functional range of motion in hinged braces post-operatively. At six weeks, radiographs showed healing of his previous bilateral non-unions. At that time his activity was appropriately progressed. The patient was able to return to full activity, including live wrestling. Eventually his hardware became symptomatic and was removed.

**DISCUSSION**

Most of the literature relevant to epiphyseal fractures of the olecranon discusses the possible fracture/non-union mechanism in overhead athletes. The injury is also noted in tennis players, weight lifters and gymnasts. In most cases, the injury was unilateral. Maffulli et al. reported 2 cases of bilateral injuries in young gymnasts. These epiphyseal olecranon fractures likely occur through a similar mechanism as described in the overhead athlete. Maffulli et al. note that these injuries likely occur in gymnasts due to weight-bearing exercises, over-use, rapid explosive maneuvers and repeated extension on a plastic growing skeleton creating repeated injury to the growth plates. Olecranon epiphyseal injuries may be analogous to stress fractures of the distal radius and Osgood-Schlatter apophysitis of the tibial tubercle.

These lesions appear to be age dependent. When the olecranon epiphysis is not fully ossified, shear and tensile forces likely create the non-union. When the epiphysis is more mature and calcified, the same forces likely create a stress fracture. Regardless of whether the lesion appears as a stress fracture, or non-union, the biomechanical forces and subsequent pathology appear to be related.

The treatment of the patient in this report raises several points. The incidence of this injury in wrestlers appears less reported in the literature as compared to overhead athletes. Therefore, it should be considered in
high school-aged wrestlers with chronic elbow pain and needs to be evaluated in detail in wrestlers with bilateral elbow pain. Fracture fixation in olecranon epiphyseal fractures with allograft cancellous chips and bone morphogenic protein has not previously been described, but was successful in this patient. The use of a plate and screws is also a different method of fixation as compared to the tension band constructs described in the literature reviewing treatment for this injury. We decided to place a more robust construct given the potential demands that would be placed upon the fixation, in a historically non-compliant patient population. There are some notes of K-wire tension band and intramedullary screw fixation failures in the literature. While most elite athletes who suffer epiphyseal fractures and non-unions are able to return and compete at pre-injury levels, it is unknown how a competitive wrestler with bilateral injuries will compete in the future.

REFERENCES
CERVICAL FACET JOINT SEPTIC ARTHRITIS: A CASE REPORT

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**ABSTRACT**

Facet joint septic arthritis is a rare but severe infection with the possibility of significant morbidity resulting from local or systemic spread of the infection. Pain is the most common complaint on presentation followed by fever, then neurologic impairment. While the lumbar spine is involved in the vast majority of cases presented in the literature, the case presented here occurred in the cervical spine. The patient presented with a three week history of neck and left shoulder pain and was diagnosed by MRI when his pain did not respond to analgesics and muscle relaxants. The only predisposing factor was a history of diabetes mellitus and the infection most likely resulted from hematogenous spread. MRI is highly sensitive in diagnosing septic arthritis and it is the preferred modality for demonstrating the extent of infection and secondary complications including epidural and paraspinal abscesses as seen in this case. Without familiarity with this entity's predisposing factors, clinical symptoms and appropriate lab/imaging work up, many patients experience a delay in diagnosis. Treatment involves long term parenteral antibiotics or percutaneous drainage. Surgical debridement is reserved for cases with severe neurologic impairment. The incidence of facet joint septic arthritis is increasing likely related to patient factors (increasing number of patients >50 yo, immunosuppressed patients, etc), advancement in imaging technology, availability of MRI, and heightened awareness of this rare infection which is the aim of this case presentation.

**INTRODUCTION**

Septic arthritis of the facet joint is a rare clinical entity with a similar clinical presentation to spondylodiscitis. Septic arthritis most commonly affects the larger peripheral joints and rarely the facet joint, however many of the same principles apply regarding predisposing factors, clinical presentation, lab/imaging work up and treatment modalities. Without appropriate diagnosis and treatment, infection can spread to adjacent structures resulting in abscess formation, spinal cord/nerve root impingement and sepsis. Two retrospective reviews of case reports in the literature found that septic arthritis of the facet joint causes 4-20% of pyogenic spinal infections, the average patient age is 55-59 and the overwhelming majority, 86-97%, occur in the lumbar spine.\(^1\)\(^2\) While most cases are thought to occur via hematogenous spread, there are a number of case reports in the literature where septic arthritis of the facet joint resulted from iatrogenic causes including corticosteroid injection\(^3\)\(^-\)\(^7\) and epidural catheterization.\(^8\)\(^,\)\(^9\) These infections can also occur secondary to spread from adjacent infections such as spondylodiscitis, epidural or paraspinal abscess, psoas muscle abscess or other intraabdominal infections. MRI has become the imaging modality of choice for diagnosis and determining extent of the infection. Timely and accurate diagnosis of septic arthritis of the facet joint followed by definitive therapy of this entity requires a multidisciplinary approach. Most cases are treated with up to 6 weeks of parenteral antibiotics, percutaneous drainage or open debridement depending on clinical symptoms and severity. While most patients typically experience some delay in diagnosis, the majority of patients fully recover or experience mild residual pain/neurologic sequela following appropriate therapy.\(^1\)

**CASE PRESENTATION**

The patient is a 57 year old male with a past medical history significant for type 2 diabetes mellitus who presented to an outside hospital with a three week history of left shoulder and neck pain after a trial of analgesics and muscle relaxants did not improve his symptoms. The patient was afebrile with no focal neurological deficits on physical exam. He had a normal white blood cell count with elevated Erythrocyte Sedimentation Rate (ESR) of 91 (normal 0-15 MM/HR) and C-reactive protein (CRP) of 3.2 (normal <0.5 Mg/Dl). Cervical spine MRI revealed left C5-C6 facet joint septic arthritis with extension of the infection into the paraspinal musculature, prevertebral soft tissues and epidural space with abscess formation and spinal canal narrowing. (Figure 1, Figure 2, and Figure 3).

The patient was then transferred to the University of Iowa for further care. He was started on IV Vancomycin and Ceftriaxone. Cultures from a CT guided aspiration (Figure 4) revealed *Staphylococcus aureus* as the causative agent. As the patient had no neurologic deficits,
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Figures 1A, B. Contiguous axial T2 weighted MR images at C5-6. There is high T2 signal in the left facet joint space with adjacent bony destruction. Both images show fluid collections in the paraspinous tissues consistent with abscess (white arrows). Figure 1A shows direct extension of the infection into the epidural space (arrowhead) with abscess formation.

Figures 2A-C. Two contiguous axial (A and B) and a coronal (C) T1 weighted fat saturation post gadolinium images. Figure 2A shows bony destruction at the left C5-C6 facet joint with extension into both the epidural space and bilateral paraspinal soft tissues. Figure 2B shows paraspinal abscess formation (white arrow) and enhancement extending anteriorly into the prevertebral soft tissues. Figure 2C shows direct extension of the paraspinal abscess from the level of the left C5-C6 facet (black arrow).
A

Figures 3A, B. Sagittal T2 weighted images in the midline and left of midline. Figure 3A shows the epidural abscess (white arrow) with posterior mass effect on the cervical spinal cord at C5-C6. Figure 3B demonstrates the paraspinal abscess and adjacent high T2 signal in the musculature consistent with inflammation.

B

Figure 4. Axial CT scan in bone windows at the time of CT-guided aspiration shows sclerosis, erosions and facet joint space widening at the left C5-C6 facet joint (white arrow).
negative blood cultures and no signs of sepsis, he was placed on IV Vancomycin for 6 weeks followed by two weeks of oral Linezolid by the Infectious Disease service. The patient remained afebrile, his pain subsided and the ESR and CRP returned to normal within a few weeks. Six week follow up MRI showed resolution of the abscesses and decreased soft tissue enhancement. There was no evidence of infection on the six month follow up study as well.

