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THE IOWA ORTHOPAEDIC JOURNAL

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INSTRUCTIONS FOR AUTHORS, 2007

<http://www.uihealthcare.com/depts/med/orthopaedicsurgery/research/ioj.html>

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 2007 edition is Friday, January 12, 2007.

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

When submitting an article, it is essential to include 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 for accepted articles will not be returned.

2. **References**, presented in the text by superscript numbers. The **bibliography** should list references in the order of their appearance in the text, and be double-spaced.

3. **Legends** for all illustrations, listed in order of appearance and double-spaced.

4. **Illustrations/Images:**

- a. One set of 5 x 7-inch, black-and-white, glossy prints of all photographs.
- b. Original drawings or charts.
- c. Color illustrations may not be used unless it is the opinion of the journal that they convey information not available in black and white.
- d. Each image should be sent to diana-johannes@uiowa.edu as an individual .tif or .jpg file. If images are embedded in the

manuscript, individual image files should still be sent. 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.

5. **Electronic copies of all items above**, sent 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.

Preparation of photographs/illustrations: On the back of each photo and illustration, write the figure number, author's name and indicate the *top*. Send prints unmounted - paste or glue will damage them. Drawings, charts and lettering on prints should be done in black with white backgrounds. Put dates or initials in the legends, not on prints. Make lettering large enough to be read when drawings are reduced in size. When submitting an illustration that has appeared elsewhere, give full information about previous publication and credit to be given, and state whether or not permission to reproduce it has been obtained.

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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 and Rehabilitation, 200 Hawkins Drive - 01006 J.P.P., Iowa City, Iowa, 52242-1088 or by emailing diana-johannes@uiowa.edu.

EDITORS' NOTE

We are pleased and honored to present the 2006 edition of the *Iowa Orthopaedic Journal*. This edition represents not only our work but also the contributions of several members of the University of Iowa faculty, support staff, and residents. We were greatly inspired by the accomplishments of previous editors and hope this edition lives up to the high standard that they have set.

This 2006 edition showcases articles not only from the University of Iowa, but also from several of our previous guest lecturers. For example, both of last year's senior resident's day speakers, Drs. Coughlin and Miclau, were generous enough to offer their submissions. In addition, we were pleased to receive articles from our respective medical school alma maters: New York University and Washington University. The broad range of submissions has greatly enhanced the quality of this journal.

We would also like to recognize the departing senior residents. This class has weathered some large national changes in resident education in general and our program in particular. They are largely responsible for bringing our program into compliance with work hours guidelines. Drs. Hermanson, Huang, Clifford, Mollano, and Frisella are diligent physicians, enthusiastic leaders, and, most importantly, great friends. They will be missed.

This edition is dedicated to a fine surgeon and role model here in our orthopaedic department, Dr. Curt Steyers. He is not only admired among the residents for his superb technical skill, but also ranks as one of the most fun with which to work. His efficiency, knowledge base, and compassion are the standards to which we all aspire. It has been our great privilege to learn from him.

Finally, we would like to thank the faculty advisors to this journal: Drs. Jose Morcuende and Joseph Buckwalter. Their guidance and experience have made this edition possible. We would also like to thank our corporate sponsors for their ongoing support and generosity. In addition, Dr. Kirk Clifford deserves special mention for volunteering to stay on the editorial board as business manager despite an already hectic fifth-year schedule. Also, several of our faculty and residents served as reviewers for articles, and our computer department worked diligently to make our copy as clear as possible. Finally, we would like to thank Diana Johannes, a master proofreader, graphic artist, and organizer of all things from the important to the menial. Her ability to make



this journal happen each year, while still performing all her other numerous duties, continues to astound and amaze generations of *IOJ* editors.

It has been our great pleasure to edit this year's *Iowa Orthopaedic Journal*. It is the culmination of many hours of work by a diverse and talented group of people. We hope you enjoy it.

Mohana Amirtharajah, M.D.
Christina Ward, M.D.

IOWA ORTHOPAEDIC JOURNAL EDITORS EMERITI

1981

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Christopher Sliva, M.D.

2004

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Michael Sander

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Anthony V. Mollano, M.D.

2006

Mohana Amirtharajah, M.D.
Christina M. Ward, M.D.

DR. CURTIS M. STEYERS 2006 IOWA ORTHOPAEDIC JOURNAL DEDICATION



The publication of the 2006 edition of the *Iowa Orthopaedic Journal* gives us the opportunity to dedicate the journal to an individual who has made Iowa orthopaedics and the specialty of orthopaedics better. No individual is more deserving of this honor and recognition than Curtis Steyers.

Dr. Steyers received his medical and orthopaedic residency education at Temple University in Philadelphia. He completed a fellowship in hand and microsurgery at the University of Louisville, Kentucky, in 1981 and then moved to Reading, Pennsylvania, where he joined a friend in practice. In 1985, it was the great good fortune of the University of Iowa Department of Orthopaedics and Rehabilitation that Dr. Steyers joined the faculty at Iowa. He rapidly earned the respect and admiration of his colleagues and was promoted to associate professor in 1989 and full professor in 1994.

Referring surgeons quickly learned to appreciate his exceptional clinical skills. The respect he has earned is documented by his national recognition for clinical excellence by the *Best Doctors in America*, a process that involves peer review and critical evaluations of care and treatment of patients. Perhaps more important, he exemplifies the highest standards of professionalism and ethics as well as compassion and thoughtful clinical care.

He is not only a superb surgeon who has served his patients well, he has made every resident that has passed through the program for more than 20 years a better surgeon. When residents want to learn how to operate and, in particular, how to perform surgery while respecting tissues and tissue planes, they watch Dr. Steyers. He enjoys teaching the “dynamic and ever-changing” field of human anatomy and never tires of helping students, residents, faculty, and referring physicians understand challenging and complex hand and upper extremity

problems. Many former residents continue to rely on him as a resource.

In addition to his commitment to resident education at Iowa, Dr. Steyers has made important contributions to orthopaedic education throughout the United States. He was instrumental in the development of the self-assessment exam for hand surgery, multiple other educational and examination materials for the American Academy of Orthopaedic Surgeons, and led the academy’s committee on evaluation from 1990 until 1993.

Dr. Steyers has a strong interest in critically questioning currently accepted clinical concepts and advancing understanding of disorders of the hand and upper extremity. Over the last several years, he has worked with Dr. Tom Brown to develop studies of the biomechanics of the carpal tunnel. This work was the basis of a poster at the 2006 Orthopaedic Research Society and a recently submitted National Institutes of Health grant.

Some of the newer members of the Iowa orthopaedic family will be surprised to learn that Dr. Steyers had a distinguished role in the Iowa Sports Medicine Program. For a decade he served as the team physician for the University of Iowa Wrestling Team. During that time, the wrestling team consistently won the Big Ten Championship and National Championship; a dual meet loss to anyone or second place finish in the Big Ten or National tournament was not acceptable during Dr. Steyers’ tenure. Although Dr. Steyers has retired from his position as the wrestling team physician, he continues to give Dr. McKinley much-needed advice.

Dr. Steyers is also an athlete. He ran his first marathon three years ago and finished in less than four hours. He plans to run his fourth marathon with his daughter Jessica this spring. His performance in the 2005 Ortho Challenge team triathlon was worthy of an ABC “thrill of victory” highlight. After the swim and bike legs of the triathlon, his teammates handed Dr. Steyers the timing chip, being well behind a prominent local runner from a much younger team. Dr. Steyers gave his team a stunning come-from-behind victory, running sub-eight-minute miles on a very challenging 10 kilometer course. His team members, Dr. Ward and Dr. Buckwalter, will rely on him again on June 4, 2006, at the Pigman Triathlon.

Curt and Nancy Steyers have two children, Jessica and Curt III. Jessica completed her undergraduate studies at the University of Michigan before moving to New York University to earn a degree in journalism. She lives in New York City and works for ABC’s news division. Curt III is attending Brown University, but he

has worked in the Orthopaedic Department laboratories and made important contributions to research projects including Dr. Amirtharajah's investigations of the effects of telomerase inhibitors on chondrosarcoma cells. This work has been recognized by awards from the Ruth Jackson Society and the Orthopaedic Research and Education Foundation and has been presented at the Orthopaedic Research Society.

We are pleased to dedicate volume 26 of the *Iowa Orthopaedic Journal* to an outstanding athlete, clinician, teacher, and ethical and professional role model, who, by his teaching and example, has made generations of residents and faculty better orthopaedists and better people.

2006-2007 DEPARTMENT OF ORTHOPAEDICS AND REHABILITATION SCHEDULE OF LECTURESHIPS AND CONFERENCES

(Larson Conference Room, 01090 JPP)

Iowa Orthopaedic Alumni Meeting

October 27-29, 2005
Ken Yamaguchi, M.D.
Washington University
St. Louis, Missouri

Jo Hanafin, M.D.
2nd Ruth Jackson Memorial Lecturer
Hospital for Special Surgery
New York, New York

2006 meeting yet to be determined*

21st Annual Hawkeye Sports Medicine Symposium

December 2-3, 2005
Scott F. Dye, M.D.
Associate Clinical Professor of Orthopaedic Surgery
University of California
San Francisco, California

Tim Hewett, Ph.D.
Director, Sports Medicine Research
Cincinnati Children's Hospital
Cincinnati, Ohio

2006 symposium yet to be determined*

Carroll B. Larson Shrine Memorial Lecture

May 12-13, 2006

Dr. John Dormans
Chief, Division of Orthopaedic Surgery
Children's Hospital of Philadelphia
Professor of Orthopaedic Surgery, University
Pennsylvania School of Medicine

2006 Senior Residents and Fellows Day

June 2-3, 2006
Thomas DeCoster, M.D., Vice Chair
Department of Orthopaedics and Rehabilitation
Chief, Division of Trauma
University of New Mexico
Albuquerque, New Mexico

Thomas Einhorn, M.D., Chairman
Department of Orthopaedic Surgery
Professor, Orthopaedic Surgery, Biochemistry and
Biomedical Engineering
Boston University
Boston, Massachusetts

Eighth Biennial Johnston Lectureship in Hip Reconstruction

October 2006

Reginald R. Cooper Orthopaedic Leadership Lectures

April 2007

*Please check with us at a later time for exact dates, times and speakers.

Department of Orthopaedics

	John E. Femino 2006-present	Arthur Steindler 1912-1949	
	Joseph D. Smucker 2005-present	Theodore Willis 1917-1918	
	Jin-soo Suh 2004-2005	Joseph Milgram 1926-1932	
	Brian Wolf 2003-present	Ernest Freund 1932-1936	
	Michael O'Rourke 2003-present	Thomas Waring 1932-1939	
	Sergio Mendoza 2003-present	James Vernon Luck 1936-1939	
	Jose Morcuende 2001-present	Ignacio Ponseti 1946-present	
Annunziato Amendola 2001-present		Eberly Thornton 1946-1952	
Joseph Chen 2000-present		Robert Newman 1948-1956	
Todd McKinley 1999-present		Michael Bonfiglio 1950-1995	
R. Kumar Kadiyala 1998-2004		Carroll Larson 1950-1978	
Leon Grobler 1996-1999		Adrian Flatt 1956-1979	
Brian Adams 1993-present		Reginald Cooper 1962-present	
Charles Saltzman 1991-2005		Howard Hogshead 1964-1965	
John Callaghan 1990-present		Maurice Schnell 1964-1965	
David Tearse 1989-2000		Richard Johnston 1967-1970, 1998-present	
Ernest Found 1987-present		Donald Kettelkamp 1968-1971	
Lawrence Marsh 1987-present		Gerald Laros 1968-1971	
Curtis Steyers 1985-present		Richard Stauffer 1970-1972	
James Nepola 1984-present		John Albright 1971-present	
Fred Dietz 1984-present		Doug Mains 1972-1973	
James Weinstein 1983-1996		Bruce Sprague 1972-1979	
Barbara Campbell 1982-1984		Richard Brand 1974-2002	
Charles Clark 1980-present		Mike Mickelson 1976-1981	
William Blair 1980-1997		Stuart Weinstein 1976-present	
William Pontarelli 1980-1984; 1999-2004		Thomas Lehmann 1978-1987	
Joseph Buckwalter 1979-present			



The University of Iowa
Roy J. and Lucille A. Carver College of Medicine

**DEPARTMENT OF ORTHOPAEDICS AND REHABILITATION
STAFF, FELLOWS, AND RESIDENTS 2005-2006**



Row 1: John Callaghan, James Nepola, Reginald Cooper, John Albright, Joseph A. Buckwalter, Teresa Mosqueda, Kirk Clifford, Anthony Mollano.

Row 2: J. Lawrence Marsh, Neil Segal, Michael Daines, Todd McKinley, John Femino, Michael Chang, Matt Karam.

Row 3: Joseph Smucker, Michael O'Rourke, Matthew Lavery, Matthew Dewall, Sergio Mendoza, Kevin Jones, Todd Fairchild, Cory Christiansen.

Row 4: Brian Wolf, Ned Amendola, Jonathan Donigan, Christopher VanHofwegen, Evan Hermanson, Richard Johnston.

2006 GRADUATING ORTHOPAEDIC RESIDENTS



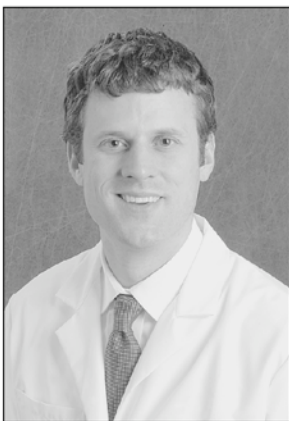
Kirk Clifford, M.D.

Kirk Clifford was born in Loveland, Colorado, and raised in Idaho. He received his bachelor of science in zoology from Idaho State University. More importantly, at ISU he met his future wife, Tarra. They were married in 1994. They then traveled to Connecticut where Kirk attended Yale University School of Medicine. They now have three wonderful

boys and are expecting their first girl prior to Kirk's graduation.

Next year they will be off to Utah where Kirk will complete a combined Orthopedic and Neurosurgical Spine Fellowship. After the fellowship year, they hope to settle in the intermountain west where skiing, biking, hiking and family are near.

Kirk and Tarra are very grateful for the wonderful classmates and residents with whom they have worked so closely. They feel it has been a privilege to receive training under some of the most well-respected faculty in the world.



W. Anthony Frisella, M.D.

Anthony was born in St. Louis, the oldest of six siblings and one of 45 grandchildren (the Frisella Family or just "the Family"). He attended Harvard University in Cambridge, Massachusetts, and earned his B.A. *magna cum laude* in biology. After college, he spent a year living in Boston and then attended medical school at

Washington University in St. Louis, where he earned his M.D. and master's degrees. Anthony considers himself a mid-westerner and that influenced his decision to come to Iowa City. Outside of medicine he enjoys flying (which he has been doing since college), reading, movies, and travel.

In August he will move to New York to spend a year with Drs. Fran Cuomo and Peter McCann as a shoulder and elbow fellow.

Anthony appreciates the opportunity to continue his education at the University of Iowa and would like to thank the faculty for their teaching and patience, and the nurses and support staff for their hard work and good nature. They made his time here more productive and pleasant.



Evan Hermanson, M.D.

Evan was born in Pierre, South Dakota, where he lived until high school. He then moved to and graduated from high school in Sioux Falls, South Dakota. It was here that he met his wife, Kristi. They attended the University of Nebraska in Lincoln and the University of Nebraska Medical Center in Omaha together.

He credits her diligent note-taking for much of his success throughout both.

Upon completion of his residency, Evan will begin a one-year fellowship at the Southern California Orthopaedic Institute in Van Nuys, California. He then plans on returning to Sioux Falls to practice.

The personal statement for Evan's orthopaedic surgery residency application briefly discussed one of his life's guiding principles: "regret minimization." He imagined being an old man reflecting back on life, not wanting to have any regrets on choices made or chances taken. He approached residency with this same mentality. Looking back now, he realizes he has failed miserably. (Just kidding.) He states this has been an amazing life experience and educational journey, and something he will certainly never regret.

2006 GRADUATING ORTHOPAEDIC RESIDENTS

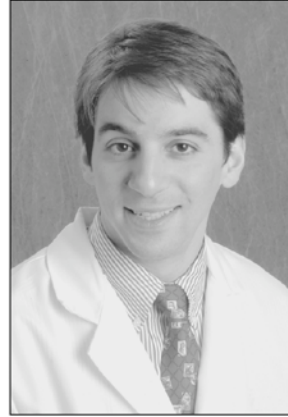


Michael Huang, M.D.

Mike Huang was born in Atlanta, but lived most of his life in Colorado. He received his undergraduate degree from the University of Pennsylvania. Thereafter, he attended the Washington University School of Medicine. Mike has known his wife, Lora, since high school and they now share a wonderful child—Emma.

Upon completion of residency, Mike will begin a one-year fellowship at the Steadman Hawkins Clinic in sports medicine.

He thanks all the faculty for the privilege of training at the University of Iowa, and thanks all his fellow residents for their teamwork, teaching, and above all, their camaraderie and friendship. Most importantly, he would like to thank his wife, Lora, for her unending support through this experience.



Anthony Mollano, M.D.

Anthony was born and raised in New York City. He graduated from Columbia University with a B.A. in biochemistry in 1996, and from the University of Rochester with an M.D. with Special Distinction in Research in 2001, having spent one year doing research in their orthopaedic molecular biology laboratory.

Anthony has thoroughly enjoyed the outstanding orthopaedic clinical, surgical, and research training at the University of Iowa, including work in the Ponseti laboratory. His family, including his wife, Kara, and children, Theodore and Conrad, appreciate all the professional and social support from friends and colleagues in the Orthopaedics Department.

Next year, he will train further at the Hospital for Special Surgery as a hand and upper extremity fellow.

2006 GRADUATING FELLOWS



Paul Connolly, M.D.

Paul Connolly is from Ireland. He studied medicine in Trinity College, Dublin, and did his orthopaedic residency in Dublin. He is currently a fellow in Pediatric Orthopaedic Surgery here at the University of Iowa Hospitals and Clinics. He and his family (Ita and James) moved to Iowa from Dallas, where he also did a fellowship in Pediatric

Orthopaedic Surgery and Pediatric Upper Limb Surgery. They have really enjoyed living in Iowa City and have made some lifelong friends while here. There is an open invitation for people to come visit Ireland.

After fellowship training Paul intends to return to Ireland and specialize in Pediatric Orthopaedics in Dublin.

Jeffrey Todd Junko, M.D.

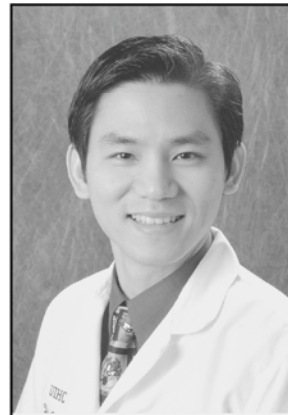
Jeffrey Todd Junko is from Akron, Ohio. He studied orthopaedic surgery at Summa Health System in Akron. He completed a six-month fellowship at the University of Iowa Hospitals and Clinics in foot and ankle surgery and will complete the next six months of his foot and ankle fellowship at the Hospital for Special Orthopaedic Surgery in Salt Lake City, Utah, under the direction of Dr. Charles Saltzman. Following his fellowships, Jeff and his family plan to move back to the Akron, Ohio, area.



Ericka Lawler, M.D.

Ericka grew up in Woodhaven, Michigan. She attended Yale University where she earned a Bachelor of Science degree in Molecular Biophysics and Biochemistry. She received her medical degree from George Washington University in Washington, DC before moving to New York for her orthopaedic residency at the Hospital for Joint Diseases.

Ericka is currently completing her fellowship training in Hand and Upper Extremity Surgery. After fellowship, she will remain here on staff at the University of Iowa.



Phinit Phisitkul, M.D.

Phinit was born in Bangkok, the capital of Thailand. In 1996 he was awarded his medical degree from Chulalongkorn University. He completed his internship in Prajaksillapakom Army hospital, where he became a 1st Lieutenant in the Royal Thai Army. He completed a four-year orthopaedics residency at Phramongkutklo Hospital in 2001.

Phinit became a staff physician at Phramongkutklo Hospital and Sulprasittiprasong Hospital. Dr. Keokarn, President of the Royal College of Orthopaedics (who worked with colleagues of Dr. Michael Bonfiglio), recommended Phinit go to The University of Iowa for a specialized orthopaedic fellowship, focused on foot and ankle, sports, and shoulder surgery, since these areas of expertise are relatively new to Thailand.

Ultimately, Phinit plans to return to Thailand to provide specialized orthopaedic care. Phinit and his wife are enjoying Iowa City, and appreciate all that people in the Orthopaedics Department have done for them.

2006 DORIS DUKE FELLOW

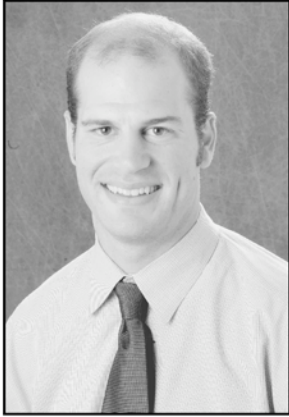


David Oji

David was born in Kobe, Japan, but has lived in Cedar Rapids, Iowa, for most of his life. He attended Carleton College where he earned his Bachelor of Arts degree in chemistry. David is currently taking a year off from medical school at Case Western Reserve University School of Medicine to do the Doris Duke Clinical Research Fellowship at the University of Iowa Department

of Orthopaedics. The fellowship allows medical students the opportunity to experience clinical research with close mentorship from the faculty. David is spending his year researching the treatment of clubfeet. At the conclusion of his fellowship, David will be returning to finish his fourth year of medical school and will be graduating in May 2007. He is looking forward to pursuing his residency in orthopaedics.

NEW ORTHOPAEDIC FACULTY



Joseph D. Smucker, M.D.

Dr. Joseph D. Smucker is an Assistant Professor of Orthopaedic Surgery at the University of Iowa. He attended Indiana University School of Medicine and completed his orthopaedic residency at Case Western Reserve University. His fellowship in spine surgery at Emory University was accomplished under the guidance of Dr. John G. Heller and Dr. Scott D. Boden.

Dr. Smucker has authored multiple peer-reviewed publications, and maintains an active basic science laboratory at the University of Iowa. He has presented his research at both national and international orthopaedic and spine meetings. He maintains active memberships in the premier orthopaedic and spine societies.



John E. Femino, M.D.

Dr. Femino joined the University of Iowa Department of Orthopaedic Surgery and Rehabilitation in January of 2006, after spending over seven years as a faculty member at the University of Michigan Department of Orthopaedic Surgery. He is a board certified orthopaedic surgeon with fellowship training in surgery of the foot and ankle. Dr. Femino graduated from medical

school at the University of North Dakota School of Medicine in 1992, and completed his residency training in orthopaedic surgery at the Grace Hospital program of the Detroit Medical Center, in Detroit, Michigan, in 1997. He completed his fellowship training in orthopaedic foot and ankle surgery at the New England Baptist Hospital in Boston, Massachusetts, in 1998.

Dr. Femino's areas of interest include ankle and foot arthritis, ankle instability, and problems of the talus including avascular necrosis and osteochondral lesions. In addition, he commonly treats a wide variety of problems of the foot and ankle such as correction of deformities, ankle and foot fractures, and tendon problems. His current research interests include the biomechanics of ankle and midfoot fractures, and the use of ultrasound in the diagnosis of foot and ankle conditions.

The Michael Bonfiglio Award for Student Research in Orthopaedic Surgery

The Iowa Orthopaedic Society Medical Student Research Award for Musculoskeletal Research

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

The first, the Michael Bonfiglio Award, originated in 1988 and was named in honor of Mike, who had an avid interest in students, teaching, and research. The award is given annually at a medical convocation. It consists of a plaque and a stipend to be used for the purchase of an orthopaedic text. It is awarded to a senior medical student in the College of Medicine who has done outstanding orthopaedic research during his or her tenure as a medical student. The student often 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.

The second award is the Medical Student Research Award for Musculoskeletal Research. This award is for students in the College of Medicine who complete a research project involving orthopaedic surgery, during one of their first three years of medical school. The award consists of a \$2,000 stipend, \$500 of which is designated as a direct award to the student, and \$1,500 of which is designated to help defray continuing costs of the project and its publication. The student must provide an abstract and a progress report on the ongoing research. The aim of this award 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 their work at the spring meeting of the Iowa Orthopaedic Society and at a conference in the Department of Orthopaedics and Rehabilitation.

This year, the committee, consisting of a member of the Iowa Orthopaedic Society (Dr. Devon Goetz, President), as well as members of the Orthopaedics and Rehabilitation Department (Dr. Charles Clark, Dr. Joseph Buckwalter, Dr. Brian Wolf, and Dr. Jose Morcuende), recommended that awards be given to the following two students: Benjamin Beecher, M4, and Matthew Lovell, M3. Benjamin Beecher is the recipient of the 2006 Michael Bonfiglio Student Research Award. His award is based on his project, "Vitamin E Blocks Shear Stress-Induced Chondrocyte Death in Cartilage." His advisors were Drs. Joseph A. Buckwalter, James Martin, and Anneliese Heiner. Matthew E. Lovell, M3, has won the 2006 Iowa Orthopaedic Society Student Research Award based on his project, "Health and Function of Patients Treated with Idiopathic Clubfeet - A 50-Year Follow-up Study." His advisor was Jose A. Morcuende, M.D., Ph.D.

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

ANKLE MORPHOMETRY ON 3D-CT IMAGES

Andrea Hayes, B.S.E., Yuki Tochigi, M.D., Ph.D., and Charles L. Saltzman, M.D.

ABSTRACT

Understanding three-dimensional (3D) morphology of the ankle is essential for a better total ankle replacement. Current designs neither mimic the articular geometry at the bearing surface interfaces nor match the native bony bed with the implant's external dimensions. This is likely due to insufficient anthropometric data on sizing and geometry. We performed this study to determine the range of possible sizes of ankle joints based on high-resolution 3D-CT images. Clinical 3D-CT images from twenty-one normal ankles (11 males, 10 females) were subjected to morphometric evaluation. A local coordinate system for measurement was established based on talar anatomic landmarks. Measurements included the width of the superior talar dome surface (measured at the anterior, middle, and posterior portions) and the arc radius of the talar dome. The results yielded an average anterior width of 29.9 ± 2.6 mm, a middle width of 27.9 ± 3.0 mm, and a posterior width of 25.2 ± 3.7 mm. The talar dome radius was 20.7 ± 2.6 mm. The width linearly decreased from anterior to posterior ($p < 0.001$). A significant gender difference was found in both the width and the radius (p -values < 0.05), except at the middle width ($p = 0.07$). The data describe talar topography in a Caucasian U.S. adult cohort, suggesting the capability of the 3D-CT approach for ankle morphometric evaluation and sizing for the fabrication of total ankle replacements.

INTRODUCTION

Advanced understanding of ankle anatomy is essential for designing better implants for total ankle replacement (TAR), especially when aiming to restore natural joint kinetics.¹ Although ankle morphology has been described in classic anatomical studies,^{2,3} the cadaver specimens utilized in these studies were from populations of subjects likely different from current U.S. norms due to differences in nutrition and ethnicity. Furthermore, in order to template for a best fit implant size for a patient, or to design a patient-specific custom-made implant, morphometric evaluation for the individual is necessary. This study was performed to develop a system for quickly measuring the essential geometric parameters required to characterize ankle morphology *in vivo*.

To date, ankle morphometry has been assessed based on plain radiographic measurements.^{4,5} However, this technique does not permit true estimation of ankle 3D morphology. For example, because of the wedged shape of the talar dome in the transverse plane (wider anteriorly than posteriorly on the superior surface),³ the maximum value would most likely be measured in a mortise view plain radiographic measurement. In addition, the intrinsic error on plain radiographic measurement is very sensitive to ankle positioning.⁶ Technological advances in high-resolution CT now permit for isotropic 3D evaluation of bone morphometry *in vivo*.^{7,8} We undertook this study to demonstrate the potential for using isotropic CT data to describe the distribution of talar morphologies in the population of patients we treat in Iowa.

METHODS

Three-dimensional ankle CT images were collected from a total of twenty-one patients (11 males, 10 females; average age 40 ± 10 years) who suffered from unilateral ankle osteoarthritis. These patients had bilateral ankle CT scanning for a research purpose in a related study under institutional IRB approval. Written, informed consent was obtained for all subjects. The CT examination was done with a multi-detector scanner (SOMATOM® Emotion 6, Siemens Medical Solutions, Munich, Germany), and the parameters for image acquisition were as follows: collimation 0.5 mm, slice thickness 0.63 mm with a reconstruction overlap of 0.3 mm, kV 130, mA 75, exposure time 1 sec, and FOV 150 mm. In this study, the images of only the unaffected ankles were utilized.

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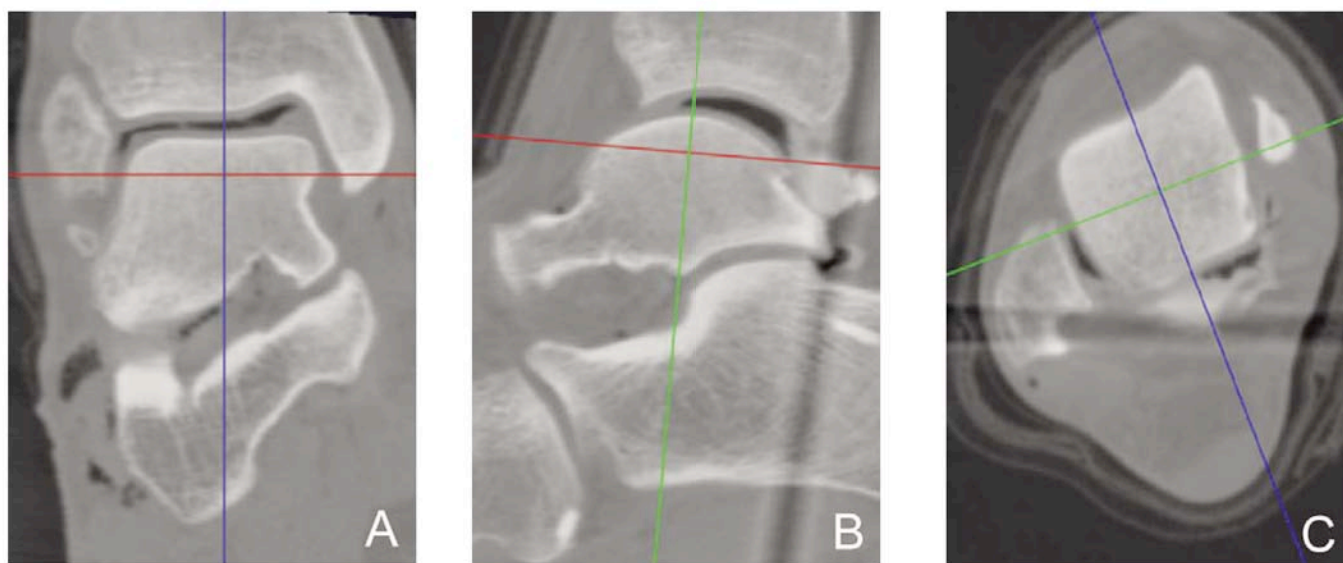


Figure 1. Determination of local reference planes based on anatomical landmarks. The blue, green, and red axes on the images indicate the reference planes of the 3D-CT image coordinate system (sagittal, coronal, and transverse planes, respectively). First, in a coronal section passing the middle of the talar dome (A), the coordinate system is rotated and translated so that the red axis is parallel to the superior talar surface and the blue axis will bisect the talar dome width in the middle. Next, in the sagittal section (B), the coordinate system is rotated and translated so that the red axis is parallel to the line passing through the anterior and posterior ends of the articular surface, and the green line transects the talar dome at the middle. Finally, in the transverse section (C), the coordinate system is aligned so that the blue and green axes perpendicularly transect the talar dome.



Figure 2. Measurement of the talar width on a mid-coronal slice. The vertical lines are drawn in alignment with the medial and lateral surfaces. The horizontal line is drawn connecting the two superior peaks on the talar dome, and the distance between the medial and lateral lines is the width on this slice.

The CT images were subjected to on-display measurement of the talar dome dimensions with use of image visualization software (Vitrea® Version 2, Vital Images Inc., Minneapolis, MN). In order to reproducibly position sectional images (slices) for measurement, local reference planes based on talar anatomical landmarks were identified in a predetermined sequence (Figure 1). In the resulting “anatomical” local coordinate system, the transverse plane was defined as a plane parallel to both the tangential line of the superior surface and the line passing through the anterior and posterior ends of the dome surface. The coronal plane was parallel to the line passing through the middle points of the medial and lateral condyles and perpendicular to the transverse plane. The sagittal plane was perpendicular to both the transverse and coronal planes.

The width of the talar dome was measured at the anterior, middle, and posterior portions. The middle width was measured on the mid-coronal section. The anterior and posterior widths were measured on the 30°-oblique coronal sections rotated about the approximate center of the talar dome on the mid-sagittal plane. On each section, two lines were drawn in alignment with the medial and lateral sides of the talus, and a line connecting the two peaks on the superior talar surface was drawn to intersect the two vertical lines (Figure 2). Talar width was then measured as a distance between these intersections, similar to the method described by Stagni et al.⁵

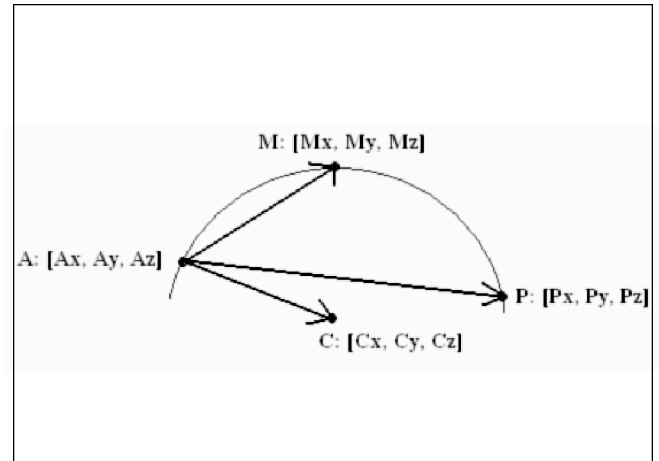
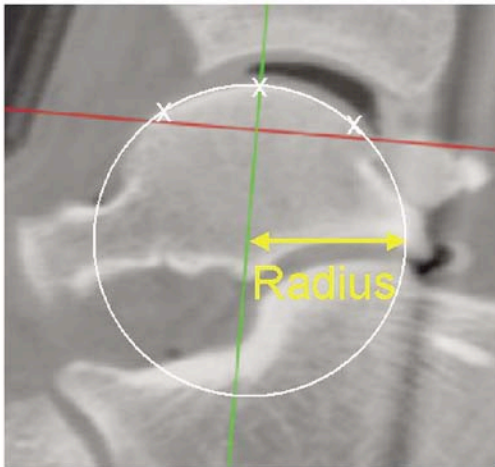


Figure 3. Talar dome arc radius is calculated from the 3D-coordinate data of three surface points digitized in a mid-sagittal slice as the radius of the circle passing through them. As the three surface points (points A, M, and P, in the model view) and the center of the circle passing them (point C) lie in the same plane, the vector AC can be identified as a function of the vectors AM and AP.

For determination of the approximate radius of the superior talar surface on the mid-sagittal section image, three points at the anterior, middle, or posterior portion of the surface (points A, M, or P, respectively) were digitized, and the x, y, z coordinates for each point were recorded. When the supposed center of the arc passing through these three points is defined as point C, because point C must be in the same plane of the other three points (Figure 3), the vector AC can be described as a function of the vectors AM and AP, with variables a and b as actual numbers, as shown in the following equation:

$$\vec{AC} \equiv a * \vec{AM} + b * \vec{AP}$$

With use of the ‘solver’ tool in Microsoft® Excel 2000 (Microsoft Corp., Redmond, WA), the position of the supposed center C was optimized in order to minimize the absolute difference across the distances from each surface point while varying the variables. The distance from the optimized arc center to each surface point should be equal, and this distance was identified as the approximate radius.

To identify the difference of talar width across anterior-posterior locations, a single factor ANOVA was utilized for statistical analysis. When a difference was found with a significance level at $p < 0.05$, pairwise comparisons were applied. For every measure, gender difference was assessed with a two-tailed unpaired *t*-test (significance level at $p < 0.05$).

RESULTS

The width of the superior talar dome surface averaged 29.9 ± 2.6 mm (mean \pm standard deviation) at the anterior, 27.9 ± 3.0 mm at the middle, and 25.2 ± 3.7 mm at the posterior portions (Figure 4). The width linearly

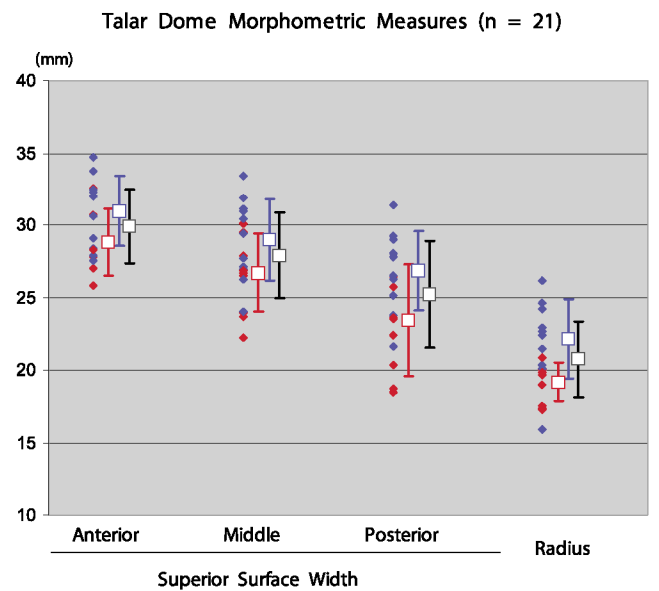


Figure 4. Morphometric data of the talar dome in the twenty-one subjects (10 females and 11 males). For each individual subject, the three talar dome widths (at the anterior, middle, and posterior parts of the superior talar surface) and arc radius (on the mid-sagittal section) are plotted as red (female) or blue (male) filled diamonds. The neighboring unfilled squares and error bars indicate the averages and standard deviations for each gender (red or blue) and those across all subjects (black.)

decreased from anterior to posterior ($p < 0.001$), and the average difference between the anterior and posterior widths was 4.7 ± 2.6 mm. The radius of the surface contour on the mid-sagittal section was 20.7 ± 2.6 mm. Both the width and radius were larger in males than in females (p -values < 0.05), except for the width at the middle ($p = 0.07$).

DISCUSSION

This study shows the potential efficacy of using isotropic CT image data to describe complex surface topographies of the talus in patients. When we compare the data acquired herein, we find that the average data of both the width and the radius of the talar dome are equivalent to those in previous studies.^{4,5} However, the “wedged” shape of the superior talar surface is well detailed by the current methodology but not by 2-D radiographic evaluation. Although cartilage thickness was not counted in the measurement, the technique utilized is likely useful for assessing ankle morphology and can be used as a tool to template ankle replacements or to suggest a range for the fabrication of talar surface implants.

In the present study, prior to making measurements for each subject, a local coordinate system was established using talar topography as a reference. This anatomical coordinate system allowed characterization of talar morphological features. However, determination of the coordinate system included visual identification of landmarks, which may affect reproducibility. Fortunately, slight differences in coordinate system positioning actually have minimal effects on measurements. For example, when the talar dome is assumed to be a half-cylinder, the effect of 5° of difference about the vertical axis on the width measurement is theoretically less than 1%. An automated system could be developed that would eliminate the need for manual identification of landmarks and in theory produce more reproducible results. In addition, automatic identification of the bony boundaries at each level of measurement could potentially improve reproducibility. However, the challenge of identifying distinct landmarks that could be used in an automated fashion is considerable, particularly in the setting of osteoarthritis. Thus, the current methods are likely more applicable in patients with osteoarthritis where bony landmarks can be difficult to identify.

The talar dome radius was determined by vector calculations from three points chosen on the talar dome surface under the assumption that the talar dome contour in the sagittal plane is a single arc passing through the three surface points. This assumption did not allow exploration of the previously reported feature that the talar dome radius is different across its anterior-posterior locations.² The difference between the medial and lateral radii, another feature reported in the literature,² also could not be explored, as talar dome radius was measured only at the mid-sagittal section. On the sagittal images taken at the medial and lateral condyles, the superior talar surface was often sectioned obliquely due to the wedged shape of the talus. This feature obscured its contour and did not allow reliable digitization of its

posterior surface. Detailed morphologic evaluation of the ankle *in vivo* is a subject inviting future investigation.

In conclusion, the morphometric data reported in this study describe the topographical features of the superior talar dome surface *in vivo* more precisely than previous 2-D plain radiographic measures and is not sensitive to ankle malpositioning at the time of image capture. The 3D-CT image approach for assessing ankle geometry appears to have the potential to provide information useful for designing ankle replacement implants or for templating the optimum size of an implant.

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LOADING AND BOUNDARY CONDITION INFLUENCES IN A POROELASTIC FINITE ELEMENT MODEL OF CARTILAGE STRESSES IN A TRIAXIAL COMPRESSION BIOREACTOR

Nicole A. Kallemeyn,² Nicole M. Grosland,^{1,2} Doug R. Pedersen,^{1,2} James A. Martin,¹ and Thomas D. Brown^{1,2}

ABSTRACT

Background: We developed a poroelastic finite element (FE) model of cartilage in dynamic triaxial compression to parametrically analyze the effects of loading and boundary conditions on a baseline model. Conventional mechanical tests on articular cartilage such as confined and unconfined compression, indentation, etc., do not fully allow for modulation of compression and shear at physiological levels whereas triaxial compression does. A Triaxial Compression Bioreactor, or TRIAX, has been developed to study chondrocyte responses to multi-axial stress conditions under cyclic loading. In the triaxial setting, however, a cartilage explant's physical testing environment departs from the ideal homogeneous stress state that would occur from strict linear superposition of the applied axial and transverse pressure.

Method of Approach: An axisymmetric poroelastic FE model of a cartilage explant (4 mm diameter, 1.5 mm thick) in cyclic triaxial compression was created. Axial and transverse loads (2 MPa at 1 Hz.) were applied via a platen and containment sheath. Parameters of interest included the rise time and magnitude of the applied load, in addition to the containment sheath modulus and the friction coefficient at the cartilage/platen interfaces. Metrics of interest in addition to whole explant axial strain included axial (surface normal) stress, shear stress, pore pressure, and the fluid load carriage fraction within the explant.

Results: Strain results were compared to experimental data from explants tested in the TRIAX under conditions similar to the baseline model. Explant biomechanics varied considerably over numbers of load cycles and parameter values. Cyclic loading caused an increase in accumulated strain for the various loading and boundary conditions.

Conclusions: Unlike what would be expected from linear superposition of the homogeneous stresses from the applied axial and transverse pressure, we have shown that the stress state within the TRIAX is considerably heterogeneous. Both the boundary influences (variation in the sheath modulus and friction coefficient) and the loading history (due to poroelastic material behavior) interact in a highly nonlinear manner to influence that heterogeneity.

INTRODUCTION

Articular cartilage has been studied extensively under a variety of quasi-static conditions in order to characterize its time-dependent response due to the frictional interaction between the solid and fluid phases. Protocols for most of these investigations have included creep and stress relaxation tests, in which constant forces or displacements are applied to the cartilage,^{1,2} or cyclic loading at low frequency (much less than physiological 1 Hz).^{3,4} However, these types of tests do not simulate the type of loading to which cartilage is exposed *in vivo*, and few studies address the dynamic cyclic loading of cartilage encountered during normal joint motion (where loading rise times can be in the range of 30-150 ms).⁵

It is difficult to mimic realistic cartilage loading conditions *in vitro*. Traditional mechanobiological studies of cartilage include unconfined compression and completely confined compression, neither of which allow for the modulation of transverse restraint. Triaxial compression offers a potentially more mechanobiologically realistic modality for studying cartilage, owing to the capability for modulation of compression and shear at physiologic levels through independent control of axial and radially transverse compression. The idea is modeled after triaxial compression systems commonly used in soil mechanics analyses. Heiner and Martin

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employed this modality, embodied in a device they termed a Triaxial Compression Bioreactor (TRIAx), in order to study chondrocyte responses to multi-axial stress conditions under cyclic loading.⁶ The TRIAX has the capability to modulate shear stresses in cartilage explants at physiological levels (up to 2 MPa, at 1 Hz frequency, 50 ms loading rise time) via the independent control of cyclic axial and transverse compression. Cylindrical cartilage explants can be subjected to cyclic axial compressive loads through platen contact and to cyclic radially transverse loads via external fluid compression of an impermeable containment sheath. This allows for investigation of variations in the multi-axial stress state within the explant (specifically the shear stress) arising from partial transverse buttressing. However, within the TRIAX, a cartilage explant's physical testing environment departs from the ideal homogeneous stress state that would occur from strict linear superposition of the applied axial and transverse pressure due to the proximity of boundary conditions (platens and containment sheath) in relation to the size of the explant. The goal of this study was to develop a poroelastic finite element (FE) model to parametrically analyze heterogeneities within explants due to loading and boundary conditions in order to lay the foundation for better understanding of chondrocyte metabolic response to loading.