**DISCUSSION**

Septic arthritis is most commonly secondary to a bacterial infection with less common, more indolent infections resulting from fungal or mycobacterial causes. Predisposing factors include elderly patients, diabetes mellitus, immunosuppressed patients, rheumatoid arthritis, skin infection, IV drug abuse, and previous joint manipulation including joint prosthesis, recent joint surgery and intra-articular corticosteroid injections. Septic arthritis is caused by hematogenous spread (where the presenting sign can be bacterial endocarditis), direct inoculation of the joint from corticosteroid injection, surgery or trauma, or from spread of adjacent infection into the joint space. One retrospective review of 191 cases of septic arthritis found that 72% of cases were thought to arise from hematogenous spread. The majority of cases in adults is caused by *Staphylococcus aureus* and occur in the larger peripheral joints including knees, wrists, shoulders, elbows, ankles and hips. Smaller joints are rarely affected including the sternoclavicular joint, sacroiliac joint, pubic symphysis and the spinal facet joint.

One or more predisposing factors was seen in 38-58% of patients diagnosed with facet joint septic arthritis with the most common being concomitant infection and immunosuppression (most notably diabetes mellitus, liver disease, transplant patients, long-term corticosteroid use and malignancy). Another predisposing factor is underlying joint disease which is reportedly found in almost 50% of cases of septic arthritis. Related to underlying facet disease, there was a retrospective study where 209 consecutive lumbar spine MRIs were reviewed regardless of patient history or clinical indication which revealed that 41% of patients were found to have facet synovitis based on signal abnormality within the joint capsule and peri-articular region.

A high index of suspicion is needed to prevent a delay in diagnosis and therapy. Mean time from symptom onset to diagnosis has been reported to be 36-43 days with a large range from 2 days to 6 months. This delay in diagnosis can result in increased patient morbidity and highlights the need for consideration of this disease in the differential diagnosis of patients presenting with neck/back pain, fever and with any of the risk factors discussed above. Further evaluation includes lab work up (white blood cell count, ESR, CRP and blood cultures) followed by appropriate imaging studies.

Plain radiographs are not sensitive in diagnosing early disease as radiographic findings may not be evident for weeks to months following onset of symptoms. However there are a few reports where facet joint space widening suggesting joint pathology was noted at 4 and 21 days after onset of symptoms. Radionuclide studies including Technitium-99m MDP bone scan, Gallium-67, and In-111 labeled white blood cell scans have shown very high sensitivity for this entity as early as one week after onset of symptoms. Tc-99m MDP bone scan can be helpful for assessing osteoblastic activity or bony remodeling secondary to infection. However, the low specificity of this test limits its utility in diagnosing septic arthritis. Ga-67 and more recently In-111 are being used to evaluate for infection/inflammation with very high sensitivity, more specificity than Tc-99m bone scans and improved spatial resolution with the implementation of SPECT and co-registered SPECT-CT images.

Non-contrast CT is able to show joint space widening, pre-existing joint disease, bony erosions and either a fluid collection or soft tissue air that could suggest abscess formation. CT is also very helpful for establishing the diagnosis via obtaining synovial fluid for isolation of the organism and for drainage of the affected joint. MRI is the imaging modality of choice for diagnosing facet joint septic arthritis due to its high sensitivity, specificity and soft tissue contrast. MRI is also essential for therapeutic planning.

Soft tissue gadolinium enhancement may be seen on MRI within 2 days from the onset of symptoms. Reportedly 81% of cases show epidural and/or paraspinal extension of the infection, and MRI is superior at demonstrating extension into the epidural or disc spaces, paraspinal soft tissues, vertebra and abscess formation. Many case reports of facet joint septic arthritis are associated with epidural or paraspinal abscesses. It may be difficult to distinguish on imaging whether the infection started in the facet joint or if the infection spread to the facet joint. Some authors have postulated that the incidence of this infection may be underestimated if the infection decompresses into the surrounding paraspinal tissues or epidural space prior to diagnosis.

Facet joint septic arthritis should be considered when a patient presents with back pain, fever and elevated inflammatory markers (ESR and CRP), however the presentation and at risk populations are nearly identical to that of spondylodiscitis. Over 90% of patients present with pain, roughly 75% present with fever and about 33-50% present with neurologic symptoms. Facet joint septic arthritis may be suspected in patients with unilateral
symptoms or when there is a more rapid symptom progression (4 weeks) compared to the typical presentation of the more common spondylodiscitis (2-3 months). Other differential diagnosis considerations include non-pyogenic infection such as Tuberculosis, degenerative or inflammatory arthritis and malignancy. Lytic or destructive lesions involving the posterior elements are most often neoplastic in etiology. One retrospective study using CT to determine infection vs. tumor in the spine noted that severe neurological impairment was more common with spinal infection (39%) than tumor (14%).

Complications of septic arthritis of the spinal facet joint include chronic pain, joint/bony destruction, pyomyositis, abscess (epidural, psoas muscle and paraspinal), neurologic sequelae, spondylodiscitis, endocarditis, meningitis, septic emboli and rarely death. In one review of 42 patients excluding cases involving pediatric patients, IV drug users and prior surgical instrumentation/surgery, the most severe complications were paraplegia in one patient and death during surgery in another patient. The majority of patients in the case reports recovered fully or had minimal residual pain following treatment.

Patients are typically treated with long-term (at least 6 weeks) parenteral antibiotics followed by oral antibiotics or a combination of percutaneous drainage and long-term antibiotics. Open arthroscopy and surgical drainage/debridement is typically reserved for the patient with infection refractory to antibiotic trial or with acute neurological compromise. MRI is less helpful in assessing for treatment response as soft tissue enhancement can persist following clearance of infection. Treatment response can be assessed using the patient’s subjective improvement in symptoms and improvement in inflammatory serum markers.

In conclusion, septic arthritis of the facet joint is an uncommon infection that requires a high clinical suspicion for accurate and timely diagnosis. This infection shares many features with septic arthritis in the more commonly affected large peripheral joints as well as with spondylodiscitis. The incidence of this entity is increasing and MRI will continue to play an important role in diagnosis and surgical planning. Lastly, while most patients recover with little or no neurologic sequelae, prompt diagnosis and definitive therapy are essential for decreasing patient morbidity and mortality.

REFERENCES


CASE REPORT: SUCCESSFUL TREATMENT OF ACUTE EXERTIONAL PARASPINAL COMPARTMENT SYNDROME WITH HYPERBARIC OXYGEN THERAPY

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ABSTRACT
An NCAA football player developed an acute paraspinal compartment syndrome after a weightlifting strain. The patient presented with myonecrosis (CK up to 77,400 U/L), and myoglobinuria. Treatment consisted of forced diuresis and six sessions in the hyperbaric oxygen chamber.

BACKGROUND
Acute compartment syndrome is defined as the pathologic elevation of the hydrostatic tissue pressure within a closed compartment inducing ischemia and myonecrosis. Acute paraspinal compartment syndrome, although rare, has been well described in a few case reports. In addition, exertional compartment syndrome, well described in the extremities, rarely progresses to the acute form. Both operative and non-operative modalities have been described as treatment alternatives. Hyperbaric oxygen therapy has been successfully used for the treatment of extremity compartment syndrome. In our review of the literature, we were unable to find a description of the use of HBO in acute paraspinal compartment syndrome. We report a case of acute exertional paraspinal compartment syndrome managed successfully with hyperbaric oxygenation.

METHODS
A 23-year-old African-American NCAA football player presented to the emergency room with a 36-hour history of rapidly-increasing low back pain. The pain was described as throbbing, and started acutely during a weight-lifting session (squats). The intensity of the pain increased rapidly until it became unbearable.

Four hours after the incident he was taken to his local emergency room and admitted for pain control. His past medical history was uneventful, and no previous episodes of back pain were documented. He was then transferred to our institution, arriving approximately 12 hours later.

Upon admission, initial examination revealed severe pain and tenderness in the lower aspect of the back. Fullness and tenderness of the paraspinal muscles was noted, particularly on the left side. Due to the acute and unbearable nature of the pain, an MRI was ordered: The T2-weighted MRI of the lumbar spine (Figure 1) revealed significant edema throughout the paraspinal muscles, particularly of the erector spinae. The volume of the medial muscle compartment at the level of the L4 vertebral body was measured as 22 cm² on the left, in sharp contrast with 14 cm² on the right, a greater than 50% increase in volume.

The patient’s laboratory studies revealed negative sickle cell screening, and normal electrolytes, CBC, CRP and ESR. The urinalysis revealed myoglobinuria, and the creatine kinase (CK) upon admission was 64,863 U/L. He was admitted and treated with forced diuresis, and pain was only poorly controlled with opioid analgesics.

Figure 1. Axial T2-weighted MRI section at the level of the L4 vertebral body. Note the diffuse edema of the paraspinal muscles, involving the bilateral erector spinae and the longissimus on the left side. The cross sectional area of the right medial compartment was 14 cm² which contrasts with 21.8 cm² on the left side.

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The CK was repeated 12 hours later, and continued to increase until it reached a maximum of 77,440 U/L (Figure 2).

**RESULTS**

With the diagnosis of paraspinal compartment syndrome, treatment was commenced in the hyperbaric oxygen chamber on the second day. After the first session, the CK had decreased to 68,010 U/L (Figure 2), and after the second session the pain was much better controlled. The patient was able to mobilize with only moderate discomfort after the third session. He underwent a total of six sessions, and was discharged after one week with a CK of 8,805 U/L. His renal function remained unchanged.

Over the next four months the patient was periodically followed. Within this time period, the CK was completely normalized and the back pain continued to progressively improve. He was able to resume physical activities, and complained only of pain upon exertion which slowly improved during this period.

**CONCLUSION**

Acute, exertional, paraspinal compartment syndrome should be suspected in young athletes who present with acute-onset back pain following intense physical activity. Anatomical studies have demonstrated a well-defined paraspinal compartment within the thoracolumbar fascia, consisting of the erector spinae muscles. In a manner similar to that which occurs in extremity compartments, prolonged increases in tissue pressures within these compartments can lead to myonecrosis. Hyperbaric oxygen (HBO) therapy can provide increased amounts of dissolved oxygen in plasma, improving oxygen delivery and tissue viability in ischemic areas. Serum creatine kinase (CK) was utilized as an indicator of tissue ischemia and rhabdomyolysis. As demonstrated in graph 1, initiation of HBO coincided with a rapid and prolonged decline in the level of circulating serum creatine kinase until normal levels were reached. Additionally, the acute and unrelenting pain was well controlled within 24 to 36 hours following institution of HBO therapy.

Previously described cases of acute paraspinal compartment syndrome related to exertion have occurred in young male athletes; onset of symptoms was also acute and related to recent high-intensity physical activity. Some of these cases were treated with fasciotomy, while others were treated conservatively with pain management and forced diuresis. All patients were able to resume physical activity, nevertheless, the nonsurgical patients continued to experience mild chronic pain with vigorous exercise.

Figure 2. Creatine kinase (CK) values were measured on a daily basis. The values continue to rise from admission to a peak at 77,440 U/L on the second day. Following the first hyperbaric oxygen session, these values start to decline until they reach 8,805 U/L after six sessions.
In summary, this case presented as an acute exertional compartment syndrome in the paraspinal muscles in an athlete. Early diagnosis and prompt management with the use of hyperbaric oxygen, close monitoring with clinical examinations, CK levels, and renal function tests allowed effective resolution of the acute problem. We propose HBO therapy as a treatment method for acute exertional paraspinal compartment syndrome. This should be started as soon as the diagnosis has been reached. If the pain is well controlled, and the CK starts to decline, no further treatment methods need to be considered.

REFERENCES
VALGUS SLIPPED CAPITAL FEMORAL EPIPHYSIS

S. García-Mata, MD;*** A. Hidalgo-Ovejero, MD*

ABSTRACT

Valgus slips of the epiphysis are rare, making radiological diagnosis difficult. A high degree of clinical suspicion is required to diagnose the condition.

The patient was a 13-year, 7-month-old girl who had been suffering from pain in the left thigh for ten days. She had a limp and a positive Trendelenburg sign. Menstrual function had started when she was 12 years and 10 months old. Pain occurred with getting up from a chair.

Hip radiographs revealed symmetrical, bilateral caput valgum, which was a potential cause of confusion given the valgus displacement of the proximal femoral epiphysis. Axial view showed an almost imperceptible posterior slip. The patient was diagnosed as having a valgus slipped capital femoral epiphysis (SCFE). Surgical treatment was performed using in-situ fixation with a cannulated, fully threaded percutaneous screw placed through the external cortex of the femoral neck. Non-weight-bearing for six weeks was prescribed.

Although a medial approach is usually used for screw insertion using a more medial entry-point, preventing neurovascular risks, in-situ fixation (through a lateral approach) was performed more safely and distally. This was done through the outer cortex of the femoral neck (and centered in the axial view), to achieve fixation of the femoral head in the center of the femoral neck and head.

INTRODUCTION

Slipped capital femoral epiphysis, SCFE, or proximal femoral epiphysiolysis is an alteration that occurs in adolescence and preadolescence, most frequently affecting patients with an adipose-genital phenotype, hormone imbalances, and other disorders, in the presence of mechanical factors such as excessive weight or trauma.

SCFE is usually idiopathic, but in some cases can be associated with endocrinopathies and hypogonadism. Occurrence can be acute, acute-on-chronic, and chronic.

SCFE has classically been described as a posterior and inferior slip of the proximal femoral epiphysis through the physis. The basic pathological and radiological feature of the lesion is a varus, posteriorly slipped proximal femoral epiphysis. The slip, which is usually progressive, is sometimes not easy to detect on initial radiographs.

Klein et al.1 described the typical ‘Klein line,’ which is a line that can be traced along the superior aspect of the femoral neck, as an early indicator of SCFE. Failure of this line to intersect the superior aspect of the epiphysis is a subtle sign of SCFE.

When the epiphysis has slipped into valgus with minimal or no posterior displacement, radiological signs may go unnoticed. The existence of the laterally displaced femoral head in slipped capital femoral epiphysis has been a subject of debate2 but now there no doubt about the existence of a true valgus SCFE.

Valgus slips of the epiphysis are rare, making radiological diagnosis difficult. A high degree of clinical suspicion is required to diagnose the condition.

PURPOSE

We present a case of valgus slipped capital femoral epiphysis in which atypical displacement made initial radiological diagnosis difficult. We also report a successful nontypical surgical approach.

CASE REPORT

The patient was a 13-year, 7-month-old girl who had been suffering from pain in the left thigh for ten days. She had a limp and a positive Trendelenburg sign. Menstrual function had started when she was 12 years and 10 months old. Pain occurred when getting up from a chair when it was mechanical in nature, and it was worse with weight-bearing and activity. Flexion of the left hip was painful. Internal rotation of the hip was limited (–40º), with the limb adopting an externally rotated posture.