Cartilage behaves viscoelastically due to the time-dependent fluid/solid interactions within its matrix. Therefore, the loading rate and history influence not only the matrix's total instantaneous stress state but also the partitioning of that total applied stress between the solid and fluid components within the matrix.⁴ A number of constitutive models have been applied to cartilage, including linear elasticity theory,⁷ linear (KLM) biphasic theory,² nonlinear biphasic theory,^{8,9} visco-biphasic theory,^{10,11} hyperelastic biphasic theory,^{12,13} triphasic theory,¹⁴ and poroelasticity theory.¹⁵ Although the biphasic and poroelastic theories are related mathematically, they are not identical. Poroelasticity is more accessible than biphasic theory because it is implemented in the element libraries of a number of finite element (FE) programs. Many commercially available FE codes have soil analysis capabilities, which have been shown to be acceptable for analyzing linear and non-linear problems in biphasic tissue mechanics.^{16,17} One of the first studies involving ABAQUS was performed by van der Voet, who demonstrated the program's poroelastic capabilities as applied to articular cartilage.¹⁸ Wu and colleagues were the first to document the accuracy of ABAQUS for cartilage by comparing computed results with analytical solutions.¹⁹ Computational modeling of cartilage has important implications for an improved understanding of the stress-strain states in vitro (mechanical testing) or in vivo (whole joint contact).

In this study, a poroelastic FE model of a cartilage specimen in cyclic triaxial compression was developed in order to investigate the effects of loading and boundary conditions. Parametric studies were performed to specifically examine the effects of the load rate and magnitude as well as the effects of nearby boundary conditions (sheath and platens).

METHODS

An axisymmetric poroelastic finite element contact model of a cartilage explant in triaxial compression was created (Figure 1A). The model consisted of a cartilage explant (1.5 mm thick, 4.0 mm diameter) loaded between two 4.0 mm diameter porous platens each having a modulus of 10 GPa. The lower platen was fixed, while the upper platen displaced vertically to provide cyclic axial loads. A thin (0.0254 mm thick) impermeable transparent polyester sheath surrounded the cartilage and the platens providing a means for applying transverse loading. The cartilage specimen was discretized into 150 8-noded bi-quadratic axisymmetric elements. The sheath was modeled using 100 2-noded axisymmetric shell elements; its thickness was designated to be 0.0254 mm. The modulus of the containment sheath, measured experimentally, was 5.5 GPa, and its Poisson's ratio ν was 0.4. The cartilage was assigned an initial void ratio (fluid to solid volumetric ratio) of $e = 4.0$ with Poisson's ratio $\nu = 0.1667$ and a depth-dependent modulus of elasticity: 10 MPa in the superficial zone, 15 MPa in the middle zone, and 20 MPa in the deep zone. Depth-dependent permeability was employed with the superficial layer as the most permeable and the deepest layer the least permeable.²⁰ Void ratio-dependent permeability was invoked during the course of the simulation.¹⁷ Initial permeability values for each layer (superficial to deep, respectively) were 4.55×10^{-15} , 1.46×10^{-15} , and $0.50 \times 10^{-15} \text{ m}^2 \text{ Pa}^{-1} \text{ s}^{-1}$. Contact with the sheath was assumed to be frictionless. Nodes on the sheath, above and below the cartilage, were constrained in the radial (r) direction in order to simulate the interaction with the platen. The uppermost sheath node was constrained in both the r and z directions.

Axial loads were applied to the cartilage using a uniformly distributed pressure on the upper platen, which in turn displaced downward to contact and load the upper cartilage surface. The coefficient of friction between the platens and cartilage was 0.2. For transverse loading, a uniformly distributed pressure was applied to the sheath adjacent to the peripheral surface of the cartilage. A trapezoidally-modulated loading waveform (Figure 1B) was applied for 700 cycles at 1 Hz. The loading waveform consisted of axial and transverse loads simultaneously modulated over 0.5 seconds (first half of the cycle) from

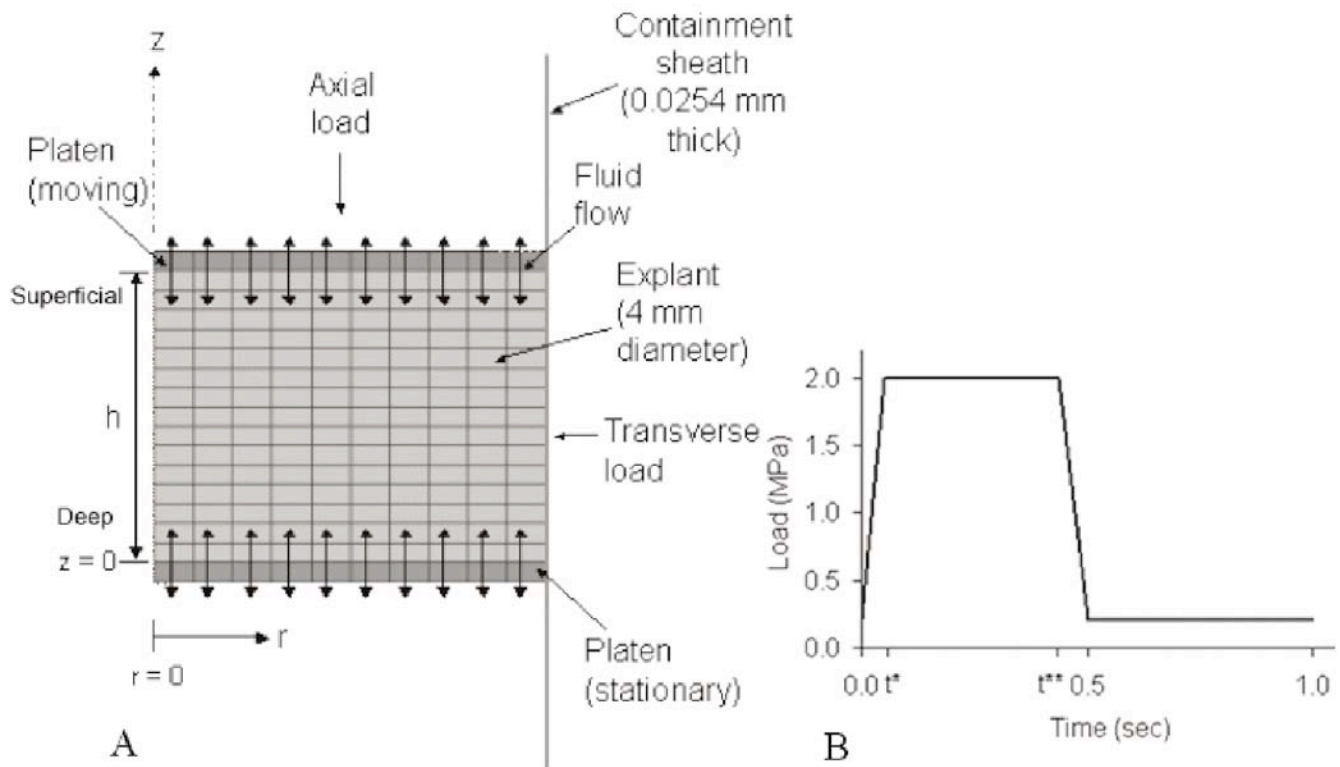


Figure 1. (A) Boundary conditions of the axisymmetric model. The z-axis is the axis of symmetry. The deep zone of the explant is at $z = 0$, and the superficial zone is at $z = h$. (B) Axial and transverse duty cycle; t^* and t^{**} delimit the points in time between which the load is maintained constant.

a 0.2 MPa tare load to a 2 MPa maximum load and then decreasing back to the 0.2 MPa tare load. During the second half of the cycle, the constant 0.2 MPa tare load was maintained. Fluid ingress/egress from the upper and lower cartilage surfaces was allowed by specifying zero pore pressure at the boundary nodes. The sheath was impermeable, thus disallowing any fluid flow to/from the peripheral surface of the cartilage. The geometry of each model component was created and meshed using PATRAN (MSC.Patran Version 2001 r3, Santa Ana, CA), and finite element solutions executed using ABAQUS (v6.3-1, ABAQUS, INC., Pawtucket, RI).

Parametric studies performed by varying individual attributes from the above described baseline model included the magnitude of the applied load and rise time of the loading cycle. Additionally, the sheath modulus and the friction coefficient between the platens and the cartilage were modified. Outcome metrics of interest were the axial displacement of the upper surface of the explant, the fluid pore pressure, and the solid phase axial (surface normal, z direction) stress. The shear stress was reported for series in which the sheath modulus and friction coefficient were varied. Additionally, the fluid load carriage fraction, defined as the pore pressure divided by the sum of the pore pressure and axial

stress, was computed at each element to examine the load sharing between the fluid and solid components of the matrix.

Each parameter was modified independently from the otherwise baseline conditions. For the applied load magnitude condition (baseline: 2 MPa axial and 2 MPa transverse), the axial and transverse loads were always equal at 2.0, 1.0, and 0.5 MPa, and the tare load was set to 10% of the applied maximum load. In each case, the upslope and downslope of the load application was equal to that of the baseline condition. A second series varied the rise time of the applied load, where the modifications included both the upslope and downslope to 25, 50, 200 and 400% of the baseline (rise time of 0.05 seconds). The magnitude of the maximum applied load was the same; however, the duration of maximum load application varied due to the rise time changes. The sheath modulus (baseline: 5.5 GPa) was modified to 1.375, 11, and 22 GPa, and the friction coefficient between the platens and the cartilage (baseline: 0.2) was changed to 0.1 and 0.4.

Validation

The Triaxial Compression Bioreactor (TRIAX) was used to validate the FE model by loading 4.0 mm di-

ameter cartilage explants in cyclic axial compression. Full thickness cartilage plugs from freshly amputated human ankle specimens were tested in the TRIAX under 2 MPa axial compression only for 3600 cycles (1 hour). A differential variable reluctance transducer (DVRT) monitored the motion of the upper platen (equal to the cartilage surface displacement) with respect to time. The DVRT displacement data were converted to strain using the cartilage thickness measured before compression began (but while under the small tare load) and were compared to the strain results for an FE model with similar dimensions and baseline material properties loaded under 2 MPa axial compression only. Explants tested in the TRIAX were excised with a 4 mm diameter dermal punch; their thickness ranged from 1.49 mm to 1.57 mm.

The deformation was digitally recorded using a Smith+NepHew Dyonics® arthroscopy system. A 4-mm 0° arthroscope was used to record real-time streaming video of the cartilage as it was cyclically loaded in the TRIAX (Figure 2). The arthroscope aided in visually monitoring the interaction of the upper and lower platens and containment sheath with the surfaces of the cartilage during compression. The temporal changes in the deformed explant silhouette were of interest in analyzing the Poisson-induced effects of the whole cartilage explant (i.e., the shape and amount of lateral bulging during axial compression).

The housing of the TRIAX was retrofitted to accommodate the arthroscope, which was mounted horizontally to view the explant and the upper and lower platens. The tip of the arthroscope was located 4 mm away from the center axis of the platens. Light to the arthroscope was provided by a Xenon light source attached to the arthroscope in addition to supplemental ambient light. Digital video was captured and recorded via a Pinnacle Systems® MovieBox DV analog to digital video converter. The image output size was 640 pixels wide by 480 pixels tall; its resolution was 10 μm when viewing an object at a distance of 4 mm. Since arthroscope optics produce a “fisheye” view in which the image is radially distorted about a center of distortion,^{21,22} it was necessary to compensate for this distortion.²³

RESULTS

Validation

The strain results for three comparable articular cartilage explants are shown (Figure 3) in addition to the FE strain results for a 1.5 mm thick, 4 mm diameter explant compressed with a 2 MPa axial load. The strain was plotted as the minimum and maximum strain for each load cycle. The total strain refers to the maximum compressive strain, and the peak-to-peak strain was defined as

the difference between this maximum and the minimum strain under tare load. At 2500 cycles of loading, the total axial strain computed by the FE model was 19.5%. The total strain for the explants shown ranged between 16.0% and 18.0%. The peak-to-peak strain computed by ABAQUS at 2500 cycles for the baseline case was 2.6%, while the experimental data varied from 2.7% to 5.4%.

Additionally, the lateral “bulging” of the cartilage silhouette after the first cycle was manually digitized and compared to the FE results for an explant with the baseline model conditions. During the first cycle of loading, the FE cartilage model expanded 0.034 mm laterally from its initial position. The amount of lateral expansion in TRIAX explants varied from 0.0096 to 0.072 mm (Table 1). Thus, the FE results for the baseline model conditions approximate the range of values observed experimentally in terms of total axial strain and peak-to-peak axial strain and fall within the mid-range of the lateral expansion values.

Parametric Studies

In the following section, all data reported at a specific cycle (unless otherwise noted) were taken at the instant in the first half of the cycle just before the load was released back down to the tare load, or what is designated as t^{**} in Figure 1B. The point in time just after the onset of the loading plateau is labeled as t^* . These t^* and t^{**} points will not necessarily fall at the same instant in time for each model in the load rate set of parameters due to changes involving the load waveform itself. The term “mid-height” refers to the transverse midsection of the explant, where z is half of the total thickness of the explant.

Baseline stress and pore pressure distribution results just prior to load release are shown in Figure 4. Overall, pore pressures were highest in the central portions of the explant, decreasing towards zero at the upper and lower surfaces (A). The pore pressures progressively decreased throughout the duration of loading (B). Shear stresses, by contrast, increased (C, D) with higher regions of shear stress located along the outer edge of the explant, attenuating towards the axis of symmetry. The axial compressive stresses also increased throughout the duration of loading and were highest in magnitude along the upper and lower surfaces of the cartilage and along the axis of symmetry (E, F).

Effects of Load Magnitude

As expected, decreasing the magnitude of the applied load from the baseline loading conditions (2 MPa axial plus 2 MPa transverse) correspondingly decreased the strain in the cartilage explant (results not shown).

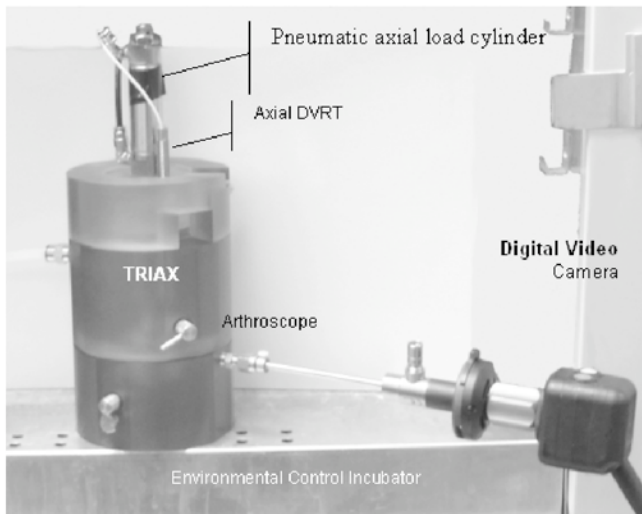


Figure 2. The TRIAX and arthroscope setup.

TABLE 1
Radial Expansion of Selected Cartilage Explants

	Lateral expansion during the first cycle [mm]	Initial height [mm]
FE	0.034	1.50
Explant A	0.0096	1.67
Explant B	0.024	1.45
Explant C	0.072	1.25

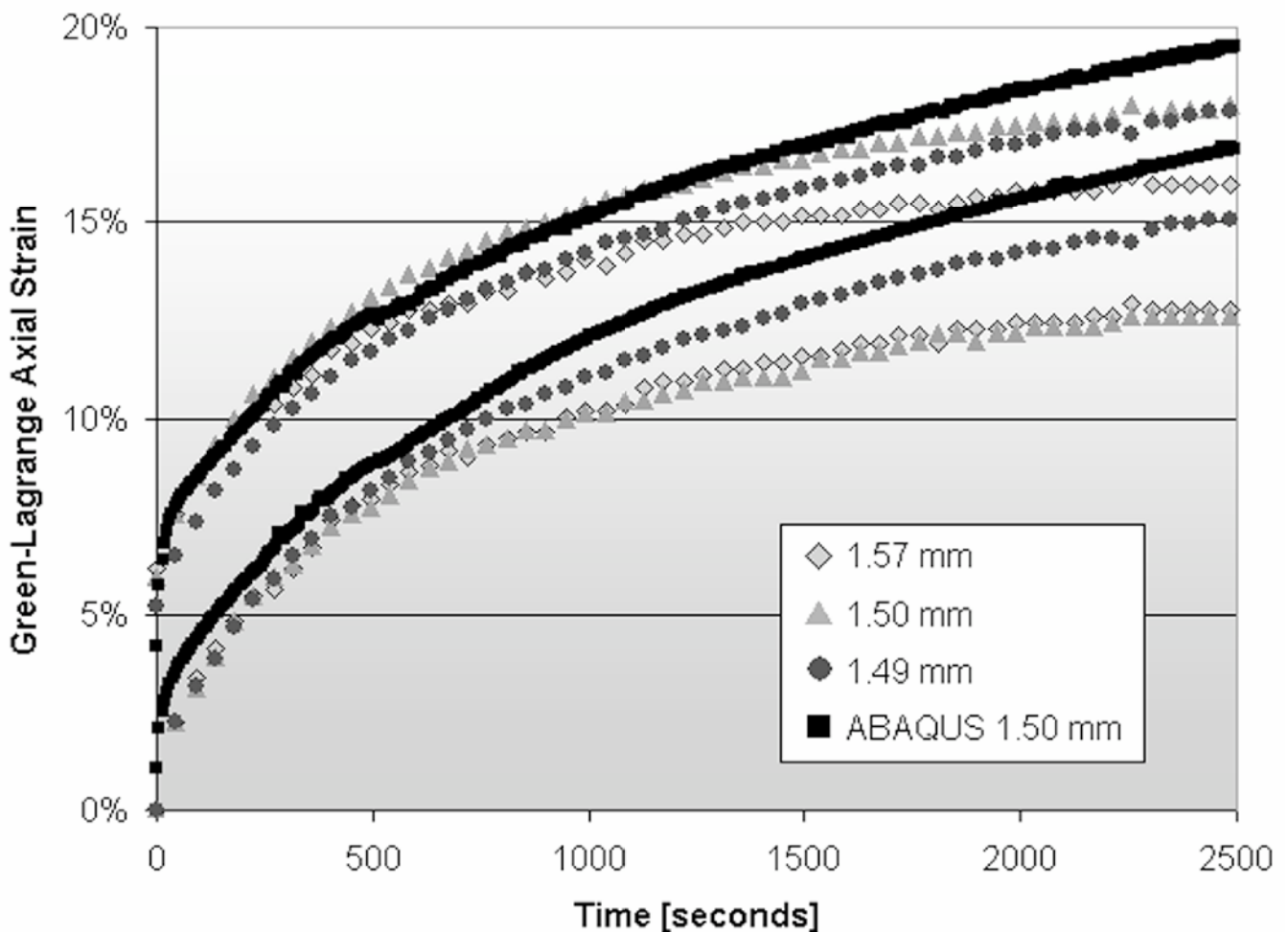


Figure 3. Green-Lagrange strain results for the FE model with baseline material properties and 2 MPa axial compression compared to actual human talar cartilage explants subjected to 2 MPa axial compression in the TRIAX.

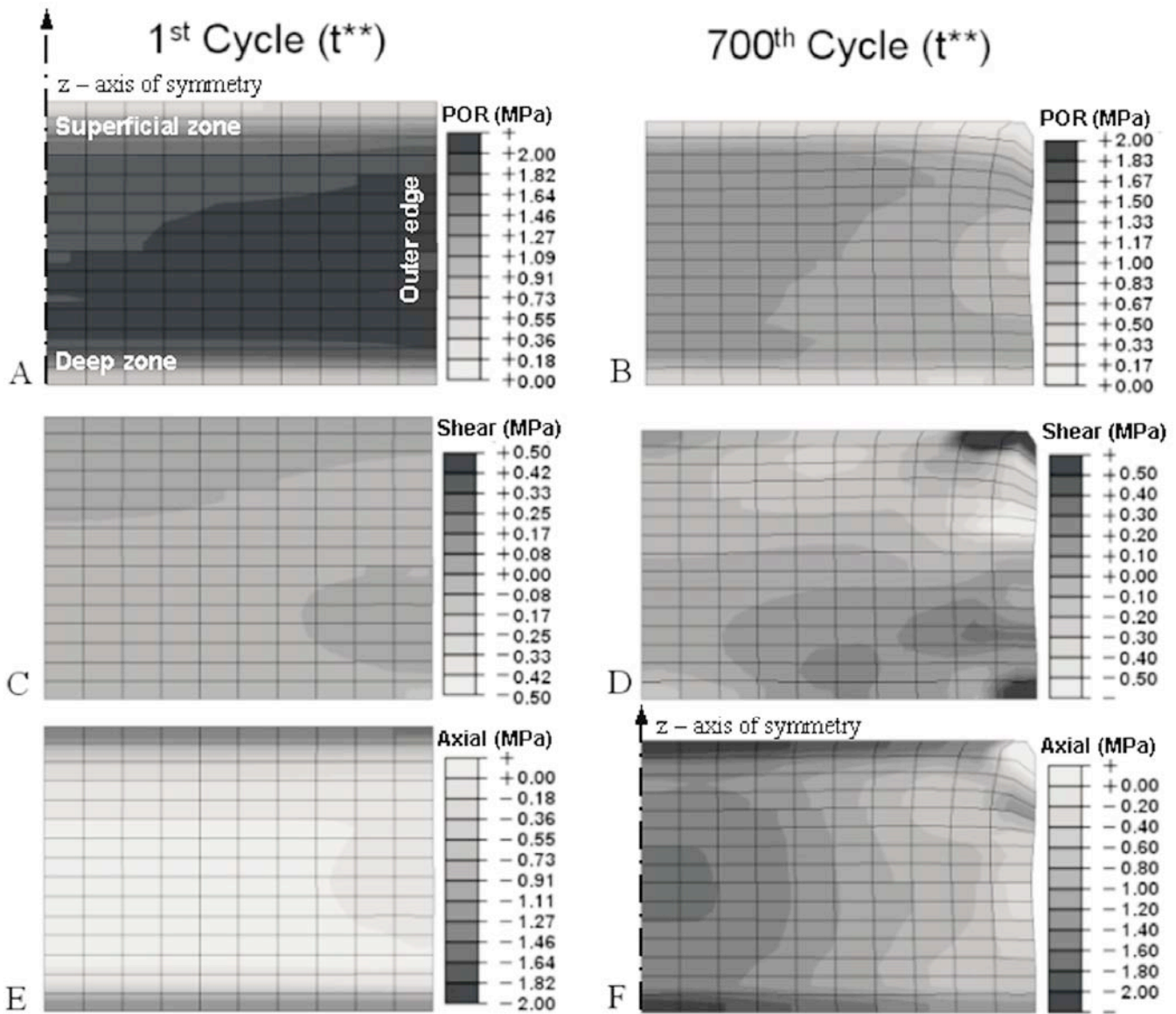


Figure 4. Effects of accumulated cyclic compression on explant stress distribution. Contour plots for the baseline model (2 MPa axial + 2 MPa transverse pressure). (A) Pore pressure at t^{**} for the 1st cycle, and (B) the 700th cycle. (C) Solid phase shear stress at t^{**} for the 1st cycle, and (D) the 700th cycle. (E) Axial stress at t^{**} for the 1st cycle, and (F) the 700th cycle.

Higher load magnitudes resulted in higher pore pressure development throughout the explant, while pore pressures progressively decreased throughout the duration of any loading magnitude.

Effects of Loading Rise Time

Rise time changes were implemented by adjustments of both the upslope and downslope of the applied load waveform. This had a variable effect on the axial strain throughout the duration of loading (Figure 5A). As the rise time decreased (i.e., the upslope increased), both the cycle average and peak-to-peak strain increased. This result appears to be counterintuitive: it would seem that

a shorter rise time (higher upslope) would allow less explant relaxation due to less fluid flow, thus leading to apparent stiffening, and as a result, less overall explant strain. However, when looking at the strains for the first 0.25 seconds of the first cycle, it was noticeable that the strains developed from the beginning of loading until the time to maximum load did decrease with decreasing rise time (Figure 6A). However, this strain reduction was more than offset by the increased strains during the correspondingly longer load plateau phase, where the maximum load was held constant before decreasing back to the tare load. During this longer load plateau phase, more interstitial fluid was exuded from the car-

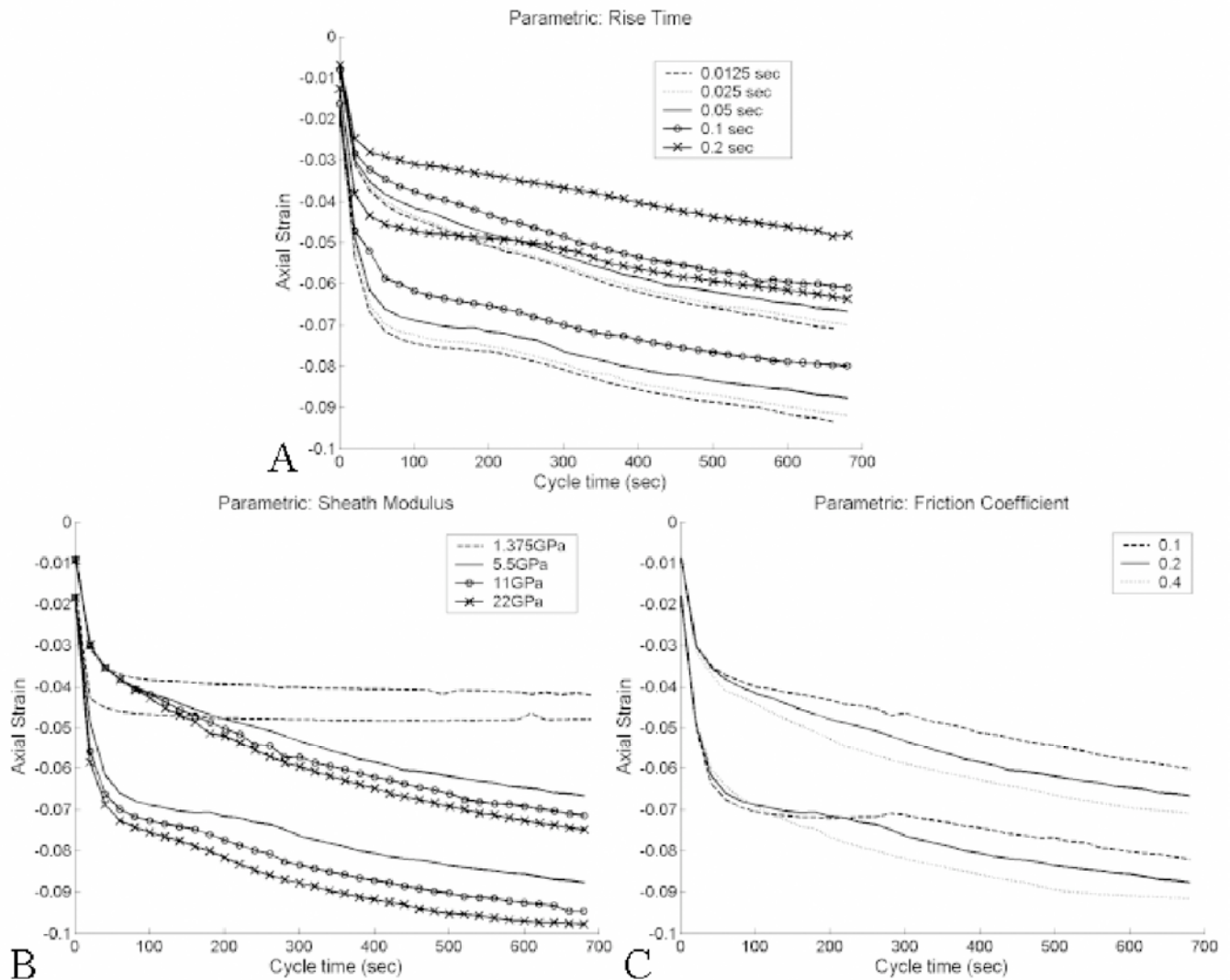


Figure 5. Effects of the model parameters on the computed axial strain. Minimum and maximum strains are plotted for each cycle, allowing inference of peak-to-peak strain as well as total strain. The baseline case is the solid line. (A) Rise time of the applied load. (B) Sheath modulus. (C) Friction coefficient.

tilage, therefore allowing for more strain in the explant, as compared to explants given a shorter amount of time in the load plateau phase.

The fluid load carriage fraction shown at t^* for the first cycle of loading (Figure 6B) involved more fluid load carriage at the midsection of the explant than near the upper and lower surfaces. For increasing rise times (slower load application), the decreased fluid load carriage fraction near the upper and lower edges of the explant is likely due to the fact that fluid egress plays a more prominent role, thereby developing lower pore pressures, which resulted in a smaller fluid contribution to load sharing. The fluid load carriage fraction was lower in the superficial layer of cartilage as compared to the deep layer, presumably due to the differences in

material properties. The lower fluid load carriage fractions towards the end of the prescribed loading (Figure 6C) as compared to the first cycle of loading (Figure 6B) indicate less of a shielding effect of the solid matrix by the fluid within the cartilage.

Effects of Sheath Modulus

As the sheath modulus increased, so did the total strain and peak-to-peak strain (Figure 5B). These results also seem counterintuitive: one might expect that a stiffer sheath would provide higher resistance to deformation of the cartilage explant. However, a stiffer sheath would tend to transfer less of the applied transverse pressure to the cartilage than would a less stiff sheath, therefore allowing for more axial strain. The 1.375 GPa sheath case

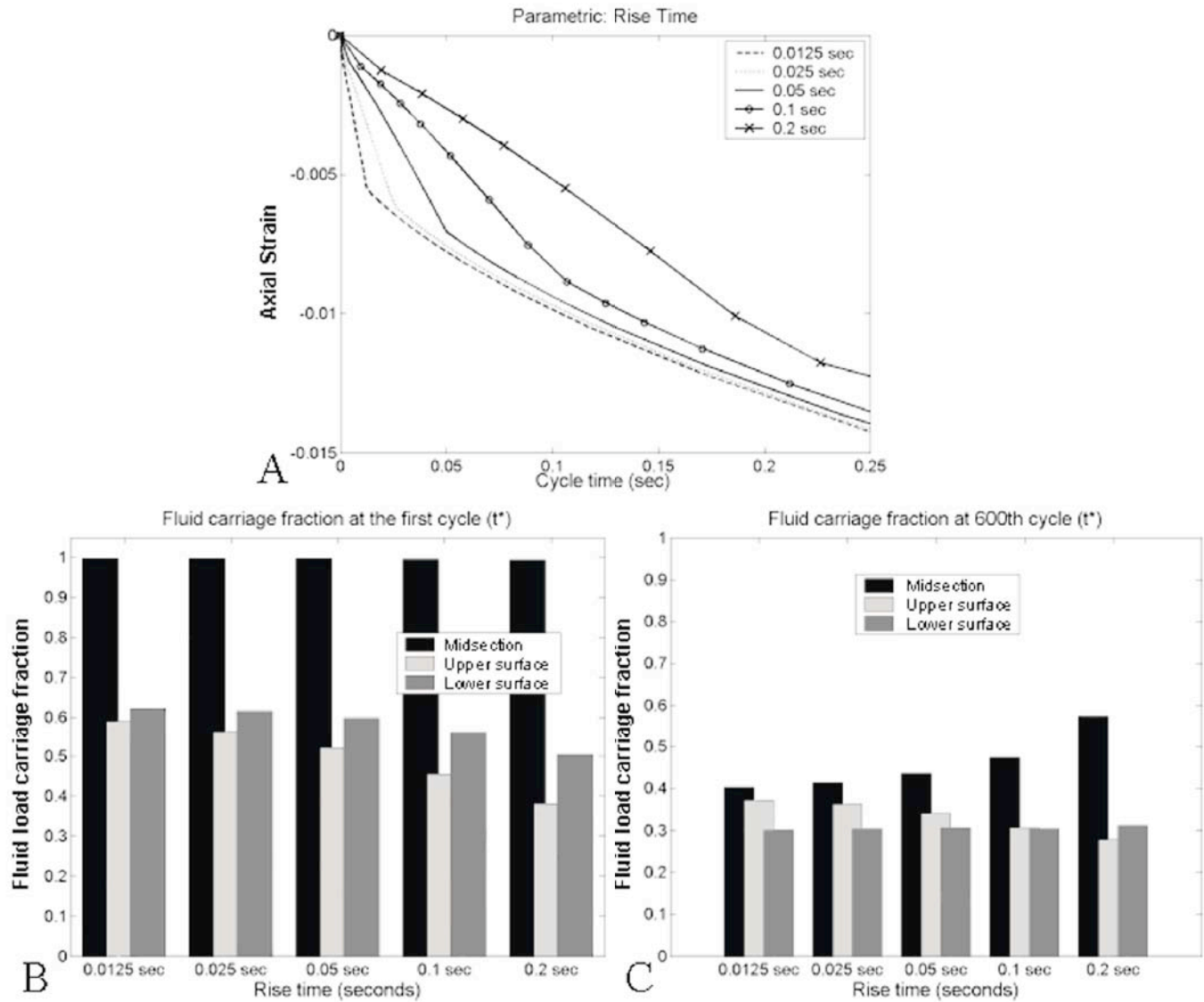


Figure 6. Effects of the rise time. (A) Axial strain for the first 0.25 seconds of loading. The baseline case is the solid line. (B) The fluid load carriage fraction at initial peak load t^* for the first cycle and (C) the 600th cycle at the center of the explant and the upper and lower surfaces.

did not continue to accrue increased axial strain over the duration of loading after approximately 50 cycles; instead, the total strain remained relatively constant, at $\sim 4.8\%$. At the end of the loading protocol, the shear stresses in the radial direction for this case were almost zero, except near the outer edge of the cartilage where their magnitude reached 1.2 MPa for the upper- and lower-most elements. The pore pressure showed little variation in the radial direction; whereas, for the higher-modulus-sheath models, the pore pressure decreased towards the outer edge (Figure 7A). Sheath moduli higher than the baseline case resulted in slightly higher shear stress magnitudes where $r = 0.9$ mm (Figure 7B). Unlike for the other cases, the shape of the profiles of

the pore pressure and of the axial compressive stress curves along the axial z direction for the 1.375 GPa sheath modulus case had little variation between the symmetry axis of the explant and its outer edge after the duration of loading (Figure 7C, D). The containment sheath exerted apparently less of an effect on the outer edge of the cartilage when the sheath modulus was 1.375 GPa, as compared to 5.5 GPa or higher, which is consistent with diminished transverse pressure transfer through the sheath for higher sheath moduli.

Effects of Friction Coefficient

Changing the friction coefficient at the cartilage/platen interface had a modest effect on the cycle average carti-

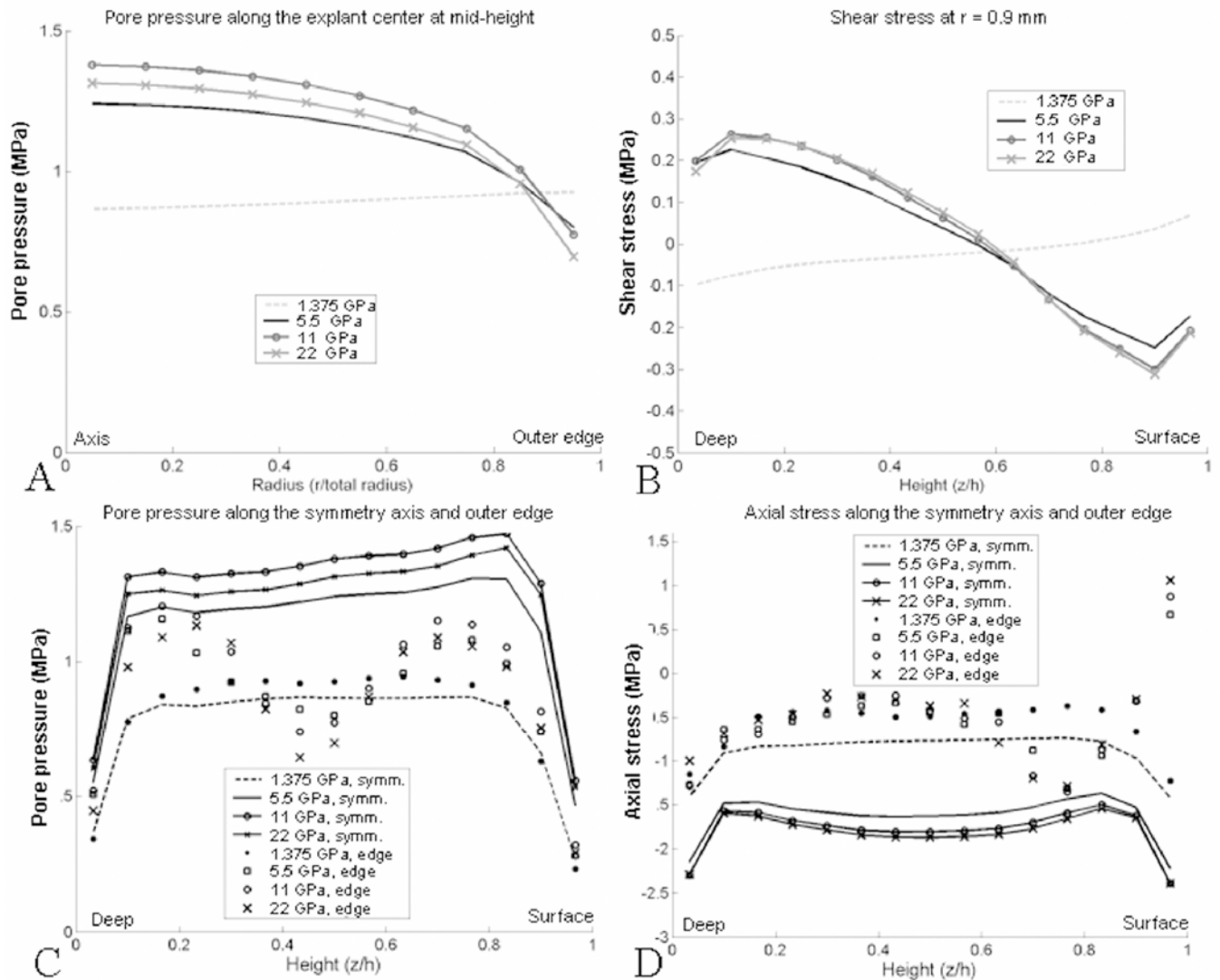


Figure 7. Effects of the sheath modulus. The baseline case is the solid line and open square. (A) Pore pressure along the explant at mid-height. (B) Shear stress along the height of the explant at $r = 0.9$ mm. (C) Pore pressure along the symmetry axis and along the outer edge. (D) Axial compressive stress along the symmetry axis and along the outer edge of the explant. The bottom of the explant is at $z = 0$, h is the total height of the explant.

lage strain, with smaller coefficients of friction resulting in a progressive decrease in total strain throughout the load duration. However, the peak-to-peak strain was not notably affected by the friction coefficient (Figure 5C). The pore pressures after the duration of loading did not vary appreciably with friction coefficient changes, but the shear stress and axial compressive stress changed slightly (Figure 8). The trends of variation of the shear stress and fluid load carriage fraction were different at different regions of the explant. For example, at $r = 0.5$ mm, a friction coefficient of 0.1 led to higher shear stress magnitudes and higher fluid load carriage fractions as compared to the 0.2 and 0.4 cases. However, the opposite trend was true at $r = 1.5$ mm (closer to the outer edge

of the 2 mm radius explant). For the most part, the case with a friction coefficient of 0.4 had higher shear stress magnitudes and fluid load carriage fractions. The shear stress fluctuated more toward the outer edge.

DISCUSSION

Conventional methods of testing articular cartilage in vitro generally do not allow for modulation of transverse restraint, unlike the situation for triaxial compression. The partial buttressing effect seen for increasing transverse pressure in triaxial compression arguably better represents cartilage loading in vivo as compared to purely unconfined or rigidly confined compression. Computational stress analyses of this novel testing regi-

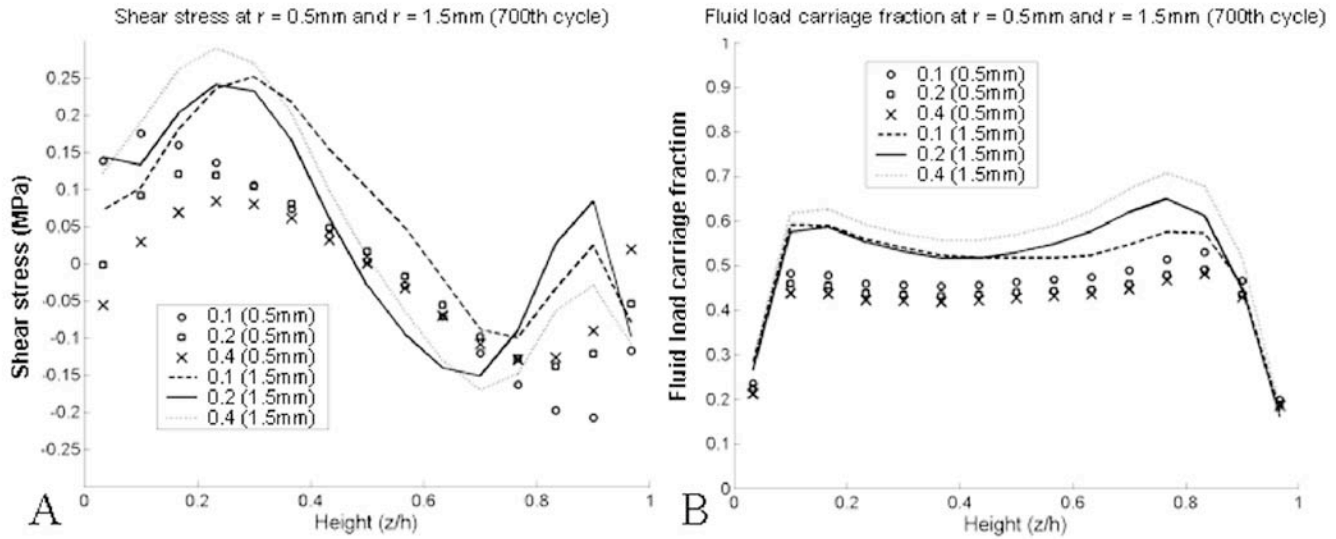


Figure 8. Effects of the friction coefficient. The baseline case is the solid line and open square. (A) Shear stress and (B) fluid load carriage fraction at $r = 0.5$ mm and 1.5 mm.

men are helpful for interpreting in vitro experiments exploiting this modality. In the current analysis, the finite element model was used to quantify the material effects of the sheath surrounding the cartilage explant in order to explore the effect the mechanical buttressing has on the behavior of the explant.

Furthermore, the FE model is a potentially helpful tool for understanding load transmission abnormalities for degenerative states of cartilage, particularly osteoarthritis (OA). When cartilage degenerates, the matrix undergoes a number of morphological, molecular, and mechanical changes. Early attributes of OA include fibrillation of the articular surface, increased water content, and changes in proteoglycan composition and structure, which combine to make the cartilage substantially softer and more permeable.^{24,25} It is possible to modify the present poroelastic constitutive properties of the cartilage to reflect mechanical changes of OA in order to better understand the interactions between the fluid and solid components of the tissue under degenerative conditions.