At the age of 12 years and 8 months, the patient underwent a bilateral hemiepiphysodesis of the proximal tibia for bilateral idiopathic genu valgum (13º and 12º of valgus of the mechanical axis, with an intermalleolar distance of 14 cm when bearing weight). During intubation for anaesthesia, a lump was discovered in the
thyroid area. This turned out to be a medullary thyroid carcinoma, which was treated by total thyroidectomy and node excision. The patient required replacement hormone therapy for hypothyroidism. Hip radiographs revealed symmetrical, bilateral camptocormia, which was a potential cause of confusion given the valgus displacement of the proximal femoral epiphysis. The axial view showed an almost imperceptible posterior slip of the left hip. The patient was diagnosed as having valgus slipped proximal femoral epiphysis of the left hip. Surgical treatment was performed using in-situ fixation with a cannulated, fully threaded percutaneous screw placed through the external cortex of the femoral neck. During the immediate postoperative period, pain disappeared. Non-weight-bearing for six weeks was prescribed. Four years later, the patient remained asymptomatic, with no pain or limping, and was leading a normal life.

External rotation of the hip was 60° on the right side and 45° on the left side; internal rotation was 45° on the right side and 60° on the left side. Roentgenogram showed physeal fusion, with caput valgum.

DISCUSSION

Valgus SCFE was first described by Müller in 1926. Twenty-seven patients, involving a total of 34 hips, have been reported to date. The condition is often not noticeable on AP radiographs. In valgus SCFE, the Klein line will always be normal, emphasizing the need for lateral radiographs in all cases when evaluating children for SCFE. Valgus SCFE occurs mostly in girls (76%). It is also surprising that many of the cases reported in the literature were recorded between 1940 and 1960, or recently, with a higher male predominance in earlier series. One of the possible explanations of the higher female predominance in valgus SCFE is the increased femoral anteversion in females. Loder et al. found a
prevalence of valgus SCFE of 1.9% when reviewing the literature. Thus, 1-2% of children with SCFE will have the valgus-displacement type.

Mechanical factors have been cited in connection with the appearance of SCFE but the etiology of this pattern of SCFE remains uncertain or not clear. Ogden postulated that the valgus slip can occur in an older child with an acute SCFE, where a thin remnant of cartilage along the posterior femoral neck is present, enabling the epiphysis to be pushed laterally as it is slipping posteriorly.

A marked coxa valga orients the physis to a relative horizontal position. Griffith, in 1976, and later Morrisy in 1990, believed that the direction of displacement in SCFE was strictly posterior as defined by the femoral neck and no true medial or lateral displacement of the capital femoral epiphysis occurs. The typical appearance of varus and exceptionally valgus, on AP radiographs of the hip was thought to be attributable to the effect of parallax. External rotation of the lower extremity results in varus appearance and internal rotation results in apparent valgus displacement of the epiphysis.

But Segal reported two cases of true valgus SCFE, confirmed by CT scan and MRI with posterolateral epiphyseal displacement. Increased femoral anteversion will lead to the appearance of an increased neck-shaft angle on AP radiograph of the hip. Increased femoral anteversion, in addition to exaggerating the degree of coxa valga and contributing to the projectional phenomena of parallax, may play a role in the mechanical etiology of valgus SCFE. These are patients with coxa valga whose hips exhibit a previously increased cervico-diaphyseal angle (20°) and an increased lateral tilt (27°), which are the cause of greater loads during weight-bearing, and facilitate the development of deformity in the same direction during gait. A slip may frequently occur in the coronal plane only, without posterior displacement. Our patient did not have coxa valga, but her hips displayed a rare case of bilateral, idiopathic caput valgum; although no such instances have as yet been described in the literature, this could clearly represent a mechanical predisposing factor. Only Rothermel described a patient with valgus SCFE secondary to acute trauma, but with one month of hip pain. He believed that lateral epiphyseal displacement may have occurred secondarily to forced femoral abduction on a horizontal physis. Meyer et al., and Fahey and O’Brien described valgus SCFE in children after traumatic events. Pritchett and Perdue, through a 3-dimensional force analysis, support that the relationship of femoral retroversion more than normal increases the shear stress that the femoral growth plate will experience by 20%.

Yngve et al. have shown that valgus SCFE can occur on a biomechanical basis. A transphyseal shear force of 2.7 times body weight is seen in a child with valgus neck-shaft angle and lateral tilt of the capital femoral physis, which is greater than the 2.2-times body weight needed to cause physeal slip in slowly walking obese children. Thus, a valgus SCFE can occur because of biomechanical factors alone.

It is important to detect the above variant, since surgical treatment demands in-situ fixation. Medial approach is usually performed in valgus SCFE. This medial approach will require open surgery to protect the neurovascular structures (Segal). Loder and Segal warned that the valgus SCFE needs a much more medial entry point for a single central-screw fixation than the typical “varus” SCFE. Therefore, the proximity of the femoral neurovascular bundle makes this approach risky.

An external approach is difficult because of the minimal space available. In order to avoid screw insertion using a more medial entry point to prevent neurovascular risks, Shea performed in-situ fixation through
the external femoral metaphysis. In our patient, due to the greater epiphysis displacement and the lack of space available, percutaneous in-situ fixation with one cannulated screw was also performed more safely and distally, from the metaphysis through the outer cortex of the femoral neck (and centered in the axial view). This situation made it necessary to pass screw threads through the outer cortex of the femoral neck to achieve fixation of the femoral head in the center of the femoral neck and head. We recommend keeping in mind this possibility when facing a valgus SCFE.

CONCLUSIONS

Idiopathic caput valgum is an infrequent morphological alteration of the femoral head which produces a mechanical predisposition to valgus displacement of the latter.

Diagnosis of SCFE requires a high degree of suspicion.

When in-situ fixation is attempted we recommend lateral osteosynthesis even, if necessary, through the outer cortex of the femoral neck. This approach helps to avoid a medial entry-point, thus preventing the risk of injuring the neurovascular structures.

REFERENCES

DIFFERENTIAL DIAGNOSIS IN PAINFUL ISCHIOPUBLIC SYNCHONDROSIS (IPS): A CASE REPORT

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ABSTRACT

Synchondroses are temporary joints that only exist during skeletal maturation. Bilateral widening of the ischiopubic synchondrosis (IPS) is a normal growth phenomenon, but when it is unilateral and painful it can become a diagnostic challenge. An eight-year-old child with an enlarged symptomatic unilateral synchondrosis is presented. Failure of conservative treatment and its pseudo-tumoral appearance led us to intervene surgically. Pathology revealed a stress fracture. Based on this clinical case, we made a revision of policy regarding pathology, diagnostic workup and treatment strategies for symptomatic synchondrosis.

INTRODUCTION

Development of the ischio-pubic region begins between the fifth and sixth months of intra-uterine life and it is almost fully formed at birth. It grows from two different ossification centers, the superomedial pubic center and the inferolateral ischial center. Between these two nuclei there is a strip of cartilaginous tissue extending from the pubis to the ischium, called the ischio-pubic synchondrosis (IPS).1,2

Synchondroses exist almost uniquely during skeletal maturation and work as temporary joints.3,4 The most studied one is the subdental synchondrosis of the axis because of the probable connection with a high incidence of Anderson and D’Alonzo type II fractures and development of pseudarthrosis.5,6,7,8 Ischio-pubic-synchondrosis is less studied but is also a source of difficulties whenever distinction from a pathological condition is needed.