Sheng et al. performed a finite element analysis using ABAQUS to determine the effects of end restraint (platen/soil interaction) and strain rate in triaxial testing of soils.²⁶ Inhomogeneities due to end restraint and insufficient drainage existed within the soil specimen, and shear stresses developed from the end edges into the specimen (similar to the current study) for frictional and rough contact between the specimen and platens. They concluded that stress-strain and strength properties based on global specimen measurements are not a complete representation of the true behavior of the soil

at the constitutive level due to the inhomogeneities that exist. The FE results in the current study showed that the stress state of an explant subjected to triaxial compression is heterogeneous, unlike the straightforward homogeneous strength-of-materials relationship assumed in earlier work.⁶ Both the boundary influences (variation in the sheath modulus and friction coefficient) and the loading history (due to poroelastic material behavior) interact in a highly nonlinear manner to develop that heterogeneity.

The data from the FE model and supporting experiments show that the triaxial compression modality avoids the excessive levels of axial compaction typical of unconfined compression experiments.²⁷ At the same time, the triaxial modality develops shear stresses whose magnitudes are an appreciable fraction of those of axial compressive or hydrostatic stresses, unlike the situation for confined compression.^{28,29}

Explant biomechanics varied considerably over numbers of cycles typically used for TRIAX experiments. This appears to be due to net exudation of a substantial fraction of the fluid initially present. Typically, the total strain magnitude was ~3-4 times the peak-to-peak strain. This suggests that the biological response during a typical TRIAX experiment might vary substantially during the course of the experiment. Biological investigators would be well advised to be aware of that possibility, rather than making interpretations inappropriately specific to a given instant.

The present study was exploratory in nature in that it utilized perturbations of baseline poroelastic values inferred from the literature. One limitation, at present, is

that the behavior at the interface between the cartilage and the sheath is not completely known with respect to fluid flow. Also, the present poroelastic formulation is only a first approximation of material behavioral complexity and does not include effects such as anisotropy, matrix viscoelasticity, or physiochemical effects that might be important in specific contexts.

ACKNOWLEDGMENTS

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ASSESSING ANGIOGENESIS DURING FRACTURE HEALING

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ABSTRACT

Angiogenesis, the sprouting of new capillaries from existing blood vessels, is crucial for normal fracture healing. Angiogenesis is a complex process involving a variety of growth factors and several cell types. The mechanism regulating angiogenesis during fracture repair is not well understood, and the relationships between angiogenesis, chondrogenesis, and osteogenesis are also undefined. *In vivo* animal models have been useful for determining angiogenic mechanisms. In particular, a murine model has been developed that offers the advantages of easy animal handling, low cost, reliable healing, and the availability of molecular and genetic techniques for research. However, the small size of mice provides challenges, including the inability to assess vascularization using techniques that have been employed in larger animals. Therefore, we developed and optimized techniques specifically for studying angiogenesis during mouse fracture repair. These techniques include blood vessel casting, micro-computed tomography (micro-CT), immunohistochemistry, *in situ* hybridization, and genetic labeling of endothelial cells. Blood vessel casting and micro-CT are useful for visualization of small blood vessels. Immunohistochemistry using anti-PECAM (platelet endothelial cell adhesion molecule) or CD34 antibodies and genetic approaches using Tie2-cre transgenic mice can be used to label endothelial cells, visualize blood vessels including capillaries, and provide structural information about the vascularization of the fracture callous. Lastly, expression patterns of important growth factors regulating angiogenesis could be assessed by molecular approaches such as *in situ* hybridization.

INTRODUCTION

Bone fractures are usually accompanied by injuries to the vasculature. A hematoma forms around the fracture site, and an inflammatory response is initiated. This initial reaction stimulates angiogenesis, and the blood supply to the injured bone returns. Previous clinical observations and experimental studies have determined that angiogenesis is necessary for normal fracture repair. Inhibition of new blood vessel formation induced by the administration of TNP-470 was shown to prevent fracture healing in rats.¹ Conversely, exogenous application of vascular endothelial growth factor (VEGF), a potent pro-angiogenic agent, significantly accelerates fracture healing.^{2,3,4,5}

The importance of the blood supply to fracture healing has been long recognized. However, the cellular and molecular mechanisms that govern angiogenesis and the role that the blood supply plays during fracture healing remain largely unknown. Regulation of angiogenesis during endochondral ossification of the fracture callus involves complex signaling processes, including that via VEGF,^{6,7} but the mechanisms regulating vascular repair during the early stages of healing are unknown. The blood supply certainly provides essential nutrients to cells, but whether and through what mechanism vascularity influences events that occur during fracture repair is not clear. For instance, *in vitro* chondrocyte differentiation can be enhanced by low oxygen tension (hypoxia);^{8,9} however, this phenomenon was not confirmed in an animal fracture model that had impaired vascular regeneration.¹ Additionally, the blood supply could be a route for migration of systemic stem cells to sites of bone injury. In both of these cases the extent of the vascular injury and the rate of vascular repair could significantly influence cell differentiation during skeletal repair. To address the extent to which angiogenesis impacts cell fate decisions during fracture repair, a thorough assessment of angiogenesis during healing is required.

Rodent models are excellent tools to study bone biology and skeletal repair for a variety of reasons. Mouse models in particular are desirable due to the availability of a plethora of genetically engineered strains and the abundance and availability of reagents for cellular and molecular analyses. Our laboratory has developed several mouse models of tibia fractures that have provided valuable information regarding mechanical, cellular, and molecular mechanisms that control bone regen-

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eration.^{10,11,12,13} However, due to the small size of mice, assessing vascularization during fracture healing using techniques developed for larger animals has proven difficult. The goal of this work was to assess a variety of methods to analyze structural and functional aspects of angiogenesis during fracture healing. We have developed and/or optimized a variety of techniques to analyze the structural, functional, cellular, and molecular features of angiogenesis during healing of non-stabilized fractures of mouse tibias.

MATERIALS AND METHODS

Animals

Ten to 14 week old male wild type (129J/B6, The Jackson Laboratory, Bar Harbor, Maine, USA) and transgenic (Tie2-cre,¹⁴ Rosa26R) mice were used in this study. All animal procedures were approved by the UCSF Institutional Animal Care and Use Committee and conformed to state and federal regulations for use of vertebrate animals in research.

Creating tibia fractures

Animals were anesthetized with 2% Avertin (2,2,2 tribromoethanol, Sigma-Aldrich), and then a closed transverse fracture was created by three-point-bending of the mid-diaphysis of the right tibia.^{10,11} These fractures were not stabilized, and animals were allowed to move freely after recovering from anesthesia. Buprenex was administered subcutaneously to relieve post-surgical pain.

Blood vessel casting and micro-CT scanning

At 14 days post-fracture, animals were euthanized with an overdose of 2% Avertin, and the femoral vessels and the heart were exposed. The right atrium was opened. The entire vascular system was then flushed by injecting heparinized saline (100U/ml) into the left ventricle until the femoral vessels turned white and the saline flowing out of the right atrium became clear. Microfil (Flow Tech. MV-diluent: MV-compound (5:1) and MV-curing agent (10% of the total volume)) was prepared immediately before injection. The entire vascular system was then perfused by intracardiac injection (left ventricle) of 3-5 ml of the Microfil. After perfusion, animals were placed at 4°C for 2 hours or overnight in order for the compound to polymerize. The fractured tibiae were then collected, fixed, dehydrated through a series of ethanol washes, and cleared in methyl salicylate. The vasculature was then evaluated using a Leica MZFLII dissecting microscope. One of the samples was rehydrated and examined by x-ray radiography and micro-CT (micro-computed tomography) scanning (Scanco, 20 µm) system.

For micro-CT scanning, the vasculature was perfused with a barium sulfate suspension (Liquid Barospense, Lafayette Pharmaceuticals, Inc. Yorba Linda, CA) following the same technique described above. The fractured leg was ligated at the mid-femur level and cut proximal to the ligation to minimize the barium leakage from open blood vessels. The entire leg was fixed in 4% Paraformaldehyde (PFA; 4°C overnight), decalcified in 19% EDTA for 3-5 days, and then examined by x-ray radiography and micro-CT scanning.

Processing tissue for histology

Ten 129J/B6 mice were sacrificed at 14 days after fracture and the fractured legs were collected, fixed in 4% PFA (4°C overnight), and decalcified in 19% EDTA for 10-14 days (4°C). Decalcification was confirmed by x-ray radiography. Decalcified tissues from five mice were dehydrated in a graded series of ethanol washes, cleared with xylene and then embedded in paraffin. Sections (10 µm) were prepared with a Leica microtome and mounted on glass slides. Tissue from the other five mice were infused with 30% sucrose in PBS (overnight) and then embedded in O.C.T. compound (Tissue-Tek, Sakura Finetek U.S.A., Inc, Torrance, CA) on dry ice. Sections of 20 µm were prepared using a cryostat. Frozen sections were kept in a sealed box at -20°C until analysis.

Immunohistochemistry

Paraffin sections were dewaxed with HemoD (histoclear, Fisher Scientific), rehydrated through a graded series of ethanol washes, and maintained in phosphate buffered saline (pH 7.4; PBS). Frozen sections were air dried for two hours and then placed in PBS. Sections were treated with 0.3% H₂O₂ in methanol for 1 hour to quench endogenous peroxidase activity. Blocking solution (5% powder milk, 0.1% ovalbumin, and 5% goat serum in PBS) was applied for 10-30 minutes to reduce non-specific binding of the antibodies. Antigen retrieval of freshly prepared paraffin sections (<1 week old) was performed by incubation in 0.1% trypsin in PBS for 15 minutes at room temperature. To unmask antigens from old paraffin tissues (stained more than 3 to 4 months after section), different protocols were tested: 0.1% trypsin for 15 or 30 minutes, Ficin solution (Zymed) for 10 minutes, or heat mediated antigen retrieval (citrate buffer epitope retrieval, 100°C for 20 minutes). Ficin solution (5 minutes at room temperature) was used to recover antigens on frozen sections. All sections were incubated (overnight, 4°C) with an anti-mouse PECAM (Platelet endothelial cell adhesion molecule-1, also called CD31) antibody (IgG, Pharmingen, cat#: 553370, diluted 1:500 in 5% goat serum) or an anti-mouse CD34 anti-

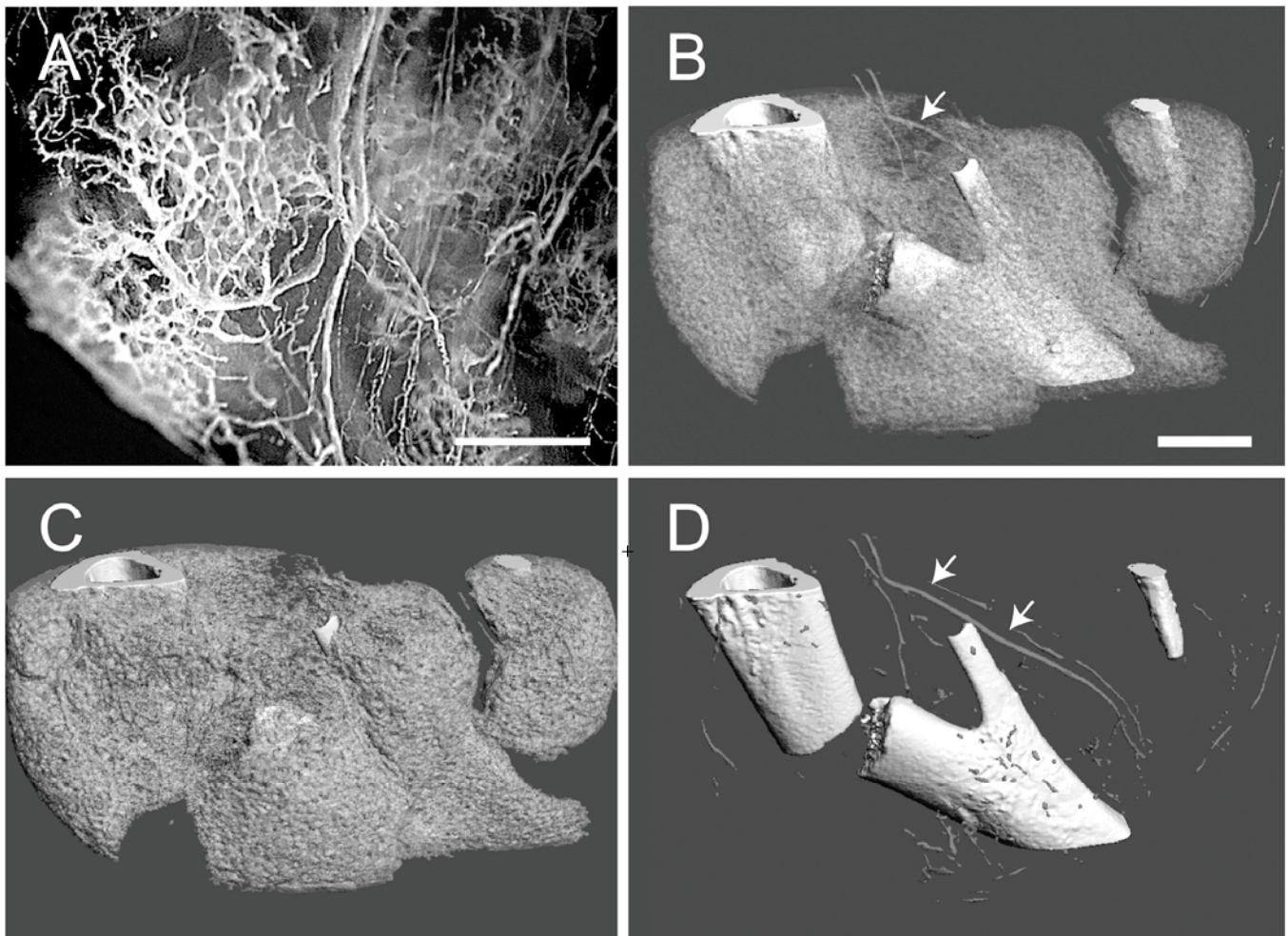


Figure 1. Microfil blood vessel casting and micro-CT imaging. (A) Microfil casting demonstrated a network of blood vessels around the callus of a day 14 non-stabilized mouse tibia fracture. The same sample was scanned at 20 μm under micro-CT, and 3-dimensional images were reconstructed to show (B) the site of fracture, the mineralized callus, and blood vessels (arrow); (C) the mineralized callus only; and (D) the site of fracture and blood vessels (arrows). Scale bar = 1mm.

body (IgG, Abcam, cat#: ab8158, diluted 1:25 in 5% goat serum) that was generated in rats. A biotinylated goat anti-rat IgG (Pharmlingen, cat#: 554014) was used (1 hour at room temperature, diluted 1:100 in 5% goat serum) as the second antibody to detect each of the primary antibodies. Streptavidin-horseradish peroxidase (diluted 1:100, Amersham, cat#: RPN1231) was then applied and the sections were incubated at room temperature for 1 hour. The immune complexes were visualized using diaminobenzidine (DAB) as the substrate.^{11,15}

***In situ* hybridization**

In situ hybridization was performed as previously described.¹¹ Briefly, a subclone of cDNA corresponding to the murine VEGF gene was linearized and used to generate an antisense ³⁵S-UTP-labelled riboprobe. Paraffin sections were hybridized with probes overnight at 48°C

and post-washed at 53°C with increasing stringency. After drying, slides were coated with emulsion and exposed for 7-14 days. After developing, sections were stained with Hoechst dye to visualize the nuclei. A dark-field image of the exposed silver grains was superimposed on the fluorescent image of the nuclei in Adobe Photoshop CS.

Detecting beta-galactosidase in Tie2-cre/R26R mice

Transgenic mice that express Cre-recombinase under the control of the Tie2 promoter (Tie2-cre) were mated to the reporter mouse strain Rosa26R, generating Tie2-cre/R26R mice that exhibit beta-galactosidase activity in cells of Tie2 lineage. The expression of beta-galactosidase was detected using a standard X-gal reaction. Fractures were created as described above in the mid-

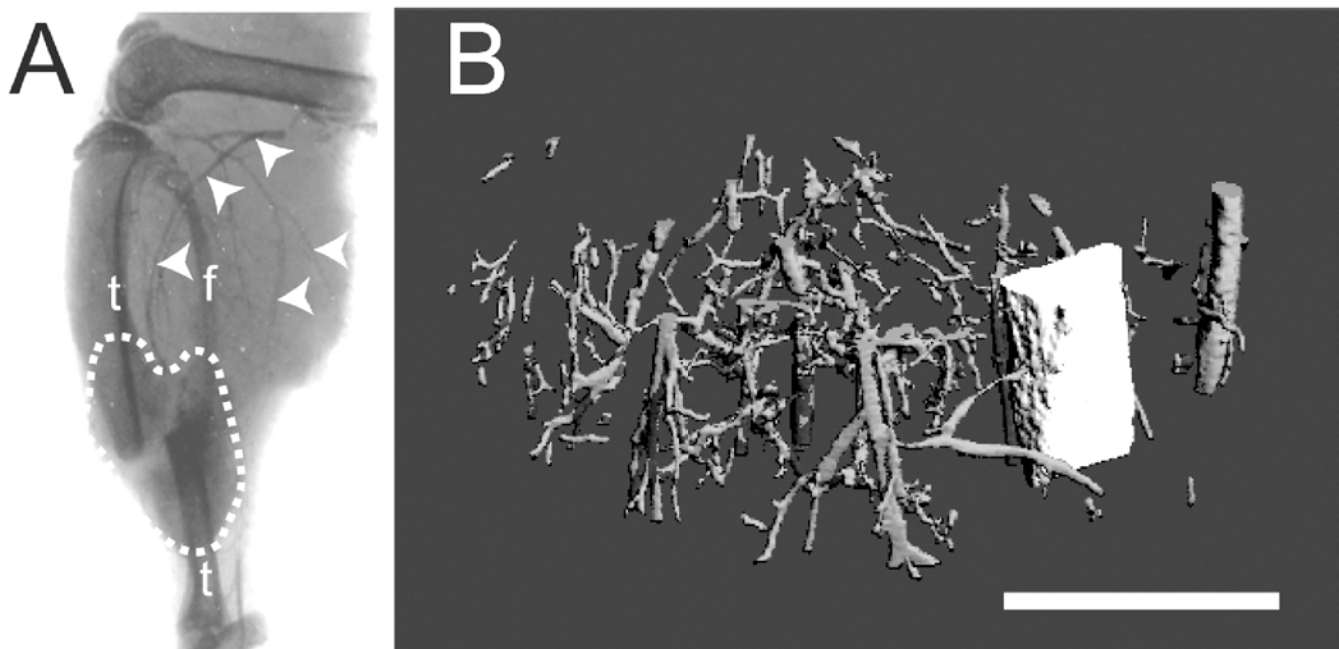


Figure 2. Blood vessels perfused by intracardiac barium suspension injection. (A) X-ray radiography was used to image the fracture, fracture callus (outlined), and the filled blood vessels (arrowheads) of a day 14 non-stabilized mouse tibia fracture. (B) A 3-dimensional image of blood vessels around the fractured bone was created after micro-CT scanning. t = tibia, f = fibula. Scale bar: B = 1mm.

diaphysis of the right tibia of 3 mice and the animals were euthanized 7 days after injury. Tissue was fixed in 0.4% PFA/PBS with 5mM EDTA and 2mM MgCl₂ overnight at 4°C, decalcified in 19% EDTA for 10-14 days, and embedded in O.C.T. Compound. Frozen sections (10 µm) were prepared, air dried for 2 hours, fixed in 0.2% Glutaraldehyde/PBS containing 5mM EDTA and 2 mM MgCl₂ for 30 minutes (room temperature), and washed with wash buffer (PBS with 0.1% Tween20 and 2 mM MgCl₂). The tissues were then incubated overnight at 37°C in X-gal staining solution (wash buffer with 1mg/ml X-Gal, 5mM Potassium Ferrocyanide, 5 mM Potassium Ferricyanide, and 20 mM Tris) in order to stain endothelial cells blue.

RESULTS

Visualizing the circulatory system of the mouse hind limb

The Microfil compound was successfully used to perfuse the whole circulatory system. This technique allowed visualization of the blood vessels in the leg and around the fracture site using a dissecting microscope (Figure 1A). Micro-CT scanning was then performed on one of the injected samples. When scanned at a resolution of 20 µm, the bone and mineralized portion of the callus were clearly visible, but only big blood vessels were observed (Figures 1B-D). The smaller blood ves-

sels were successfully imaged by micro-CT scanning using a suspension of barium sulfate as a contrast agent (Figure 2A). Partial decalcification enhanced the contrast between blood vessels and the surrounding tissues without affecting the radio-opacity of the intravascular barium sulfate. After reconstructing the micro-CT images, many blood vessels, both large and small, could be observed (Figure 2B).

Identification of endothelial cells

In order to identify endothelial cells in tissue section, two distinct approaches were used. In the first approach, endothelial-specific gene products (PECAM and CD34) were visualized using immunohistochemistry on paraffin and frozen sections. In the second approach genetically labeled endothelial cells (Tie2-cre/R26R) were visualized *in situ* during fracture healing.

PECAM: Immuno-detection of PECAM allowed visualization of blood vessels and endothelial cells in and around the fracture callus (Figure 3). Endothelial cells were present at sites of vascular invasion during endochondral ossification (Figures 3A, B), throughout newly formed bone (Figures 3C, D), and in muscle (Figure 3E) and bone marrow (Figure 3F). In addition to endothelial cells, other cell types in bone marrow, primarily monocytes, were also recognized by the anti-PECAM antibody (Figure 3F). Consistent PECAM immunostaining was

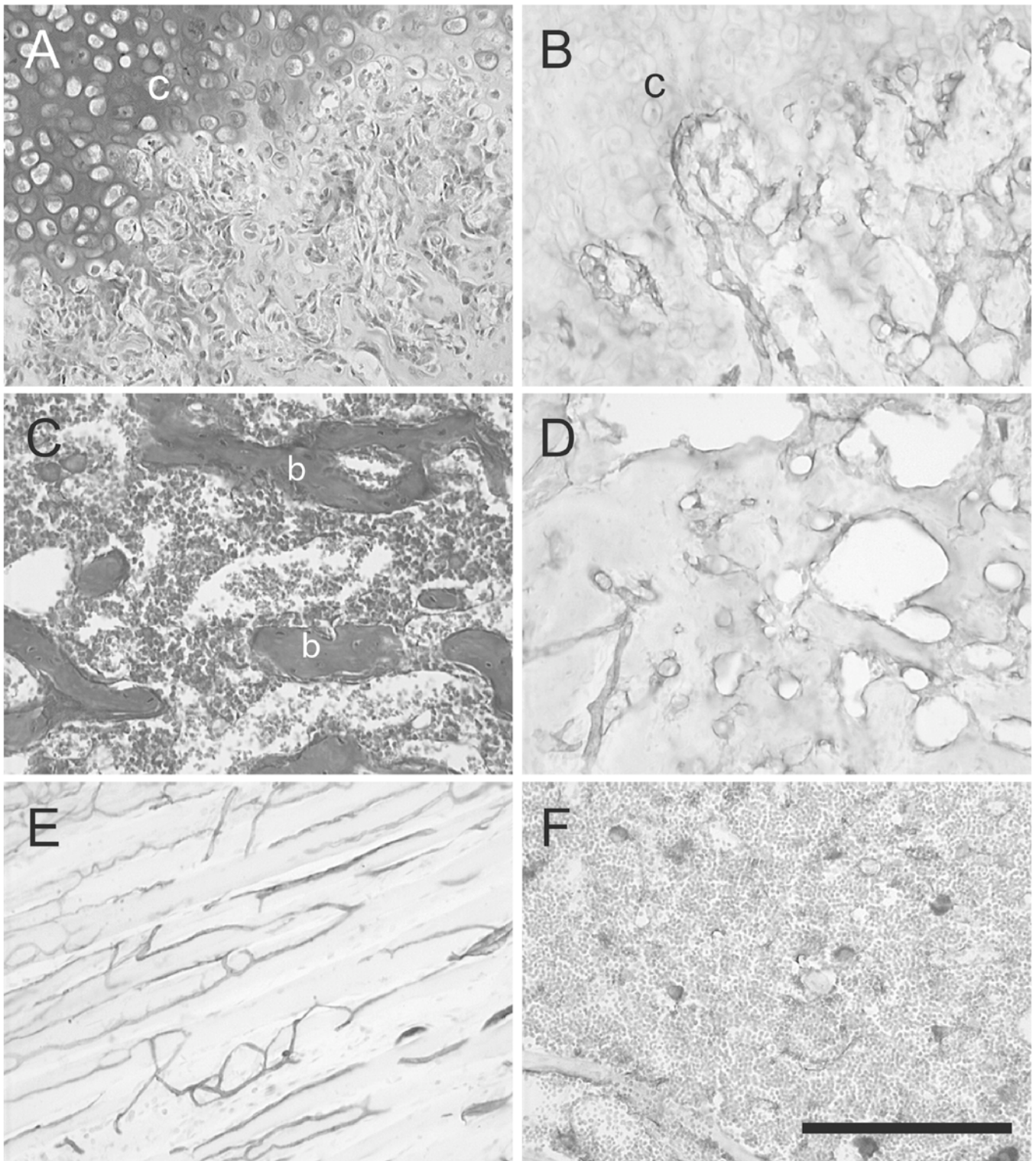


Figure 3. PECAM immunohistochemistry on frozen section (A) Safranin O/Fast Green staining shows that cartilage (c) is being replaced by new bone in the callus of day 14 non-stabilized mouse tibia fractures. (B) PECAM immunostaining shows blood vessels (black) invading cartilage (c). (C) Trichrome staining shows the newly formed trabeculae (b). (D) PECAM positive cells formed tubes within lumens between trabeculae. (E) A large number of blood vessels in muscle were labeled after PECAM immunostaining. (F) Some monocytes in bone marrow were also PECAM-positive. Scale bar = 200 μ m.

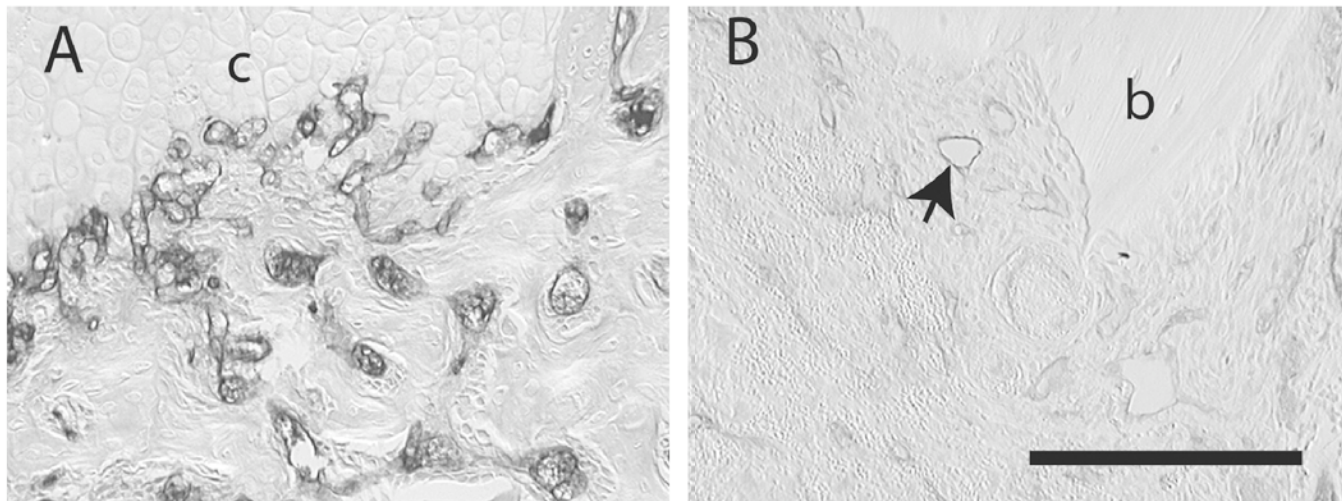


Figure 4. PECAM immunohistochemistry on paraffin section
(A) Strong PECAM staining was achieved on freshly cut paraffin sections through a day 14 non-stabilized fracture. (B) PECAM yielded weak (arrow) and inconsistent staining on old paraffin sections of a day 5 non-stabilized fracture. Scale bar = 200 μ m.

achieved on fresh cut sections with 0.1% trypsin digestion (Figure 4A). However, efforts to unmask PECAM antigen using multiple antigen retrieval techniques on stored paraffin sections were not successful, providing weak and inconsistent staining (Figure 4B).

CD34: The CD34 antibody tested in this study also worked on frozen but not paraffin sections. Endothelial cells in the fracture callus (Figure 5A) and new bone (Figure 5B) were clearly recognized by this antibody. However, detection of endothelial cells in muscle was inadequate, and only a relatively weak immuno-reaction was observed (Figure 5C).

Tie2-cre/R26R: Endothelial cells were clearly and unequivocally observable adjacent to the fracture callus (Figure 6). The X-gal reaction renders the labeled endothelial cells blue due to Cre-mediated recombination to activate expression of latent β -galactosidase. In addition to the large number of blood vessels near the fracture callus and in the surrounding tissues, a large number of bone marrow cells were also blue as a result of X-gal staining (data not shown).

Analysis of an angiogenic factor

In situ hybridization for VEGF transcripts was successfully performed and revealed VEGF expression in hypertrophic chondrocytes that comprise the cartilaginous scaffold of the fracture callus (Figure 7).

DISCUSSION

In order to better understand angiogenesis during fracture healing, we optimized several techniques to assess different aspects of vasculature using a murine tibia fracture model. These techniques allow visualiza-

tion of the macro-, micro-, and molecular organization of the circulatory system. Casting of the entire circulatory system in mice allows investigators to assess the extent of vascular damage in a manner similar to angiography in patients. Additionally, this approach allows researchers to assess only the patent circulatory system and provides a method to determine the volume of the blood vessels in a given region. Identification of endothelial cells in tissue sections provides a means to begin to understand the histological components required for blood vessel formation and reconstitution of an intact vascular supply. Lastly, determination of the temporal and spatial patterns of expression of various angiogenic molecules during fracture repair will enhance the understanding of how vascular repair is regulated.

Assessing vasculature at a macroscopic level

The technique of vascular perfusion has been used to visualize the circulatory system for a long period of time and has gained wide clinical use. Adaptation of this technique to rodent models allows the vasculature to be examined at a macroscopic level during fracture repair. Perfusion of the vessels with Microfil and subsequent evaluation by micro-CT is an easy and efficient way to visualize the circulatory system. Microfil casting requires no special equipment, is cheap, and provides decent perfusion of large blood vessels. In the field of angiogenesis research, micro-CT is superior to conventional angiography or blood vessel casting. Three-dimensional images can be generated from micro-CT scans, which can be used to determine the volume of the perfused vasculature in order to provide a quantitative assessment of vascularization.

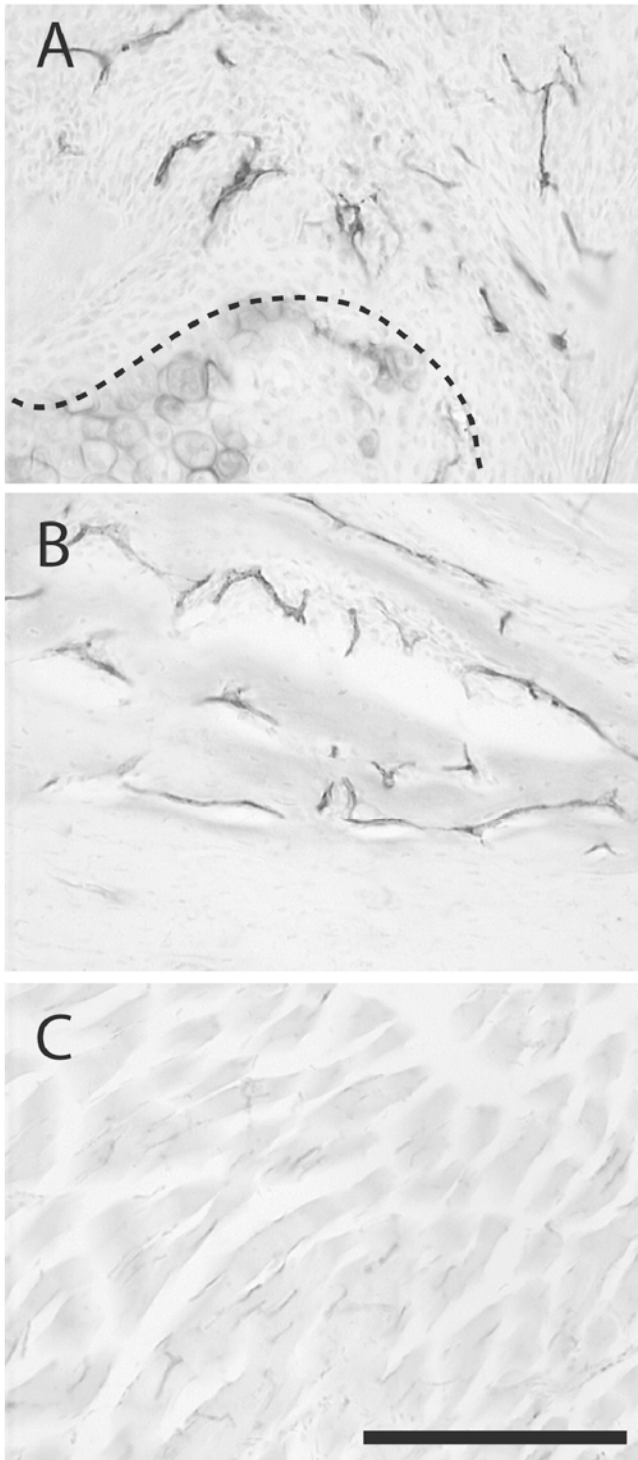


Figure 5. CD34 immunohistochemistry on frozen section (A) CD34 immunostaining was detected in blood vessels around a cartilage island (outlined) and (B) in newly formed bone of a day 14 non-stabilized mouse tibia fracture. (C) Blood vessels in muscle were weakly stained. Scale bar = 200 μm .

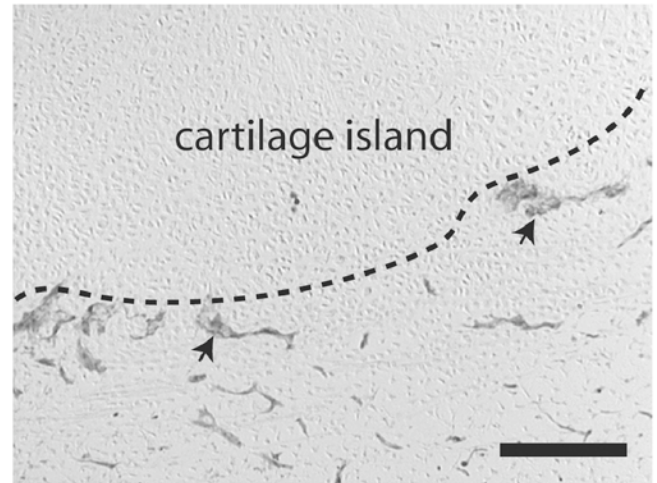


Figure 6. Visualization of blood vessels in Tie2-cre/R26R mice. Beta-galactosidase activity was assessed by a standard X-gal reaction on frozen section of a day 7 fracture. Blood vessels (arrows) around a cartilage island (outlined) were stained blue. Scale bar = 200 μm .

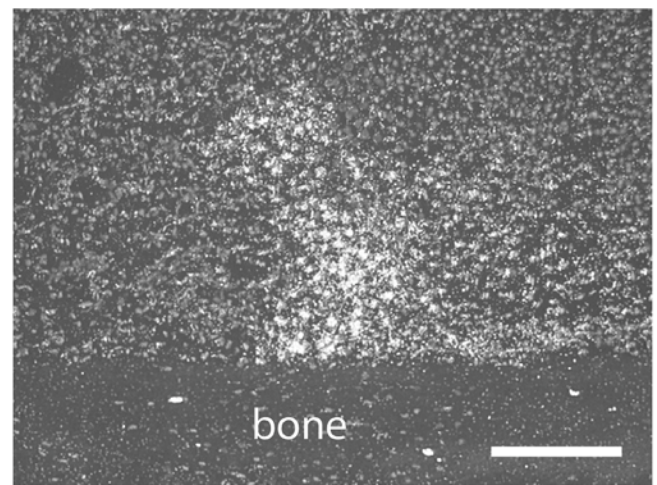


Figure 7. VEGF expression in fracture callus. VEGF transcripts were detected by *in situ* hybridization in a day 7 fracture. Hypertrophic chondrocytes expressed high level of VEGF. Scale bar = 200 μm .

Micro-CT scanning does have drawbacks. First, it requires an investment in equipment and trained personnel to undertake the required analyses. In addition, it is challenging to achieve high quality images of blood vessels by micro-CT scanning. Results could be affected by the quality of blood vessel perfusion, unknown characteristics of the fracture callus, and the resolution used for scanning. For instance, the absence of blood vessels in certain areas or the appearance of “dead ends” may reflect physiologically relevant processes: the dead ends could be areas where blood vessels are damaged, sealed, or undergoing active angiogenesis. Alternatively, these regions could have simply not been filled due to fluctuations in perfusion pressures or other unknown variables.

Similarly, mineralization of the fracture callus may render the contrast dye ineffective. The data presented in this work illustrate that perfusion with a suspension of barium sulfate followed by partial decalcification of tissues may be used to achieve high quality imaging. Lastly, while the resolution of micro-CT imaging has improved dramatically, adequate visualization of micro-vessels may still be limited. Unfortunately, these vessels are probably more important for vascular function than the larger vessels, since the microcirculation provides a larger surface area for gas and nutrient exchange.

Assessing angiogenesis on tissue sections

Small blood vessels are composed of endothelial cells, a basement membrane, and pericytes. Markers expressed by endothelial cells or pericytes are commonly used to label blood vessels by immunohistochemical approaches. In this study, we tested two markers of endothelial cells: PECAM¹¹ and CD34. PECAM is a 130 kd transmembrane glycoprotein belonging to the immunoglobulin superfamily of cell adhesion molecules. This protein functions as an adhesive molecule and a mediator of signal transduction through modulation of integrin function in order to regulate vascular integrity and cell survival.¹⁶ PECAM protein is found at the cell-cell borders of neighboring endothelial cells and is also expressed by platelets, monocytes, neutrophils, or some T cells. CD34 is another transmembrane glycoprotein present on endothelial cells, leukemic cells, and some progenitor cells. The function of the CD34 protein remains unknown. Nonetheless, detection of these two molecules provides an easy way to identify blood vessels and endothelial cells in tissues adjacent to the fracture site.

In general, immunohistochemistry to detect PECAM on frozen sections was much more effective and consistent compared to paraffin embedded tissues. On freshly cut paraffin sections less than 1 week old, antigen retrieval was effective at unmasking the epitope recognized by the antibody. However, if sections were stored, then results of immunohistochemical detection of PECAM became inconsistent. The reason for this is unclear but could involve either degradation of the protein upon storage or alteration of the protein that makes it resistant to unmasking via antigen retrieval methods.

A novel approach to the study of angiogenesis utilizes a creative molecular technique that indelibly marks specific cell types and thus allows a lineage analysis in embryonic and adult mice. This approach uses the Cre/loxP system and a tissue specific promoter to stimulate expression of a transgene in specific cells. Cre is a bacteriophage P1-derived recombinase that efficiently excises DNA that is flanked by two repeated

loxP recognition sites. The DNA is then recombined, and the result is removal of the piece of DNA flanked by the two loxP sites (usually referred to as “floxed”). The ease of creating DNA constructs containing a specific promoter that drives expression of Cre recombinase has made use of the Cre/loxP system to mediate site-specific DNA recombination versatile.^{17,18}

The Tie2-cre mice¹⁴ provide a mechanism of identifying endothelial cells that does not require the use of immune reagents or other stains that often give inadequate results. In adult mice, an endothelial cell specific enhancer has been co-opted to drive Cre-expression. Hence, wherever the Tie2 enhancer is activated, Cre is also expressed. Since this enhancer functions exclusively in endothelial cells and their precursors, Cre recombinase is expressed only in derivatives of the endothelial cells and their precursors.¹⁴ The Tie2-cre mouse was mated to the Rosa26R mouse, which is widely used to analyze expression of Cre recombinase. β -galactosidase is separated from a ubiquitous promoter by a large region of floxed DNA. Upon Cre-mediated recombination, the β -galactosidase gets “placed” adjacent to the promoter and becomes activated. Thus, endothelial cells express β -galactosidase and can be tracked during fracture repair.

The data presented demonstrate that PECAM immunostaining and genetic labeling of endothelial cells using the Tie2-cre/R26R system are reliable techniques to visualize blood vessels in mouse fracture calluses at the microscopic level. One advantage of these techniques is that the tissues surrounding the blood vessels could easily be evaluated by histological or molecular (i.e., *in situ* hybridization) approaches, thus allowing analyses of the interaction between vascularization and tissue formation (such as chondrogenesis or osteogenesis) during fracture healing. Another advantage is that qualitative analysis can be achieved on these PECAM or X-gal stained sections by stereology or other histomorphometric methods to generate important parameters of vascular structure, such as vascular density and vascular bifurcation ratio.^{19, 20,21} However, one must keep in mind that neither PECAM immunostaining nor genetic labeling of endothelial cells using the Tie2-cre/R26R system is specific for new blood vessels. Markers specifically expressed by new blood vessels have been extensively explored during recent years. Among the most promising markers are the extra-B domain of fibronectin,²² prostate-specific membrane antigen (PSMA),^{23,24,25,26,27} and antibody E4G10,²⁸ which are reported to be expressed by tumor blood vessels but not vessels in surrounding normal tissues.

Lastly, commonly employed techniques such as *in situ* hybridization work well to assess expression patterns of key angiogenic genes during fracture healing.

These studies are necessary in order to identify key molecular and cellular regulators of angiogenesis during fracture repair. Future work is related to utilizing these methodologies to define in detail the molecular and cellular events that regulate angiogenesis during fracture healing and to assess the role of the vasculature during bone repair.

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MEDIUM TERM FOLLOW-UP OF ACHILLES TENDON LENGTHENING IN THE TREATMENT OF ANKLE EQUINUS IN CEREBRAL PALSY

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ABSTRACT

Introduction: The optimal treatment for equinus of the ankle in ambulatory patients with cerebral palsy is not known. This study assessed the medium term follow-up results of treatment of spastic ankle equinus deformity in cerebral palsy using Hoke or coronal Z-lengthening of the Achilles tendon. It was hypothesized that the use of Achilles tendon lengthening (TAL) as a treatment for spastic ankle equinus during gait results in a high rate of over-weakening of the triceps surae resulting in crouch gait. We also investigated patient characteristics that could identify which patients are at risk for crouch gait due to triceps surae weakening from Achilles tendon lengthening.

Materials and Methods: Seventy-nine patients (114 procedures) who had undergone Achilles lengthening were retrospectively reviewed to determine how many patients developed crouch gait with dorsiflexion of the ankle throughout stance phase requiring anterior-floor-reaction bracing. The following patient characteristics were evaluated: age at surgery, geographic type of cerebral palsy, length of follow-up, need for anterior-floor-reaction bracing, length of time after surgery when brace was prescribed, age at time of need for bracing, side of surgery, technique used, additional procedures performed at time of TAL, previous or later procedures performed, and walking ability.

Results: The average age at the time of TAL was 7 years and 3 months, and the average follow-up was seven years. The geographic type of cerebral palsy greatly affected the outcome. None of the twenty-three hemiplegic patients required bracing. Fourteen of 34 (41%) patients

with spastic diplegia and seven of fourteen (50%) patients with spastic quadriplegia required bracing. There was no significant difference in outcome between the Hoke and the Z-lengthening procedures. Patients who underwent more procedures and bilateral procedures were more likely to require anterior-floor-reaction bracing.

Conclusions: Achilles tendon lengthening as practiced by the senior author results in a high rate of over-weakening of the triceps surae as defined by the need for a floor reaction brace. Results are best in patients with hemiplegia and non-hemiplegic patients who require only single leg surgery, and who do not require concomitant or subsequent surgery. Alternative treatment, such as gastrocnemius fascial lengthening, or non-surgical treatment may be the optimal treatment of ambulatory patients with spastic diplegia and quadriplegia who have spastic ankle equinus during gait.

INTRODUCTION

Equinus deformity of the ankle is one of the most common problems encountered in cerebral palsy.^{1,2,3,4} Equinus disrupts the gait cycle by decreasing stability in stance phase and causing inadequate clearance in swing phase.^{5,6} Nonoperative treatments for an equinus deformity of the ankle include stretching exercises, serial casting, bracing,⁷ and temporary or permanent denervation with botox,^{8,9} alcohol, or phenol.¹⁰ Operative treatments include surgical denervation, Achilles tendon lengthening, gastrocnemius and/or soleus fascial lengthening, and anterior advancement of the Achilles insertion.^{11,12,13} Numerous heel cord-lengthening techniques have been described including tendon "slides" performed open or percutaneously, coronal Z-lengthening, and sagittal Z-lengthening.^{14,15,16,17} Three of the most common gastrocnemius lengthening techniques are those described by Baker,¹⁸ Strayer,¹⁹ and Vulpius.²⁰ The Baker and Vulpius procedures may or may not include soleus fascial lengthening as well as gastrocnemius fascial lengthening.

Which technique is most appropriate for a given patient is still unknown and controversial.²¹ Advocates of the selective gastrocnemius lengthening procedures stress the improved push off and decreased risk of over-lengthening,^{15,22,23,24,25} while accepting the reported increased rate of recurrent deformity.^{4,22} Advocates of Achilles tendon lengthening cite reported recurrence rates of equinus of 30 to 41 percent after gastroc-soleus fascial

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lengthening.^{4,22} Rates of recurrence and over-lengthening are reported to be unaffected by technique of tendon lengthening or by the performance of concurrent procedures.^{20,26,27,28,29,30} The amount of lengthening of the tendo Achilles is usually determined by bringing the foot into neutral, five, ten, or fifteen degrees of dorsiflexion during suturing of the lengthened tendon. Quantifying the appropriate length of fixation of the tendon is difficult, but attempts at standardization have been made based on an assessment of the patient's spasticity or on geometrical measurements.^{2,27} Many surgeons assess these patients under anesthesia using the Silverskiöld test to determine whether to perform a gastrocnemius lengthening or an Achilles tendon lengthening.³¹

The goal of the treatment of ankle equinus is to obtain a plantigrade foot without compromising triceps surae function. Next to recurrence of equinus deformity, over-lengthening is the most common complication. The functional limitation created by over-lengthening of the Achilles tendon is crouched or calcaneus gait.⁵ This occurs due to the inability of the weakened triceps surae to restrain the forward movement of the tibia when the center of gravity moves in front of the ankle center of rotation during gait. The patient loses the normal plantar-flexion/knee extension couple. The weight bearing line becomes anterior to the ankle and hip center and posterior to the knee joint resulting in flexion at both the knee and hip with dorsiflexion of the ankle (crouch gait).⁵ Crouch gait results in increased work of gait, early fatigue, and decreased stride length. Secondary hip and knee flexion contractures develop over time. The increase in patellofemoral joint reaction force commonly results in patellofemoral pain, which is often severe and may precipitate the cessation of walking.

Uniformly successful treatment of crouch gait due to over-lengthening of the triceps surae has not been reported. The senior author treats children with crouch gait with anterior-floor-reaction bracing to substitute external bracing for weak triceps surae. These braces are cumbersome for the patient to doff and don. Most patients find getting up and down from the floor as well as stair climbing more difficult with anterior-floor-reaction braces. Although alignment and endurance may improve, stability may worsen due to the rigidity of the brace. In many patients, anterior-floor-reaction braces are not effective in alleviating crouch, particularly in patients with poor mechanical foot alignment.

The controversy over the best surgical technique has important implications for patient care. Specifically, proponents of gastrocnemius fascial lengthening maintain that weakening the soleus contributes to the development of crouch gait.³² Crouch gait is the most common gait pattern in previously ambulatory patients

with spastic diplegia/quadruplegia who abandon walking. This retrospective case series review was prompted by the senior author's observation that many of his older patients were crouching and requiring anterior-floor-reaction braces. The study was performed to assess the magnitude of the problem in his patient population.

The purpose of this study is to evaluate the post-surgical results of one surgeon in the treatment of spastic ankle equinus deformity in cerebral palsy at an intermediate postoperative follow-up. It was hypothesized that TAL as a treatment for ankle equinus during gait contributes to a high rate of crouch gait in adolescence. We also sought patient characteristics that distinguish patients who develop crouch gait after TAL from those who do not.

MATERIALS AND METHODS

From 1984 to 2000, 80 patients with cerebral palsy who had operations for ankle equinus during gait by the senior author (FRD) were identified from the hospital coding records (total of 115 procedures to lengthen the Achilles tendon). One patient did not return for follow up after cast removal and was excluded from the analysis. The charts of the remaining 79 patients (114 procedures) were retrospectively reviewed to identify the following: age at surgery, age at most recent follow-up, type of cerebral palsy, whether anterior-floor-reaction braces were prescribed for crouch gait, length of time after surgery brace was prescribed, age at time of brace prescription, side of surgery, surgical technique employed, concomitant procedures performed at time of TAL, and previous or later procedures performed. Type of cerebral palsy was identified as hemiplegia, diplegia, triplegic, quadriplegia, mixed athetoid/spastic, or dyskinetic based on the diagnosis in the clinical records from the orthopaedic and the developmental pediatrics clinics. Patients who had not been seen recently in clinic were contacted by phone to confirm the bracing status.

All patients in this case series were treated by a single physician with a philosophy of treatment of ambulatory children with cerebral palsy as follows: Bracing and physical therapy are the mainstays of treatment until the gait pattern has stabilized, usually between 4 and 7 years of age. When the gait pattern has stabilized, all sagittal and coronal plain deformities are corrected with soft tissue procedures in one operation. As needed, the psoas is lengthened at the brim of the pelvis for hip flexion contracture; the hamstrings are lengthened for knee flexion; the rectus femoris is transferred to the hamstrings for stiff knee gait; the Achilles tendon is lengthened for ankle equinus; and the adductor longus and gracilis are released for scissoring gait.

Bony procedures were performed only for hip instability and were not done at the same time because the senior author believes that rehabilitation is more rapid and successful if the soft tissue procedures are not combined with prolonged immobilization (typically 6 weeks in a spica cast) that he employs following VDO and/or San Diego acetabular osteotomy for hip instability.

Achilles tendon lengthening is accomplished by a coronal Z-plasty or by an open Hoke "sliding" lengthening. The Hoke lengthening is used in milder cases, and the Z-plasty is employed with more severe contractures too great to treat with a sliding lengthening without risk of tendon rupture. A patient was indicated for surgical intervention when bracing had failed to control the equinus deformity during gait.

The Hoke procedure was done through a posteromedial incision. Three cuts were made horizontally in the tendon. Two cuts were made medially (one proximal and one distal) half-way across the width of the tendon, and one cut was made laterally midway between the two medial cuts. The foot was then passively dorsiflexed to neutral. The leg was immobilized in either a below or above knee cast for a minimum of 6 weeks, with the exception of one patient who was immobilized for four weeks. Full weight bearing was encouraged.

The coronal Z-lengthening was also performed through a posteromedial incision. The tendon sheath was incised along the medial border of the tendon. One centimeter of the plantaris tendon was excised if present. The posterior aspect of the tendon was exposed with care taken to not expose the tendon anteriorly, preserving the peritendinous attachments of the proximal tendon in order to avoid excessive proximal migration. The tendon was then cut in a step cut fashion coming out anteriorly in the distal tendon and posteriorly in the proximal tendon. The ankle was dorsiflexed to neutral. The foot was then positioned in neutral while the tendon was sutured under maximum tension obtained by thumb forceps on both limbs of the tendon. The wound was then irrigated and closed in a standard fashion. Postoperative immobilization consisted of six weeks in a below or above knee cast with full weight bearing.

The clinical diagnosis of crouch gait was determined during follow-up visits by observational gait analysis by the senior author (FD). The diagnosis of crouch gait and treatment with anterior-floor-reaction braces was made when a patient exhibited more than 30 degrees of knee flexion throughout stance phase AND the ankle was in dorsiflexion throughout stance phase. The single outcome variable of interest is the prescription of anterior-floor-reaction braces for crouch gait.³³

We assessed the incidence of crouch gait as reflected by the prescription of anterior-floor-reaction braces with

respect to the following: Hoke vs. coronal Z-lengthening, type of cerebral palsy, bilateral vs. unilateral Achilles tendon lengthening, age at surgery; age at final follow up, and performance of concomitant procedures. Student's t-tests and Fisher exact test were used for comparative analyses as appropriate.

RESULTS

The average age at the time of surgery was 7 years and 3 months (range 18 months to 47 years). The average age at time of most recent clinic follow-up was 14 years and 2 months (range 4 years to 47 and 8 months). Twenty-three (29%) were classified as spastic hemiplegic. Thirty-four patients (43%) were spastic diplegic. Fifteen (19%) were spastic quadriplegic. Four (5%) had mixed cerebral palsy, two were triplegic, and one patient was diagnosed with dyskinetic cerebral palsy. Surgery was performed bilaterally in 34 patients (43%), on the right side only in 22 patients (28%), and on the left side only in 23 patients (29%). A Hoke lengthening was performed 56 times (49%) and the coronal Z-lengthening was performed 56 times (49%). One operative note did not specify which of the two types of lengthening procedures was performed. In a single procedure, a White type of lengthening (two rather than three step cuts) was performed. A total of 151 additional procedures were performed on fifty of the seventy-nine patients (63%) at the time of the TAL.

The patient's type of cerebral palsy had the greatest affect on the need for anterior-floor-reaction bracing. None of the 23 hemiplegic patients required bracing. Twenty-three of the 56 (42%) of the non-hemiplegics required anterior-floor-reaction bracing. Fourteen of the 34 spastic diplegic patients (41%) required bracing. Seven of fourteen quadriplegic patients (50%) required bracing. There was no significant difference in bracing incidence comparing the diplegic and quadriplegic patients ($p = 0.75$), but there was a significant difference between the hemiplegic and non-hemiplegic patients ($p=0.0003$). Two patients of the eight with "other" diagnoses required bracing (25%). Because hemiplegics never developed crouch gait and the "other" diagnoses group is small, all further evaluation was done only on the diplegic and quadriplegic groups.

The type of procedure employed to lengthen the Achilles tendon did not affect the need for anterior-floor-reaction bracing. Because some patients had a Hoke lengthening of one side and a coronal Z lengthening of the other, the different procedures were compared by limb rather than by patient. Following a Hoke procedure, 17 of 40 limbs were braced (43%), while 23 of 43 limbs were braced (53%) following coronal Z-lengthening ($p<1.00$ for the right side and $p<0.35$ for the left side).

Surgical lengthening of both Achilles tendons tended to affect the likelihood of patients' requiring anterior-floor-reaction braces. Eighteen of 33 patients (55%) undergoing bilateral TAL's were prescribed anterior-floor-reaction braces, while only 4 of 17 patients (24%) with unilateral procedures were braced ($p < 0.086$).

Patients who underwent concomitant procedures tended to require braces more often. Three of 11 patients (28%) without concomitant procedures were braced, while 19 of 36 patients with concomitant procedures were braced (53%) ($p < 0.06$). Patients requiring subsequent orthopaedic surgery did not have a statistically higher rate of anterior-floor-reaction bracing. Twelve of 22 patients (55%) were braced who had subsequent orthopaedic surgery, whereas 10 of 18 patients (36%) without subsequent orthopaedic surgery were braced ($p < 0.25$).

There was no statistical difference in the age at surgery or the age at follow-up. Mean patient age at the time of surgery was 7.7 years (standard deviation of 8.5 years) for the un-braced patients and 6.8 years (standard deviation of 2.2 years) for the braced patients ($p = 0.64$). Mean patient age at final follow up was 13.1 years (standard deviation of 8.5 years) for the un-braced patients and 14.5 years (standard deviation of 4.5 years) for the braced patients ($p = 0.50$). Mean time after surgery when anterior-floor-reaction braces were prescribed was 3.5 years (standard deviation of 2.2 years).

DISCUSSION

A single surgeon case series study has limited scientific value, except perhaps as a warning if poor results are found. We believe that a 50% incidence of crouch gait requiring the prescription of anterior-floor-reaction braces is a poor result in the treatment of ambulatory patients with spastic diplegia and quadriplegia. Alone, this study is a modest warning. Coupled with the results of Borton's report of H. Kerr Graham's results of Achilles tendon lengthenings, we think this constitutes a strong warning.³⁴ Borton et al. reported on 65 diplegic and 45 quadriplegic patients treated by percutaneous Hoke, open TAL, or Baker gastroc-soleus fascial lengthening as isolated procedures for spastic equinus gait. Treatment was performed at an average age of 7.5 years and follow-up was almost 7 years. Forty percent of their diplegic patients and 60% of their quadriplegic patients showed calcaneus gait. Our conclusion is that treatment of ankle equinus by lengthening the Achilles tendon contributes to the development of crouch gait in an unacceptably large number of spastic diplegic and quadriplegic children. The extent of this contribution is uncertain. Johnson et al. have documented gradual deterioration as the natural history of gait in many ambulatory patients with

spastic diplegia.³⁵ Some of our patients were probably destined to develop crouch gait regardless of the type of intervention. We cannot, at present, distinguish these patients from those with a good long-term prognosis for functional walking with optimal treatment. We did find a trend toward more severely involved patients developing crouch gait after TAL.

The literature on triceps surae lengthening for equinus gait is difficult to evaluate. The reported rates of over-lengthening of the Achilles tendon vary from 0-60%.^{4,12,14,15,17,18,19,20,25,26,27,28,29,30,34,36,37,38} Many reports fail to mention this complication at all. Indications for surgery, outcome assessment methods, and patient populations are quite varied. Many studies have 3 years or less of follow-up after surgery.^{2,16,26,27,39,40} In our series, the diagnosis of over-lengthening was made most often within the first five years after surgery. However, a significant number were diagnosed up to ten years post-operatively. A multidisciplinary workshop was convened in 2000, sponsored by the American Academy of Cerebral Palsy and Developmental Medicine and the United Cerebral Palsy Research and Educational Foundation to "explore the current state of knowledge, best clinical practice, and research needs for the management of equinus gait associated with cerebral palsy."²¹ This group concluded that there is not enough evidence to recommend a best clinical practice. The senior author sent a survey to all members of the Pediatric Orthopaedic Society of North America (POSNA) with active e-mail addresses querying the treatment of spastic ankle equinus. One hundred and six pediatric orthopaedic surgeons responded and 78% performed TAL's or Hoke Achilles lengthening as part of their treatment for spastic ankle equinus. Only eight (7.5%) practitioners reported using gastrocnemius lengthening as their sole treatment for this problem.

Many variables could alter the outcome reported here for the treatment of ankle equinus during gait. Gastrocnemius lengthening/recession alone or, if necessary, separate lengthening of the gastrocnemius and soleus muscles may result in amelioration of ankle equinus with a decreased risk of over-weakening as argued by Gage et al.³² Delaying surgery to an older age might improve results. Assiduous attention to mechanical alignment, especially correction of plano-abductus feet, might improve results of heel cord lengthening. Only lengthening mildly affected patients would doubtless improve results. Prolonged AFO bracing after TAL might decrease the incidence of excessive weakening the triceps surae. It is clear that some spastic patients will walk indefinitely with ankle equinus if untreated from personal observations of adults with cerebral palsy.^{21,39} It seems likely that some children with ankle equinus, if untreated, will become plantigrade with increasing age and weight. On the other

hand, some patients with ankle equinus in childhood will develop crouch gait with increasing age and weight. Distinguishing between these groups would be important in designing optimal treatment protocols. Another group of patients probably exists who walk reasonably well during childhood and are aided in their walking while young by eliminating the equinus ankle, but are destined to not walk as adolescents or adults regardless of treatment.³⁵

We must consider the possibility that lever arm dysfunction at the hip, knee, or foot may predispose these patients to crouch gait as well. Further study is needed to evaluate the indications for each type of lengthening procedure. A randomized prospective trial including these varying procedures is conceivable considering most surgeons self-report performing Achilles tendon lengthening as well as gastroc-soleus fascial lengthening.

CONCLUSIONS

This retrospective, non-randomized, single surgeon case series study shows that questions exist regarding the complications of Achilles tendon lengthening procedures performed on children with a diagnosis of cerebral palsy. This is a single-surgeon assessment of the incidence of crouch gait, which cannot reliably be treated well. The high rate of over-lengthening after either a Hoke or coronal Z-lengthening resulting in crouch gait requires further examination. The increasing incidence of crouch gait in this series as these children get older lends itself to the conclusion that these patients are overpowering their triceps surae as they become older and heavier. Overall, the Achilles tendon lengthening procedure carries with it a high rate of failure as defined by the need for an anterior-floor-reaction brace. Results are best in patients with hemiplegia, in non-hemiplegic patients who require only single leg surgery, and in patients who do not require concomitant or subsequent surgery.

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COMPARISON OF FRACTURE VERSUS RADIOLUCENT TABLE IN THE TREATMENT OF SLIPPED CAPITAL FEMORAL EPIPHYSIS

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ABSTRACT

Purpose: Compare slipped capital femoral epiphysis stabilized on fracture versus radiolucent table.

Methods: Twenty unilateral stable mild slipped capital femoral epiphyses were stabilized in-situ with a single screw. Age, sex, side, body-mass index, type of table, anesthesia time, surgery time, fluoroscopy time, number of fluoroscopy images, preoperative/postoperative lateral head-shaft angle, and number of screw threads engaging the epiphysis were noted.

Results: There were no differences in the measured parameters.

Conclusions: Stabilization of mild slipped capital femoral epiphysis can be accomplished reliably and safely with the use of either a radiolucent or fracture table.

INTRODUCTION

The treatment goals of slipped capital femoral epiphysis (SCFE) are to stabilize the physis, achieve epiphysiodesis, and avoid complications. Successful proximal femoral physeal fusion without slip progression has been reported using a single centrally placed screw.^{1,2} SCFE can be stabilized on either a fracture table or a radiolucent table. Lee and Chapman described in-situ fixation for slipped capital femoral epiphysis on a radiolucent operating table.³ The authors found the procedure to be easy and reliable.

The relationship between table selection, time required, and screw placement has been studied.⁴ Blasler et al. noted greater operating room and surgery times for the fracture versus the radiolucent table. The purpose of the current study was to compare the perioperative outcomes of unilateral mild stable slipped capital femoral epiphysis treated with in-situ single-screw fixation using either a radiolucent table or a fracture table.

METHODS

The medical records and radiographs of all children who underwent in-situ fixation of SCFE with a single cannulated screw at a single institution were reviewed. The medical records were reviewed for stability, sex, side, age at surgery, height, weight, surgery time, anesthesia time, fluoroscopy time, and number of fluoroscopic images taken. A patient who was able to walk with or without crutches was classified as having a stable SCFE.⁵ Frog-leg lateral radiographs were reviewed for the head-shaft angle, the number of threads engaging the epiphysis, and slip progression. The choice of surgical table was by surgeon preference. Only unilateral mild slips were included in order to have a similar population for comparison.

The lateral head-shaft angle was calculated according to the method described by Southwick.⁶ The value for the lateral head-shaft angle of the normal hip was subtracted from the head-shaft angle on the affected side to obtain the slip angle. A mild slip was defined as a difference in the head-shaft angle of less than 30 degrees; a moderate slip was a difference of 30-50 degrees; and a severe slip was a difference of more than 50 degrees.⁷

The number of threads was determined on the first postoperative frog-leg lateral radiograph as the most threads on either side of the screw contained within the epiphysis. The number of threads was recorded as either five, or more or less than five. Slip progression was based on the difference between pre- and post-operative lateral head-shaft angles. A difference of 10 degrees or more was considered slip progression.⁸

The body mass index (BMI) was calculated as $[\text{body wt in kg}/(\text{body ht in cm})^2] \times 10^4$.⁹ Chi square p-values were calculated on observed frequencies of nominal data. Analysis of variance (ANOVA) was performed on grouped continuous data. A p-value <0.05 was considered significant.

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TABLE 1
Patient Data

Pt. No.	Sex	Side	Age	BMI	Table	Anes. Time	Surgery Time	Preop head-shaft angle	Postop head-shaft angle	Fluoro time	Fluoro Images	Threads
1	F	L	10.4	31	Fracture	95	25	18	24	109	61	<5
2	F	R	9.75	30	Fracture	78	32	20	23	82	43	<5
3	M	L	10.3	32	Fracture	75	32	21	19	102	49	<5
4	M	R	12.2	38	Fracture	109	66	19	16	259	190	<5
5	F	R	12.1	25	Fracture	191	41	24	26	187	116	>5
6	M	L	14.8	26	Fracture	127	36	22	20	75.8	54	<5
7	F	R	9.5	31.6	Fracture	104	42	20	17	241	130	>5
8	M	R	12.9	37	Fracture	95	37	17	25	144	84	>5
9	F	L	11.1	37	Fracture	70	29	25	33	120	74	<5
10	M	L	11.5	22	Radioluc	163	33	28	31	251	124	<5
11	M	L	10.3	35	Radioluc	110	45	17	21	205	132	<5
12	F	L	10	29	Radioluc	65	29	27	26	78	58	<5
13	M	L	13.1	28	Radioluc	60	18	29	31	80.2	46	<5
14	M	L	13.5	36	Radioluc	60	20	23	24	100	78	<5
15	M	R	11.8	31	Radioluc	66	19	27	23	65.5	49	<5
16	M	R	11.1	30	Radioluc	66	20	25	33	101	88	>5
17	M	R	12.3	28	Radioluc	62	24	25	26	106	66	>5
18	F	R	10.6	24	Radioluc	125	58	19	14	254	145	<5
19	M	L	12.4	24	Radioluc	73	46	5	13	N/A	75	>5
20	M	R	11.5	25	Radioluc	35	20	18	15	120	56	>5

RESULTS

Forty-eight children were diagnosed with a stable slipped capital femoral epiphysis and treated with in-situ single-screw fixation. Of these 48 children, 20 were classified as having a mild unilateral stable slip, and comprise the study population. Eleven children were treated on a radiolucent table and nine children were treated on a fracture table. There were 13 males and seven females. There were 10 slips on the right side and 10 slips on the left side. Table 1 shows the patient data.

The mean age at surgery was 11.7 years ± 1.5 (range 9.5-14.8). The mean head-shaft angle on the preoperative frog-leg lateral radiographs was 21 degrees ± 5 (range 5-29). The mean BMI was 30.0 ± 4.9 (range 21.6-38.0). The mean anesthesia time was 91 minutes ± 38 (range 35-191). The mean surgery time was 33 minutes ± 13 (range 18-66). The mean number of fluoroscopic images was 86 ± 40 (range 43-190). The mean fluoroscopy time was 141 seconds ± 68 (range 66-259) (Table 2). The number of screw threads that engaged the femoral epiphysis on the first post-operative frog-leg lateral radiograph was five or greater in seven slips, and less than five in 13 slips.

Table 2 shows the comparison of selected variables. There was no statistical difference between the radiolucent table group and the fracture table group for any of the measured outcomes. There was no statistical difference when comparing for side (right or left) and table (p=0.65). There were four left slips and five right slips that had surgery on the fracture table. There were six left slips and five right slips that had surgery on the

TABLE 2
Selected Variables

	Radiolucent table (mean)	Fracture Table (mean)	Outcome (p-value)
Age	11.7	11.7	0.97
BMI	28	32	0.11
Preoperative head-shaft angle (degrees)	22	21	0.57
Anesthesia time (minutes)	81	105	0.16
Surgery time (minutes)	30	38	0.21
Fluoroscopy time (seconds)	136	147	0.75
Fluoroscopic images	83	89	0.77

radiolucent table. There was no statistical difference when comparing the sex of the patient and the table used (p=0.081). There were five females and four males that had surgery on the fracture table. There were two females and nine males that had surgery on the radiolucent table.

Analysis of table and the number of threads engaging the femoral epiphysis showed no statistical difference between the fracture and radiolucent table (p=0.89). Of those children that had surgery on the fracture table, three had five or more threads engaging the epiphysis and six had less than five threads. On the radiolucent table, four patients had five or more threads and seven had less than five threads engaging the epiphysis. There were no slips that progressed 10 degrees or more.

DISCUSSION

Both radiolucent and fracture tables have been used while performing in-situ single-screw fixation of SCFE. Aronson and Carlson, Ward et al., and Goodman et al. have all reported series in which a fracture table was utilized for in-situ single-screw fixation of SCFE.^{1,2,10} An advantage of using a fracture table is that no further manipulation of the hip may be required once the patient is positioned. The procedure then involves placement of the screw under fluoroscopic guidance.

Lee and Chapman have previously described the technique of in-situ single-screw fixation using a radiolucent table.³ Proposed advantages of using a radiolucent table are a decrease in operating room time (because there is no need to transfer and set up the patient on the fracture table), better visualization of the lateral image, and the ability to perform bilateral procedures more easily. However, because fluoroscopic imaging is obtained with manipulation of the limb, there is the potential of guide-wire breakage.¹¹

Blasier et al. compared the use of radiolucent and fracture tables.⁴ All patients were treated with single-screw fixation. Thirty-six patients were treated on a fracture table and 29 on a radiolucent table. Time on the table and time for surgery were significantly greater for the fracture table versus the radiolucent table. Mean operating room time on the fracture table (63 minutes) was greater than that on the radiolucent table (51 minutes). Mean surgery time for the fracture table (39 minutes) was greater than that for the radiolucent table (25 minutes). The authors felt that use of the radiolucent table was a useful alternative to use of the fracture table for fixation of SCFE. Although we noted a trend in increased times, our study did not confirm the significance reported by Blasier et al. Our slip population was restricted to stable unilateral mild SCFE. The study of Blasier et al. included slips with a range of slip angles (16-88 degrees) and 12 bilateral patients.

Slip progression following fixation for slipped capital femoral epiphysis has been previously evaluated.^{8,12} Carney et al. retrospectively evaluated the progression of stable SCFE treated by single cannulated screw epiphyseodesis in-situ.⁸ The surgery was accomplished on either a radiolucent or a fracture table. Slip progression of more than 10 degrees occurred in 20% of cases and appeared to be inversely related to the number of threads crossing the physis. Placement of the screw with five threads engaging the epiphysis was suggested. The comparison of results following use of a radiolucent versus a fracture table was not performed, but provided motivation for this study. In the current series, there was no statistical difference between table groups with respect

to the number of threads engaging the femoral epiphysis. When using the fracture table, 33% of screws had more than five threads engaging the epiphysis. When using the radiolucent table, 36% of screws had more than five threads engaging the epiphysis.

This study compared the perioperative outcomes of in-situ single-screw fixation of mild unilateral stable slipped capital femoral epiphysis using either a radiolucent or fracture table. There was no difference between the table groups with respect to age, side of slip, or BMI. The outcomes of anesthesia time, surgery time, fluoroscopic time, the number of fluoroscopic images taken, slip progression, and the number of threads engaging the epiphysis were not statistically different when comparing table groups. In-situ single-screw fixation of a unilateral stable slipped capital femoral epiphysis can be accomplished reliably and safely with the use of either a fracture or radiolucent table.

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BONE PLATING IN PATIENTS WITH TYPE III OSTEOGENESIS IMPERFECTA: RESULTS AND COMPLICATIONS

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ABSTRACT

The results of bone plating in four children (6 femurs, 2 tibias) with osteogenesis imperfecta type III were analyzed. Average age at time of operation was 44 months. In three of the femurs, multiple platings were performed for a total of 13 bone platings in the eight bones studied. Average time to revision following plating was 27 months. Indications for revision included fracture (6), deformity (3), hardware failure (3), and nonunion (1). Other complications included one case of compartment syndrome. All eight bones were ultimately revised to elongating intramedullary Bailey-Dubow rods. Bone plating in skeletally immature patients with osteogenesis imperfecta does not provide better outcome than elongating rods. Complications from bone plating leading to revision, such as refracture or hardware failure, are higher than in those children managed with elongating rods, as previously reported in the literature.

INTRODUCTION

Osteogenesis imperfecta (OI) is a group of inherited disorders caused by defective type I collagen synthesis. Using the Sillence classification, one can determine the type of OI based on clinical, radiographic, and genetic findings.¹³ Patients with OI can suffer from frequent fractures and deformity of the long bones during development, resulting in impaired ambulation. The goal of orthopedic surgery for OI is twofold: Reduce the incidence of fractures and correct long bone deformity. Contemporary surgical options for deformed bones in OI include osteotomy and stabilization with non-elongating nails (Rush rods, flexible nails), elongating nails (Bailey-Dubow, Frasier-Duval), and bone plating.^{1-4,7,8,10,14,15} Elongating rods allow for growth of the bone, thereby

decreasing the number of repeat operations. The advantages of elongating rods over fixed intramedullary rods include benefit to growing bones, lower incidence of re-fracture, and longer time to re-operation.^{4,5,11,12} There is also evidence that suggests that elongating rods used in the femur do not require revision as often as those placed in the tibia.¹⁶

At our institution, we have utilized plate fixation for stabilization of osteotomies in young patients with severe OI. Plate fixation was initially appealing in this group of patients given the age of the individuals and the difficulty of placing expandable rods in small bones. In addition, the treating surgeon felt that these rods were too large for the smallest children, thus resulting in stress shielding and bone atrophy. The purpose of this study is to review our experience in this small but select group of patients.

MATERIALS AND METHODS

This study is a retrospective review of all patients with osteogenesis type III treated with bone plating for correction of deformity or treatment of fracture. All operations were performed by the same pediatric orthopedic surgeon between 1994 and 2001. Inclusion criteria for this study were a diagnosis of type III osteogenesis imperfecta, history of bone plating, and recent clinical follow-up.

After review of the medical files of all patients treated for osteogenesis imperfecta at the University of Wisconsin Hospital and Clinics, we were able to find four patients who had undergone at least one bone plating as treatment for fracture or deformity. Clinical records and imaging studies were reviewed. We recorded the indications for initial plating, types of plates and screws used, time to evidence of healing on radiograph, time to revision, indications for revisions, hardware used in revision (plate or rod), number and location of fractures following each plating, complications including hardware failure, and number of revisions for each bone. Regarding the measurement of time to fracture and time to revision, the authors considered each plating separately. There were cases of sequential platings of the same bone in patients where initial plating was revised with further plating. Initial plating was considered as the start point for this study, and revision with expandable rods was considered the end point.

Study conducted at University of Wisconsin Hospital and Clinics, Madison, WI

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Figure 1A. Post-operative radiograph following plating of a femur.

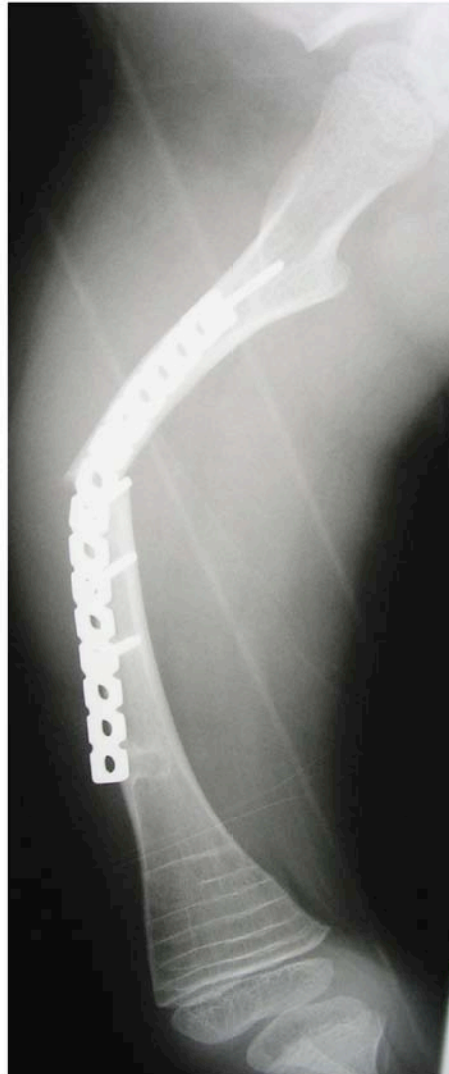


Figure 1B shows the intraoperative radiograph of the same femur during revision for fracture. The most distal screw has already been removed.



Figure 2. Radiograph showing screw pull-out. Note the proximal and distal cancellous screws have pulled out, allowing the plate to displace from the bone and leading to hardware prominence.

RESULTS

All four patients were diagnosed with osteogenesis type III using the Sillence classification.¹³ There were three males and one female, ranging in age from 14 to 82 months (44.7 months mean age) at the time of surgery. Ages ranged from five to eight years (7.7 years mean age) at last follow-up. The average time from initial plating to final follow-up period was four years.

Thirteen bone platings were performed on eight bones. The eight bones included six femurs and two tibias. Three of the femurs underwent multiple platings before being ultimately revised to Bailey-Dubow rods. Of these three femurs, two were plated twice, and one femur was plated four times for a total of 13 platings. All platings were separate operations. No two bones were

plated at the same time. The indications for initial plating of the eight bones included fracture and deformity. Of the six femurs, four were plated because of fracture, and two were plated for correction of deformity. Of the two tibias, one was plated for correction of deformity and the other because of fracture.

All eight bones ultimately required revision. Three of the femurs underwent further plating for revision, while the two tibias and three other femurs were revised to Bailey-Dubow rods. Indications for revision included fracture (6), deformity (3), hardware failure (3), and nonunion (1). Rate of fracture following plating was 46% (six fractures). Location of fracture was distal to the plate in two cases, under the plate in two cases, and through the plate in two cases. In the two cases of

fracture through the plate, fracture of bone with broken plate was considered the reason for revision and also considered a complication (Figures 1 and 2). The average time to revision was 27 months (range 4 to 71 months). The average time from initial plating to final revision with Bailey-Dubow rods was 42 months (range 9 to 89 months) for all bones.

The complication rate in these patients was 69.2% (9 plates). The most common complication following plating was screw pull-out. Screw pull-out was seen following plating in five cases. One case involved multiple screws and required revision for stabilization. Two fractures through the plate were seen, and these underwent revision. Bending of two of the plates was observed. Of these nine complications, three instances of hardware failure led to revision: Screw pull-out required revision in one case, and two fractures went through the plate as mentioned above. Complications are listed in Table 1.

There was one case of compartment syndrome following plating of a tibia, which required fasciotomy. There was one case of nonunion in a femur. This nonunion was noted five months after the initial plating and was revised with bone plating seven months after the initial operation. There were three instances of prominent hardware, one of which was symptomatic.

DISCUSSION

Bone plating is an option in the treatment of fracture and deformity in children with osteogenesis imperfecta. Previous studies in the orthopedic literature report treatment of these patients with intramedullary rods, both fixed and elongating. The benefits of elongating rods over fixed rods have been demonstrated in regard to reduction in the number of operations performed and facilitation of growth.^{4,5,12} There are no studies, however, examining the results of bone plating in comparison to the results obtained with elongating intramedullary rods.

The purpose of this study was to examine the results of bone plating in patients with osteogenesis imperfecta. Average time to revision following plating was 27 months. This compares quite unfavorably with the five years to revision following placement of Bailey-Dubow rods reported by Luhmann et al.⁹ It compares more favorably with the average time to revision of 2.5 years following placement of non-elongating rods reported by Marafioti and Westin.¹⁰ The most common indication for revision following plating was fracture (6), followed by deformity (3) and hardware failure (3).

The complication rate of plating was 69.2%. This rate was slightly higher than the 63.5% complication rate previously reported by Jerosch et al. and signifi-

TABLE 1

Complication	Number
Screw pull-out	2
Fractured plate	2
Bent plate	2
Refracture	6
Nonunion	1
Compartment syndrome	1

cantly higher than the 27% complication rate reported by Marafioti and Westin in their treatment of patients with OI.^{6,10} Jerosch et al. implanted Bailey-Dubow rods in 107 bones and Kirschner wires in eight bones.⁶ In their study, the Kirschner wires were implemented because of small bone diameter. The most common complication of Bailey-Dubow rods has been reported to be rod migration.^{6,7} The most common complication seen after plating was screw pull-out. This seems intuitive given the quality of bone in patients with osteogenesis imperfecta. Not only does the bone quality not allow for purchase of the screws, the bowing of bones may act to further any screw pull-out. Screw pull-out was not a clinical problem in this series unless it was associated with increasing deformity or fracture.

The treatment plan for skeletally immature patients with osteogenesis imperfecta must include consideration of growth. The advantage of the elongating rod is that it allows for longitudinal bone growth. The rod does cross the physis, but the diameter of the rod is small enough not to affect growth.² Bone plating does not disturb the physis in most cases, but it does not migrate with growth, thus leaving unsupported bone. Higher revision and failure rates in the bone adjacent to the plate are also most likely due to the sharp disparity in construct rigidity and osteopenic metaphyseal bone.

Considering the higher complication rates, shorter length of time to revision, and unknown effect on longitudinal growth, bone plating does not compare favorably to elongating rods in patients with osteogenesis imperfecta. We recommend elongating rods when considering treatment of deformity or fracture in patients with osteogenesis imperfecta.

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SAGITTAL KNEE KINEMATICS FOLLOWING HAMSTRING LENGTHENING

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ABSTRACT

The purpose of this study was to analyze sagittal knee kinematics following hamstring lengthening. A retrospective analysis was performed of 16 children (32 knees) with cerebral palsy who underwent hamstring lengthening as an isolated surgical procedure. Gait analysis was performed prior to surgery and at a minimum of one year after surgery. Decreased stance maximum knee flexion, stance minimum knee flexion, swing maximum knee flexion, and swing minimum knee flexion were noted. Total knee excursion increased. The present study confirmed the previously reported increase in total knee excursion with decrease in stance minimum and swing maximum knee flexion after hamstring lengthening.

INTRODUCTION

Children with cerebral palsy (CP) typically ambulate with flexed knees. Hamstring spasticity leads to increased stance knee flexion and decreased knee extension during swing. Multiple surgical procedures, often including hamstring lengthening (HSL), are performed to improve the walking ability of children with CP.^{1,2}

Increased total knee excursion with decreased stance minimum knee flexion and swing maximum knee flexion have been reported in studies of HSL.^{3,4} Most published studies on HSL have included children who underwent HSL combined with other simultaneous surgical procedures including rectus femoris transfer (RFT). Kinematic changes following the combined procedures are reported in magnitude for stance maximum knee flexion, stance minimum knee flexion, and swing maximum knee flexion. Changes in the timing of swing maximum knee

flexion and swing minimum knee flexion and in total knee excursion have also been reported.^{5,6,7,8,9,10,11,12,13}

The outcome of HSL in children with CP is a topic of interest to those who care for such children. The purpose of this study was to compare pre- and post-operative kinematics (focusing on the magnitude and timing of maximum and minimum knee flexion in stance and swing phases) in children with CP who had undergone HSL without other simultaneous surgical procedures. Throughout the rest of this manuscript, findings of magnitude are reported in degrees, and the timing of specific events is reported as a percent of the gait cycle.

METHODS

A retrospective analysis was performed of 16 children (32 knees) with the diagnosis of CP who underwent HSL without any other concomitant surgical procedure including RFT. Multiple procedures had previously been performed, including HSL, in four children. At the author's institution, all children with cerebral palsy able to walk underwent gait analysis as part of surgical decision-making. The choice of surgical procedures, however, was at the discretion of the operating surgeon.

The surgical procedure involved fractional lengthening of the semimembranosus and biceps femoris muscles with either fractional lengthening or tenotomy of the gracilis and semitendinosus muscles. Knee immobilizers were used postoperatively. As soon as the child was comfortable, ambulation was allowed with assistive devices as required. Re-admission for rehabilitation was done at four weeks following surgery with goals of passive knee flexion beyond 90 degrees and demonstrated active knee extension strength for ambulation.

The level of involvement for each child was classified using the Gross Motor Function Classification System (GMFCS).¹⁴ Three children were classified as GMFCS Level I, five children were classified as GMFCS Level II, and eight children were classified as GMFCS Level III.

Gait analysis was performed before surgery and at a minimum of one year after surgery. Sagittal knee kinematic data were analyzed. Data was collected using the Motion Analysis Corporation system (Motion Analysis Corp., Santa Rosa, CA). Twenty-five retro-reflective markers were placed on the children using the Cleveland Clinic marker set. Data was collected at 60 Hz for

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TABLE 1
Knee flexion maximum and minimum mean values and standard deviations
in stance phase and swing phase and level of statistical significance

Knee Flexion	Preoperative Mean (SD)	Postoperative Mean (SD)	Difference Postop/Preop	P-value
Stance maximum (degrees)	54 (7)	37 (1)	-17	p<0.05
Stance maximum (%gait cycle)	43 (25)	45 (24)	2	p=0.53
Stance minimum (degrees)	33 (10)	10 (13)	-23	p<0.05
Stance minimum (% gait cycle)	26 (14)	26 (14)	0	p=0.97
Swing maximum (degrees)	64 (9)	48 (11)	-16	p<0.05
Swing maximum (%gait cycle)	83 (7)	82 (6)	-1	p=0.22
Swing minimum (degrees)	42 (9)	22 (10)	-20	p<0.05
Swing minimum (% gait cycle)	90 (12)	91 (11)	1	p=0.27
Total knee excursion (degrees)	31 (12)	39 (12)	8	p<0.05

a minimum of four seconds. A minimum of three good trials were collected for each child. OrthoTrak software (Motion Analysis Corp., Santa Rosa, CA) was used to reduce and plot kinematic data. All data was normalized to 100% gait cycle so that data could be compared between children. For each child, a minimum of three trials was averaged. Sagittal knee motion was labeled relative to flexion so that minimum knee flexion is the same as maximum extension. The maximum and minimum values for knee flexion in stance and swing were determined. The timing of these values was extracted from the averaged data. The preoperative values were compared to the postoperative values using a paired t-test method with significance set at p<0.05.

The current study reviewed sagittal knee kinematic values only and does not include other measures such gait velocity, cadence, energy consumption, sagittal plane hip and knee kinematics, or muscle activation patterns as shown by dynamic electromyography.

RESULTS

The study group consisted of 16 children with a mean age of 12 years at the time of surgery (range 8-16 years). There were eight males and eight females. The study group's mean, standard deviation, and p-value for preoperative/postoperative comparisons of the kinematic data are given in Table 1.

There was a statistically significant difference between preoperative and postoperative values for maximum stance knee flexion, minimum stance knee flexion, maximum swing knee flexion, minimum swing knee flexion, and total knee excursion. Stance maximum knee flexion decreased 17 degrees, from 54 degrees preoperatively to 37 degrees postoperatively. Stance minimum knee flexion decreased 23 degrees, from 33 degrees preoperatively to 10 degrees postoperatively. Swing maximum knee flexion decreased 16 degrees, from 64 degrees preoperatively to 48 degrees postoperatively. Swing minimum knee flexion decreased 20 degrees, from 42 degrees preoperatively to 22 degrees postoperatively. Total knee excursion

increased 8 degrees, from 31 degrees preoperatively to 39 degrees postoperatively. There were no statistically significant differences seen between postoperative and preoperative values in the timing of any measured value.

DISCUSSION

Previous researchers have reported on the outcomes of HSL surgery. Thometz et al. reported on 62 limbs with medial HSL without concurrent RFT.³ Stance minimum knee flexion decreased 19 degrees, from 49 degrees preoperatively to 30 degrees postoperatively. Swing knee flexion decreased 10 degrees, from 48 degrees preoperatively to 38 degrees postoperatively. Total knee excursion increased 5 degrees, from 35 degrees preoperatively to 40 degrees postoperatively.

Van der Linden et al. reported on 32 limbs that underwent HSL.⁴ Most of the patients had simultaneous surgical interventions other than RFT. A significant decrease in stance minimum knee flexion and swing maximum knee flexion was observed. Stance minimum knee flexion decreased 12 degrees, from 32 degrees preoperatively to 20 degrees postoperatively. Swing maximum knee flexion decreased nine degrees, from 63 degrees preoperatively to 54 degrees postoperatively. Total knee excursion increased four degrees, from 30 degrees preoperatively to 34 degrees postoperatively.

Our study group showed statistically significant differences between preoperative and postoperative values for stance minimum knee flexion, swing maximum knee flexion, and total knee excursion. Stance minimum knee flexion decreased 23 degrees, from 33 degrees preoperatively to 10 degrees postoperatively. Swing maximum knee flexion decreased 16 degrees, from 64 degrees preoperatively to 48 degrees postoperatively. Total knee excursion increased eight degrees, from 31 degrees preoperatively to 39 degrees postoperatively. This data confirms previously reported findings.