The ossification of this synchondrosis begins early in childhood and is usually complete before puberty.5,10,11 During this process the IPS become thinner until its final obliteration upon bony union.1,2,12,13 IPS enlargement is a frequent radiological finding with no usual pathological significance. Actually, IPS enlargement is considered a normal phenomenon of growth and frequently shows an age correlation.10,13,14,15 In younger children it commonly occurs bilaterally, corresponding to a symmetrical beginning of fusion in both hemipelves. Later, before closure, unilateral enlargement is more frequent.15

In most cases, synchondrosis ossification is an asymptomatic process though in some children groin pain and restriction of hip mobility may be present. In this context, it is frequently found on pelvic radiographs as a unilateral enlarged and fusiform tumor-like image. The scenario for parental apprehension is set and most times, if symptoms don’t resolve, a differential diagnose should be considered including stress fracture, post traumatic osteolysis, osteomyelitis or neoplasia.3,4,10,15,16,17,18 Herneth et al.15 raised a possible correlation between unilateral enlargement of IPS in pre-pubertal children and foot dominance. This explanation would be that increased ground reaction forces were applied on the weight-bearing standing leg (usually the nondominant) compared to the swinging leg (usually the dominant). For these authors, increased mechanical stress probably prolongs the fusion of cartilage layers and delays ossification of the IPS.15,18 Hubner described asymmetric ossification of the IPS in patients with unilateral hip dislocation, hip arthritis, congenital coxa vara, Legg-Perthes disease, beginning at the healthy hemipelvis and occurring earlier than in normal children.15,18 These findings were considered by Herneth et al., some years later, as a supplementary basis for his theory.

CASE REPORT

An otherwise healthy eight-year-old male developed severe left groin pain after an extended walk. There was no history of significant trauma, recent respiratory illness or other infection. He couldn’t bear any weight on his left lower limb; pain was well localized in the groin, radiating to the knee through the anteromedial side of the thigh. The patient was unable to perform a straight-
leg raise on this side, hip adductor muscles were very tender to touch, and no signs of hip irritability were found. He had no systemic symptoms such as fever, and no superficial inflammatory signs around the hip or pelvis. He was seen in our clinic with four weeks of symptoms, and was already on oral medication (ibuprofen and paracetamol) for a possible transient hip synovitis.

The pelvic AP radiograph revealed a left unilateral enlargement of the IPS with a tumor-like appearance (Figure 1). Blood samples showed no abnormality, with normal leucocytes, C-reactive protein and sedimentation rate. Bone scan showed an intense uptake of radionuclide in the left IPS (Figure 2). CT scan (Figures 3A, 3B and 4) and MRI (Figures 5A and 5B) confirmed widening of the IPS and showed no involvement of the surrounding soft tissues.

At this stage, symptomatic treatment was reinforced, as IPS enlargement is usually a benign entity though the patient was still unable to bear any weight on the affected side. After six weeks of conservative treatment without any improvement of complaints, options were discussed with the parents and IPS curettage was decided upon to rule out any of the possible complications related to IPS delayed ossification. A direct approach was selected and white cartilage tissue was found macroscopically surrounding a cystic-type lesion which was removed with a
Differential Diagnosis in Painful Ischiopubic Synchondrosis (IPS)

curette (Figures 6A and 6B). There was no discharge or any abnormal soft tissue infiltration surrounding the IPS.

In the post-operative period, immediate and complete relief of previous symptoms was documented. Cultures were negative and histology revealed cartilage with focal enchondral ossification and fragments of woven bone, corresponding to the soft callus phase of fracture healing compatible with a stress fracture (Figures 7A and 7B). At six weeks the patient had regained full and painless

Figure 4. CT scan – 3D reconstruction.

Figures 5A, 5B. MRI scan (T1- and T2-weighted images) exhibiting hypo- and hyperintensity respectively without any soft tissue involvement.

Figures 6A, 6B. Intra-operative localization and curettage of IPS.
physical activity and at one-year follow-up, radiographs showed complete fusion of the IPS (Figure 8).

**DISCUSSION**

In 1924, Van Neck found several cases of enlargement of the IPS, and named this new supposed pathology “osteocondritis ischiopubica.” Later, because of its apparent benign and spontaneous evolution, other designation were used such as “osteocondrosis” or “osteochondropathia,” until the present designation of IPS came into use.\textsuperscript{10,15,16,18,20,22}

Asymmetrical enlargement of the IPS is a physiologic phenomenon related to asymmetrical mechanical stress of the adductors, iliopsoas and gemellus over each hemipelvis. This causes constant movement of the IPS, with an inflammatory reaction, and delayed union of the cartilage layers and ossification centers.\textsuperscript{3,4,15,23,24} Although this is an unusual finding, the orthopedic surgeon should always keep in mind that a pathological condition can be hidden under such non-specific complaints and images.

Histological studies of the enlarged IPS before fusion reveal cells with a strong enhancement for Hematoxylin and Eosin staining. This pattern is typical of joint or joint-like structures subjected to mechanical stress.\textsuperscript{15,22}

Signal alteration of the bone marrow on MRI was the most frequent finding in the IPS. This is usually hyperintense in T2-weighted sequences and hypointense in T1-weighted sequences. Herneth et al. described in 2/3 of his cases a hypointense band-like structure that is perpendicular to the pubic axis. This finding just before fusion was considered to be the first linkage which he named “fibrous bridging.” According to the authors, fibrous bridging seems to be the only specific radiologic finding of this structure.\textsuperscript{3,25,26} Other findings were fusiform swelling on T1-weighted sequences, and hyperintense signal alteration of the adjacent soft tissues on T2-weighted sequences as well as irregular margins.\textsuperscript{3,25,26} All three findings are suggestive of hyperemia and edema and can correspond to mechanical stress on these temporary joints.

Stress fractures are the most common pathological condition of IPS and can occur in relation to intense physical activities or in patients after radiation therapy.\textsuperscript{3,25,26} Usually this appears on MRI as a hypointense line perpendicular to the pubic axis, surrounded by bone-marrow edema and an irregular course instead of a smooth shape as in “fibrous bridging.”\textsuperscript{3,27}

Bone near IPS is histologically equivalent to bone found in the metaphyses with large venous channels where blood flow slows down, creating the ideal conditions for haematogeneous bacterial seeding.\textsuperscript{25,29} Peak incidence of osteomyelitis in this location is between the
ages of five and eight, which corresponds to the period when irregular ossifications are usually found.30 Differential diagnoses can be more difficult with a subacute or chronic osteomyelitis type such as Brodie abscess.31

Chondral tumors, enchondromas or chondrosarcomas, are rare in children younger than 10 years old, and their radiographic pattern differs from IPS. Though Ewing’s sarcoma is a small blue-cell tumor, it has a high incidence before 10 years of age and the pelvis is one of the most common locations, especially the ischiopubic region. The insidious development of complaints, the bony nonspecific lytic lesions and considerable involvement of the soft tissues on MRI differentiate these tumors from an enlarged IPS.

In any work-up for symptomatic IPS, an MRI should be considered after plain radiographs, with a sensitivity of 82% to 100%.29,32 CT-scan is usually helpful in showing loss of bone mass or the development of sequestrum or involucrum in osteomyelitis.3 The use of contrast can show the degree of vascularization, which is different in each pathologic condition of IPS.

Bone scintigraphy has been a very helpful tool in the differential diagnosis. The high bone turnover at this area explains the high intensity of the radionuclide uptake usually seen only in pathological conditions.35 Uptake is most intense during fusion without detection of activity before or after that.21 Various patterns and degrees of uptake are described, and they should always be compared to the triradiate cartilage as a reference. Greater values are considered abnormal, and further investigation should follow.21,29,35

In our patient all the workup pointed to a normal delayed IPS fusion. Although the CT scan showed gas in the middle of the IPS there were no other findings to recommend immediate surgery. We were forced to intervene based not only on the clinical persistence of severe symptoms for more than six weeks but also because of the parent’s anxiety about an absence of definitive diagnoses.