Forty-five limbs that underwent combined HSL with RFT were previously reported.⁵ Multiple simultaneous

surgical procedures were performed under the same anesthetic in 23 children. Gastrocnemius/soleus lengthenings were completed in 15 children. Iliopsoas recessions were performed in five children, and various osteotomies were performed in seven children. Statistically significant changes were seen in stance maximum knee flexion (decreased 12 degrees, from 49 degrees preoperatively to 37 degrees postoperatively), stance minimum knee flexion (decreased 14 degrees, from 26 degrees preoperatively to 12 degrees postoperatively), swing maximum knee flexion (decreased seven degrees, from 57 degrees preoperatively to 50 degrees postoperatively), and swing minimum knee flexion (decreased 12 degrees, from 39 degrees preoperatively to 27 degrees postoperatively). In addition, statistically significant changes were seen in the timing of swing maximum knee flexion (decreased 5%, from 85% preoperatively to 80% postoperatively), and in total knee excursion (increased 36 degrees, from 31 degrees preoperatively to 67 degrees postoperatively).

When the current study data was compared to the previous study, both HSL combined with RFT, and HSL without RFT demonstrated decreased stance maximum knee flexion, stance minimum knee flexion, swing maximum knee flexion, and swing minimum knee flexion. However, HSL without RFT did not demonstrate the decrease in the timing of swing maximum knee flexion that was seen when HSL was combined with RFT. An increase in total knee excursion was found for both the HSL combined with RFT, and HSL without RFT.

In conclusion, following HSL alone (without RFT), maximum knee flexion in stance decreased, minimum knee flexion in stance decreased, maximum knee flexion in swing decreased, minimum knee flexion in swing decreased, and total knee excursion increased. The present study confirmed previously reported increases in total knee excursion with decreases in stance minimum knee flexion and swing maximum knee flexion. HSL, performed with or without RFT, decreased stance maximum knee flexion, stance minimum knee flexion, swing maximum knee flexion, and swing minimum knee flexion. HSL, performed with or without RFT, increased total knee excursion. The decrease in timing of swing maximum knee flexion noted when HSL was combined with RFT was not seen when HSL was performed without RFT. This difference may be clinically important for limb clearance during swing.

The data presented in this study adds information to the current literature on important treatment outcomes and sagittal knee kinematics of children with CP treated with hamstring lengthening. The group of children studied had HSL alone without any concomitant surgical procedure, including rectus femoris transfer. The variation in reported results may be due to differences

in the study groups, such as different indications for the procedure, associated procedures, or severity of CP involvement.

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SEPTIC ARTHRITIS IN A NIGERIAN TERTIARY HOSPITAL

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ABSTRACT

Background: Septic arthritis is a disabling disease that requires early diagnosis and prompt management for optimal outcome. Late presentations with deformities were noticed in our clinic. The aim of this study was to determine the pattern of septic arthritis in our environment.

Methods: This was an 18-month prospective study in a Nigerian teaching hospital. Thirty-nine consecutive patients with 45 incidences of septic arthritis were studied. Joint aspirates were taken for microbiologic investigation.

Results: Patient ages ranged between 0.5-60 years and the mean age was 7.4 years. The male to female ratio was 2.9:1, and the knee was the most commonly affected joint. The duration of symptoms before presentation ranged between 4-17 days with a mean of 11.1 ± 3.6 days. Twenty-five (64.1%) of the patients were on inadequate antibiotics before presentation. Seventy-three percent of septic arthritis involving the upper limb joints occurred below the age of one year and 92.3% of the involved lower limb joints occurred after one year of age.

Conclusion: The upper limb joints were significantly affected below one year of age and the joints of the lower limb were more involved after one year of age (p=0.001). Improper prescription of antibiotics before presentation to the hospital was noticed in 64.1% and should be discouraged.

INTRODUCTION

Septic arthritis is a pyogenic infection within a joint that is a surgical emergency. Not only can it rapidly destroy a joint or irreversibly impair joint function, but it may also be fatal, especially when it occurs in a neonate. Neonatal septic arthritis can result in permanent skeletal deformity.¹ Although septic arthritis can occur at any age, children are particularly susceptible and must be treated rapidly.⁹ Septic arthritis has been reported to be more common in males.³ An overview of the joints involved shows that the large joints are more often involved, and the knee is the most commonly involved joint.^{3,5,6,7,8,10} The risk is higher when the joint is traumatized. The causative organisms are diverse in septic arthritis, but *Staphylococcus aureus* infection is the most common.^{6,8,10,11} The recognition of septic arthritis in the young before excessive infection has occurred is often difficult; thus, there is a need to maintain a high index of suspicion.

Diagnosis can be made based on clinical findings but can also be aided by ultrasound, which allows early diagnosis of joint effusion with high accuracy.^{5,12} This diagnosis must be made and definitive management instituted promptly in order to avoid severe complications which are difficult and unrewarding to manage. Definitive management includes parenteral antibiotics, immobilization, and open or arthroscopic arthrotomy.^{6,10,13}

MATERIALS AND METHODS

This is an 18-month prospective study carried out at Wesley Guild Hospital Ilesa in Osun State, Nigeria. The patients with features of septic arthritis were recruited upon their presentation to the hospital. History and clinical examination were obtained and data were entered into a prepared form. Thirty-nine patients with 45 cases of septic arthritis were included in the study. Aspirates were obtained from all of the joints, and samples were sent for gram staining (GS) and microscopic culture and sensitivity (MCS) in 41 aspirates. This was not done in

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TABLE 1
Frequency of Joints Involved

Joint	Number
Knee	17
Shoulder	11
Hip	11
Ankle	3
Wrist	2
Elbow	1
Total	45

TABLE 3
Culture Results

Causative agent	Frequency
<i>Staphylococcus aureus</i>	16
<i>Escherichia coli</i>	9
<i>Alpha-hemolytic Streptococcus</i>	1
<i>Klebsiella</i>	1
No growth	14
Total	41

*Four joint aspirates were not cultured because of faulty equipment.

TABLE 2
Age Versus Limb Involvement

Limb involved	No. of patients ≤1 year	No. of patients > 1 year	Total no. of patients	No. of joints involved
Septic arthritis of upper limb joints only	8	3	11	12
Septic arthritis of lower limb joints only	2	24	26	28
Total	10	27	37	40
	<i>P</i> =0.001	<i>χ</i> ² =16.58		

*Two patients with septic arthritis of both upper and lower limbs are excluded from the table.

four samples because of equipment failure when the samples were taken.

Arthrotomy was carried out on the affected joints in 33 patients under the combination of sedation (with diazepam) and local anesthesia, and under general anesthesia in six patients with septic arthritis of the hip. The patients were placed on a parenteral antibiotic which was converted to an oral antibiotic after their temperature patterns returned to normal. When the wrist, elbow, and knee were involved, immobilization was done with a back-slab of Plaster of Paris; skin traction was applied for septic arthritis of the hip, and collar-and-cuff for septic arthritis of the shoulder. The patients were followed for nine months.

The data were analyzed using 11.0 SPSS (Statistical Programme for Social Sciences) Inc., Standard Version 2001.

RESULTS

A total of 39 patients with 45 cases of septic arthritis were studied. Twenty-nine were male and ten were female with a male to female ratio of 2.9:1. Patients' ages ranged between 0.5-60 years. Thirty-four of the patients were children between the ages of 0.5-15 years with a mean age of 4.4 ± 4.2 years, while five were adults between 17 and 60 years old with a mean age of 28.2 ± 18.6 years. The duration of symptoms before presentation ranged between 4 and 17 days with a mean of 11.1 ± 3.6 days. These symptoms included fever in 29 patients (74.3%), joint pain in 27 patients (69.2%), and a limping

gait in 19 patients (48.7%). Twenty five (64.1%) of the patients had already been treated with various inadequate antibiotics before presentation.

Trauma preceded the development of joint pathology in six patients. Three of the patients studied had systemic illnesses, which were sickle cell disease, a convalescent stage of meningitis, and septicemia. The patients with meningitis and septicemia developed polyarticular septic arthritis.

In these 39 patients, 34 had monoarticular septic arthritis and five had polyarticular involvement for a total of 45 infected joints. The frequencies of the joints involved are shown in Table 1, while the limb involvement as related to the age of the patient is shown in Table 2. Two patients had septic arthritis involving five joints in both the upper and lower limbs. Twenty-one (87.5%) out of the 24 patients with septic arthritis of the lower limb joints were above two years of age. The results of the cultures are shown in Table 3.

DISCUSSION

In developed countries, favorable long-term outcome of septic arthritis is not uncommon.² This cannot be said of developing countries like Nigeria, where septic arthritis is a disabling and life-threatening disease that requires early diagnosis for optimal outcome.⁴ In this study, the knee was found to be the most common joint involved, and this agrees with other studies done elsewhere.^{5,6,7,10} It was observed that 72.7% of septic arthritis cases involving the upper limb joints occurred in patients

below the age of one year, and 92.3% of the cases of the lower limb joints occurred after the age of one year. A literature search did not reveal similar observations from anywhere in the world prior to this study. An explanation for these findings could be that microtrauma is repeatedly inflicted on a child's upper limbs while the child is being lifted and carried, as most children do not start walking until approximately one year of age. Also, in this environment, different twisting maneuvers on the upper limbs are carried out while bathing or feeding these children. Thus, the upper limb joints could be more prone to septic arthritis below one year of age. When the child starts walking (usually after one year), the lower limb joints are more often traumatized than the upper limb joints, which may explain the occurrence of septic arthritis in lower limbs more often than the upper limb joints after age one.

Staphylococcus aureus was the most common organism found, which agrees with previous works,^{3,6,8,10,11} but *Escherichia coli* was the second most common organism in our series. This differs from the work done by Stutz et al., where *Escherichia coli* was the fourth most common organism.¹¹ In 14 aspirates from 12 patients, there was no growth. Ten of these patients were already on inadequate dosages of either parenteral or oral antibiotic prescribed by parents or health institutions for two to seven days before presenting to our unit. Involvement of two or more joints was seen in patients who were initially being treated for septicemia and meningitis. The overwhelming systemic infections would have accounted for the vulnerability of these patients to polyarticular septic arthritis. Close follow-up is needed to monitor the growth of the affected limbs until skeletal maturity;¹⁰ but sadly, most of the patients were lost to follow up within nine months. Therefore, more deformities secondary to septic arthritis will probably be seen at our institution.

We concluded that the upper limb joints were significantly affected below the age of one year while the joints of the lower limb were more involved after the age of one year ($p=0.001$). There is a need to educate patients about early presentation, avoidance of improper use of antibiotics, and regular follow-up after the acute pathology.

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THE EFFECTS OF SILVER COATED EXTERNAL FIXATION PINS

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ABSTRACT

We performed a randomized controlled trial in order to assess the effect silver coating of an external fixator pin has on pin infection. The experimental silver coated pins (SC) were compared to control stainless steel (SS) pins. A clamp design monolateral fixator was used, and pins were randomized to clamp position to allow side-by-side comparisons of pins in a similar environment. Nineteen patients and 33 clamps were entered and completed the study. There were no significant differences between the two types of pins in the rate of pin tract infection, clinical appearances of the pin sites, bacteriology of the pin tracts, torque to remove the pins, or radiographic lucency around the pin. We concluded that with the numbers available in this study, there were no detectable differences between the performance of SC and SS pins.

INTRODUCTION

Pin tract infection is the most significant complication associated with the use of external fixation and has been reported to occur in up to 63% of pins.¹⁻¹⁵ This high infection rate has been attributed to the conduit that the pins provide between the skin and underlying soft tissue and bone. Complications related to pin tract infection include need for pin change or removal, failure of fracture healing, septic arthritis, and osteomyelitis. A method to decrease the rate of pin infection, therefore, has tremendous clinical appeal.

Silver, with its potent, broad-spectrum antibacterial activity, has had many clinical uses.¹⁶ Silver-based creams for wound care and silver coatings for catheters have decreased infection rates with minimal systemic effects.^{17,18} Silver coating has been advocated for use on external fixation pins to decrease infection rate, and a small, animal study has demonstrated decreased infection and motion at the pin-bone interface.¹⁹ Although silver coated pins are now commercially available, no clinical study has been performed to confirm their efficacy.

We designed and performed this prospective, randomized study to test the hypothesis that silver-coated pins decrease the pin infection rate and improve the pin-bone interface characteristics when compared to traditional stainless steel pins.

METHODS

The study was approved by the institutional review board at the University of Iowa. Between June, 1998 and June, 1999 we enrolled 22 patients treated with a monolateral clamp design external fixator for fractures of the tibia into this prospective, randomized study. We excluded patients treated with temporary frames, as well as patients with obvious sources of infection, pathologic fractures, and immunosuppression. Also excluded were wire fixators and metaphyseal T-clamps. Three initially enrolled patients were excluded from analysis because their external fixator was removed and their fracture was internally fixed within two weeks of injury. The remaining nineteen patients included fifteen men and four women. Eight patients were smokers and eleven were non-smokers. Three patients had prior fractures of the tibia, two patients had crush injuries, and one patient each had psoriasis, a transient popliteal artery occlusion, and foot compartment syndrome. No patient had diabetes. Nine fractures occurred in the right tibia, nine in the left tibia, and one patient had bilateral tibia fractures. The average age of the patients was 43 years (range 18-65 years). Open fractures occurred in seven patients. There were six fractures of the tibial shaft, twelve distal tibia fractures, and two tibial plateau fractures (Table 1).

Since silver does not leach either locally or systemically from a coated pin, we used each external fixator clamp as an individual experiment to minimize patient and mechanical variability. The proximal and distal clamps of the fixator were each eligible for inclusion in the study. In each clamp, one silver-coated and one stainless steel pin was placed. Pins were randomized within each fixator clamp to allow a side-by-side comparison of each experimental (SC) and control (SS) pin. Randomization for each clamp was by position in the clamp as "closest to" or "farthest away" from the fracture site. If a patient had one clamp eligible for participation in the study, the two study pins (SC & SS) were randomized between "closest to" and "farthest away" using a random number table. If a patient had two clamps eligible for study participation, the randomization table was utilized for the proximal clamp, and the pins in the distal clamp were placed opposite to those in the proximal clamp. For example, if SS was placed "closest to" the fracture site and SC was placed "farthest away" from the fracture site in the proximal clamp (as determined by the ran-

TABLE 1
Classification of Fracture Types

Patient	Fracture Type (AO classification)
1	41C3.3
2	43C3.2
3	41A2.1
4 - Left	43C3.3
4 - Right	43C3.3
5	43B3.2
6	42A2.3
7	43C3.2
8	43C2.1
9	42A2.3
10	43C3.2
11	43C3.2
12	43C1.1
13	42A3.3
14	41C3.2
15	43C3.2
16	43C1.3
17	42A2.3
18	43C2.1
19	42C1.1

domization table), then the SS pin was placed “farthest away” from the fracture site and the SC pin was placed “closest to” the fracture site in the distal clamp. This was done to maintain an appropriate balance of type of pin “closest to” and “farthest away” from the fracture site and to balance out the types of pins in metaphyseal and diaphyseal bone.

Standard pin insertion and external fixator placement technique was utilized. Bicortical purchase was obtained with each pin and was confirmed with fluoroscopy. An SC and SS pin were placed in each eligible clamp. The position of these pins was as far from each other in the clamp as possible to increase the rigidity of the construct, with the 1-5 position being preferred; however, the 1-4 and 2-5 positions were also accepted. The 1-3 and 3-5 position combinations were not acceptable for participation in the study since clustering of pins has been demonstrated to decrease the rigidity of the external fixation system.²⁰ Straight clamps and C-clamps for the hindfoot were eligible for placement of study pins.

Postoperative care was identical for each patient. Perioperative antibiotic treatment (intravenous Ancef) was given to all patients. Swab cleansing of the pin sites with normal saline two to three times a day followed by application of dry dressings was started on the second postoperative day and was continued until fixator removal. Hydrogen peroxide was not used because it increases the leaching rate of the silver approximately 1,000 fold.²¹ All pin care was taught by the same clinical nurse. Each pin complication was treated at the discretion of the treating surgeon.

The performance of the SS and SC pins was measured in four ways: clinically, bacteriologically, radiographically, and mechanically. All clinical ratings were accomplished with use of a “1-10” visual (photo) analog scale that was developed prior to the study, (with “1” as the worst and “10” as the best pin site ever seen). Prior to commencement of the study, the investigators developed this standardized visual analog scale utilizing pin tract photos taken of non-study patients. A series of photos were chosen by the investigators from these pre-study photos and subsequently became the clinical guide for the study, i.e. the visual analog scale. A Likert Scale of 1-10 was used that assumed a continuous scale with equal intervals. Representative photos for each number on the scale were chosen for this guide. Issues addressed in the development of this visual scale included amount of inflammation, amount of erythema, and the amount and type of drainage.

The clinical performance of each pin was assessed at each visit, by at least one, and often two of the investigators (two staff surgeons, a nurse clinician and a resident). Data was recorded at the pre-determined observation times of 2 weeks, 4 weeks, 2 months, 3 months, time of fixator removal, and one month after fixator removal. In addition, photographs were used in a second way. Each of the study pin sites was photographed at the clinic visits (observation times) and these photos were subsequently used by all four investigators to rate each pin site. The aforementioned visual analog scale was used as a guide in rating the pin sites for both the direct clinical encounter and the subsequent photographic evaluation.

In addition to the Likert Scale, any pin tract complication that developed during treatment was classified into one of four types in order to directly compare our pin tract infection rate with other studies.⁵⁻¹² These four types included 1) those that resolved with oral or intravenous antibiotics, 2) those requiring pin change or removal, 3) those resulting in failure of the method and subsequent fixator removal, and 4) those resulting in osteomyelitis.

Bacteriologic data was obtained through gram stain and aerobic and anaerobic cultures of aseptically collected culture swab samples of each pin site at the time of fixator pin removal. This was accomplished by direct application of the culture swab tip into the tract left by each removed pin.

Radiographic evaluation of the pin sites was obtained at the time of fixator removal or one month after fixator removal. Periosteal reaction was documented as being absent or present. The area of radiographic lucency was measured for each pin tract by directly measuring the height and width of the pin tract and multiplying these two numbers. This was done in both the AP and lateral planes for each pin site.

TABLE 2
Comparison between SC (experimental)
and SS (control) Pins

	SC	SS
Percentage of pin infections	30%	21%
Average direct clinical score	7.4	7.6
Average indirect clinical score from photographs	7.4	7.4
Average removal torque	4.8	5.9
Average size of pin track lucency	85 mm ²	64 mm ²

Mechanical integrity of the pin-bone interface was assessed at the time of pin removal. A torque wrench was mounted on each pin and the maximal torque required to begin removal of each pin was recorded.

Fracture type, clamp type, patient comorbidities, length of fixator placement, time to healing, time to weight-bearing, position in clamp, patient age, and patient sex were examined independently to determine each one's correlation with pin performance.

Statistically, the clinical and photographic ratings for SC and SS pins were compared using a mixed model, repeated measures analysis of variance. This model designated the pin type (SC vs. SS) as the fixed effect, and rater, patient, and clamp as the random effects. A p-value <.05 was considered significant when comparing the pin type mean scores.

RESULTS

Average length of fixator placement was 16.7 weeks (range 8-31 weeks), and average time to weight bearing was 9.2 weeks (0 - 21 weeks). Eighteen of the 20 fractures healed, and average time to healing was 22.3 weeks (12 - 45 weeks). Four patients required intravenous and/or oral antibiotics to resolve infection related to their open fracture wound and not their pin sites. One patient required intravenous and oral antibiotics to treat a separate distal radius fracture external fixator pin site infection.

The major comparisons between the two pin types are displayed in Table 2. No difference between number of pin tract infections occurred; infections were seen in ten (30%) SC pins and seven (21%) SS pins. All ten SC pin tract infections resolved with oral antibiotics; whereas, five of the seven SS pin tract infections resolved with oral antibiotics. The remaining two SS pin tract infections were treated with intravenous antibiotics and resolved. No fixator pin infection required pin change, pin removal, or fixator removal. No pin tract infection led to the development of osteomyelitis.

No difference occurred between the average direct clinical score for SC pins (7.4) and that for SS pins (7.6). Similarly, no difference occurred between the average

TABLE 3
Number of Pins Containing Each Species
of Bacteriological Growth

Bacteria	No. of Pins
No growth	6
S. aureus	28
Coag Neg Staph	20
Mixed Flora	14
Gram positive rods	7
Beta Hemolytic Strep	2
Klebsiella/Enterobacter	2
Micrococcus	2
Pseudomonas	1

TABLE 4
Differences in Bacterial Growth
between Paired Pins

Bacterial Differences	Less significant bacterial growth at SC pins	Less significant bacterial growth at SS pins
No difference (12)		
Minor difference (5)	2	3
Moderate difference (8)	8	0
Major difference (4)	2	2
Cultures not taken (1)		

No difference—exact same amount and type of bacterial growth at each pin site within a clamp.
 Minor difference—type of bacteria was the same; however, a smaller amount of bacteria was grown.
 Moderate difference—both grew bacteria, but amounts and types varied.
 Major difference—no bacterial growth at one pin site compared to presence of bacterial growth at other pin site.

indirect photo score for SC pins (7.4) and that for SS pins (7.4).

A spectrum of bacteria was cultured; however, within each clamp little variation occurred (Tables 3 and 4). Twelve of the 33 clamps revealed no difference between the SC and SS pins in either the bacteria type or amount grown from the pin tract site. Five clamps revealed no difference in the type of bacteria grown, but a small difference in the amount of bacteria grown, i.e. few Staph. aureus grew from one pin site and rare Staph. aureus from the other pin site. Two clamps within this group grew a smaller amount of the same bacteria in the SC pin tract, and three clamps revealed a smaller amount of growth at the SS pin tract.

A major difference occurred within four clamps, with two SC and two SS pin tracts exhibiting no growth while their counterpart pin tract had definite bacterial growth with a variety of organisms. The remaining eleven clamps revealed minor to moderate differences in flora, i.e. varied in amounts of two bacteria grown, or one pin tract grew two bacteria while the other grew one. Eight clamps within this group had either less growth or fewer numbers of types of bacteria at the SC pin tract compared to the SS tract, and three were equivocal. One clamp did not have cultures taken.

The average torque required to remove an SC pin was 4.8 Nm, and the average torque required to remove an SS pin was 5.9 Nm. This difference was not statistically significant. Eight clamps revealed a large difference (7) between the torque required to remove the two pins, with three being more secure within the SC pin tract, and five being more secure within the SS pin tract. Twenty-three clamps revealed minimal or no differences in removal torque between the two pin types.

Radiographic pin tract lucency averaged 85 mm² for SC pins and 64 mm² for SS pins and was not significantly different. The amount of radiographic lucency and the presence of periosteal reaction did not have any significant effect on the SC or SS clinical ratings. The presence of increased lucency did not correlate with need for oral or intravenous antibiotics (i.e. pin tract infection). Increased lucency significantly correlated with decreased torque required to remove pins.

The following variables had no statistically significant effect on the rating for the SC versus SS pin: patient sex, open versus closed fracture, smoking status, clamp position, time spent in fixator, time to healing, and time to weight-bearing. Increasing patient age was associated with an increase in rating for both SC and SS pins for both the clinical and photographic data.

There were 544 matched clinical and photographic pin ratings corresponding to 270 clamps with both SC and SS pins being rated. No statistical difference was noted between the clinical and photographic ratings for the same pin, i.e. the photographic rating was representative of the clinical rating.

DISCUSSION

The most significant complication with external fixators is pin tract infection, which has been reported in up to 63% of patients.¹⁻¹⁵ At our own facility, pin tract complications have been reported in various studies at rates ranging from 19% to 63% of patients.⁵⁻¹²

Silver-coating external fixation pins has been proposed as one means to decrease the pin infection rate and subsequent pin tract complications. Bacteria colonize the surface of the pin and form a resistant biofilm of polysaccharides that serves as a barrier to antibiotics and the body's immune system. This film therefore serves as a conduit for bacteria to migrate from the surface of the skin via the pin to the bone. The silver coating provides an antimicrobial layer on the pin that prevents bacterial colonization and pin tract infections.²²

The potential effectiveness of silver-coating external fixator pins has been supported by one animal study. Collinge, et al., demonstrated a decrease in infection rate (62% vs. 84%) after direct inoculation of pin tracts with *Staph. aureus* to 36 SC and 12 SS pins placed in the iliac

crest of six sheep. The pin sites were examined for motion, inflammation, and bacterial growth at 2 1/2 weeks. Scanning electron microscopy revealed a decreased level of glycocalyx-protected colonization on the surface of the SC pins. The authors postulated that bacterial adherence to the surface of the SC pins was prevented by inhibition of the formation of a bacterial glycocalyx membrane on the pin itself, rather than silver leaching from the pins into the local environment.¹⁹

To determine if SC pins prevent pin infection in patients, we developed a study design that compared SC and SS pins side-by-side in a similar environment, i.e. the same clamp and same patient. This side-by-side comparison of the two pins in a similar environment eliminated some of the problems associated with comparative analysis of pin performance, such as differing mechanical and bacteriological environments in different patients. This design was justified since silver does not leach from the pin and, therefore, cannot affect a neighboring pin. The zone of inhibition of bacterial growth (*E. coli*, *P. aeruginosa*, *S. epi*), has been found to be 4-6 mm around silver pellets and 0 mm around SC pins, eliminating any possibility of a local zone of inhibition.^{21,23} Leaching rates have been studied to determine if systemic effects of silver from an SC pin would affect another pin's performance within the same patient and have been measured at 1.92 1.42 mg/m²-week. At this leaching rate, it would take 50 years for all of the silver coating to come off. However, treatment with hydrogen peroxide would cause the leaching rate to increase 1,000 fold, and was prohibited in this study.^{21,23} This provides strong evidence that the antibacterial effect of the SC pins would not affect the control SS pins within the same clamp or same patient.

Our study results provide strong evidence that there is no difference between SC and SS pin performance overall. Clinically, both the direct clinical and indirect photographic scores revealed no differences between the performance of the SC and SS pins. Bacterial growth and radiographic appearance were similar between both groups. There was no difference in the mechanical performance, except for a small trend towards SC being less mechanically sound.

This study does not preclude the possibility of a difference in severe pin infection between the two types of pins because of the small number of patients entered and the relative rarity of these occurrences. A very large clinical trial would be required to detect this difference or exclude its absence. With the number of clamps we entered (33), we had a 90% power to detect a difference of 13% (a 1.0 difference on the Likert 1-10 scale) in the clinical grading if this difference had existed. Most assessments of clinical pin performance are made by visual

observation, which was the main outcome variable that we used in this study.

Although we found no statistically significant differences between the bacterial growth of the SC and SS pins, there was a trend for SC pins to have less bacterial growth. Twelve out of the thirty-two clamps cultured showed less significant growth at the SC pins compared to five clamps showing less significant growth at the SS pins. Additionally, no SC pins required intravenous antibiotics for treatment of infection; whereas, two SS pins did require intravenous antibiotics. Quantitative bacterial cultures taken at multiple times during treatment might have yielded more discerning results. Our clinically based study results differed from Collinge's animal-based laboratory experiment results. The biggest difference between the two studies occurred with the study design. A direct inoculation of bacteria was performed in Collinge's study, which is clearly different from the clinical setting in our study where pins were kept clean. It is possible that a direct inoculation of one type of bacteria would alter the development of the natural flora for both an SC and SS pin, thus altering the overall results of what would occur clinically. Other potential reasons for the differences between the two studies could have occurred secondary to fixator application technique, postoperative care, differences in control of environment, use of antibiotics, amount of time in fixator, and location of pins in metaphyseal versus diaphyseal bone. The data from our study indicates that factors other than local antibacterial coatings may have a bigger effect on pin performance. These include the mechanical environment of the pin, local bacterial flora, loading characteristics of the frame-bone composite, and perhaps other incompletely understood factors.

We used a novel method for clinical evaluation of pin site performance with the use of a Likert 1-10 photo scale, which allowed us to use a more continuous measure of pin performance rather than arbitrary categorical definitions of a pin classification. We did not assign any definitions to any number along the 1-10 scale guide, which enabled the investigators to utilize their own experience to rate a pin anywhere along the scale they felt was appropriate. This eliminated problems with failures of understanding or disagreements with categorizations, and produced a high inter-rater intra-class correlation (ICC) of .70 for these clinical ratings using the photo scale guide. This novel approach potentially provides a reliable and reproducible method of evaluating pin sites that may be used in future multi-center studies; however, further investigation is warranted.

Early in this study, we recognized that all four investigators would not be able to be present at every clinic visit, which introduced the possibility of variable assessments by different observers. To eliminate this potential problem, we augmented the direct clinical evaluation of a pin site by one or two investigators with photographs taken at the time of the clinic visit. These photos were subsequently evaluated and rated using the same 1-10 photo scale guide used in clinic by all four investigators. We compared the inter-observer reliability of the direct clinical assessment with the subsequent indirect photographic assessments, and found the observations to be reliable (clinical inter-rater ICC = .70, photo inter-rater ICC = .65).

In summary, we performed a prospective, randomized clinical trial testing the hypothesis that SC pins decrease clinical pin infection rate and improve mechanical integrity at the pin bone interface when compared to SS pins. In this study, each clamp offered a direct side-by-side comparison of an SC and SS pin existing in a similar environment, and a novel method of continuously ranking clinical pin infection was used. We found no statistically significant clinical, bacteriologic, mechanical, or radiographic differences between these two pin types. However, the small numbers of enrolled patients precludes us from eliminating the possibility of a difference in severe clinical infection.

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AMPUTATION OSTEOPLASTY

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ABSTRACT

Amputation osteoplasty is a technique modification promoted by Ertl to enhance rehabilitation after transtibial amputation. Two different techniques for creating sealing of the medullary canal and a distal bone block have been described in the literature. One technique consists of a periosteal sleeve that is sutured over the cut end of the bone. The second technique consists of hinging a segment of fibula into a slot in the cut end of the tibia. The desired goal of amputation osteoplasty is to create an end-bearing limb to enhance rehabilitation. In addition to creation of a bone bridge, Ertl also recommends myoplasty, neuroplasty, individual vessel ligation, and a special skin closure. This report is a small case series of five patients successfully treated with lower extremity amputation osteoplasty, to illustrate the techniques and report initial good results. Two patients had each of the techniques and one patient had both of the techniques. All five patients had good wound healing, accelerated rehabilitation, and the ability to use end-bearing prostheses.

INTRODUCTION

Amputations have been performed for severe disease since the beginning of recorded human history. There is probably no other orthopaedic procedure that has been performed longer or more often than amputation. Many of the important techniques and principles of amputation have remained standard for decades. However, over the past 20 years, new ideas and techniques have been developed that may improve the outcomes, recovery rates, and ultimate function of patients with amputations.^{1,2}

One of these concepts is osteoplasty, or sealing of the medullary canal of the amputated bone. This technique is potentially applicable to all amputations, regardless of location or disease process.^{3,4,5} It can be utilized with amputations done for post-traumatic, diabetic, infectious, dysvascular, neoplastic, developmental, or other conditions. The technique can be used for adult or pediatric amputations.

It is useful to compare and contrast amputations and disarticulations, which have both been used for centuries.⁶ A disarticulation is removal of a limb through a joint and requires resection of ligaments. Amputation is removal of a limb by cutting through bone, typically requiring a saw or other bone-cutting instruments. The primary motivation for disarticulation versus amputation in the past has been the fact that disarticulation does not require an instrument to cut the bone, but rather a knife to cut through soft tissue ligaments. In addition, disarticulation preserves length, allows for end-bearing ability, and is not complicated by overgrowth in skeletally immature patients. With a disarticulation, the medullary canal of the bone is not exposed to the surrounding tissue. In contrast, conventional amputation without osteoplasty does expose the medullary canal of the bone to the surrounding tissue. Historically, this has not been thought to present a significant problem for the patient. However, there has been growing evidence over the last 20 years that the open medullary canal may be the source of significant post-amputation problems for patients.^{7,8,9}

Vascularity of the residual limb may be enhanced in several ways. Sealing of the end of the bone may improve medullary blood flow as it restores a more normal osseous contour to the bone end. Angiographic studies by Ertl showed sluggish flow and bulbous vessels within and distal to the cut bone of traditional amputations but

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a near-normal medullary vessel pattern after amputation osteoplasty. Individual ligation of vessels helps to prevent arteriovenous fistulas and pseudoaneurysms associated with traditional methods of ligation of vessel bundles. These vascular abnormalities can cause pain and interfere with residual limb function, especially with an end-bearing prosthesis. End-bearing also helps to mechanically pump blood out of the residual limb, similar to what occurs in the normal foot during walking.

Ertl has devised specific techniques to create sealing callus at the end of the cut bone of an amputation through what has been termed “amputation osteoplasty.”⁹ He has also promoted a variety of other modifications and specific techniques for amputations.^{9,10} The osteoplasty concept has also been associated with an end-bearing limb for prosthetic wear. Especially for transtibial amputations (TTA’s), end-loading prostheses were historically avoided because of their association with unacceptable rates of wound and residual limb breakdown. Instead, prostheses were designed to transfer weight-bearing to the knee and more proximally in order to functionally unload the end of the residual limb.^{5,11}

Traditional amputation prostheses were designed to be suspended on the residual limb, bypassing the end of the limb and obtaining their support more proximally. For TTA’s, this required weight-bearing contours around the knee. For trans-femoral amputations this meant quadrilateral sockets and ischial weight bearing. Traditionally, diabetic patients were known to have particular problems with skin breakdown with end-bearing prostheses.

With Ertl osteoplasty, an end-bearing limb is the desired result to facilitate rehabilitation. This is completely different from traditional thinking. Ertl believes that the residual limb should be as normal as possible, and this includes the transmission of load along the length of the residual bone and end bearing as occurs in normal walking with a normal limb. The surgical techniques are designed to create an end-bearing “organ” that is capable of holding up to axial load. The osteoplasty is designed to provide a broad base to accept load and eliminate motion (chop-sticking) between the distal tibia and fibula. The periosteal sleeve and myoplasty help create a soft tissue “organ” capable of end-bearing load that will withstand the forces of body weight. The skin closure technique also helps.

While end-bearing on the residual limb of a traditional amputation leads to breakdown, end-bearing on the residual limb after amputation osteoplasty can be beneficial. End bearing can actually stimulate this skin and deep tissue “organ” to become stronger and tougher over time. The loaded end-bearing limb promotes tissue maintenance rather than atrophy of the residual limb attributable to disuse (pencil).

The proposed advantages to end-bearing include tissue maintenance (less atrophy), less pain, more normal sensation and blood flow, improved walking, and improved prosthetic wear. In contrast to a suspended prosthesis that gives the patient the sensation of instability, end-bearing facilitates rehabilitation by providing better proprioception. End-bearing prostheses are easier to apply and remove and some patients may even be able to get around somewhat without a prosthesis—something that is virtually impossible with traditional amputations.

Two major forms of osteoplasty have been recommended for TTA’s. One is an osteoperiosteal flap over the end of the tibia. The other is a fibular bone block transversely rotated. Both of these techniques are designed to seal the medullary canal, stabilize the distal tibia and fibula, and provide the potential for end-bearing of the residual limb with use of a prosthesis.²

The Ertl osteoplasty consists of the development of a short anterior and a long posterior periosteal flap off of the tibial shaft. The posterior periosteal flap should measure approximately six centimeters distal to the level of tibial amputation. This periosteal flap is several millimeters thick and is taken with an osteotome and some flakes of bone, especially from the posterior cortex of the tibia. Muscle origin tissue, tendinous in nature, is also utilized in the development of these anterior and posterior flaps. These flaps are then sutured over the tibial osteotomy site as a pouch to help seal off the medullary canal. In addition to the bone chips adherent to the periosteum, supplemental cancellous bone slurry is placed into the pouch once it is sewn over the end of the tibia. A similar technique can be accomplished with the fibula, or the periosteum can be sutured in such a way as to cover the cut ends of both the tibia and the fibula. This osteoplasty is then combined with myoplasty and soft tissue closure under no tension to create a residual limb capable of end bearing.^{9,10,12}

The fibular bone block technique consists of an osteotomy of the fibula, which is then hinged on a lateral periosteal sleeve transversely into a notch on the lateral aspect of the amputated distal tibia. Sutures through drill holes can be utilized to secure this bone block on both the tibia and fibula. The periosteal blood supply to this bone block is maintained through muscle attachments during the preparation. This bone block can also be covered with a periosteal sleeve as described above to further stabilize the bone block and improve sealing of the medullary canal and development of a tough tissue at the end of the bone capable of end bearing. This also helps transmit load to the distal fibula. The bone block technique also stabilizes the distal tibia and fibula, which has been postulated to improve rehabilitation and prosthetic usage.^{2,12}



Figure 1A. (Case 1) AP radiograph of a transtibial amputation with fibular cortical bone block.



Figure 1B. Lateral radiograph. Note the notching of the tibia to provide maximum bone surface for healing and the drill holes that were utilized for suture fixation.



Figure 1C. AP radiograph at 6 months demonstrates healing of the bone bridge.



Figure 1D. Lateral radiograph confirms healing. There is some ectopic bone formation posterior to the fibula.

MATERIALS AND METHODS

We report five cases utilizing osteoplasty as a part of lower limb amputation (four transtibial amputations and one transfemoral amputation). The cases are shown to illustrate indications, techniques, and short-term outcome with early weight bearing.

The first two cases in the series utilized a fibular cortical bridge without a periosteal sleeve. There were two cases that utilized the periosteal sleeve without a fibular cortical bridge. The fifth case utilized a fibular cortical bridge combined with a periosteal sleeve.

Case 1

A 29-year-old male with chronic recalcitrant osteomyelitis was referred eight years after an open right tibial shaft fracture at the junction of the distal one-quarter and proximal three-quarters of the tibia. He had undergone 12 previous operations that succeeded in achieving bony union but had a persistent draining infection and pain that prevented him from working. Despite rotational, free flap, and split thickness skin grafting, he had unstable skin posteromedially. He was treated with a transtibial amputation with a hinged fibular cortical bone bridge that was recessed into the lateral aspect of the tibia using the technique described previously (Figures 1A, 1B).

Although there was adequate fibular length, the area of chronic osteomyelitis of the tibia was too proximal to develop a good periosteal flap and maintain a margin of normal tibia between the infection and the amputation site. Therefore the periosteal flap technique was not used. The wound healed and the bone bridge consolidated by six months (Figures 1C, 1D). There was no recurrence of infection. The patient was able to walk with an end-bearing prosthesis at eight weeks, which facilitated his eventual return to work at 11 months.

Case 2

A 47-year-old female had a chronic recalcitrant infected nonunion of a distal metaphyseal tibia fracture that had been initially treated with a plate. After multiple operative procedures, she still had a malpositioned nonunion with *Pseudomonas* osteomyelitis and a very poor soft tissue envelope. She underwent transtibial amputation with a fibular cortical bone block. Again the area of infection was thought to be too proximal to safely allow the development of a periosteal flap. The wound healed and the bone bridge consolidated by eight months. The patient was



Figure 2A

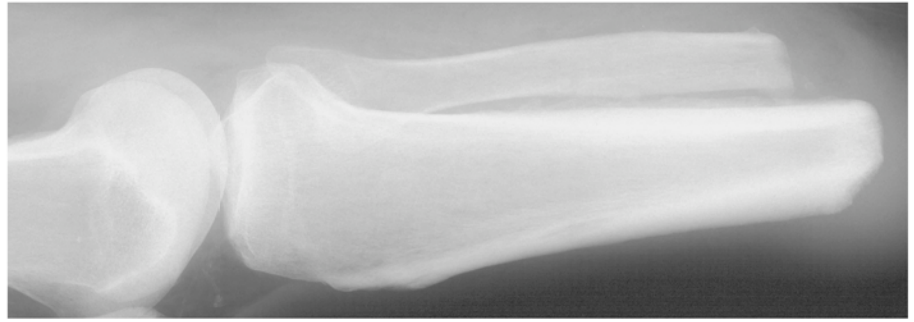


Figure 2B

Figures 2A, B. (Case 4) AP (a) and lateral (b) radiograph of a TTA with periosteal sleeve osteoplasty. At one year it has the radiographic appearance of a standard TTA. There is sealing callus over the medullary canal of the distal tibia with periosteal new bone.

able to walk with an end-bearing prosthesis at 12 weeks and eventually returned to work at 12 months.

Case 3

A 32-year-old male sustained multiple trauma (ISS 25) with injuries including left 3C open femur and tibial shaft fractures. The other extremities were successfully salvaged, but he required an acute guillotine transfemoral amputation (TFA). The patient survived and the TFA was revised with a periosteal sleeve amputation osteoplasty and wound closure 14 days after injury. The limb healed and sealing callus developed by 14 weeks. The patient was able to walk with an end-bearing prosthesis and returned to work after seven months.

Case 4

A 52-year-old male had brittle insulin-dependent diabetes and chronic recurring ulcers. In 1999, he was treated with a disarticulation at the first MTP. In 2002, he underwent a transmetatarsal amputation for new ulcers. The amputation site healed, but he developed ulcers over the heel and ankle two years later. In 2004, he underwent a TTA with a periosteal sleeve osteoplasty of the tibia. No bone block was used due to concerns about cortical bone healing. The wound healed, and sealing callus developed by 20 weeks postoperatively. The patient was able to walk with an end-bearing prosthesis and returned to work after three months. Figures 2A and 2B show the radiographic appearance after twelve months.

Case 5

A 49-year-old unemployed diabetic had chronic recurring ulcers over the heel and ankle. He sustained an open trimalleolar fracture of the distal tibia and fibula with plafond involvement. He was neuropathic with no pain and little sensation. Despite operative stabilization, he developed an infected nonunion. He underwent TTA with osteoplasty that included a hinged fibular cortical bone block covered by a periosteal sleeve with bone slurry as described previously (Figures 3A, 3B). His wound healed, and he was wearing a prosthesis by three months after surgery. An end-bearing prosthesis was allowed at that point. The bone block consolidated by six months (Figures 3C, 3D) with additional subperiosteal bone formation distal to the bone block. Unfortunately he remained unemployed.



Figure 3B



Figure 3C



Figure 3D

Figure 3A

Figures 3A, B. (Case 5) AP and lateral radiographs of patient with a TTA with both fibular bone block and ostealperiosteal sleeve. Figures 3C, D. AP and lateral radiographs at 6 months demonstrating good healing of the fibular bone block with additional new bone formation beneath the periosteal sleeve.

RESULTS

All five patients underwent amputation osteoplasty. Five of five patients had good wound healing and function of the residual limb. All patients had radiographic evidence of sealing of the medullary canal and healing of the bone bridge by six months. All patients were able to use an end-bearing prosthesis, including the two patients with diabetes.

DISCUSSION

This small case series with short follow-up illustrates the techniques of amputation osteoplasty. Although adult tibial periosteum itself may only be a few cell layers thick, we found that it was possible to raise a soft tissue flap from the surface of the tibia that included some tendinous tissue that was 1-2 mm thick. This flap could be sutured over the cut end of bone or the fibular cortical bone block to create an osteoplasty. Similarly, it was possible to osteotomize the fibula and obtain sufficient stability of the bone block, by suture fixation through drill holes and the creation of a slot in the posterolateral aspect of the tibia, to achieve healing in these cases. All of the patients healed and had good functional use of end-bearing prostheses. For transtibial amputations with ample available length, the use of a fibular bone bridge

supplemented by a periosteal sleeve is the most appealing technique. The periosteal sleeve method can be used alone for transfemoral and other amputation sites.

The Ertl website gives additional information about the technique.^{9,10} They emphasize that osteoplasty alone is not the only important step in the “osteomyoplastic amputation reconstruction.” Five key steps are recommended:¹⁰

1. Osteoplasty with periosteal sleeve.
2. Individual ligation of vessels.
3. Injection of all five nerves followed by proximal resection.
4. Myoplasty.
5. Even skin closure.

A variety of misconceptions appear in the literature. The use of a fibular cortical bone block is a form of osteoplasty but is not the technique recommended by Ertl. This cortical bone block is another way to achieve stabilization of the distal tibia and fibula, sealing of the medullary canal, and the potential for end bearing.

Although a variety of anesthetic and sclerosing medications have been advocated to prevent neuroma formation, in this series we injected the cut end of each of the nerves with 0.5cc of 0.25% marcaine to provide initial post-operative pain relief. The nerves were individu-

ally identified and put on tension before being sharply divided, injected, and allowed to retract deep within the residual limb. For TTAs, these nerves included the tibial, superficial peroneal, deep peroneal, saphenous, and sural nerves.