CONCLUSION

Enlarged IPS is a frequent finding that can assume a pseudotumoral pattern. Clinical symptoms at the time of normal closure can create a diagnostic challenge. Usually, enlargement without a history of trauma or positive laboratory findings do not need further workup.33 In cases of clinical doubt, MRI should be the first choice to rule out a pathologic condition. Conservative treatment is usually effective for stress fractures or infection, although in case of persistent complaints, surgical exploration may be necessary.33,34

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ABSTRACT

Background: In cases of suspected isolated greater trochanteric fracture, difficulty exists in establishing a definitive diagnosis when plain film is equivocal for fracture extension. There are reports of magnetic resonance imaging (MRI) being used to diagnose greater trochanter fractures, with varying treatment and follow-up, however validation of treatment based on MRI findings is lacking. To date, there is no consensus on the best way to manage isolated greater trochanteric fractures. Current treatment protocols are based on plain films. The purpose of this study is to offer a more effective means of treating patients with these fractures, and to stimulate further study of isolated greater trochanteric fractures based on MRI interpretation.

Methods: Patients from May 2001 to May 2003 with a clinical picture consistent with that of a hip fracture who had equivocal plain film evidence of an isolated greater trochanteric fracture received MRI scanning. Ten patients (five male and five female) ranging in age from 59-90 (mean age 79) showed a presumed isolated greater trochanteric fracture on MRI defined as a linear, vertical band of decreased signal (T1-weighted) extending from the greater trochanter that did not cross the midline. These patients were allowed immediate weight bearing as tolerated and followed for an average of 15 months. Patients were contacted by telephone during this period and any problems were noted. Problems were defined as any limitations (pain, inability to ambulate) due to the presumed hip fracture.

Results: All ten patients diagnosed with an isolated greater trochanteric fracture on MRI reported no limitations during the follow-up period.

Conclusions: The linear, vertical bands of decreased signal (T1-weighted) extending from the greater trochanter and not crossing the midline on MRI can be considered isolated greater trochanteric avulsions, and can be managed with immediate weight-bearing.

INTRODUCTION

The greater availability of MRI has had an increasing role in the diagnosis and treatment of hip fractures. It has been recommended that in cases of suspected occult hip fractures, MRI should be performed if plain radiographs are not diagnostic. It has also been indicated when plain film radiographs show a fracture of the greater trochanter, due to plain film’s inability to show the extent of the lesion, leading to questions about safe treatment. Since CT scans may be inaccurate and bone scans are less cost effective, a better understanding of MRI findings is indicated.

Fractures isolated to the greater trochanter region are rare. Recommended treatments for greater trochanteric fractures can include bedrest, taping, hip spica casting, and internal fixation. Recently, Omura employed only bed rest in a single patient, but no follow-up outcome was reported. Craig used unspecified non-operative treatment in three patients, also with no clinical outcomes reported. Feldman employed bed rest for patients, with clinical and radiographic healing at two months follow-up.

To date, however, there has been no definition of what constitutes an isolated greater trochanter fracture on MRI. Ingari found that a low signal on MRI (typically black in appearance) indicated an impaction of the trabecular bone. The literature has focused on MRI’s ability to detect previously overlooked fractures, but has neglected definitive lesion description. Although the consensus is that MRI can detect the presence of a lesion with great accuracy, there has been no definition of the appearance of suspected greater trochanteric fractures on MRI, and what differentiates them from intertrochanteric fractures.

Despite this lack of knowledge, work has been done...
using presumed criteria\textsuperscript{17} to make diagnoses of isolated greater trochanter fractures, and treatments have been recommended.

The primary hypothesis we tested is that a linear, vertical band of decreased signal (T1-weighted) extending from the greater trochanter without crossing the midline is consistent with an isolated greater trochanteric avulsion. Schultz states that intertrochanteric fractures that do not cross the midline on MRI may be treated conservatively.\textsuperscript{17} Therefore, we allowed immediate weight-bearing in our cohort of patients presumed to have isolated greater trochanteric fractures. Because there was no progression of fractures despite weight bearing, we can offer both a more effective treatment for presumed greater trochanter fractures and describe the appearance of a presumed isolated greater trochanter fracture as seen on MRI.

\section*{MATERIALS AND METHODS}

Patients from May 2001 to May 2003 who were admitted due to an initial diagnosis of hip fracture were scanned by MRI. Initial diagnoses were made by the following criteria: hip pain, difficulty with weight bearing and irritable passive range of motion of that joint. Study patients had plain films which were interpreted as showing a greater trochanteric fracture but which were equivocal for the degree of extension into the intertrochanteric region (Figure 1). Inclusion criteria for the study required a presumed isolated greater trochanter fracture on MRI. The fracture was defined as a linear, vertical band of decreased signal extending from the greater trochanter that did not cross the midline on MRI. There were five males and five females who met the inclusion criteria, with a mean age of 79 (range, 53-90). MRIs were taken using a GE 1.5 Tesla Signa scanner running on 5.4.2 software. Coronal T1 images were taken with a slice thickness of 4mm, and an inter-slice gap of 1mm. Repetition time was 633 and echo time was 14.

All patients showing a presumed isolated greater trochanteric fracture were then permitted immediate weight bearing as tolerated, often with the assistance of a walker. Patients were followed for an average of 15 months (range, 6-31 months). Patients were contacted by telephone during this period and any problems were noted. Problems were defined as any limitations (pain, inability to ambulate) due to the hip fracture.

\section*{RESULTS}

Examples of presumed greater trochanteric fractures which met our inclusion criteria are depicted in Figure 2. All ten patients diagnosed with a presumed isolated greater trochanteric fracture reported no limitations.
during the follow-up period. One patient passed away during this period, but reported no problems with the hip prior to death.

**DISCUSSION**

Suspected hip fractures in the Emergency Department can be challenging. In our study, patients complained of hip pain and had difficulty weight bearing, but had equivocal plain films for a diagnosis of an isolated greater trochanteric fracture. Hip fractures are now being diagnosed by MRI even when they are not demonstrated by plain films,1,2,3,4 bone scans1,2 or CT.2 MRI also more accurately defines the true extent of the injury.8,9,10 With the ever-increasing availability of MRI it is widely believed that isolated greater trochanter fractures (a linear vertical band of decreased signal extending from the greater trochanter and not crossing the midline) will be better identified.

We used Ingari’s work in defining the appearance of hip fractures on MRI to make a presumed diagnosis of isolated greater trochanter fractures in our patients.16 Shultz reported that conservative treatment for incomplete intertrochanteric fractures, based on abnormal signal on MRI, yielded good outcomes with no reported complications. Therefore, we treated our patients who had a presumed diagnosis of isolated greater trochanter fractures with immediate weight-bearing.

Our study suffers from a small patient population which makes definitive assertions difficult. In addition, our conclusion is based solely on clinical data, as our goal of better treatment preclude surgical and pathological confirmation of the fracture. This problem means that we cannot make any conclusions about a link between the abnormal MRI signal and a pathologic diagnosis of greater trochanter fracture.

We allowed immediate weight bearing also because it possibly shorted hospitalization and decreased morbidity/mortality.21 Our results indicate that the linear, vertical bands of decreased signal (T1-weighted) extending from the greater trochanter on MRI suggest an isolated greater trochanteric avulsion rather than an intertrochanteric fracture and that these fractures can be managed conservatively.

**REFERENCES**


MECHANICAL FAILURE OF THE LONG GAMMA NAIL IN TWO PROXIMAL FEMUR FRACTURES

Soheil Najibi, M.D., Ph.D.,* Mark Lemos, M.D.,** David Fehnel, M.D.†

ABSTRACT
Mechanical failure of the long gamma nail was encountered in two elderly patients with proximal femur fractures over a 6-month period. One of the patients had a known history of lymphoma. The other patient had a history of rheumatoid arthritis but no history of cancer or other metabolic bone disease. Both nails failed at the junction of the compression screw and the nail. The angle of failure of the nail was the same in both cases. The index of suspicion for imminent mechanical failure of the gamma nail should be higher in pathologic fractures and fractures which are malreduced during nailing.