There are drawbacks to osteoplasty. It is more time consuming to perform than traditional amputation. There are concerns about healing problems with the more extensive dissection. The rate and reliability of the formation of the bone bridge has not been completely established. The benefits are primarily theoretical. Although there is significant data and clinical interest, Level I data to demonstrate improved outcomes is not yet available.^{13,14,15} There may be specific contraindications to the procedure, particularly within the zone of traumatic injury.^{2,16}

Although end bearing has traditionally been avoided, especially in diabetic patients, there is also a different perspective developing among prosthetists. Some have observed that diabetic patients initially have significant edema, followed by severe atrophy of the residual limb. Such patients will almost always “bottom out” in their prostheses eventually. This requires multiple adjustments, and liner and socket changes over time. These same patients may also suffer from skin breakdown around the knee and fibular head. By creating a residual limb with the capacity for end loading, the diabetic patients in this series appeared to have less initial swelling, less tissue atrophy, and fewer problems with pressure sores from their prostheses. We did delay weight bearing for six weeks to allow for good soft tissue healing. Determining if the bone bridge is healed on radiographs is somewhat difficult. However, we did observe a slower rate of bone bridge consolidation in the diabetic patients, who required six months to achieve the radiographic appearance seen in non-diabetic patients after three months.

Further study will be required to determine healing rates, optimal techniques, indications and contraindications, and to conclusively demonstrate functional advantages of the technique of amputation osteoplasty over traditional amputation techniques.

SUMMARY

The technique of amputation osteoplasty is an intriguing modification of a common procedure, and early success with this technique warrants further investigation and consideration.

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INTRAPELVIC MIGRATION OF THE TRIAL FEMORAL HEAD DURING TOTAL HIP ARTHROPLASTY: IS RETRIEVAL NECESSARY? A REPORT OF FOUR CASES

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ABSTRACT

When testing intra-operative range of motion during a total hip arthroplasty procedure with trial components, there is potential for the femoral head to dissociate from the trial neck. We report the dissociation of the trial femoral head with migration of the head into the pelvis while checking for anterior stability of the total hip arthroplasty construct. Options for retrieval of the head are outlined.

Use of modular trial components to assess optimal component positioning for stability, soft tissue tensioning, and leg length equalization during total hip arthroplasty has become a common routine. A previous case of trial femoral head dissociation with migration of the head into the pelvis without retrieval has been reported.¹ Two letters to the editor following this report questioned this approach.^{2,3} The present report describes four cases of this occurrence with recommendations based on the cumulative experience.

Case 1: A 67-year-old male with a history of hypertension and coronary artery disease underwent a left cementless total hip replacement for osteoarthritis through a posterolateral approach to the hip in the lateral position. After preparation of the acetabulum, the acetabular component was placed in approximately 35 to 40 degrees of lateral opening and 20 degrees of anteversion. Dome screws were placed to augment shell fixation, and a 26-millimeter inner diameter neutral trial acetabular liner was placed. Extensive anterior and posterior acetabular osteophytes were debrided. The femoral canal was reamed and broached to prepare for the insertion of an extensively coated cementless stem. A modular head and neck trial was assembled and placed on the femoral broach. While checking for anterior hip stability by hyperextending and externally rotating the femur, the trial femoral head dissociated from the neck and migrated through a rent in the anterior capsule created during anterior acetabular osteophyte excision. It then passed along the psoas tendon and into the pelvis. Numerous attempts were made to retrieve the head by placing one or two fingers along the psoas tendon into the pelvis with the hip flexed and extended. The head could be spun around but not retrieved. Because of the patient's relatively poor health and the fact that the



Figure 1. Postoperative pelvis radiograph with arrows around the migrated femoral head trial.

head had no sharp corners to perforate any intrapelvic structures, it was decided to leave the head in the pelvis. The components were placed with excellent anterior and posterior stability. The total operative time was 105 minutes. The patient and family were told of the occurrence and agreed to no further intervention unless the patient became symptomatic. The femoral head shadow was seen on the postoperative pelvis radiograph (Figure



Figure 2. Postoperative pelvis radiograph with arrows around the migrated femoral head trial.

1). The patient developed a myocardial infarction three days later and had a coronary artery bypass seven weeks postoperatively, from which he completely recovered. He is walking unlimited distances without pain or impingement symptoms two years postoperatively.

Case 2: A 66-year-old male underwent right cementless total hip arthroplasty for osteoarthritis. The procedure was similar to that described in case one. Once again while checking for anterior stability, the femoral head dissociated and migrated into the pelvis along the psoas tendon. Retrieval using the same maneuvers was again unsuccessful. The patient and family were told of the occurrence as well as our previous experience and



Figure 3. Pelvis anatomy demonstrating the femoral head trial positioned anterior to the iliacus and psoas muscle as in Case 3 with arrow demonstrating the position of the trial at the time of retrieval in Case 2 and Case 4.

agreed with the approach to observe for symptoms. Postoperative radiographs demonstrated the trial femoral head to be located within the pelvis (Figure 2). The patient recovered uneventfully until the sixth postoperative week when he felt a clicking noise in his hip with loss of motion. He was taken to the operating room where an eight-centimeter incision was made starting two centimeters proximal and posterior to the anterior superior iliac spine and extending distally along the lines of the proximal portion of a Smith-Petersen incision. The dissection was then carried medial to the sartorius. The femoral head trial was palpated between the iliacus and the bony pelvis and was held securely between two fingers while bluntly dissecting onto the ball in order to retrieve it. The procedure took 20 minutes. The patient is functioning well two years later without symptoms.

Case 3: A 78-year-old female underwent a hybrid total hip arthroplasty through a posterolateral approach. After placement of the acetabular component and broaching for the cemented femoral component, trial reduction was performed. The trial femoral head dissociated from

the neck and migrated into the pelvis along the psoas tendon. It could not be retrieved through the incision. It was decided to retrieve the component through another incision. The permanent femoral component was cemented into place and the wound closed.

The patient was repositioned in the supine position, and the pelvis was prepped and draped for an ilioinguinal approach. An incision was made starting two centimeters medial to the anterior-superior iliac spine and extending toward the pubic tubercle. The external oblique muscle was divided along its fibers and the internal oblique was separated from its insertion with electrocautery. A retroperitoneal approach was followed to the psoas muscle and the trial head was easily retrieved. The wound was closed, and the patient recovered uneventfully and was functioning well six months postoperatively.

Case 4: A 58-year-old female with a previous spinal cord stroke underwent a revision total hip replacement for instability through a posterolateral approach to the hip in the lateral decubitus position. The acetabular component was revised using a 52-millimeter cementless acetabular component, and a 28-millimeter trial liner was placed. A trial femoral head was placed on the secure stem and, while checking anterior stability, the head dissociated and migrated along the psoas tendon into the pelvis. As in the other three cases it could not be retrieved. The permanent acetabular liner and femoral head were inserted. The hip was closed. The patient was placed supine and the pelvis prepped. Once again the same retroperitoneal approach was used to retrieve the trial component, which was situated beneath the iliacus as in case two. The patient was functioning well six months postoperatively.

DISCUSSION

It is always concerning to the surgeon when hardware that is used during a procedure breaks or migrates to an unretrievable position. When a trial femoral head dissociates from the neck and migrates along the psoas tendon and muscle into the pelvis, it is especially frustrating. As described in the present study and a previous report, as well as letters to the editor, the trial femoral head probably cannot be retrieved from the pelvis through only a hip incision (Figure 3). If the head dissociates during trialing for anterior stability, one should tell the tissue-retracting assistant not to move and try to retrieve the head before it migrates along the psoas tendon into the pelvis. Furthermore, one should try not to push it superiorly along the tendon. If it migrates, one can usually palpate the ball with a finger, but it spins away from the finger and cannot be retrieved. Although this should be attempted, it will probably not be successful. We recommend making a six to seven centimeter

incision along the iliac crest and extending it slightly anterior and medial to the anterior superior iliac spine. Then one should place his or her finger along the inner wall of the iliac wing by reflecting the iliacus medially. This may allow the surgeon to push the femoral head (using one's finger or napkin ring forcep) back down to the pelvic rim and anterior to the hip joint, allowing retrieval. The senior author recently recommended this strategy to a surgeon who called him from an operating room with this same problem. If this maneuver does not work, by extending the incision distally (if the area is prepped) and retracting the tissues medial to the sartorius, the head can be retrieved or pushed back into the hip incision wound. If this maneuver does not work, one should complete the hip replacement procedure and consider redraping in the supine position and making a retroperitoneal approach to the pelvis to retrieve the head. If the decision is made not to retrieve the trial head, the surgeon should inform the patient and family that he or she may become symptomatic and require trial component removal at a later date.

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SURGICAL PROCEDURE PROFILE IN A COMPREHENSIVE HIP SURGERY PROGRAM

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ABSTRACT

Surgical management of hip disease in adolescents and young to middle-aged adults is rapidly evolving, and a variety of operative techniques are needed to provide comprehensive care. The purpose of this study was to determine the utilization of surgical procedures and recent changes in procedure utilization in a comprehensive hip surgery program. We performed a retrospective review of 983 hip procedures in 854 patients performed over a seven year time period. The average patient age was 37.4 years (range 10-55). Five hundred fifty-six procedures were performed in female patients and 427 in male patients. Total hip arthroplasty (32.9%), hip arthroscopy (25.1%), and periacetabular osteotomy (13.1%) were the most common surgical procedures. Techniques utilized less often included osteochondroplasty of the femoral head-neck junction (7.9%), hip implant revisions (7.9%), and proximal femoral osteotomy (4.1%). Uncommon procedures included core decompression (2.2%), soft tissue releases (1.2%), femoral head resurfacing (0.6%), arthrodesis (0.3%), and Chiari pelvic osteotomy (0.2%). The most dramatic changes in utilization over the seven year time period included a marked increase in hip arthroscopies and osteochondroplasties of the femoral head-neck junction. These data underscore the variety of surgical techniques needed to treat this patient population, and emphasize an expanding role for nonarthroplasty surgical interventions.

INTRODUCTION

Comprehensive surgical management of hip disease in skeletally mature patients poses a distinct challenge to orthopaedic surgeons. This discipline demands treatment for a wide spectrum of hip conditions in patients of varying age, and requires a diverse armamentarium of surgical techniques.^{1,3} Recent advances in this field, including an improved understanding of the pathophysiology of pre-arthritis hip conditions, improved diagnostic tools, and refined surgical techniques have all led to a rapid evolution of surgical treatment alternatives.^{2,4-11} Additionally, these patients may seek treatment from orthopaedic surgeons of varying subspecialties including general orthopaedics, pediatrics, sports medicine, traumatology, and adult reconstructive surgery. Because this emerging discipline spans various subspecialty areas and encompasses a wide spectrum of surgical techniques (arthroscopy, osteotomy, osteoplasty, arthrodesis, and arthroplasty), there exists a major need to develop an improved consensus regarding optimal diagnostic and treatment strategies.

Over the past seven years we have developed a comprehensive hip surgery program that employs a full array of surgical techniques to treat the various hip conditions of adolescence and adulthood. This effort has focused on patients less than 55 years old because they are more likely to be appropriate candidates for alternative hip procedures. There exists a major need for specialized orthopaedic care directed at this patient population. In this study we review our "learning curve" experience with this initiative. The primary purpose of this report is to define the spectrum and proportionality of surgical procedures required to administer comprehensive surgical care to this patient population. Secondly, we characterize the emerging trends in surgical procedure utilization in our practice. These data will provide a framework for surgical practice planning for individual surgeons or surgical teams who are intent upon providing comprehensive surgical care of the hip.

METHODS

We retrospectively reviewed the surgical database of one of the senior authors (JCC), and identified all hip procedures performed in patients 55 years old or younger over a seven year time frame (January 1999 to December 2005). These procedures were all performed

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TABLE 1
Diagnoses and Preferred Hip Procedures

Hip Diagnosis	Preferred Procedures (over time course of study)
Advanced articular disease	Total hip replacement Hip arthrodesis (considered in active, young male patients <25 years old) Hip arthroscopy
Internal derangement (labral tears, chondral flaps, loose bodies, synovitis)	Periacetabular osteotomy (osteochondroplasty if needed)
Acetabular dysplasia	Hip revision
Failed total hip arthroplasty	Core decompression (no collapse)
Osteonecrosis of femoral head	Femoral head resurfacing (early collapse) Total hip replacement (late collapse)
Proximal femoral deformities (DDH, Perthes, SCFE, posttraumatic)	Proximal femoral osteotomy (osteochondroplasty if needed)
Focal anterior femoroacetabular impingement (cam-type)	Hip arthroscopy with combined open osteochondroplasty of femoral head-neck junction
Non-focal femoroacetabular impingement (cam or pincer-type)	Surgical hip dislocation, labral debridement/repair with osteochondroplasty of femoral head-neck junction and/or acetabular rim
Soft tissue disorders (snapping psoas, piriformis syndrome)	Psoas lengthening or piriformis release
Retained hardware	Hardware removal

*These are general treatment preferences over the time course of the study, but specific surgical treatment recommendations were dependent upon multiple disease and patient related factors.

TABLE 2
Hip Procedure Distribution and Patient Characteristics

Procedure	Number (%)	Mean age years (range)	Gender (M/F)
All procedures	983	37.4 (10 – 55)	427/556
Total hip arthroplasty	323 (32.9%)	42.4 (13 – 55)	158/165
Hip arthroscopy	247 (25.1%)	34.7 (15 – 55)	86/161
Periacetabular osteotomy	129 (13.1%)	24.6 (10 – 51)	29/100
Osteochondroplasty	78 (7.9%)	30.6 (15 – 48)	46/32
Hip implant revision	78 (7.9%)	44.8 (23 – 55)	25/53
Proximal femoral osteotomy	44 (4.1%)	26.0 (12 – 48)	17/27
Hardware removal	39 (4.0%)	30.7 (16 – 51)	9/30
Core decompression	22 (2.2%)	35.6 (16 – 52)	14/8
Soft tissue problems (snapping psoas, piriformis syndrome)	12 (1.2%)	37.3 (26 – 55)	7/5
Femoral head resurfacing	6 (0.6%)	31.8 (23 – 40)	3/3
Hip arthrodesis	3 (0.3%)	21 (18 – 23)	2/1
Chiari pelvic osteotomy	2 (0.2%)	19.5 (12 – 27)	1/1

by one surgeon or in collaboration with the other senior surgeon (PLS). The majority of these patients were derived from an adult reconstructive surgery practice with a special emphasis on early intervention hip surgery. The remainder of patients presented for a pediatric or adolescent hip evaluation. Collectively, this patient cohort represents the “learning curve” experience for our adolescent and young adult hip surgery program. Although our patient selection criteria and indications for surgery have evolved over this time interval, the basic principles of patient evaluation and selection for surgery have, for the most part, remained the same.¹

Surgical decision making was based on defining the anatomic location of disease (extraarticular, intraarticular, referred), the presence or absence of a structural hip abnormality (impingement, developmental hip dys-

plasia (DDH), Perthes deformity, slipped capital femoral epiphysis), and the severity of articular cartilage degeneration.¹² This information was considered in the context of patient-related factors (age, weight, activity status, comorbidities) and physical exam findings in order to outline a surgical treatment recommendation for each patient. Our surgical treatment preferences based on disease type are summarized in Table 1.

Nine hundred and eighty-three procedures in 854 patients were identified with the database search and included in this study. The average age of the patients at the time of surgery was 37.4 years (range 10-55 years). Five hundred and fifty-six (62.5%) procedures were in female patients and 427 (37.5%) were in male patients. For patients undergoing simultaneous procedures, each procedure was recorded separately. For example, when

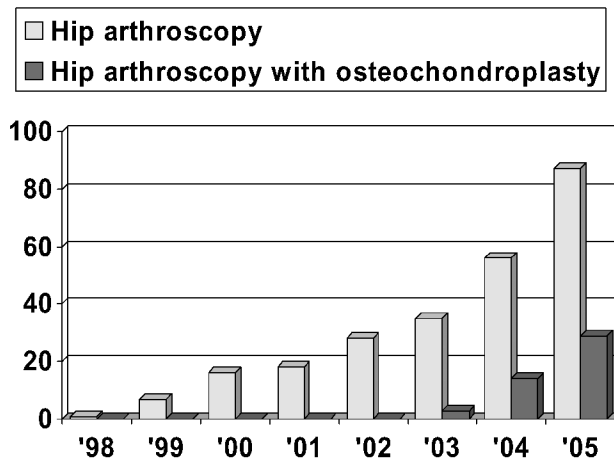


Figure 1. Annual utilization of hip arthroscopy and hip arthroscopy with limited open osteochondroplasty of the femoral head-neck junction. The number of hip arthroscopy procedures per year and the number of adjunctive limited open osteochondroplasties are shown. Limited open osteochondroplasty, in combination with hip arthroscopy, has been utilized for the treatment of focal anterior femoroacetabular impingement.

a hip was treated with arthroscopy and a combined osteotomy (or osteochondroplasty), both components of the surgical treatment were considered distinct procedures. The type of surgical procedure(s), date of surgery, procedure utilization on an annual basis, and the utilization of combined procedures on an annual basis were recorded.

RESULTS

The most common surgical procedures utilized over the time period of this study were primary total hip replacement, hip arthroscopy, and reconstructive acetabular osteotomy. Surgical procedure utilization is summarized in Table 2. Of the 983 total procedures, 323 (32.9%) were primary total hip replacements performed for endstage articular disease. The average age of patients undergoing primary total hip replacement was 42.4 years (range 13-55 years). Hip arthroscopy was the second most common surgical intervention, and was performed alone or in combination with an additional procedure in 247 (25.1%) of the cases. The average age of hip arthroscopy patients was 34.7 years (range 15-55 years). The utilization of hip arthroscopy has increased on an annual basis throughout the time course of this study (Figure 1). Periacetabular osteotomy (PAO)^{7,10,12} was utilized for the treatment of symptomatic acetabular dysplasia in 129 cases (13.1%), and the average age of these patients was 24.6 years (range 10-51 years).

After these three more common procedures, a variety of additional techniques were employed less frequently. Osteochondroplasty of the femoral head-neck junction⁶ for the treatment of anterior femoroacetabular impinge-

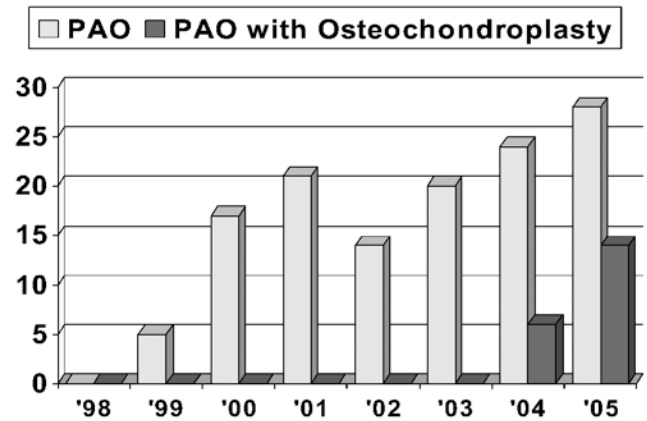


Figure 2. Annual utilization of periacetabular osteotomy and concurrent osteochondroplasty of the femoral head-neck junction. The yearly utilization of periacetabular osteotomy and concurrent osteochondroplasty is demonstrated in the bar graph. Osteochondroplasty is performed to optimize impingement-free hip flexion motion after periacetabular osteotomy.

ment or in combination with a PAO^{13,14} was performed in 78 (7.9%) hips. Similarly, 78 (7.9%) hip implant revision procedures were performed. Proximal femoral osteotomy was performed alone or in conjunction with an additional procedure in 44 (4.1%) cases. Procedures utilized infrequently included core decompression (22, 2.2%), soft tissue procedures (psoas tendon lengthening, piriformis release) (12, 1.2%), femoral head resurfacing (6, 0.6%), hip arthrodesis (3, 0.3%), and Chiari salvage pelvic osteotomy (2, 0.2%).

The most notable change in procedure utilization was a marked increase in hip arthroscopy cases and osteochondroplasties of the femoral head-neck junction. After introduction into our practice, hip arthroscopy was initially performed on an infrequent basis (Figure 1). Nevertheless, the utilization of this procedure has continued to increase on an annual basis, and is now one of the most common procedures performed. Over the past year, 87 hip arthroscopies were performed which represents 31% of all hip procedures in patients 55 years or less. It is important to note that hip arthroscopy techniques are frequently employed in combination with osteotomy or osteochondroplasty procedures.

Osteochondroplasty of the femoral head neck junction is another technique that has recently assumed a major role in our non-arthroplasty hip cases. We treat femoroacetabular impingement disorders with hip arthroscopy and a combined limited open osteochondroplasty (for focal anterior impingement)⁴ or with surgical dislocation of the hip (for nonfocal impingement disease).^{6,15-17} Both of these techniques require an osteochondroplasty of the femoral head-neck junction to decompress bony

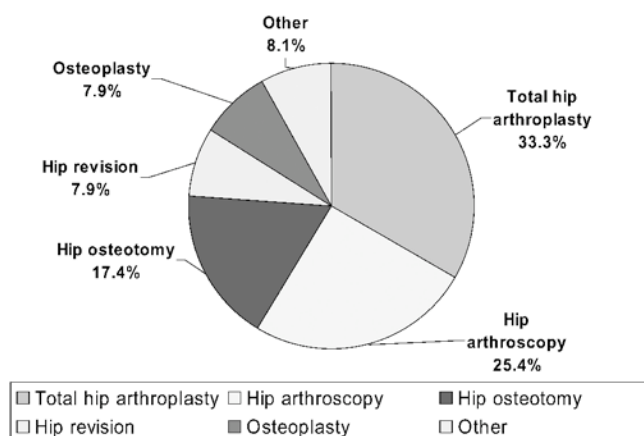


Figure 3. Surgical technique utilization for 983 hip procedures in skeletally mature patients less than 55 years old. All surgical procedures over the time course of the study are summarized. "Hip osteotomy" includes periacetabular and proximal femoral osteotomies. "Osteoplasty" refers to osteochondroplasty of the femoral head-neck junction. "Other" includes hardware removal, core decompression, soft tissue problems, and femoral head resurfacing.

impingement lesions. Osteochondroplasty has become a common adjunct to hip arthroscopy for patients with focal anterior femoroacetabular impingement (Figure 1). Over the past one year, 33% of arthroscopies were performed concurrently with an osteochondroplasty. Another major indication for an osteochondroplasty is to prevent secondary anterior femoroacetabular impingement after a PAO.¹⁸ We now employ this technique in approximately 50% of periacetabular osteotomies (Figure 2) to optimize impingement free range of motion after acetabular reorientation.^{13, 14}

DISCUSSION

The diagnosis and surgical management of hip disease in adolescents and adult patients less than 55 years old is an expanding and evolving discipline.^{1,2} Comprehensive treatment of this patient population should employ a wide variety of surgical techniques, yet the appropriate indications for specific techniques and the efficacy of various surgical interventions needs to be investigated further. In this study, we have summarized the utilization of surgical procedures over a seven year developmental phase of our comprehensive hip surgery program. Primary hip replacement, hip arthroscopy, and hip osteotomies were the dominant procedures during this time frame (Figure 3). Primary total hip replacement for endstage articular disease is the most common procedure in our practice, which underscores the important role of this operation, even in this relatively young patient cohort. Advances in the development of low-wear, alternative bearing surfaces¹⁹ and the renewed interest in total

resurfacing of the hip will maintain hip replacement procedures and resurfacing as dominant treatment modalities.²⁰ Nevertheless, future emphasis must be placed on early diagnosis and early non-arthroplasty surgical intervention to prevent or delay the onset of secondary osteoarthritis.^{2,3,12}

As knowledge regarding the diagnosis and treatment of pre-arthritic hip disease is disseminated, hip arthroscopy and osteotomy procedures will become more commonplace. The growth of our hip arthroscopy practice (Figure 1) demonstrates the need for technical expertise with this procedure. Clearly, hip arthroscopy has an important role in treating a specific subgroup of young patients.^{5,9,21,22} Arthroscopy can also be employed to address intraarticular disease in conjunction with reconstructive procedures like periacetabular or proximal femoral osteotomies. Despite our strong endorsement of hip arthroscopy as a surgical tool, we^{21,23} and others²⁴ have emphasized that intraarticular problems like labral tears are commonly associated with structural hip abnormalities. Thus, an optimal surgical plan should address the underlying cause of intraarticular disease (DDH, Perthes deformity, SCFE, and impingement disorders) as well as the symptomatic manifestation (labral tear, chondral flap) of the structural disease. As our experience has expanded, we have become more adept at diagnosing subtle structural abnormalities.^{21,23} In addition, we have developed a more aggressive surgical approach to treat any significant structural problem associated with intraarticular disease. Hip arthroscopy techniques alone are frequently inadequate to correct significant structural disease of the hip.

Perhaps the most interesting trend in our procedure utilization has been the marked increase of femoral head-neck junction osteochondroplasties over the past two years (Figures 1 and 2). Improved understanding of the pathoanatomy of femoroacetabular impingement,^{6,15,16,25-30} and the potential for secondary anterior femoroacetabular impingement after PAO¹⁴ (or proximal femoral osteotomy) are the two dominant reasons for the increased utilization of this technique. Our early clinical experience supports previous reports that recommend osteochondroplasty for optimizing the treatment of impingement disorders,²⁵ and in refining hip reconstruction after periacetabular osteotomy.¹⁸

Our study is unique in that it outlines the specific procedure demands of a surgical program targeted at providing care to skeletally mature patients less than 55 years old. These data provide important information for surgeons who are intent on developing practices or programs that provide comprehensive surgical care of the hip. Nevertheless, there are certain inherent weaknesses in this study. The surgical procedures analyzed

are derived from one clinical practice, and procedure utilization clearly reflects the treatment and patient selection biases of the treating surgeons. The majority of these cases presented to an adult reconstructive surgeon who has a special interest in early intervention hip surgery. Certain adolescent disorders, like acute slipped capital femoral epiphysis, are under-represented in this patient cohort. Similarly, we do not perform vascularized fibular grafting for the treatment of femoral head osteonecrosis. This procedure and other alternative procedures may be more common in other practice settings. The specific proportionality of procedures will definitely vary depending upon the practice pattern and biases of the surgeon. Additionally, our cases were performed during the "learning curve" experience for several of these procedures. Although our basic treatment guidelines have not changed in a major way, our specific treatment preferences have evolved. For example, an improved understanding of femoroacetabular impingement disorders has resulted in a marked increase in the utilization of femoral head-neck junction osteochondroplasties. Perhaps the largest limitation of this study is the lack of clinical outcomes data. Over the long term, these data are essential to refine patient selection criteria for surgical intervention, and for assessing the efficacy of different surgical interventions. We intend to continue to follow these patients over time, and to report clinical outcome results at appropriate follow-up intervals.

In summary, we have documented the surgical procedure utilization patterns over the "learning curve" phase of a comprehensive hip surgery program. Our data emphasize the importance of a complete armamentarium of surgical techniques including prosthetic replacement, arthroscopy, osteotomy, osteochondroplasty, and other less-commonly utilized procedures (outlined in Table 2). We feel that the variety of surgical procedures utilized and the wide age range of these patients argue strongly for a "team" approach in providing comprehensive surgical care. A collaborative effort between pediatric, arthroscopic, adult reconstruction, and/or pelvic reconstruction orthopaedic surgeons is ideal to cover the spectrum of disease and treatment alternatives needed for this very challenging patient population.

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ETHANOL AS A LOCAL ADJUVANT FOR GIANT CELL TUMOR OF BONE

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ABSTRACT

Giant cell tumor is an aggressive benign neoplasm of bone. A number of adjuvant agents have been used to supplement intralesional curettage to reduce the otherwise high local recurrence rate. High concentration ethanol is more readily available and less toxic to use than some common alternatives. No report on its use in a group of patients with giant cell tumor is available. Records were retrospectively reviewed for all giant cell tumors treated by intralesional curettage and high concentration ethanol irrigation as the only chemical adjuvant. Twenty-five primary excisional curettages and 12 repeat curettages for giant cell tumors of bone were performed in 31 patients. Patients were followed for a mean of three years and 10 months. There were five recurrences after primary excision procedures, and three after repeat excisions. Only use of a high-speed burr and lower Campanacci staging correlated with reduced recurrence rate, and these were not statistically significant. Most defects were filled with allograft or calcium sulfate. In the 11 patients treated primarily with curettage using a high-speed burr and adjuvant ethanol with minimum two-year follow-up, only one stage 3 lesion in a distal radius recurred. Multiple washes with high concentration ethanol, when used in conjunction with aggressive curettage including high-speed burring, is an effective and safe adjuvant. The necessity of any chemical adjuvant after appropriately aggressive curettage

and burring can only be definitively demonstrated with a prospective, randomized, multi-center trial. Until such evidence becomes available, the use of adjuvant ethanol offers a compromise between higher toxicity adjuvants and no chemical adjuvant at all.

INTRODUCTION

Jaffe and colleagues offered the first thorough characterization of giant cell tumor (GCT) of bone in 1940.¹ Since then, large series of bone tumors have found GCTs to represent approximately 20 percent of all benign bone tumors and five percent of all osseous neoplasms.²

Giant cell tumor is a locally aggressive but usually benign neoplastic disease of bone. In the appendicular skeleton, it typically arises eccentrically in the metaphysis, but usually extends into the epiphysis, often involving the subchondral bone.

Because of its periarticular location, resection for wide oncologic margins would require complex joint reconstructions and incur significant morbidity with regard to joint function in the long term. Intralesional curettage through a broad cortical window therefore remains the treatment of choice for most GCTs of bone in most treatment centers.

Early reports of curettage alone noted high rates of local recurrence.^{3,7} This prompted the use of a variety of local adjuvants, most commonly including phenol and liquid nitrogen cryotherapy. Concomitant to the use of these adjuvants are complexities and complications that some surgeons find undesirable.

For the last few years, three to four 60-second washes with 95 percent ethanol have been used at the University of Iowa as local adjuvant treatment after aggressive curettage of giant cell tumors in the appendicular skeleton. We retrospectively review this experience.

METHODS

With the permission of the Institutional Review Board, electronic pathology records were searched to identify all giant cell tumors of bone treated at the University of Iowa Hospitals and Clinics over the last 20 years. Extant medical records were reviewed. Patients were excluded if the tumor was located in the axial skeleton or if adjuvant ethanol was not used during intralesional curettage. For the included patients, basic demographic data

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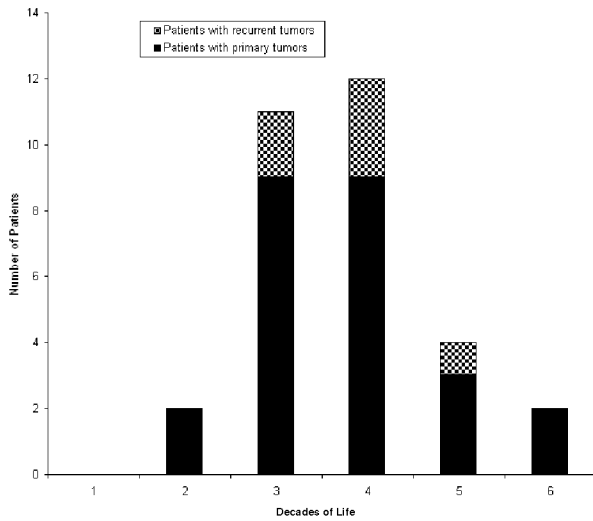


Figure 1. Distribution of ages of presentation among patients with giant cell tumor of bone treated by intralesional excisional curettage, adjuvant ethanol irrigation, and defect filling.

were recorded in addition to lesion location, Campanacci staging,⁸ use of a high-speed burr, defect-filling material selected, perioperative complications, and details of longer-term follow-up such as recurrence and metastasis. Patients were not excluded for follow-up of less than two years, so as not to bias the study group.

With recurrence as the primary outcome, survival curves were independently generated for both primary excisions and recurrence excisions. Fisher's exact test was used to test categorical variables such as use of a high-speed burr, defect-filling agent used, and Campanacci staging for their relationships with rate of recurrence.

RESULTS

The electronic pathology records identified 87 tissue reports containing "giant cell" and "bone" since 1985. Of these, 26 were other bone lesions containing giant cells, such as aneurysmal bone cysts and giant-cell rich osteosarcomas. Sixty-one records showed giant cell tumors of bone, prompting review of additional medical records. With additional medical record information, two were incisional biopsies, one was a lung wedge resection of a benign metastasis from a GCT of bone, 12 were GCTs of the axial skeleton, six were GCT resection specimens from the appendicular skeleton, and 40 were excisional curettage specimens from appendicular skeleton GCTs. The six resections had been performed for three highly aggressive GCTs with widely displaced intra-articular fractures, two typical GCTs in expendable bones, and one highly aggressive, multiply recurrent GCT of the proximal tibia. Of the 40 excisional curettages, three did not use ethanol as an adjuvant.

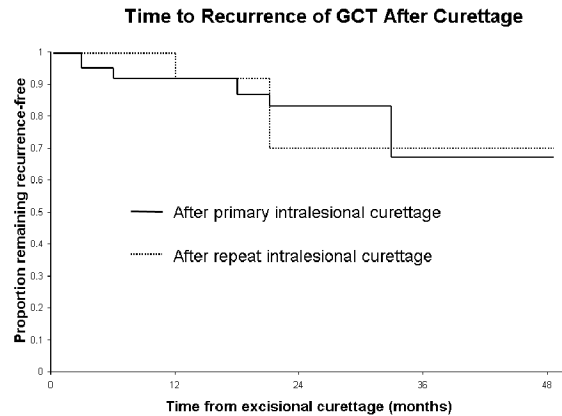


Figure 2. Kaplan-Meier plot of time to recurrence following primary intralesional excisional curettage with adjuvant ethanol for giant cell tumor of bone, and following repeat intralesional excisional curettage with adjuvant ethanol for recurrent giant cell tumor of bone, given a variable length of follow-up.

The final study group included 37 excisional curettages in 31 patients. Twenty-five patients presented primarily and six presented with a recurrent GCT after previous curettage by another surgeon. Among the patients receiving primary excisional curettage, 16 were female and nine male. The average age at surgery was 31.6 years (range 19 to 58 years) (Figure 1). Among patients presenting with recurrent lesions, four were male and two female, with an average age of 32 years, (range 27 to 42 years). Patients were followed for a mean of three years and ten months.

One of the GCTs in the primary group was Campanacci stage 1, 11 were stage 2, and 10 were stage 3. Three others had associated fractures with significant displacement. For 12 of the primary excisions, a high-speed burr was used after curettage prior to ethanol irrigation. For 13 primary excisions, no burr was used. All defects were filled after lesion ablation, one with autograft, nine with allograft, nine with calcium sulfate putty or pellets, three with a mixture of allograft and calcium sulfate, and three with polymethylmethacrylate cement.

Following primary excisional curettage, five GCTs recurred (Figures 2 and 3). One tumor recurred after use of a high-speed burr and acrylic cement in addition to adjuvant ethanol. The other four recurrences followed curettage with ethanol irrigation but without the aid of a high-speed burr. No wound problems or post-operative fractures were noted following primary excisions. Two patients without recurrence had further surgery, one to replace acrylic cement with allograft and another to fill with acrylic cement an area where allograft had poorly incorporated.

Soft-tissue involvement was noted on most of the 12 repeat excisional curettages for recurrence. A high-speed

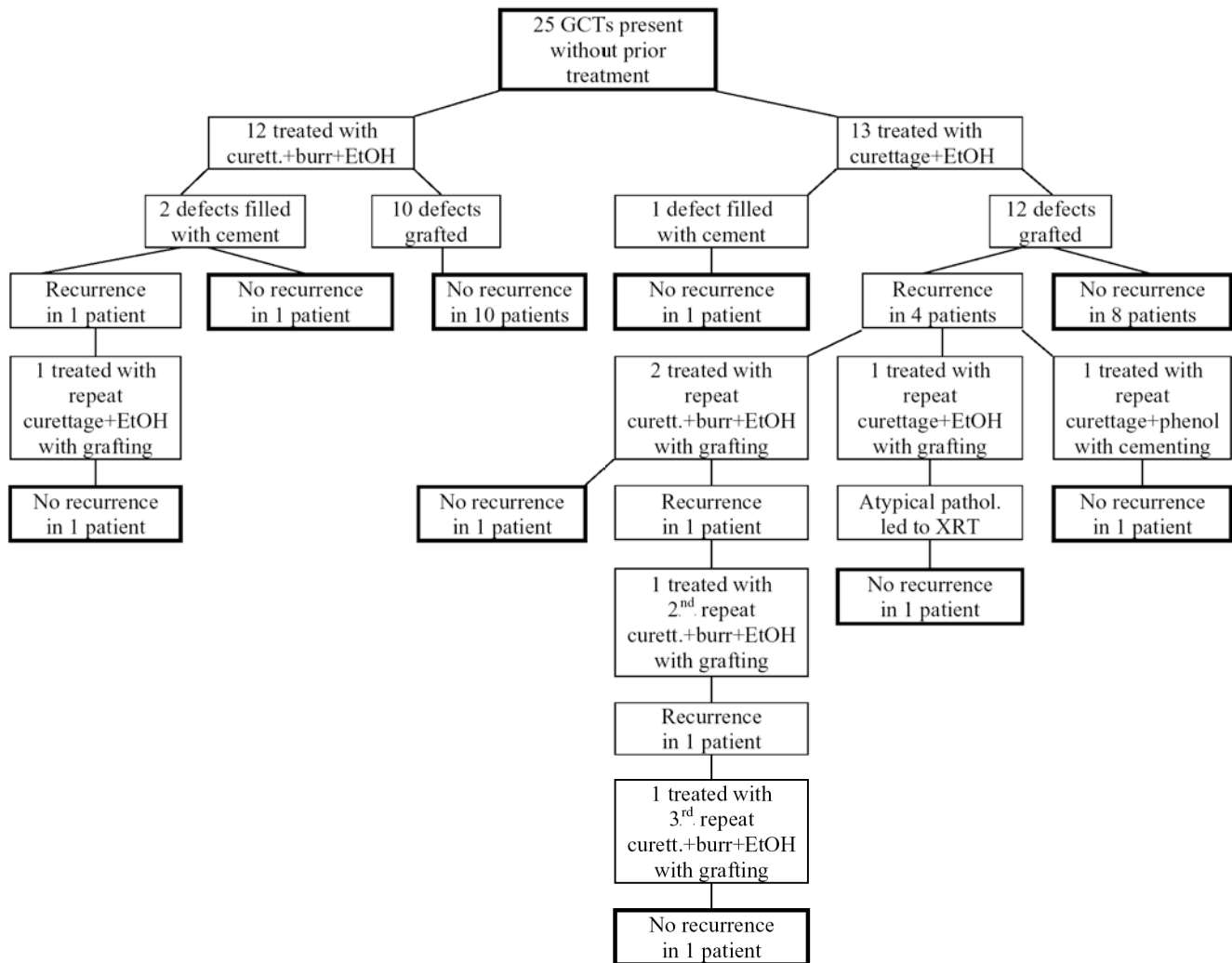


Figure 3. Treatment course and outcome at latest follow-up of patients with giant cell tumor of bone treated primarily with intralesional excisional curettage and adjuvant ethanol irrigation.

burr was used during nine of these repeat excisions, with the other three utilizing curettage alone prior to adjuvant ethanol. Defects were filled with allograft in two cases, calcium sulfate in two cases, a mix of allograft and calcium sulfate in four cases, and polymethylmethacrylate in four cases. One of the patients had moderate atypia noted histologically in his recurrent tumor. He was treated with adjuvant external beam irradiation after a brief delay for early graft incorporation (Figure 5).

Three recurrences followed these 12 repeat excisional curettages (Figures 2, 3, and 4), two in a single patient (Figure 6). The other re-recurrence was also associated with benign pulmonary metastases. These metastases were wedge-resected and the recurrent bone lesion was widely resected prior to endoprosthetic reconstruction.

Two patients without recurrences had noteworthy complications after repeat excisional curettage. One patient sustained an intra-articular fracture around the cemented defect, which was treated conservatively, but led to significant osteoarthritis 12 years later. Another patient had persistent wound drainage, which was treated with graft removal, antibiotics, and delayed re-grafting. Whether this represented a low-grade infection or the wound drainage occasionally associated with calcium sulfate filling of non-contained bone defects⁹ was never concluded, but all cultures were negative.

Fisher's exact test noted statistically insignificant trends toward use of a high-speed burr associating with lower recurrence rate ($p = 0.16$), and higher Campanacci stage associating with a higher recurrence rate ($p = 0.32$) for primary excisions. Defect filling material did not appreciably correlate with recurrence rate.

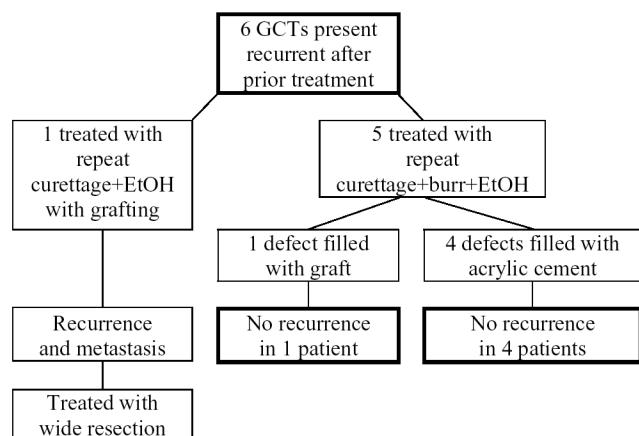


Figure 4. Treatment course and outcome at latest follow-up of patients with recurrent giant cell tumor of bone treated with repeat intral- excisional curettage and adjuvant ethanol irrigation.

DISCUSSION

Early reports of intralesional curettage for GCTs of bone noted recurrence rates ranging greater than 50 percent.^{4,7} As recurrence can make joint-preserving strategies much more difficult, such frequent recurrence is to be avoided if possible.

A number of different techniques (Table 1) and chemical agents have been used as adjuvants to intralesional curettage of benign aggressive bone tumors such as GCT. These have included the use of a high speed burr, painting or irrigating with phenol,^{3,6,10-16} cryotherapy with liquid nitrogen,¹⁷⁻¹⁹ irrigation with hydrogen peroxide,²⁰ irrigation with aqueous zinc chloride,²¹ thermal cautery with a carbon dioxide laser,²² defect filling with polymethylmethacrylate (for its heating properties),^{3,11,12,23-26} and the use of defect-filling agents that elute methotrexate²⁷ or adriamycin.²⁸

Most surgeons agree that aggressive curettage through a sufficiently wide cortical window for visibility is of paramount importance. Typically, a high-speed burr is used to extend the intralesional margins after removal of the gross tumor. Some authors argue that these more aggressive excision techniques are sufficient to achieve an acceptably low frequency of recurrence, ranging from 0 to 19 percent.²⁹⁻³³ These authors argue that benefits attributed to chemical adjuvants may stem from their association with more recent curettage and burr techniques.

Of chemical techniques, adjuvant phenolization and cryotherapy have surfaced as the most popular. Phenol, which has been shown to be cytotoxic to GCT cells in vitro,³⁴ has been associated with favorable results ranging from six to 18 percent recurrence rates in recent series.^{10,11,14,15} While some data exist to confirm low systemic toxicity from the use of phenol as a local adjuvant,³⁵ it is a caustic substance and must be handled carefully

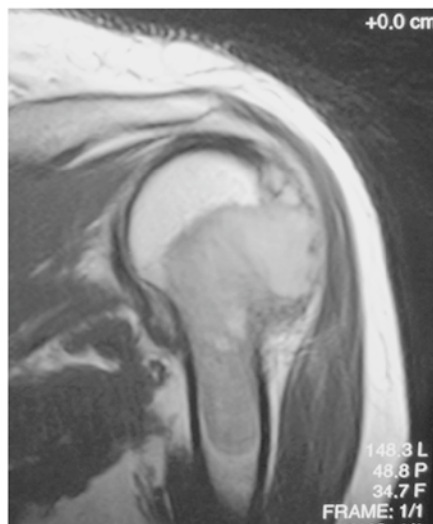


Figure 5A

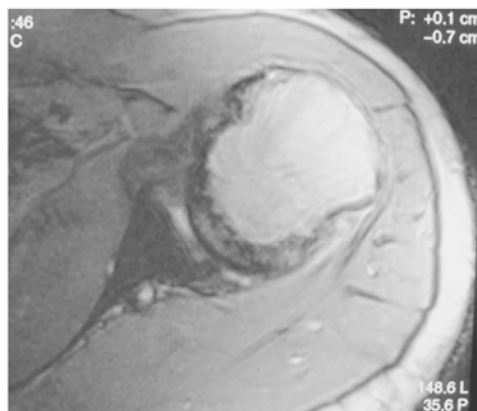


Figure 5B

Figure 5. Magnetic resonance images (A and B) demonstrating the presentation of a Campanacci stage 3 giant cell tumor of the proximal humerus in a 32-year-old male. Four months after curettage, ethanol irrigation, and grafting, this lesion recurred. Histopathology from excisional curettage of the recurrence was atypical, prompting postoperative external-beam radiation therapy.

with respect to the patient's adjacent tissues and operating suite personnel. Cryotherapy with liquid nitrogen also results in reportedly low recurrence rates, but has associated risks of fracture and skin necrosis.^{17,18}

We are unaware of any previous reports of the use of ethanol irrigation as an adjuvant to intralesional curettage for GCT of bone. High concentration ethanol is readily available in most surgical suites and relatively safe to use. The cytotoxicity from ethanol does not likely extend deeply into surrounding bone, but its adverse effects on adjacent tissues are also minimal.