INTRODUCTION
With an increase in the life span of the general population, a significant rise in the number of fractures of the proximal femur has occurred. The gamma nail has been used in treatment of traumatic and pathologic peritrochanteric femur fractures throughout the world since its development in 1985. Prior to this report, ten cases of mechanical failure of the gamma nail in nine patients have been reported in the English literature. We present two cases of mechanical failure of the long gamma nail.

CASE SUMMARY
Case 1
78-year-old female with diagnosis of non-Hodgkin’s lymphoma with involvement of the liver, spleen, retroperitoneum, and left proximal femur, sustained a pathologic subtrochanteric fracture of the left femur. She underwent fixation with a long gamma nail by another surgeon at a different institution than the author (Figures 1A, B). The reduction of the fracture intra-operatively was noted to be difficult secondary to severe comminution. A 135-degree, 340 mm nail and a 95 mm lag screw were used. The nail was locked distally with two distal locking screws and the set screw and cap screw were

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Figures 1A, B. 78 year old female treated for pathologic left subtrochanteric femur fracture with a long gamma nail.
used in the proximal portion of the nail. The estimated blood loss was 1300 milliliters. The patient received four units of PRBC’s intraoperatively. The patient’s weight bearing status was increased gradually over the next several weeks to as tolerated. Thirteen months after implantation of the long gamma nail, the patient had severe left hip pain and was unable to ambulate. Radiographs obtained showed mechanical failure of the gamma nail (Figures 2A, B). Revision open reduction and internal fixation with a 95 degree blade plate was performed (Figure 3). Twelve months after revision ORIF, 25 months after the index procedure, the patient is weight bearing as tolerated with a cane and the fracture shows radiographic signs of healing.

Case 2

76-year-old female with a history of severe end stage rheumatoid arthritis, sustained a subtrochanteric fracture of the left femur as a result of a fall. She underwent fixation of the fracture with a long gamma nail by another surgeon at a different institution than the author (Figures 4A, B). A 130-degree, 340 mm nail and a 95
mm lag screw were used. The nail was locked distally with a single distal locking screw in the more proximal locking hole with a 6.26 x 30 mm screw. The set screw was placed in and tightened to lock the lag screw within the nail. The estimated blood loss was 500 milliliters. No blood products were transfused intraoperatively.

The patient’s weight bearing status was increased slowly from non-weight bearing to weight bearing as tolerated over the following 4 months. She was able to ambulate with a walker without pain until 10 months from the index procedure. The patient reported increasing pain in the left thigh and hip over a five-day period without a preceding traumatic event or fall. Ten months post operatively, she was unable to bear weight. Radiographs of the left hip showed mechanical failure of the Gamma nail (Figure 5). Revision open reduction and internal fixation with a dynamic compression screw and autologous bone grafting was performed. Her weight bearing status was increased gradually to as tolerated. Four months from the revision ORIF, fourteen months from the index surgery, the patient was again unable to bear weight and had increasing pain in the left hip. Radiographs of the left hip revealed mechanical failure of the DCS plate (Figure 6). The patient underwent revision of ORIF with a DCS and anterior plate, and bone graft fourteen months from the index surgery (Figure 7). On follow up, five and half months from revision ORIF, nineteen and half months from the index surgery, the weight bearing was advanced to as tolerated and radiographic exam revealed healing at the fracture site.
The gamma nail combines the sliding feature of a hip screw with the load sharing properties of an intramedullary nail. This combination allows for 25 to 30% reduction in the bending stress on the nail as compared to extramedullary devices.6,7 This would theoretically reduce the implant failure rate for the gamma nail as compared with the extramedullary devices, and indeed the very low rate of mechanical failure of gamma nail attests to this.

Figure 8 shows the two long gamma nails which were removed. The angle, obliquity and location of the mechanical failure in both nails is identical.

**DISCUSSION**

The gamma nail and other third generation cephalomedullary nails are used in treatment of unstable
proximal femur fractures, including subtrochanteric and reverse oblique intertrochanteric femur fractures. These cephalomedullary nails allow load sharing by the medial and lateral cortex, and decreases the moment arm at the sliding screw. As with any implant these nails have complications, and once implanted, is subject to the same race between fracture union and implant failure. Including the two cases in this report, we were able to find 10 other cases of gamma nail mechanical failure in the English literature. This attests to the high rate of success with this implant in achieving union in peritrochanteric fractures. The first case of gamma nail mechanical failure was reported by Zafiropoulos et al. 2. This nail was a short gamma nail, which had distracted the fracture site. The cortices were not in contact and hence were not load sharing. This nail fractured at the lag screw-nail interface where the nail is 73% thinner. However, after revision of the fractured nail and compression of the fracture site, the second nail eventually failed at the same location as the first nail.

Including the two cases presented in this report, there are a total of 12 gamma nail failures in eleven patients in the English literature (Table 1). Of these, eight are short and four are long gamma nails. Five patients out of eleven had metastatic disease; one had metabolic bone disease. Four patients (five nails) had no documented metastatic or metabolic bone disease. Of these five nails, four had distraction at the fracture site. The mean time to failure for the long and short gamma nails was 9.5 ± 3.4 months (n=11). The mean time to failure for the long gamma nail was 9.8 ± 2.5 months (n=4), and for the short gamma nail was 9.4 ± 4.1 months (n=7). Eleven of the twelve nails failed at the hip screw-nail junction. The symptoms were increasing pain with weight bearing in the effected hip four to five days prior to inability to ambulate.

Metabolic bone disease, metastatic disease, and malreduction of the fracture with distraction of the fracture site are risk factors for non-union and eventual failure of the implant. Presence of any of these factors should alert the surgeon to possibility of implant failure. Our review of the literature shows that 10 of 12 failures occurred at or after 6 months subsequent to implantation of the gamma nail. None of the four long gamma nails

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<th>Author</th>
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<th>Fracture</th>
<th>Nail</th>
<th>Failure time</th>
<th>Failure location</th>
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* The fracture was distracted, i.e., no cortical contact after nailing, which led to eventual mechanical failure of the nail.
failed before six months. The average time to failure for
the long gamma nail was $9.8 \pm 2.5$ months. Follow up
with radiographic and physical examination in the first
six months in the post operative period is necessary to
evaluate the process of fracture healing in peritrochan-
teric fractures treated with the gamma nail. Hence, if
there is little or no radiographic evidence of healing at
the fracture site six months postoperatively, the surgeon
may consider changing the weight bearing status to
non-weight bearing and plan for exchange nailing of the
gamma nail to avoid fatigue failure of the nail.

In our hands, a third generation cephalomedulary nail
is the implant of choice in treatment of unstable proximal
femur fractures and impending pathologic fractures as a
result of metastatic disease afflicting the proximal femur.
Van den Brink et al reported a 0.16% mechanical failure
rate of the gamma nail. This rate of mechanical failure
of the gamma nail is lower than that of extramedulary
devices. However rare, mechanical failure is a possible
complication of the gamma nail especially in pathologic
or impending fractures and distracted or malreduced
fractures. It is incumbent upon the surgeon to have a
high index of suspicion to evaluate the patient and
recognize this complication.