Overall, the recurrence rate after the use of adjuvant ethanol is not widely different from the use of other adjuvants for GCT of bone. This series does reiterate the argument for the use of a high-speed burr, regard-



Figure 6A

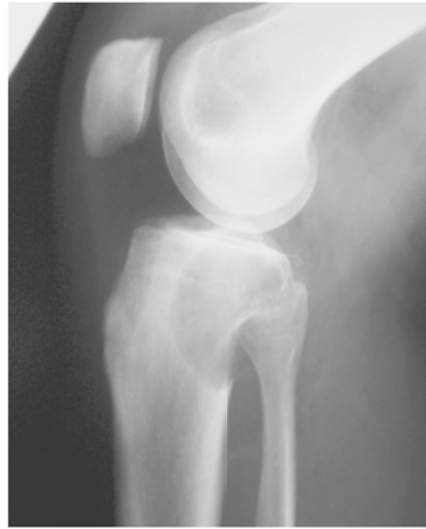


Figure 6B

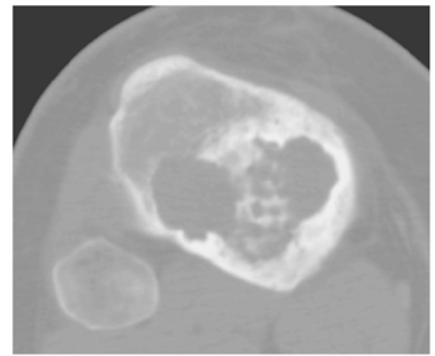


Figure 6C

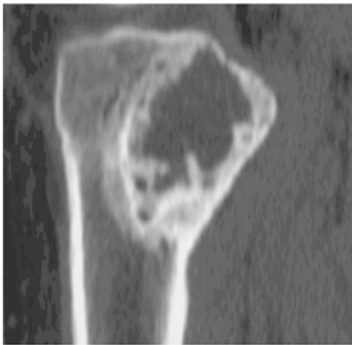


Figure 6D



Figure 6E



Figure 6F



Figure 6G

Figure 6. Images representing the clinical course of a 22-year-old male who presented with this Campanacci stage 3 giant cell tumor of bone (A and B). After curettage, ethanol irrigation, and grafting, it recurred (C). After repeat curettage, high-speed burring, ethanol irrigation, and grafting, it recurred two more times (D and E, respectively). Plain radiographs obtained 15 months after a fourth intralesional excisional curettage with high-speed burring, ethanol irrigation, and calcium sulfate grafting show no recurrence (F and G).

TABLE 1
Recurrence rates reported after curettage of giant cell tumors of bone

Author	Year	Tumor Characteristics	Adjuvant Treatments	Number of Patients	Recurrence Rate
Capanna et al. ³	1990		none	280	45%
Shih et al. ³³	1998		none*	22	0%
Richardson et al. ³²	1998		none	16	0%
Blackley et al. ²⁹	1999		none	59	12%
Durr et al. ¹⁰	1999		none	7	43%
Saglik et al. ⁴¹	1999		none	21	33%
Trieb et al. ¹⁶	2001		none	14	21%
Turcotte et al. ⁴⁰	2002		none	~50	17%
Khan et al. ³⁰	2004	distal radius only	none	23	17%
Prosser et al. ³¹	2005	stage 1 & 2	none	61	7%
		stage 3	none	52	29%
		recurrent	none	29	34%
Capanna et al. ³	1990		PMMA	187	19%
O'Donnell et al. ¹²	1994		PMMA	49	24%
Bini et al. ²³	1995		PMMA	38	8%
Saglik et al. ⁴¹	1999		PMMA	6	0%
Wada et al. ⁴²	2002		PMMA	15	7%
Turcotte et al. ⁴⁰	2002		PMMA	62	19%
McDonald et al. ⁵	1986		phenol	80	34%
Capanna et al. ³	1990		phenol	147	19%
Durr et al. ¹⁰	1999		phenol	11	9%
Trieb et al. ¹⁶	2001		phenol	12	25%
Turcotte et al. ⁴⁰	2002		phenol	37	19%
Su et al. ¹⁵	2004		phenol	56	18%
Capanna et al. ³	1990		cryotherapy	20	19%
Sheth et al. ¹⁹	1995	distal radius only	cryotherapy	12	25%
Malawer et al. ¹⁷	1999	primary	cryotherapy	86	2.3%
		recurrent	cryotherapy	16	37.5%
Turcotte et al. ⁴⁰	2002		cryotherapy	10	0%
Zhen et al. ²¹	2004		Zinc Chloride	92	13%
Capanna et al. ³	1990		phenol+PMMA	33	3%
Ghert et al. ⁴³	2002		phenol+PMMA	47	13%
Lackman et al. ¹¹	2005	stage 2 & 3 only	phenol+PMMA	63	6%
O'Donnell et al. ¹²	1994		phenol+PMMA	11	27%
Saiz et al. ¹⁴	2004		phenol+PMMA	40	13%
Ward and Li ²⁰	2002		H ₂ O ₂ +phenol+ electrocautery+ PMMA (in half)	24	8%

PMMA = polymethylmethacrylate cement.

* "none" may include the use of a high speed burr, which some authors consider an adjuvant.

less of the chemical adjuvant selected. While numbers were too small to reach statistical significance, of the 12 primary intralesional curettages that utilized a high-speed burr and adjuvant ethanol, only one led to lesion recurrence. Only one of the 12 patients was followed for less than two years.

A number of factors must be considered in comparing different series of GCT patients for rates of recurrence. While histologic grading (other than malignancy) is not predictive of recurrence in GCT of bone,³⁶ Campanacci staging is considered to be important, as stage 3 lesions,

or those that have breached the cortex and involved the adjacent soft tissues, have a higher recurrence rate in series that distinguish them from lower stage lesions.³¹ Unfortunately, not all series distinguish them. Many others have skewed numbers due to the institutional practice of treating most stage 3 GCTs with wide resection rather than intralesional curettage. Our series had more recurrences after stage 3 primary lesions (three of 10) than after stage 2 lesions (two of 11), but the difference did not reach statistical significance.

Others have noted preoperative fractures as a major risk for recurrence.³⁷ Three patients in the study group had preoperative fractures with significant displacement but none had a recurrence of their tumor.

Location can also play a role in prognosis, with the distal radius being a location notorious for more rampant soft tissue involvement and frequent recurrence.^{12,19,30,38,39} Only one of the four distal radius GCTs in this series recurred. However, notably, it was the only recurrence after use of a high-speed burr and adjuvant ethanol.

Treatment of recurrent lesions with repeat intralesional curettage is debated by some practitioners who believe that GCT recurrence merits wide excision. Rates of re-recurrence after repeat intralesional curettage range between 30 and 40 percent among the varied techniques reported.^{5,17,19,31,40} The three re-recurrences of 12 repeat intralesional curettages represent a respectable local control rate with the use of ethanol as an adjuvant. The contribution of the use of acrylic cement as the filling material more frequently in these repeat surgeries is difficult to isolate given the small numbers.

In conclusion, we feel that high concentration ethanol is an effective and safe adjuvant for the treatment of GCT when used in conjunction with aggressive curettage including high-speed burring. Whether any chemical adjuvant is necessary after performance of an appropriately aggressive curettage can probably only be answered definitively with a prospective, randomized comparison including many centers. Until such evidence becomes available, we feel that the use of ethanol is a safe compromise between higher-toxicity adjuvants and no adjuvant at all.

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MCL INJURIES OF THE KNEE: CURRENT CONCEPTS REVIEW

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ABSTRACT

Medial collateral ligament (MCL) injury is one of the most common knee injuries, especially in young athletic patients. Most MCL injuries can be managed conservatively with good results. However, a complete understanding of knee anatomy and the involved structures is necessary to make intelligent treatment decisions. We will review the anatomy and biomechanics of the MCL, classification systems for MCL injuries, and operative and nonoperative treatment for acute and chronic MCL injuries.

INTRODUCTION

The medial collateral ligament (MCL) is one of the most commonly injured ligamentous structures of the knee joint.^{1,3} The popularity of sports, particularly those involving valgus knee loading such as ice hockey, skiing, and football, has contributed to the frequent occurrence of MCL injuries.^{3,5} The role of prophylactic bracing has been biomechanically and clinically studied, and in the majority of studies was of limited benefit.^{3,5,7} Other preventive measures such as skill training, rule modifications, proper equipment, and promotion of fair play have been proposed, but the efficacy of these changes is not known.^{2,5,8}

The majority of patients who sustain MCL injuries of varying severity can achieve pre-injury activity level with nonoperative treatment alone.⁹⁻¹⁸ The most severe injuries, especially those with multiple ligament involvement, may require operative repair or augmentation on an acute basis. In addition, surgical reconstruction is indicated for isolated symptomatic chronic MCL laxity. We will discuss the functional anatomy, clinical evaluation, and treatment of MCL injuries. We will review the original work by James, which still applies today in understanding the functional anatomy of medial knee structures, and our approach to the treatment of acute and chronic medial-sided knee injuries. The authors'

preferred surgical techniques for ligamentous repair, augmentation, and reconstruction, as well as postoperative care and complications, will be discussed.

ANATOMY

The anatomy of the medial side of the knee is complex, being composed of three tissue layers and multiple components with interconnections to the joint capsule, the muscle-tendon units, and the medial meniscus. The ligamentous sleeve spans the entire medial side of the knee from the medial aspect of the extensor mechanism to the posterior aspect of the knee adjacent to the posterior cruciate ligament (Figure 1A). The majority of the basic anatomy has been described by James,^{19,21} Warren,^{22,23} Hughston,²⁴ and others. In particular, Figures 1B, 2B, and 3B are from dissections James performed at the University of Iowa during the 1970s.

The structures that are considered static stabilizers of the medial knee are the superficial MCL, the deep MCL, and the posterior oblique ligament. The superficial MCL is the primary static medial stabilizer of the knee situated in the second layer, according to Warren and Marshall's three-layer concept.²² It is positioned between the superficial sartorial fascia and the deep MCL. Its parallel fibers originate from the center of knee motion on the medial femoral epicondyle and insert on the medial aspect of the proximal tibia five to seven centimeters (cm) below the joint line, with an average length of 11 cm and an average width of 1.5 cm (Figure 1B). The ligament is deep to the crural and sartorial fascia and superficial to the deep MCL. Between the anterior border of the superficial MCL and the confluence of the first and second layers lies a vertical split of varying size and shape (Figures 2A, 2B).

The posterior aspect of the ligament has a continuum of oblique fibers referred to as the "posterior oblique ligament" that arises as a conjoined structure from the second and the third layers forming the posteromedial capsule (Figures 2B, 3A, 3B). Hughston described the anatomy of this structure.²⁴ The posterior oblique ligament arises from the adductor tubercle of the distal femur and has three distal attachments: 1) The prominent tibial arm on the edge of the posterior surface of the tibia; 2) the capsular arm which is continuous with the posterior capsule and the proximal part of the oblique popliteal ligament; and 3) the inferior arm which blends with the sheath covering the semimembranosus tendon

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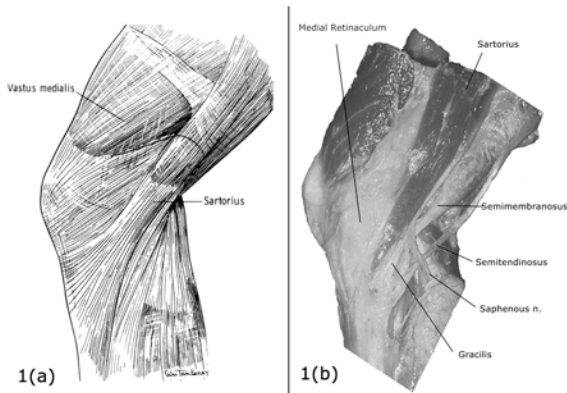


Figure 1A. Layer I is the deep crural fascia which is in continuity with the medial patellar retinaculum and the sartorial fascia. The fascia spans from the patellar tendon anteriorly to the midline of the popliteal fossa posteriorly. (From Warren LF, Marshall JL. The supporting structures and layers on the medial side of the knee, an anatomic analysis. *J Bone Joint Surg Am* 1979;61:58, permission granted.)

Figure 1B. A cadaver dissection reveals the relationship of the medial retinaculum, the pes anserinus tendons, the semimembranosus tendon, and the saphenous nerve.

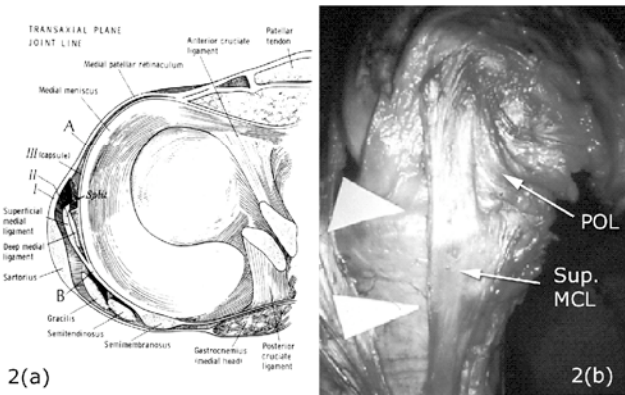


Figure 2A. Cross-section anatomy at the level of the joint line is demonstrated. A split can be seen just in front of the superficial MCL. Layer I and II blend together along a vertical line 1-2 cm anterior to the anterior border of the superficial MCL. At the posteromedial corner of the knee, layers II and III merge forming the posterior oblique ligament, which is augmented by the insertion of the semimembranosus insertions. (From Warren LF, Marshall JL. The supporting structures and layers on the medial side of the knee, an anatomic analysis. *J Bone Joint Surg Am* 1979;61:58, permission granted.)

Figure 2B. A cadaver dissection shows the slit in front of the superficial MCL (two white triangles). The ligament is long and inserts about 5-7 cm below the joint line. The posterior oblique ligament (POL) is clearly shown in continuity with the parallel fibers of the superficial MCL posteriorly.

and continues on to the tibia just distal to the direct insertion of the semimembranosus tendon. The deep MCL is the thick part of the middle third of the medial capsule, also known as the “middle capsular ligament” (Figure 2A). It lies in the third and deepest layer, extending from the femur to the mid-portion of the peripheral

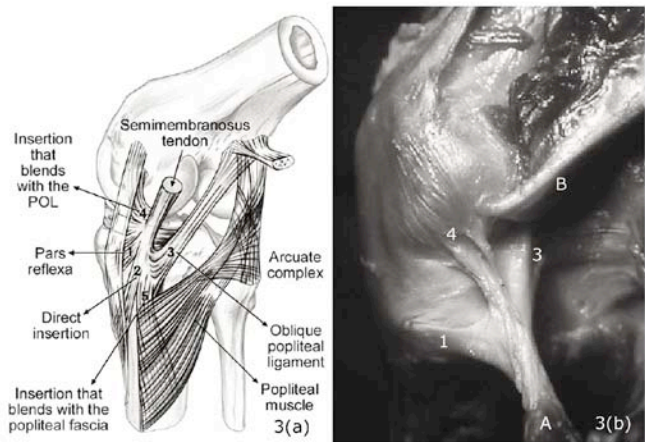


Figure 3A. The posteromedial structures of the knee are demonstrated. Note the relationship between the posterior oblique ligament, the meniscus, and the insertions of the semimembranosus tendon. The five insertions of the semimembranosus include the: (1) pars reflexa; (2) direct posteromedial tibial insertion; (3) oblique popliteal ligament insertion; (4) expansion to posterior oblique ligament; and (5) popliteus aponeurosis expansion. (From Sims, WF and Jacobson, KE. The posteromedial corner of the knee: medial-sided injury patterns revisited. *Am J Sports Med* 2004. 32(2):337-45, permission granted.)

Figure 3B. Insertions of the semimembranosus (A), with the numbers (1, 4, 3) corresponding to the Figure 3a legend, are shown in a cadaver. The medial gastrocnemius muscle is cut and elevated proximally (B).

margin of the medial meniscus and inserting just below the tibial articular margin, making meniscofemoral and meniscotibial portions. In a cadaver sectioning study, the superficial MCL limits valgus and external rotation forces. On the other hand, the deep MCL and the posterior oblique ligament failed to show a significant contribution to stability in the described planes.²³ However, the posterior oblique ligament was believed to assist the dynamic function of the semimembranosus tendon.²⁴

The dynamic stabilizers of the medial side of the knee are the semimembranosus complex, the quadriceps, and the pes anserinus. The semimembranosus tendon terminates in five different insertions on the posteromedial knee: Two bony insertions on the proximal tibia just below the joint line, one into the posterior oblique ligament, one into the oblique popliteal ligament, and one into the popliteal fascia (Figures 3A, 3B). The semimembranosus plays a significant role in the dynamic stability of the medial side of the knee by tightening the normally lax posterior oblique ligament while posteriorly displacing the posterior horn of the medial meniscus to prevent impingement during knee flexion.²⁵ The quadriceps and pes anserinus have been shown to potentially increase the effective stiffness of the MCL complex of the knee by 164 percent and 108 percent, respectively. However, the reaction time of those muscles has proved to be far too slow to protect against most sports injuries.²⁶

BIOMECHANICS

The biomechanical properties of the MCL have been studied in both human and animal models. Areas of most intense interest include structural properties of the MCL, failure modes and failure location, effects of immobilization, and ligamentous healing.

In cadaver knees, the superficial MCL provided 57 percent of the restraining valgus moment at five degrees of knee flexion, and provided 78 percent of the moment at 25 degrees of knee flexion due to decreased contribution from the posterior capsule.²⁷ The ultimate strength of the human MCL has been shown to be approximately equal to that of the anterior cruciate ligament (ACL).²⁸ When testing different components separately, the maximum load was found to be 534 N for the superficial MCL, 194 N for the deep MCL, and 425 N for the posterior oblique ligament. Failure occurred at a mean elongation of 10.2 mm, 7.1 mm, and 12.0 mm respectively.²⁹ The location of maximum strain of the entire medial collateral complex from cadaver studies was found to be near the femoral insertion when the knee was in full extension. This correlates well with a few clinical and laboratory findings that suggest the femoral insertion as the most common location for MCL injury.^{15,30-34} However, when considering each component separately, a cadaver study showed that the femoral attachment was the most common site of failure for the superficial MCL, but interstitial failure was more common for the deep MCL and the posterior oblique ligament.²⁹ In contrast, operative findings in clinical series by Sims and O'Donoghue localized the tibial attachment as the most common injury site for the superficial MCL, and the femoral attachment as the most common injury site for the deep MCL and the posterior oblique ligament.^{25,35} A clinical series by Hughston demonstrated that the tibial insertion was the most common site of injury for all the components of the MCL complex.³⁶

With continued displacement after MCL rupture, the ACL may also tear, producing a more extensive injury. In one study of MCL injuries, Fetto and Marshall reported the incidence of ACL tears to be 20 percent when there is no valgus laxity on clinical exam, 53 percent with laxity only in 30 degrees of knee flexion, and 78 percent with valgus laxity in full extension.¹ Therefore, if the knee opens medially in extension, one must suspect that an ACL injury is likely present.

Several studies have shown that immobilization has detrimental effects on the mechanical properties of the MCL, such as disorganization of collagen fibrils, decrease in the structural properties of the bone-ligament-bone complex, and resorption of bone at ligament insertion sites.³⁷ On the other hand, controlled motion has positive effects on healing in both animal models and

clinical settings.^{9,20,37} Early controlled motion has become a part of standard nonoperative treatment protocols in most current series.^{9,10,38,39}

In contrast to the ACL, the MCL has shown excellent healing capability in both animal and clinical studies.³⁹⁻⁴¹ Nevertheless, the biomechanical and biochemical properties of the healing MCL fail to return to normal, making up for the deficiency by an increased mass of healing tissue.⁴⁰ Attempts to improve the quality of the healing ligament have included motion and immobilization, NSAIDs, hyperbaric oxygen, energy application, and growth factors.⁴² From the promising results of short half-life growth factors, focus has been placed on gene transfer as a method of delivering growth factors produced by host cells over an extended treatment period.⁴³⁻⁴⁸ Lastly, the likelihood of satisfactory healing decreases with associated cruciate injury, valgus alignment of the knee, or injury to the deeper capsular ligament, the posterior oblique ligament, or oblique popliteal extensions from the semimembranosus.^{40,41,49-51}

CLINICAL EVALUATION

The mechanism of injury can be obtained either from direct observation of the injury or by careful history taking. Valgus stress is the most common mechanism of injury. However, due to the position of the knee and the force vectors, a combined flexion/valgus/external rotation injury is usually the end result.^{52,53} The vast majority of MCL injuries are from a direct blow to the outer aspect of the lower thigh or upper leg, although non-contact valgus external rotation injuries are common in skiing.^{51,54}

Other important information from the clinical history includes the location of pain, the ability to ambulate after the injury, time and onset of swelling, the sensation of a pop or tear, the presence of deformity, and the immediate site of tenderness.⁵⁵ The absence of swelling may indicate a severe tear that allows fluid to extravasate into the surrounding tissue outside the joint. An acute effusion, within two hours of injury, indicates hemarthrosis, whereas swelling that appears 12-24 hours after injury usually indicates a synovial effusion. Seventy-six percent of patients with complete MCL tears could walk into the office unaided without any support, and pain was found to be worse in incomplete tears than complete tears.³⁶

In Hughston's series, the location of edema and tenderness accurately localized the injury site of the superficial collateral ligaments in 64 and 76 percent of cases respectively.³⁶ The exact location of injuries of the deep MCL and the posterior oblique ligament were found to be difficult to palpate because of their deep-seated position, but pain and tenderness in this area may at least indicate the presence of injury to these postero-

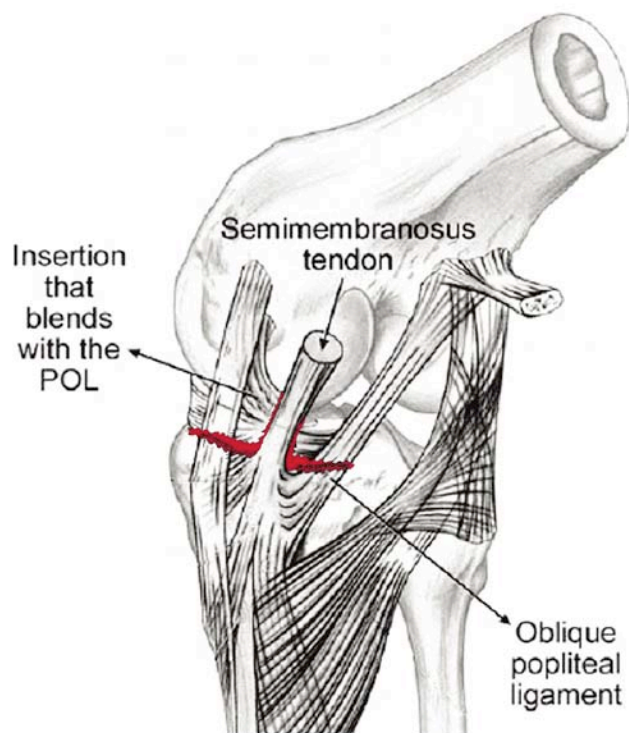


Figure 4. In complete medial-sided knee injuries, the injury completely tears the superficial and deep MCL, as well as the semimembranosus attachments to the femur as shown here. If the knee opens in valgus in extension, usually the posterior oblique and the oblique popliteal ligament extensions from the semimembranosus tendon are ruptured, leaving the semimembranosus attached to the tibia only. These should be repaired at the time of surgery. (Modified from Sims, WF and Jacobson, KE. The posteromedial corner of the knee: medial-sided injury patterns revisited. *Am J Sports Med* 2004. 32(2):337-45, permission granted.)

medial structures, including the semimembranosus attachments.²⁵

The best time for examination of the knee is immediately after the injury before muscle spasm occurs. Unfortunately, many times this opportunity is only available to team physicians present at the time of injury. In those patients with severe muscle spasms, a 24-hour period of immobilization is usually sufficient for relaxation, and examination under anesthesia is rarely necessary.³⁶ While keeping the patient relaxed, a valgus stress test should be performed with the knee in 30 degrees of flexion, and compared to the contralateral knee as a control. The examination is then repeated with the knee in 0 degrees of flexion to recruit the function of remaining posteromedial structures. Any laxity appreciated from the latter test indicates a complete medial-sided injury and should lead the examiner to suspect associated injuries to the secondary restraints such as the cruciate ligaments and the posterior capsule (Figure 4).^{1,27} The degree of joint opening in millimeters and the quality of the end point both contribute to the overall assessment of the severity of instability.

In addition, the examiner must perform a complete exam to rule out associated injuries to the knee. Injuries commonly seen in combination with MCL injuries include bone bruises, ACL tears, lateral collateral ligament (LCL) tears, medial meniscus tears, lateral meniscus tears, and posterior collateral ligament (PCL) tears.⁵⁶ Fetto and Marshall found ACL disruption to be the most common ligamentous damage associated with MCL injuries, especially high-grade MCL tears.¹ Physical examination is the most reliable method to diagnose anteromedial rotatory instability, which can occur with or without an associated ACL injury.^{25,57} Anteromedial rotatory instability is detected by performing the anterior drawer test while holding the tibia in external rotation.⁵⁸ Any evidence of anterior subluxation of the medial tibial plateau during a valgus stress test with the knee in 30 degrees of flexion might also indicate the presence of anteromedial rotatory instability.²⁵ Anterior instability should be carefully evaluated. Laxity with Lachman's testing, especially when the end-point is absent, is a reliable indicator of ACL rupture even in the face of MCL injury.⁵⁹ The pivot shift test should be interpreted vigilantly since loss of medial pivot might cause false negative results.⁵⁹ As stated earlier, the presence of a hemarthrosis is also suggestive of an associated ACL rupture. Posterior cruciate ligament injuries, meniscus injuries, and bone contusions on the lateral femoral condyle and posterolateral tibia are not unusual and should be ruled out as well.⁵²

CLASSIFICATION

The American Medical Association (AMA) classification of MCL injuries has caused confusion and difficulty in comparison of treatment results.^{1,13,60} In 1976, Hughston standardized MCL injury classification, with further clarification in 1994, into two related systems: The severity system (grade I, II, III) and the laxity system (grade 1+, 2+, 3+).⁵¹ Under this combined classification system, grade I, a first-degree tear, involves a few fibers resulting in localized tenderness but no instability. Grade II, a second-degree tear, is a disruption of more fibers, with more generalized tenderness but still no instability. Grade III, a third-degree tear, is a complete disruption of the ligament, with resultant instability. Grade III injuries are subdivided according to the extent of laxity as determined by the amount of absolute joint separation from valgus stress with the knee in 30 degrees of flexion. Grade 1+, 2+, and 3+ laxities indicate 3-5 mm, 6-10 mm, and more than 10 mm of absolute medial separation respectively. The location of a tear, the presence or absence of a firm end-point, and other modifications have been added to the AMA classification system.^{15,53,61,62}

Fetto and Marshall defined their grade I injuries as those without valgus laxity in both 0 and 30 degrees of flexion, grade II injuries as those with valgus laxity in 30 degrees of flexion but stable in 0 degrees of flexion, and grade III as those with valgus laxity in both 0 and 30 degrees of flexion.¹ Of note, the authors emphasized the importance of performing the test in 0 degrees of flexion, which is different from in full extension. In full extension, there is recruitment of ACL function that can mask the laxity of the complete medial-sided injury. There is a high incidence of associated ligamentous injuries with ACL injuries in grade III cases using this classification system. We prefer this classification because it documents the instability from loss of all medial-sided structures, which may affect the treatment options. Unfortunately, the validity and reliability of any of the classification systems have not been described in the English literature. As the treatment trend moves toward conservative treatment for all grades of isolated MCL injuries, interest in classifying this ligamentous injury has declined.²⁵ We believe that MCL injuries should, at the minimum, be classified as isolated or combined with other pathologies, which will help with treatment planning.

IMAGING STUDIES

The need for knee radiographs after injury should be determined according to the Ottawa knee rules.⁶³ If indicated, anteroposterior, lateral, and merchant views are obtained. Stress x-rays are helpful in adolescents to exclude physeal plate injuries.⁶⁴ Efforts have been made to evaluate laxity using combined stress radiographs and stress machines, but this technique has failed to become common practice, possibly due to the size and complexity of the machine.^{65,66}

The role of MRI in the classification and treatment planning of medial-sided knee injuries has been increasing. Hayes et al. classified complex knee injuries into ten types based on the mechanism of injury.⁵² Recognition of these patterns may help assess the full extent of knee injuries, particularly those involving the posterolateral and posteromedial corners of the knee. A study by Nakamura et al. showed that the location of the injury in the superficial layer on MRI could help predict the outcome after conservative treatment of grade III MCL lesions combined with ACL injuries.³³ After six weeks of immobilization in a knee brace, six out of 17 patients presented with residual valgus laxity on examination under anesthesia and were indicated for a medial collateral advancement or reconstruction at the time of the ACL reconstruction. Five out of the six patients had evidence of injury "over the whole length of the superficial layer."³³ Indelicato recommended either a routine MRI or an arthroscopic study in all patients

with laxity >10 mm to diagnose intraarticular injuries, because a capsular tear might mask a significant effusion.⁵⁵ The authors' preference is generally to use MRI only to rule out any other associated injury. In isolated Fetto and Marshall's grade I or II injuries, an MRI is not indicated. In grade III injuries, we recommend MRI evaluation to completely assess the extent of the injury and for preoperative planning.

ACUTE INJURY: TREATMENT RATIONALE AND NONOPERATIVE TREATMENT

Nonoperative care has been proposed as the mainstay treatment for the majority of isolated MCL injuries regardless of severity. Treatment with early protected range of motion exercises and progressive strengthening has been shown to produce excellent results and a high rate of return to sports.⁹⁻¹⁸ However, the current treatment recommendations have been confused by the conflicting and overlapping classification schemes. For example, Hughston's grade III injuries include different degrees of laxity from 1+ to 3+, derived from the examination of the knee in 30 degrees of flexion.³⁶ In contrast, Fetto and Marshall's grade III injuries are unstable in 0 degrees of flexion, indicating failure of all posteromedial structures with or without ACL disruption.¹

From a literature review of successful nonoperative treatment, we have found that all series claimed that "complete" or "grade III" injuries did not include patients with instability in 0 degrees of flexion, with only two exceptions.^{9,10,13,16,67,68} This data has given the impression that nonoperative treatment is routinely successful for even the most severe grade of isolated medial-sided knee injury. Good results have been achieved with Fetto and Marshall's grade II or Hughston's grade III injuries, with most reports uniformly supporting nonoperative treatment.^{15,17,18} However, for Fetto and Marshall's grade III injuries, Kannus showed that the long-term outcome of nonoperative treatment was much worse than grade I and II, with a high frequency of persistent medial instability, secondary dysfunction of the ACL, muscle weakness, and post-traumatic osteoarthritis of the injured knee.⁶⁹ This supports the recommendation from Fetto and Marshall for operative treatment of all isolated type III injuries based on slightly better results in their small series.

With MRI now able to pinpoint the exact location of injury, treatment decisions are being based on the anatomic location of the MCL failure. Operative treatment has been recommended for situations where there is injury over the whole length of the superficial layer, or a complete injury of both the superficial and deep MCL from the tibia.^{33,70} With the exception of those injuries with laxity in extension, we treat all lesser grades of MCL

injuries in a hinged knee brace with weight bearing as tolerated and crutches for initial pain relief. The patient can start isometric and range of motion exercises immediately. Crutches are discontinued when the patient can walk without limping. Anti-inflammatory medication appears to be beneficial for soft-tissue healing, but results are still inconclusive.⁷¹ For athletes, we recommend the goal-oriented rehabilitation program proposed by Reider et al. which was shown to facilitate early return to sports while having an acceptable rate of re-injury (Table 1).³⁸ When the athlete is ready to return to practice, use of a hinged brace is encouraged initially until the athlete feels completely confident about their knee. After associated cruciate ligament injuries have been ruled out by MRI, we treat those patients with laxity at 0 degrees of flexion conservatively, as previously described. The exception is those patients with valgus knee alignment and laxity in 0 degrees of flexion. In those patients, early operative repair should be considered.

ACUTE INJURY: OPERATIVE TREATMENT

Though the majority of isolated medial-sided knee injuries can be managed nonoperatively with good results, surgeons may consider operative interventions in specific situations involving complete ligament disruption. Examples include the presence of intraarticular entrapment of the end of the ligament, a large bony avulsion, a tibial plateau fracture, a complete tibial side avulsion in athletes, or when anteromedial rotatory instability is present on physical examination (Figure 5).^{25,70,72-74} In addition, valgus-aligned knees with complete medial injury likely would benefit from acute repair, since these knees do not tolerate the valgus laxity well. The authors' summary of operative indications for medial-sided knee injuries is shown in Table 2.

Primary repair of the MCL is usually performed within seven to ten days after the injury. Location of the tear and the quality of the tendon as assessed by MRI or arthroscopic examination help guide surgical planning.³³ Femoral avulsion of the ligament leaves the best tissue for repair and the ligament can be approximated using suture anchors, staples, or a screw and washer. However, repair in this location may lead to the most problems with postoperative motion because of capsular adhesions and dysfunction of the extensor mechanism.⁷⁵ Acute complete injuries with avulsion of the superficial and deep components off of the tibia can be repaired directly as well. Repair can be performed using either suture anchors or staples to secure the ligament back to its anatomic location on the proximal medial tibia after tension has been restored.⁷⁰ Often mid-substance, and occasionally tibial-sided injuries, require augmentation or an allograft reconstruction due to the quality of the remaining tendon.

SURGICAL TECHNIQUE

Examination under anesthesia is performed to completely assess the scope of the injury preoperatively. Arthroscopy is performed to rule out any other associated injuries. In addition, arthroscopy can help determine the site of the deep MCL injury, either above or below the meniscus (Figure 6). In an acute setting, arthroscopy should be performed quickly and efficiently to minimize fluid extravasation. Alternatively, the surgeon may choose to do any extended arthroscopic procedures after the exposure is made, allowing it to serve as a channel for the drainage of arthroscopic fluid.

An incision is made on the medial side of the knee over the suspected site of injury. To expose the entire MCL, an incision is made from the medial proximal tibia to the medial femoral epicondyle, curving posteriorly in line with the medial intermuscular septum of the thigh. For isolated repairs either distally or proximally, a more limited approach is used. In the case of combined treatment of acute complete MCL tear and an ACL tear, we have found exposure of the MCL easier if approached through a separate medial incision as opposed to extending the tibial incision for the ACL reconstruction. Care is necessary to preserve the infrapatellar branch of the saphenous nerve if possible.

The sartorial fascia is identified without undermining of the subcutaneous tissue sleeve. The crural and sartorial fascia is incised longitudinally. If dealing with a distal injury, the ruptured ends of the superficial MCL are identified beneath the gracilis and semitendinosus tendons (Figure 8A). Hematoma may be encountered in this plane and should be removed to allow direct visualization of all the injuries. The deep MCL is identified, and the tear is examined. The opening to the joint created by the tear and any injury to the meniscal attachment is inspected. We tend to use Hughston's concept of repairing all of the injured structures in anatomic position.²⁴ The repair should begin from the deepest structure outward. A peripheral tear of the medial meniscus is commonly seen (33 percent) and nearly all of these are repairable.⁷⁶ This can be done using an open technique under direct visualization. The suture knots should be placed on the outside aspect of the posterior oblique ligament in order to recreate the dynamic function of the meniscus.⁶¹ A meniscofemoral ligament tear can be directly repaired using sutures alone, or suture anchors if necessary. Suture anchor fixation into the tibial plateau is preferred for the meniscotibial ligament tear (Figures 7, 8B). If it is injured, the posterior oblique ligament is repaired by direct suture back to the femur.

For tibial avulsion injuries, we prefer suture anchor fixation down to the tibial plateau just distal to the subchondral bone. Repair is completed while the knee is held in varus and full extension. A gentle valgus test

TABLE 1
Goal-oriented rehabilitation program for isolated collateral ligament sprains in athletes³⁸

<p>Initial treatment Apply ice with compressive wrap for 20 minutes and repeat every 3-4 hours for the first 24-48 hours. Apply minimally restrictive lateral hinge brace (grade II or III injuries). Dispense crutches; allow weight bearing as tolerated.</p> <p>Subsequent treatment Begin active range-of-motion exercises in cold whirlpool at least twice daily. Begin straight-leg raises and electrical muscle stimulation (if available). Maintain general conditioning with upper body ergometer or swimming.</p> <p>Goal one: Walking unassisted without a limp Discard crutches. Continue range of motion, isometric strengthening, and conditioning exercises.</p> <p>Goal two: 90 degrees of knee flexion Begin stair climber and bicycle ergometer with seat high; gradually lower seat. Begin isotonic progressive restrictive exercise for quadriceps and hamstrings; supplement with isokinetic exercise if available. Continue range of motion and conditioning exercises.</p> <p>Goal Three: Full knee motion Begin running and functional exercise program. For example: Jog 1 mile. Five successive 100-yard sprints at half speed. Five successive 100-yard sprints at three-quarters speed. Five successive 100-yard sprints at full speed. Five zigzag sprints at half speed. Five zigzag sprints at full speed. Other agility drills (e.g. cariocas). Continue conditioning.</p> <p>Goal four: Complete entire running program in one session May return to competition if athlete has minimal pain, full range of motion, and 90 percent of normal strength. Continue to use brace for all sports participation for remainder of the season.³⁸</p>



Figure 5. A MRI study in an acute injury reveals complete rupture of the superficial and deep MCL from the tibia. The medial meniscus is displaced medially with entrapment of the distal part of the avulsed ligament underneath it (small arrow). Severe hemarthrosis is seen. Please note the bone bruise at the lateral aspect of the lateral femoral condyle suggesting a valgus mechanism (large arrow).

TABLE 2
Summary of surgical indications for medial-sided injuries of the knee

Operations	Surgical Indications
Acute repair	<ul style="list-style-type: none"> • Presence of intraarticular ligamentous entrapment • A large bony avulsion • Associated tibial plateau fracture • MRI finding of complete tibial side avulsion in athletes • Presence of AMRI* • Presence of valgus instability in 0 degrees of flexion in an underlying valgus knee alignment
Delayed repair	<ul style="list-style-type: none"> • Combined with anterior cruciate or other ligament reconstruction if the examination under anesthesia shows valgus laxity in 0 degrees of flexion
Augmentation	<ul style="list-style-type: none"> • Combined with any repair if local tissue is deficient
Reconstruction	<ul style="list-style-type: none"> • Symptomatic chronic valgus laxity
Distal femoral varus osteotomy	<ul style="list-style-type: none"> • Chronic valgus laxity with valgus bony alignment

* = Anteromedial rotary instability

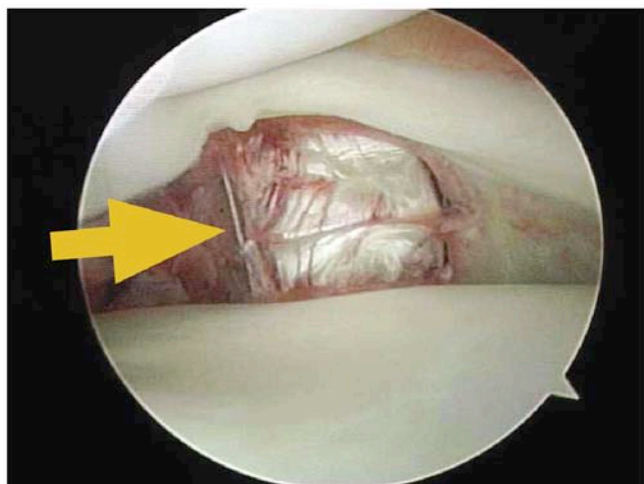


Figure 6. The arthroscopic picture in a case of complete medial-sided knee injury demonstrates pathologic widening of the medial compartment and elevation of the meniscus from the medial tibial articular surface indicating a rupture of the meniscotibial ligament. In this case, the loose fibers of the superficial MCL are seen (arrow). With combined valgus stress and probing, we were able to identify the loose part distally so as to localize the site of the injury. Arthroscopy can also be used in chronic cases to direct the surgeon to the area of laxity below or above the joint.

should not gap open the medial joint space if the repair is adequate. The avulsed superficial MCL ends can be repaired with anchors, staples, or a screw and washer (Figure 8C). This can be aided by placing a locking suture into the substance of the torn end of the ligament that allows either proximal or distal traction to be placed on the ligament as fixation is applied. The semimembranosus portion of the posterior oblique ligament is repaired using interrupted absorbable sutures. If possible, the anterior border of the torn posterior oblique ligament can be sutured to the posterior border of the repaired MCL in a pants-over-vest fashion (Figure 9A-C). Avulsion of medial patellofemoral ligament and tearing of the vastus medialis muscle have been found in association with proximal injuries of the MCL and should be repaired if identified.⁵⁷

If injury to the superficial MCL is extensive, augmentation of the repair may be required.⁷⁷ We prefer the figure-of-eight reconstruction technique described by Gorin using autologous gracilis tendon.⁷⁸ This construct has two bundles, does not interfere with the original insertion, and requires no tunnels. The augmentation can be performed through the previously described operative approach. The gracilis tendon is harvested using a tendon stripper while keeping the tibial insertion attached. The knee is brought to full extension and the deep limb of the figure-of-eight is secured with a suture anchor placed in a bony trough at the posterior aspect of the medial epicondyle. The tendon is stabilized at another an-



Figure 7. The intraoperative fluoroscopic picture of a combined ACL reconstruction and a medial-sided knee repair is shown. The two anchors are used to hold the meniscus down to the tibia and the staple is for superficial MCL stabilization.

chor fixation point just anterior to the femoral footprint. With the knee in 30 degrees of flexion, the superficial limb of the reconstruction is fixed to the tibia with a suture anchor approximately 2 cm posterior and deep to the pes anserinus insertion. Finally, the tourniquet is deflated and inspection and control of potential excessive bleeding from the inferior medial geniculate artery and its branches is performed. A compressive dressing is applied postoperatively.

POSTOPERATIVE CARE

The patient is kept non-weight bearing for three weeks in a long hinged knee brace allowing 30-90 degrees of motion. At 3 weeks the patient is allowed to do full range of motion and weight bearing as tolerated. Progressive activities are started at about six weeks and the brace is gradually weaned off.

CHRONIC INJURY

Although rare, chronic valgus instability has been described following MCL injury alone or in combination with ACL tears.^{49,77,79-81} This combination has been found to seriously compromise joint stability, and patients with this injury are more likely to experience symptoms of giving way than those with isolated ACL deficiency.^{1,57,82} Slocum defined "late" or "chronic" as three months or more after the acute injury.⁸³ By that time, the ligaments have lost their healing potential and the anatomic restoration of the traumatized tissue is no longer possible due



Figure 8A. The torn end of the superficial and deep MCL is elevated demonstrating the medial joint space and the medial meniscus.

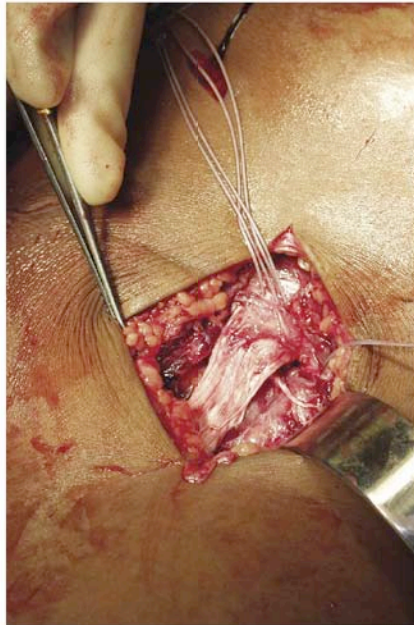


Figure 8B. Two anchors were placed and sutures were brought through the peripheral part of the meniscus to repair the deep capsular ligament.