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Fat embolus has been known to occur during major orthopedic surgery. In many cases, fat embolus syndrome is a postoperative complication of long bone orthopedic surgery, particularly femoral fractures occurring after trauma. Changes in intraoperative cardiopulmonary function have been reported in a subset of these patients, and they are associated with the degree of embolization occurring with manipulation or cementing of prostheses in the fractured femur. Intraoperative cardiovascular collapse has been reported, and this cardiac event is temporally associated with intramedullary manipulations such as reaming or cementing. We present a rare case of fatal intraoperative fat embolization diagnosed with transesophageal echocardiography.

**INTRODUCTION**

Fat embolism syndrome (FES) may occur during long bone orthopedic surgery, particularly femoral fracture surgery. Reported changes in intraoperative cardiopulmonary function are associated with the extent of embolization after fracture manipulation or cementation of proximal femoral prosthetic devices. Complete intraoperative cardiovascular collapse has been reported during intramedullary reaming or cementing. We report a case of fatal intraoperative fat embolization that was diagnosed with transesophageal echocardiography.

**REPORT OF A CASE**

An 83-year-old woman with a subcapital hip fracture underwent arthroplasty with placement of a cemented, bipolar hip prosthesis. The patient’s cardiac history included coronary bypass surgery with valve replacement and placement of an automatic internal cardiac defibrillator. The patient had a history of asthma, although she had not had any recent exacerbations. She also had a history of dementia. She did not receive treatment with anticoagulation medication or anti–platelet aggregation medication. The preoperative platelet count was 280 x 10^9/L, the prothrombin time was 15.2 seconds, and the international normalized ratio was 1.2.

After anesthetic options were reviewed with the patient, a spinal anesthetic with moderate sedation was planned for the surgical procedure. Standard monitoring procedure, including electrocardiography, pulse oximetry, and noninvasive blood pressure monitoring, was applied. Adequate sedation and analgesia (propofol, 30 mg; fentanyl, 50 mcg) were administered intravenously with supplemental oxygen (4 L/min via nasal cannulae).

A hyperbaric spinal anesthetic was administered through a 25 gauge whiticare needle with 15 mg of marcaine. After adequate spinal anesthesia was established, the patient was placed in the right, lateral, decubitus position. The patient was sedated with propofol and the incision was made without incident. The patient remained comfortable and communicative during removal of the fractured left femoral head. Blood pressure, oxygenation, and cardiac function monitoring showed that all vital signs were in the normal range.

The intramedullary femoral canal was reamed to prepare it for cementing of the bipolar hip prosthesis. Approximately three minutes after the reaming was complete, the patient had bradycardia (heart rate, 27 beats/min) and gradually worsening peripheral oxygen saturation levels. The patient quickly became unresponsive, and her peripheral blood pressure, measured tonometrically from the right humeral region, decreased to 80/37 mm Hg.

The patient was ventilated immediately by mask with positive pressure. Subsequently, intubation was necessary and was accomplished without incident. End-tidal carbon dioxide pressure was undetectable with mask assisted ventilation, but measured between 6 and 8 torr in the first minute after intubation. Equal bilateral breath sounds also were present after intubation. Volume-controlled ventilation with 100% oxygen was established. The heart rate remained slower than 30 beats/min, therefore atropine (0.4 mg) and epinephrine (1 mg) were injected intravenously. No heart rate response...
was noted immediately after atropine and epinephrine injections. More epinephrine (1 mg) was administered through the tracheal tube with no effect. Chest compression was initiated after the carotid pulse could not be palpated. Carotid and femoral pulses were present during chest compressions. Central venous access was established through the right subclavian vein, and additional epinephrine (1 mg), atropine (1 mg), calcium chloride (1 g), and sodium bicarbonate (50 mEq) were administered intravenously, approximately ten minutes after the initial bradyarrhythmic event.

With the patient’s complex cardiac history and the temporal relation between the intramedullary reaming and the apparent cardiac event, a transesophageal echocardiographic probe was placed to establish the cause of the patient’s sudden cardiovascular collapse. Upon insertion of the probe, a large mass was noted in the right atrium (Figure 1). Further examination showed that the mass was mobile and effectively obliterated the tricuspid valve inlet. No right ventricular cavity could be visualized.

The patient had a bioprosthetic mitral valve, which was stable and appeared normal (without vegetations); it opened occasionally with cardiac compressions. The left ventricle did not appear dilated or distended, but biventricular global cardiac dysfunction was evident. Further transesophageal echocardiographic examination of the right atrium in the bicaval view showed a poorly differentiated, well demarcated, untethered mass that extended from the inferior vena cava into the right atrium (Figure 2). The mass was mobile and oscillated with external cardiac compressions. Further views of the mass in the right atrium showed that it was echodense in some areas and echolucent in others.

With no forward flow evident in the right ventricle, the absence of ventricular contractility on echocardiography, and the large thrombus in the heart (Figure 3), external chest compressions were discontinued. The patient died. Postmortem examination was deferred by the patient’s family.
This case describes the complication of a fatal, intraoperative embolus that developed during hip arthroplasty. Images taken following femoral intramedullary manipulation show a large embolus obstruction of the right atrium and bicuspid valve traversing the inferior vena cava at the right atrial junction. Transesophageal echocardiography can be used to detect propagation of large emboli during femoral fracture surgery. In this case, it was used to establish an early diagnosis by imaging a massive embolus obliterating the tricuspid valve inflow and extending beyond the right atrium into the inferior vena cava, which had not responded to standard resuscitative measures.

Previous reports have described fatal cardiopulmonary events associated with intramedullary reaming, long bone fracture manipulation, or cementing during hip arthroplasty. In these reports, hypotension and hypoxemia or the absence of end-tidal carbon dioxide pressure indicated minimal or absent pulmonary flow. A large retrospective series reported a mortality rate of 0.05% that was associated with primary hip arthroplasty; patient deaths presumably were due to fulminant fat embolism syndrome. However, these reports relied on postmortem examinations to confirm the fat embolization.

Transesophageal echocardiography, performed during femur or tibia surgery, has shown showering of small emboli to the right atrium and right ventricle. Gradations of embolic severity were associated with severity of symptoms, and longer or larger showers of emboli were associated with greater deterioration of pulmonary function. Extremely large emboli, up to 8 cm in length, were noted in some patients. The authors suggested that these larger emboli were caused by venous hypercoagulability during major marrow embolization. Measurement of our patient’s echocardiographic image showed that the embolus was 7 cm in length.

The embolus that we observed in our patient prevented right ventricular filling. It extended several centimeters into the inferior vena cava and was a single mass (not a coalescence of smaller emboli). The size of the embolus was suggestive of a venous thrombus. However, the mass had a smooth capsule, particularly in the right atrial portion, and was echogenically heterogeneous, which suggested that bone marrow, rather than thrombus, was the source of the embolus. Highly echodense areas, which may represent large bone marrow emboli, were noted within the capsule of the right atrial embolic mass; this strongly suggested that the embolus was made primarily of bone marrow fat.

Intravasation of bone marrow into the venous circulation may occur as a result of increased intramedullary pressure. With severe osteoporosis, as observed in this patient, loss of trabecular bone may result in the increased venous migration of marrow because medullary fat lacks bony support. The piston effect of reaming and cementing of the femur may result in intramedullary pressures as high as 800 mm Hg in the distal femur (normal intramedullary pressures range from 30-50 mm Hg). This high intramedullary pressure is the probable main cause of fatty marrow release into the venous circulation, resulting in pulmonary emboli.

**DISCUSSION**

We report the use of transesophageal echocardiography to detect propagation of a large embolus during prosthetic hip fracture surgery. In this case, the outcome was fatal. The immediate availability of personnel trained in transesophageal echocardiography allowed us to document the embolus that blocked blood flow into the right side of the heart, resulting in cardiovascular collapse and death. These compelling images that capture an end of life event are rarely seen.
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