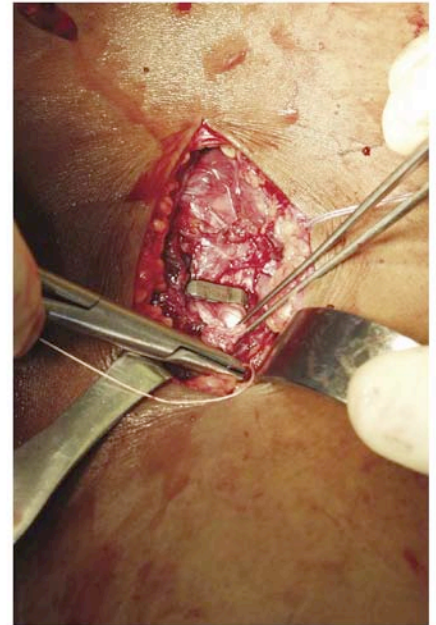


Figure 8C. The torn end of the superficial MCL was secured with a staple. The very distal part of the ligament is sutured to the remaining tissue.

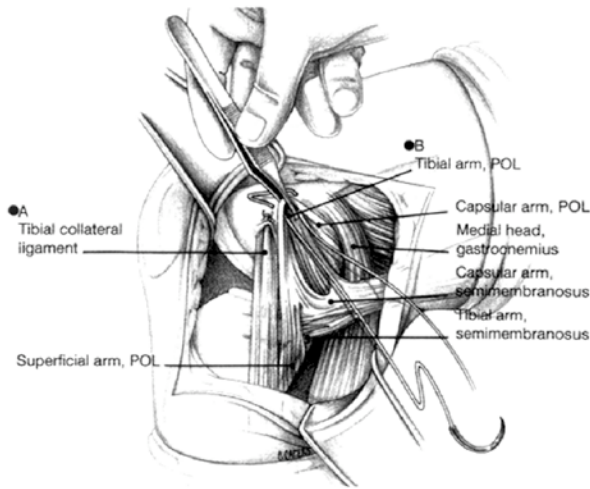
to the contracture of the ligament ends and the formation of scar tissue. Multiple reconstruction techniques have been described focusing mainly on reconstruction of the superficial MCL with quadriceps tendon autograft, hamstring autograft, hamstring allograft, or Achilles allograft.^{77,79,81} Patients with valgus deformity of the knee should have hip-to-ankle radiographs and may need a distal femur varus-producing osteotomy prior to ligament reconstruction in order to move the mechanical axis into slight varus. Persistent valgus malalignment will cause graft stretching and recurrence of the instability if not corrected.^{49,84} For chronic medial instability we prefer the technique modified from Toth and Warren's description, using Achilles allograft for reconstruction of the superficial MCL.⁸⁵

SURGICAL TECHNIQUE

Examination under anesthesia is performed to document all deficient structures. Arthroscopy can be done to rule out and treat intra-articular pathologies if indicated. The surgical exposure is performed using a hockey-stick approach as described above. The soft tissue flaps are mobilized with a larger inferior flap, allowing exposure of the fascia over the MCL. The sartorial/crural fascia is incised and reflected anteriorly and posteriorly. The native superficial MCL is identified and dissected. The soft spot between the posterior aspect of the superficial MCL and the posterior oblique ligament is sharply devel-

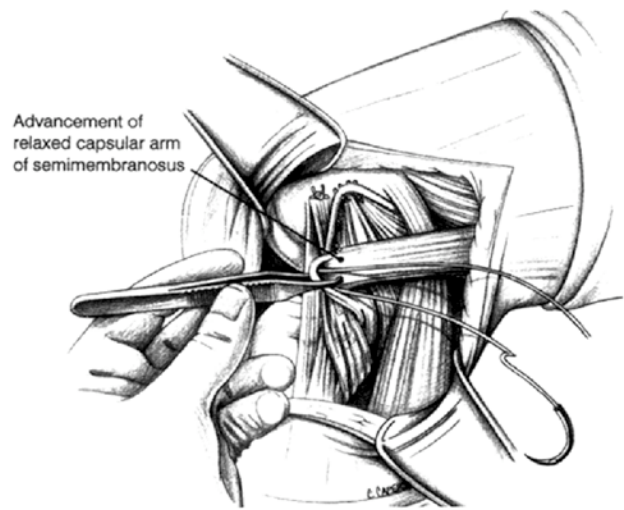
oped for future possible plication. The center of rotation of the knee joint is identified using a pin technique. A guide pin is drilled into the medial epicondyle parallel to the joint line along the epicondylar axis. One end of suture is fixed to the tibia at the approximate insertion of the superficial MCL. The other end is looped over the pin and the knee is taken through its range of motion. The length of the suture should not change more than 2 mm if the center axis is correct. An approximately 10 mm reamer is used to make a tunnel 2.5-3 cm in depth, carefully avoiding penetration into the intercondylar notch. We have found allograft bone plugs smaller than 10 mm in diameter to be less reliable and more apt to break during preparation and fixation. An Achilles allograft is prepared so that the calcaneal bone plug can fit into the 10 mm sizer with preservation of the tendon insertion and periosteum on one side. The 10 mm x 10 mm x 25 mm bone plug is inserted into the tunnel, either freely or using traction sutures and a Beath pin, and fixed with an interference screw on the cancellous side of the bone plug.

The tendinous part of the graft can be fixed to the tibia in two ways. The first method, described next, involves drilling a tunnel in the tibia. The soft tissue expanse of the Achilles graft is whip-stitched for 4-6 cm with #2 Ticron sutures and then sizing is performed. Using a 10-mm reamer, a tibial tunnel is made approximately 5 cm distal to the joint line and just posterior to



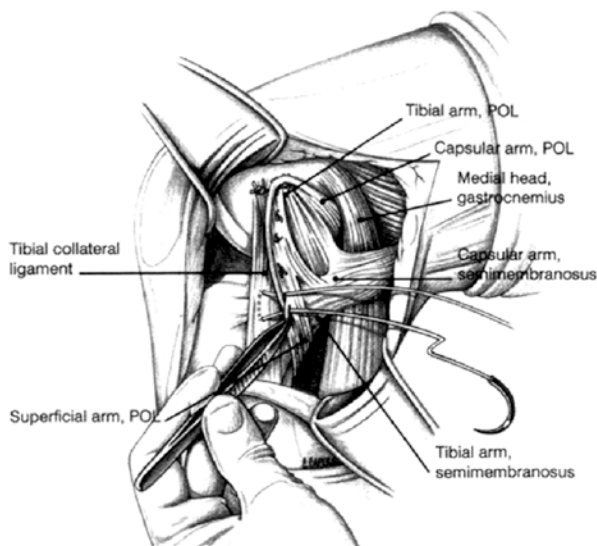
A

Figure 9a. Technique of posteromedial plication demonstrated in a case with proximal avulsion of the superficial MCL and the posterior oblique ligament. Point A demonstrates the location for suture fixation of the superficial MCL to restore tension. With the knee in 60 degrees of flexion and the hip externally rotated, the posterior oblique ligament is pulled anteriorly and proximally to point B where it is being reattached. (From Hughston, JC. The importance of the posterior oblique ligament in repairs of acute tears of the medial ligaments in knees with and without an associated rupture of the ACL. Results of long-term follow-up. *J Bone Joint Surg Am* 1994. 76(9):1328-44, permission granted.)



C

Figure 9c. The lax capsular arm of the semimembranosus tendon is plicated over the restored posterior oblique ligament. (From Hughston, JC. The importance of the posterior oblique ligament in repairs of acute tears of the medial ligaments in knees with and without an associated rupture of the ACL. Results of long-term follow-up. *J Bone Joint Surg Am* 1994. 76(9):1328-44, permission granted.)



B

Figure 9b. The anterior aspect of the posterior oblique ligament is plicated over the superficial MCL in a pants-over-vest fashion. (From Hughston, JC. The importance of the posterior oblique ligament in repairs of acute tears of the medial ligaments in knees with and without an associated rupture of the ACL. Results of long-term follow-up. *J Bone Joint Surg Am* 1994. 76(9):1328-44, permission granted.)

the gracilis insertion. The graft is pre-tensioned, and the knee is moved through a range of motion several times. A Beath pin is then inserted freehand into the tunnel aiming about one centimeter lateral to the tibial crest to avoid injury to the peroneal nerve. The graft is pulled into the tunnel and fixed with a soft tissue interference screw while the knee is held in 30 degrees of flexion, valgus, and internal rotation. Alternatively, the broad expanse of the Achilles graft is drawn distally with locking traction sutures. It then can be fixed in place with two staples or with suture anchors at its anatomic location. Again, the leg should be held in varus at 30 degrees of flexion during fixation.

We then evaluate the posterior oblique ligament. With the knee in 60 degrees of flexion and hip in external rotation, the posterior oblique ligament is advanced anteriorly and proximally. It is then fixed to the adductor tubercle using suture anchors. The sutures are tied when the knee is brought to near-full extension. The anterior border of the posterior oblique ligament is sutured over the reconstructed MCL in a pants-over-vest fashion. The wound is closed and a compressive dressing is applied.

POSTOPERATIVE CARE

Generally, we use the same protocols previously described for postoperative care after an acute repair.

COMBINED INJURY

Treatments for combined ACL and MCL injuries are still developing. Early reconstruction of both the ACL and MCL may lead to motion loss postoperatively.⁸⁶ Reconstructing only the medial-sided structures is supported only by limited groups.^{50,57} Many authors recommend ACL reconstruction after a period of rehabilitation to allow the MCL to heal.^{54,76,87} Surgery is performed after achieving full range of motion and adequate strength, and after resolution of the knee effusion, which typically occurs approximately six weeks after the injury. The caveat to this method is that the severity of the knee injuries is not totally clear in studies supporting this technique. Such variation in the original injury would definitely impact the outcome. For example, a knee with grade 3+ laxity in 30 degrees of flexion that is stable in extension is different from a knee that opens medially in extension. Therefore, at the time of ACL reconstruction, examination under anesthesia must be performed to determine the residual laxity to valgus stress. We use a residual difference between legs of more than 3-4 mm with valgus stress at full extension as an indication for MCL reconstruction.^{33,76} The techniques of MCL repair, augmentation, and reconstruction are the same as previously described in isolated injuries.

COMPLICATIONS

The most common complications from the medial-sided knee repair or reconstruction are knee stiffness and residual laxity.⁶¹ Knee stiffness can be associated with the timing of repairs, non-anatomic repairs, and problems with postoperative rehabilitation.⁶¹ Stabilizing the superficial MCL too close to the joint line can capture the knee. Residual instability generally stems from failure to address all the components of the injury, especially the meniscus and posteromedial structures. Repeated examinations during the various stages of repair are important to provide optimal stability. In addition, awareness of the restraining structures for various knee flexion angles is crucial to correct repair or reconstruction.²⁷ Pellegrini-Stieda lesions are sometimes painful, and if nonoperative treatments fail, a resection with a repair may be required.⁸⁸ In general, most complications can be avoided using the appropriate surgical and postoperative strategies as previously described.

SUMMARY

MCL and medial-sided knee injuries are still major problems in the modern era of sports medicine. With

advances in imaging techniques and refined grading of injuries, surgical treatment for medial-sided knee injuries, once popularized by Hughston, may have a role in many cases.

Long-term studies of the most severe category of MCL injuries are needed to define the best treatment. Nonetheless, most medial-sided injuries are best treated nonoperatively, with proven great success.

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PATIENT LOCATION STRATEGIES FOR PEDIATRIC LONG-TERM FOLLOW-UP STUDIES

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ABSTRACT

Background: Poor follow-up rates greatly diminish the validity of prospective and long-term studies. Therefore, locating patients is of critical importance. This is especially true in populations treated during childhood because addresses will change several times in intervening years. Recent publications have reported new strategies for patient location. The purpose of this study is to test an algorithm proposed by King et al., as well as other search methods, using a cohort of patients treated for clubfoot in childhood

Methods: The study population included 126 patients with clubfeet treated between 1950 and 1967. We followed the search algorithm proposed by King et al. In addition, we used state driver's license records, Reunitetonight.com, and Intelius.com. Patients were considered to be found when they returned a postage-paid reply letter or were contacted by phone.

Results: Using web pages recommended by King et al. we located 26 of 126 (21 percent) patients. Operator directory assistance failed to locate any patients not located by free internet sources. Additional websites had varied results. State driver's license records found 25 patients. Reunitetonight.com found none with thirty attempted. The best search engine was Intelius.com which located 68 out of 126 (54 percent) patients.

Conclusion: The algorithm proposed by King et al. is not effective for long-term follow-up studies of pediatric populations. Intelius.com is worth the small fee charged (\$22.45) as it was the most effective method of locating patients.

INTRODUCTION

The nature of pediatric orthopaedics requires that injuries and congenital deformities be corrected using current best practices. The musculoskeletal system of children is very resilient and will generally return to a normal level of function shortly after treatment.¹ It is only after decades of use of a slightly abnormal structure that the advantages of one treatment method over another will become apparent.^{1,7} For this reason, long-term follow-up studies are essential to improving the clinical practice of pediatric orthopaedics.^{4,9}

One of the primary obstacles in any long-term follow-up study is the difficulty of locating patients.⁵ This is especially true for a population treated in childhood. The patients and their parents may have changed addresses several times in the intervening years. Marriage and divorce often result in name changes which further complicate attempts to locate subjects. Other patients may have died since the last patient contact.

Reliable methods for locating subjects for long-term follow-up studies have been reported in the last few years.^{5, 10-12} However, there is increasing interest in protecting private patient information, and all methods must meet the requirements of the institution's Institutional Review Board (IRB). Few studies have examined the relative effectiveness of free internet search engines, and to our knowledge no studies have evaluated any subscription-based internet search engines.

After attempting to locate patients for a 50-year follow-up of idiopathic clubfoot, using only information available in the medical record, we began investigating alternative patient location methods. We hypothesized that the algorithm published by King using free internet search engines would enable us to easily locate a large portion of our study group.¹⁰ In addition, we evaluated the effectiveness of searching state driver's license records, telephone operator assistance, and the internet search engine Intelius.com, which requires a paid subscription.

MATERIALS AND METHODS

Study Population

We attempted to locate 126 patients who were treated for clubfoot at our institution between 1950 and 1967. All clubfeet were treated with the serial casting method described by Ponseti.¹³ Results for this same study

Investigation performed at The Ponseti Center for Clubfoot Treatment, The University of Iowa, Iowa City, Iowa

The authors indicate that they do not have any relationship with any of the people-search services discussed in this article.

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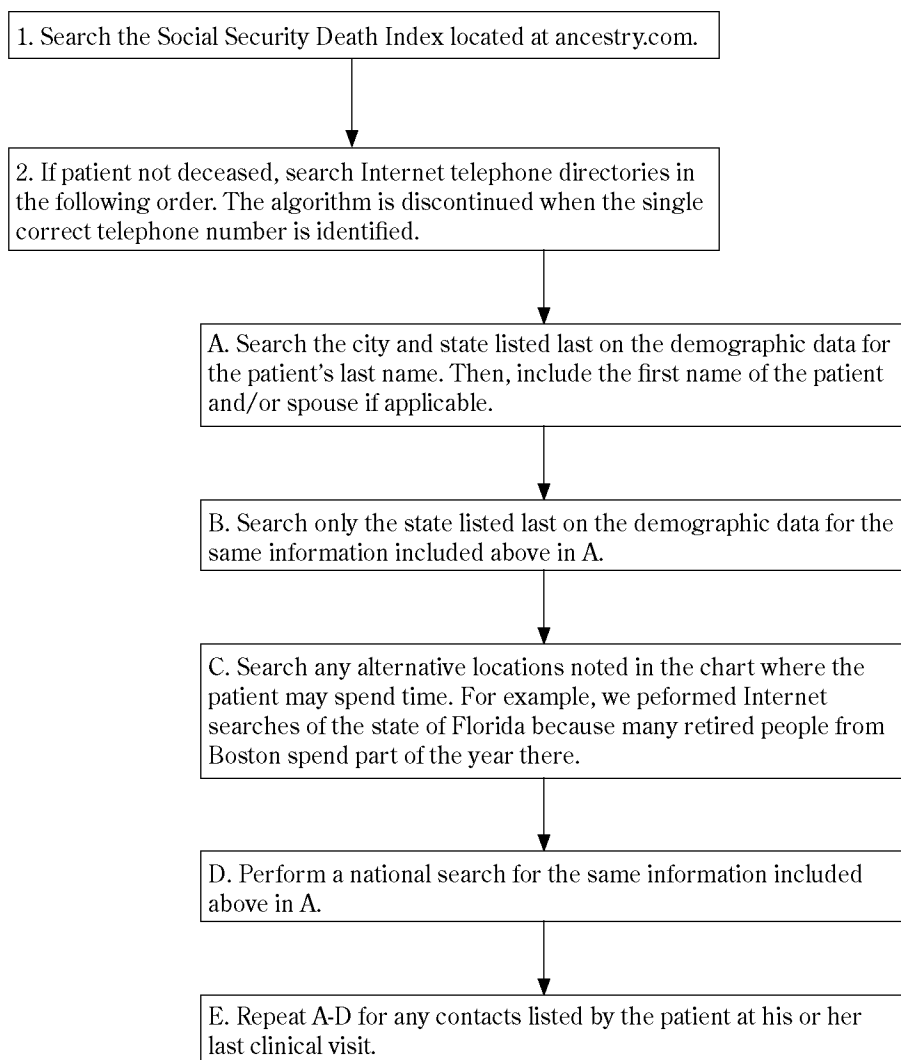


Figure 1. Internet search algorithm. From: KING: *J Bone Joint Surg Am*, Volume 86-A(5), May 2004:897-901.

population have been reported previously. Ninety-eight patients were located for the 1980 study, and 61 were located for the 1995 study.^{4,9} Seventy patients participated in the 1980 study and 45 patients participated in the 1995 study. The study population is now between the ages of 38 and 55.

Location Methods

Identifying information, including middle name, social security number, birth date, and last known address, were extracted from the patient's hospital record. When present in the hospital record, the same information was obtained for the patient's parents.

Using this information, we followed an algorithm published by King that utilizes free internet search tools. According to this algorithm, we first searched the So-

cial Security Death Index as available on Ancestry.com. This has been shown to be a moderately effective (83 percent success rate) method of identifying deceased individuals.¹¹ Next, we searched for patients through a number of internet phone and address directories including anywho.com, people.yahoo.com, superpages.com, switchboard.com, whitepages.com, and whowhere.com. We first searched the last known city and state, followed sequentially by the state only, other locations mentioned in the chart, and a national search. If the patient was still not located, we searched for anyone else mentioned in the chart using the same algorithm (Figure 1). We used all search engines to try to locate each patient, regardless of whether the patient had been correctly located by a previous search engine.

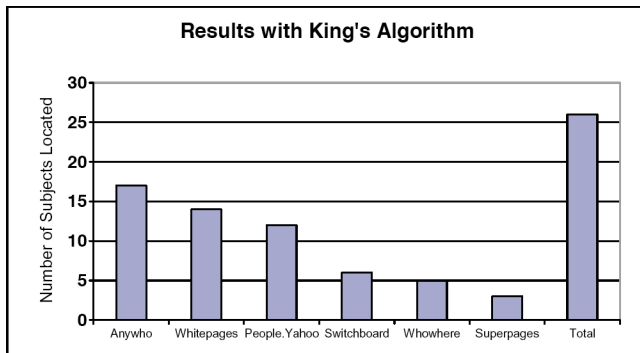


Figure 2. Results obtained with King's Algorithm. The number of correctly located patients is listed for each free internet search engine. The total located using the algorithm is also shown. Each web page ends in ".com".

In addition to the search engines specifically named by King, we also tried several other search mechanisms including other internet search engines, driver's license records, and directory operator assistance. We used the free internet search engine Reunitetonight.com and the paid internet search service Intelius.com using the same search method described above. Intelius.com was used to attempt to locate all patients, regardless of whether the patient had been correctly located by a previous search engine. Reunitetonight.com was only used in attempts to locate thirty patients. We discontinued searching with Reunitetonight.com because it failed to correctly locate any of the first 30 patients. For those patients not located by these internet search engines, we contacted operator directory assistance in the city corresponding to the patient's last known address. The last known city and state, and the names of any relatives mentioned in the chart, were given to the operator who would then provide any likely addresses and telephone numbers. We also used the patients' names, birth dates, and social security numbers to search the state driver's license records.

When a reasonable address was identified, a letter was sent to the patient inviting them to participate in the study. If no reply was received within two weeks of sending the first letter, we attempted to contact the patient over the phone. The patient was considered located when they returned a reply letter or were contacted by phone.

Results

A total of 26 patients were located using free internet search engines as described by King. The individual search engines yielded variable results (Figure 2). Anywho.com was the most successful, correctly locating 17 out of the 126 possible subjects. Whitepages.com and

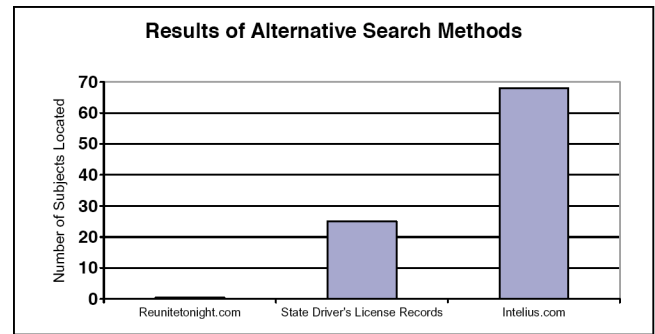


Figure 3. Results of Alternative Search methods. Intelius.com proved to be the most efficient and most effective method for locating patients.

People.yahoo.com provided similar results, correctly locating 14 and 12 subjects, respectively. Switchboard.com was able to locate six subjects. Whowhere.com located five subjects, while Superpages.com located three subjects. Ancestry.com confirmed five patients to be deceased. Two of these deaths were corroborated by hospital records. There were very few patients for whom correct contact information could be extracted directly from the medical record, and all of these patients were also correctly located using the King algorithm.

Alternative searches not included in the King algorithm displayed mixed results (Figure 3). Reunitetonight.com was unable to locate any of the 30 patients for which it was used. Operator directory assistance was used only on patients not located by any of the free internet search engines, and was unable to successfully locate any of the 57 patients. Intelius.com was the most useful, correctly locating 68 of 126 subjects. State driver's license records were able to locate 25 of 126 subjects, including one patient who was not located by any other method. Combining results from all internet search engines, we were able to locate 48 percent of female patients and 62 percent of male patients.

DISCUSSION

Long-term follow-up studies are often hampered by difficulty locating and contacting patients. Patient contact is especially difficult when the subjects were treated in childhood because the patients' names, addresses, and telephone numbers may have changed many times in the intervening years.

The amount of readily available information on the internet provides an opportunity for better and faster patient location. King reported 100 percent success locating patients five years after total knee arthroplasty using free internet search engines.⁵ Utilization of these services does not require special IRB approval because they are publicly available and do not provide the user with any

protected information. Our study found King's method was much less effective at locating patients who were treated in childhood. The King algorithm only located 26 patients out of the 126 total patients (21 percent). The difference in results between our study and King's is most likely a function of the length of time that had elapsed since the patients were last seen. King's study was looking for patients lost to follow-up only five years after total knee arthroplasty, compared to a 50-year follow-up in our study. The arthroplasty patients were also older and likely more established when initially treated. Older patients would be less likely to change names or addresses after treatment than patients who were initially treated as children.

The free internet search engines are also limited because they do not provide cellular phone numbers or unlisted numbers. As more and more people rely on their cellular phone as their primary telephone and eliminate traditional land lines, such search databases may become less and less effective.¹⁴

We found that utilizing multiple free internet search engines did improve the rate of locating patients. All patients for whom the chart contact information was correct were located using free internet search engines. The most successful single free search website was Anywho.com which located 17 patients, while a total of 26 patients were located by the entire battery of free people-search websites.

We attempted to utilize operator directory assistance to locate patients who were not located using the free internet searches. However, this method was abandoned after attempts were made on 57 different subjects and none of them were successfully located. It appears that the operators do not have access to, or cannot provide, better information than what is available on the internet for free.

Ancillary methods, such as searching the state driver's license records, may improve the ability to locate patients. In our study, this was almost as successful as the use of multiple free internet searches. However, this database contains no information about patients who have moved out of state. Also, because this database contains other protected information about the patient, separate IRB approval is required.

The most effective method for locating patients was the Intelius.com website. Intelius.com was able to locate 68 patients, including all of the patients who were located by the free search engines. Intelius.com also offers a social security number search which provides information regarding relatives, property ownership, lawsuits and other information. While the social security number search would be very helpful in narrowing down a list of

people with the same name, we did not use this particular option because it revealed excessive and unnecessary information concerning the subjects' personal lives. Use of the engine for these purposes would likely not be allowed by an Institutional Review Board. Intelius.com was both highly effective and highly efficient and is recommended for locating subjects for long-term follow-up studies of pediatric populations.

Though we selected Intelius.com, there are a number of other fee-for-service search engines available on the Internet. We made no attempt to evaluate all search engines, and other web sites may offer similar or even improved results.

The rapidly changing nature of the Internet may be both beneficial and detrimental to future patient identification attempts. Because the information can be updated relatively easily, contact information on the internet may actually be much more up to date than information in traditional telephone directories. On the other hand, web sites identified in this article may also be subject to frequent changes in cost, may fail to be updated regularly, or may disappear altogether.

In conclusion, search engines readily available on the internet are an excellent tool for locating patients. Free search engines may be useful for relatively short-term follow-up, but we found that search engines requiring a small fee were much more successful at locating patients for longer term follow-up. The efficiency and increased efficacy of the fee-for-service internet search was well worth the added cost.

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THE STATE OF PHYSICAL MEDICINE AND REHABILITATION IN IOWA: 2000-2005

Joseph J. Chen, M.D.

ABSTRACT

Background: The purpose of this study was to describe the practice of physical medicine and rehabilitation within Iowa from 2000-2005 by conducting a survey of the 30 practicing physical medicine and rehabilitation physicians in Iowa.

Results: Nine of 15 respondents completed medical school or residency training in midwest states. Physiatrists expressed numerous concerns including poor reimbursement, increasing malpractice costs, and difficulty recruiting physiatrists to Iowa. Iowa is ranked 49th in physical medicine and rehabilitation physicians per capita population. It also ranks 50th in Medicare payments per enrollee, yet is ranked fourth in the nation for percentage of citizens over the age of 65.

Conclusions: Recruitment of physical medicine and rehabilitation physicians should be tailored toward resident physicians completing training programs from midwest states. Retention of Iowa physiatrists, due to Iowa's lack of a physical medicine and rehabilitation residency training program, low Medicare reimbursement, and high percentage of patients over the age of 65, may lead to a "perfect storm" public health crisis for Iowans regarding the availability of future physical medicine and rehabilitation services.

INTRODUCTION

Physical medicine and rehabilitation is the medical specialty focused on the diagnosis and treatment of patients with acute and chronic neurologic and musculoskeletal injuries and diseases. Patients who may need physical medicine and rehabilitation care include those with brain

injuries, strokes, spinal cord injuries, peripheral nerve injuries, or other bone, muscle and joint problems that are not likely to require surgery. These patients are typically treated in an acute inpatient rehabilitation unit where a multidisciplinary team of physical therapists, occupational therapists, speech therapists, rehabilitation nurses, and medical social workers are readily available. In the outpatient setting, physiatrists (physicians trained in physical medicine and rehabilitation) treat a diverse group of patients with chronic injury and disease such as osteoarthritis, spine and musculoskeletal pain, sports injuries, osteoporosis, neuromuscular injuries, and other disabling problems. Physiatrists have a different range of expertise than an orthopaedic surgeon, rheumatologist, or a non-physician provider such as a physical therapist or chiropractor. These skills can include knowledge about and referrals for specific physical therapy treatment approaches, prescription medication management, spinal and peripheral joint injection techniques, osteopathic manipulative treatments, orthotic or prosthetic bracing options, and referral to orthopaedic or neurosurgical colleagues. Physiatrists are experts in the interdisciplinary team model of care and are frequently the leaders of physician-directed rehabilitation services.

Many Iowa physiatrists have been recruited by local hospitals or health organizations to be medical directors for their inpatient rehabilitation units. Until the 1990s, few physiatrists had only outpatient practices with no inpatient responsibilities. Some had specialized in outpatient procedures including acupuncture or electrodiagnostic medicine. Historically, outpatient musculoskeletal care in Iowa had been provided by orthopaedic surgeons. Orthopaedic surgeons trained in Iowa were taught that they must be knowledgeable about not only the surgical aspects of musculoskeletal care but also all of the non-surgical aspects. Patients in Iowa also sought out non-physician health care providers including physical therapists and chiropractors. Both specialties have generous state practice acts allowing them to care for many patients with spine or musculoskeletal conditions without direct referral from a physician.

Until 2000, the University of Iowa did not have any faculty members trained in physical medicine and rehabilitation to encourage their medical students to enter this specialty. At the osteopathic medical school at Des Moines University, faculty members in physical

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medicine and rehabilitation had some success in promoting this specialty, but because there was no residency training program in Iowa, all their interested medical students needed to seek residency training elsewhere. The nearest midwest programs are in Minnesota, Wisconsin, Illinois, and Missouri. There has never been a study of physiatrist recruitment back into Iowa following completion of their training. A study of Iowa physiatrists conducted in 2002 by Jung and Chen concluded that physiatrists trained in the midwest are most likely to develop a stable, diverse physiatry practice in Iowa.¹ Facilities trying to recruit physiatrists should tailor their efforts toward residents or fellows from midwestern physiatry programs.

We wanted to explore what other factors could improve recruitment of physiatrists to Iowa. High malpractice rates and poor reimbursement are factors that may be contributing to difficulty with recruitment. In the prior Jung/Chen study, a survey of 20 physiatrists indicated that malpractice rates increased by \$1611 (>20 percent) over the previous year, and one of 20 physiatrists had limited his or her Medicare practice. Five others indicated they planned to limit their Medicare practice due to poor reimbursement. The possibility that physiatrists may be limiting their Medicare practice was discouraging since there is a sizable percentage of Iowans over age 65, many of whom have conditions such as stroke, spine pain and injury, osteoarthritis, osteoporosis, chronic pain, and debility which can be treated by physiatrists. Therefore, the recruitment of physiatrists would benefit the public health of Iowans. Physiatrists could provide medical care above that which is currently provided by orthopaedic surgeons, physical therapists, or chiropractors for the above conditions.

A follow-up study was thus developed to reexamine physiatrists' training, practice demographics, concerns, and strategies to improve recruitment and retention of Iowa physiatrists.

METHODS

A more extensive follow-up questionnaire was sent to the 30 Iowa physiatrists in 2003. Questions covered practice setting and hours, patient demographics, additional qualifications, clinical expertise, malpractice costs, Medicare participation, and whether members felt there is a shortage of physiatrists in Iowa.

The questionnaire also asked for the reasons they had moved to Iowa, including whether they had lived in Iowa before, had completed medical school or residency training in Iowa, had lived in the midwest before and which state, had completed medical school or residency in the midwest, or had family who lived in Iowa before, and requested job details, financial packages offered,

and "other." If they were currently looking to move their practice out of Iowa, they were asked to indicate how important family needs, quality of life, the financial package, and job details (such as too much managed care or poor relationships with other clinicians) were figuring into their decision. If they were planning to keep their practice in Iowa, they were asked how much these factors had enticed them to stay.

The participants were asked to rank their top five of these twelve concerns: on-call responsibilities, hospital administrative issues, practice management, continuing medical education (CME), high workload, low workload, recruiting new physiatrists, retention of current physiatrists, costs of malpractice insurance, reimbursement, recertification, and other. They were also asked if they felt in control of making decisions on their practice's personnel, efficiency, and overhead, and where they obtain CME credits.

RESULTS

Thirty surveys were sent to physiatrists in Iowa. Results are summarized in Table 1.

Fifteen surveys were completed yielding a 50 percent response rate. Six were from solo practices, six from multispecialty practices, one from a hospital practice, and two from university practices. The average time in Iowa was 9.5 ± 4.8 years (range 2-20), with the over-all time as a practicing physiatrist 11.5 ± 6.2 years (range 3-25). On average, 37 percent of their practices were inpatient, and 63 percent were outpatient. The average age of responding physiatrists was 45 ± 7 years old.

Sixty-six percent of patients were referred to physiatrists by colleagues in orthopaedic surgery, neurosurgery, neurology, rheumatology, and medicine; six percent were referred by physical therapists. Self-referrals from the community accounted for 24 percent of the patient population, and approximately six percent were referred from other sources such as workers' compensation carriers, attorneys or other non-physician providers.

Seven physiatrists had completed their medical school training in Iowa, two from the allopathic medical school and five from the osteopathic medical school. Two others completed medical training in other midwestern states (Illinois and Ohio). Five respondents trained in Minnesota, three in Illinois, one in Kansas, and one in Michigan. Other respondents who completed their training in non-midwestern states were from Washington, California, New York, and Pennsylvania.

When respondents were asked why they chose to move to Iowa, six had lived in Iowa earlier in their lives, six specifically stated that they had medical school training in Iowa, five had lived in the midwest before, and six had family in Iowa.

TABLE 1
Summary of Iowa Physiatrists Survey, 2003

Survey Respondents/Total Physiatrists in Iowa		15 / 30 (50%)	
Demographics			
Solo 6, Multispecialty 6, Hospital 1, University 2			
Age (years)		45 ± 7	
Time in Iowa (years)		9.5 ± 4.8	Range 2-20
Time as a physiatrist		11.5 ± 6.2	Range 3-25
Reasons for Moving to Iowa		Patient Referral Sources	
Lived in Iowa before	7	Self	24%
Lived in Iowa during training	7	Other MD	66%
Lived in midwest	12	PT or OT	6%
Family lived in Iowa	6	Non-MD provider	4%
Medical Training			
Medical School Training	Iowa	7	(5 DO and 2 MD)
	Midwest	2	(IL and OH)
PM&R Residency	Iowa	0	(Not available)
	Midwest	10	(5 MN, 3 IL, 1 KS, 1 MI)
	Non-midwest	5	(WA, CA, NY, PA)
Practice Type			
Average time spent doing inpatient care		33%	
# Inpatients/week		4	
Average time spent doing outpatient care		67%	
# Consults/week		12	
Next available new patient appt		10.4 ± 9.6 days	
# Return patients/week		24	
Electrodiagnostic medicine		3	
Spinal Injections		2	
Peripheral injections		7	
Osteopathic manipulation (hours)		7	among 3 respondents
Number teaching students/residents		3	
Top Concerns of Physiatrists			
1. Poor Reimbursement	Medicare	38%	3 may limit MC practice
	Commercial Insurance	38%	
	Medicaid	12%	
	Self-pay	6%	
	Other/Work Comp	6%	
2. Increasing malpractice premiums			
	2003 average	\$9,000 ± \$1,100 (6 respondents)	
	2002 average	\$7,000 ± \$1,000 (? Respondents)	
3. Practice management problems—10/15 feel in control of practice expenses			
4. Difficulty recruiting			
	Shortage of PM&R in US?	5 Yes, 9 No	
	Shortage of PM&R in Iowa?	6 Yes, 8 No	
5. Hospital administrative issues			
6. Continuing medical education			
7. High workload			
	2003 weekly work hours	52 ± 14 (40-90)	
	2002 weekly work hours	49 ± 8 (35-70)	
8. Increasing call responsibilities			
	# nights per month on call	11	
	# with no call responsibilities	4	
9. Recertification requirements			

The Iowa physiatrists were asked to rank their top five out of a list of 12 possible concerns. These concerns were given five points if ranked #1, four points if ranked #2, three points if ranked #3, two points if ranked #4 and one point if ranked #5. The greatest concerns indicated by the physiatrists included poor reimbursement (41 points), high malpractice costs (34 points), practice management issues (26 points), difficulty recruiting (24 points), hospital administration issues (17 points),

continuing medical education (16 points), high work load (16 points), call responsibilities (12 points) and recertification (9 points).

Self-reported payer mix included, on average, 38 percent patients from Medicare, 38 percent from commercial insurance, six percent self pay, and 12 percent Medicaid. Three respondents were considering limiting their Medicare practices. In 2002, the average percentage of patients on Medicare was 35 percent ± 18.0 per-

TABLE 2
Physical Medicine & Rehabilitation Physicians per capita, its Relation to Residency Training Programs, Ranking of Medicare Payments per enrollee, and Ranking of States with Older Citizens

State or District	Rank	Persons per PM&R Physician ²	Number of PM&R Residency Training Programs ³	Medicare Payments per Enrollee by State ⁴	Rank of Medicare by State	Percent of population >65 yo ⁵	Rank of States with population >65 yo
Top 10 States in PM&R physicians per capita							
District of Columbia	1	16,395	2	NA	NA	12.2	NA
New York	2	21,299	15	\$7,489	3	12.9	24
New Jersey	3	24,959	2	\$5,702	18	13.2	18
Pennsylvania	4	27,772	5	\$7,226	4	15.6	2
Delaware	5	30,638	0	\$4,387	40	13	23
Massachusetts	6	34,979	3	\$6,202	11	13.5	12
Washington	7	36,769	1	\$4,303	41	11.2	42
Wisconsin	8	36,775	2	\$5,031	30	13.1	20
Hawaii	9	37,183	0	\$4,266	43	13.3	16
Minnesota	10	38,050	2	\$4,750	35	12.1	32
Bottom 11 States in PM&R physicians per capita							
Arkansas	41	72,830	1	\$5,478	21	14	9
Florida	42	73,423	2	\$7,603	2	17.6	1
Georgia	43	77,830	1	\$4,713	36	9.6	48
Rhode Island	44	81,512	0	\$6,675	7	14.5	6
Nebraska	45	81,907	0	\$5,367	24	13.6	11
South Carolina	46	84,628	0	\$5,791	16	12.1	31
Alabama	47	91,202	1	\$6,144	12	13	21
New Mexico	48	107,702	0	\$3,689	49	11.7	38
Iowa	49	112,768	0	\$3,414	50	14.9	4
Oklahoma	50	119,641	0	\$4,590	37	13.2	19
Mississippi	51	158,874	0	\$5,055	29	12.1	34

cent (range 5-60). One practitioner indicated that they limited their Medicare practice. Five others indicated that they planned to limit their Medicare practice. Only one Iowa physiatrist participated in the now defunct State Papers Program which has been replaced by the IowaCare program.

Malpractice rates continue to be a concern among Iowa physiatrists. Many have had a substantial increase in premiums, to an average of \$9000 ± 1100 per year among six respondents. Their malpractice rates had increased from \$7000 ± 1000 per year over the preceding year. In 2002, eight respondents reported an average increase in malpractice insurance premiums of 30 percent. No one reported rate reductions.

Physiatrists reported, on average, working 52 ± 14 hours per week (range 40-90) in 2004, which was a slight increase from 49 ± 8 hours (range 35-70) in 2002.

In 2004, physiatrists performed an average of 12 new outpatient consultations per week, four new inpatient consultations, zero ER visits, three EMGs, one acupuncture, 33 follow-up visits, 24 follow-up consultations/rehabilitation unit visits, two spinal injections, seven peripheral injections, and seven manipulation procedures. They also spent six hours performing administrative work. Three supervised medical students or residents.

The average time before seeing a scheduled new patient was 10.4 ± 9.6 days (range 1-30).

When respondents were asked if they were recruiting additional physiatrists, five said yes, three stated they planned on recruiting in the near future, and five did not plan on recruiting for at least five years. When asked whether there was a shortage of physiatrists in the United States, only five said yes. When asked whether physiatry was a specialty in shortage in Iowa, six stated yes and eight stated no.

DISCUSSION

Physical Medicine and Rehabilitation and State Demographics

The medical specialty of physical medicine and rehabilitation has exhibited lopsided growth throughout the country. Some parts of the country have many physiatrists per capita and others have many fewer practicing physiatrists. According to a 2001 Iowa Medical Society study (Table 2), the District of Columbia has one physical medicine and rehabilitation physician per 16,395 people and ranks first in the nation in having the highest number of physiatrists per capita. Mississippi has only one physiatrist for 158,874 people and is ranked 51 among the states and the District of Columbia. Oklahoma

is ranked 50 at 119,641 per capita. Iowa is ranked 49 and has one physiatrist per 112,768 people.

The under-use of physiatrists to treat musculoskeletal conditions in Iowa may be related to the fact that physical therapists have direct access and independent practices in Iowa. Iowa Code Title IV, chapter 148A.1, states, "Physical therapy evaluation and treatment may be rendered by a physical therapist with or without a referral from a physician, podiatric physician, dentist, or chiropractor." In this study, only six percent of referrals to Iowa physiatrists came from physical therapists, indicating that only a small number of physical therapists refer patients for additional rehabilitation medicine care. There is clearly a well-established role for the rehabilitation physician in the care of patients with complex neuromusculoskeletal problems. It is possible that many physical therapists view their clients as their own and may not want to upset the referring physicians by making a referral to a physiatrist. There is also a strong chiropractic community within Iowa, and many patients have previously sought treatment for musculoskeletal conditions from a physical therapist or a chiropractor rather than a physical medicine and rehabilitation physician.

Iowa has two Level I trauma units, one located at the University of Iowa Hospitals and Clinics, and one in Des Moines. There are also nine comprehensive inpatient rehabilitation units in Iowa, all located in community hospitals. The University of Iowa does not have an inpatient rehabilitation unit and relies upon community hospital-based inpatient rehabilitation units to provide such coverage. Early physiatrist involvement in rehabilitation for brain-injured and spinal cord-injured patients is a requirement to maintain American College of Surgeons certification for trauma units. If Iowa could recruit more physiatrists, it is likely that additional trauma rehabilitation care could be provided to Iowans, and rehabilitation could be provided closer to a patient's home town following medical stabilization.

Physical Medicine and Rehabilitation and Medical Schools

Today, medical student knowledge about physiatry is growing. Five medical students from the University of Iowa Carver College of Medicine are completing their physical medicine and rehabilitation residency training at institutions in Washington, Illinois, Utah, and Ohio. Although the first residency training program in physical medicine and rehabilitation was started in the midwest at the Mayo Clinic in 1936, today there are still several midwest states without physiatry residency training programs, including Iowa, Nebraska, South Dakota, and North Dakota. There are 12 physical medicine and

rehabilitation residency programs in states adjacent to Iowa, including two in Minnesota, two in Wisconsin, five in Illinois, and two in Missouri. If Iowa had a residency training program in physical medicine and rehabilitation, it is possible that Iowa would be able to recruit these graduates and possibly retain more physiatrists in the future. There are only five residency training programs in those states ranked #41-51 in number of physiatrists per capita, whereas there are 32 such residency training programs in those states that are ranked in the top ten. Wisconsin and Minnesota have two residency training programs and are ranked eighth and tenth, respectively. Nebraska, ranked at 45, is the only other midwest state in the bottom ten, and it also lacks a residency training program in physical medicine and rehabilitation. Many of the other states in the bottom ten are in the south. There is only one physiatry residency training program among the states ranked #47-51.

2005 Update

Since 2000, when there were 26 physiatrists in Iowa, ten new physiatrists have moved to Iowa, five have left, and one retired yielding a total of 30 physiatrists in Iowa in 2005. A retrospective review was done using an internet search to look at the medical school and residency training backgrounds of those physiatrists who came to Iowa after 2000 and are still practicing in Iowa. Six out of seven had medical school or residency training in Iowa or another midwestern state. This data supports the conclusion that physiatrists who have trained in the midwest are most likely to be recruited to an Iowa physiatry practice.

What This Means for Iowa

Iowa ranks 49 out of the 50 states and District of Columbia in the number of physical medicine and rehabilitation physicians per capita population. There is nearly a ten-fold difference in the number of physical medicine and rehabilitation physicians per capita between the top and bottom states. Many of the early academic departments of physical medicine and rehabilitation originated at institutions in the top ten states, such as the Rusk Institute of Rehabilitation in New York, the Kessler Institute of Rehabilitation in New Jersey, and Temple University in Pennsylvania. Citizens from states like Washington and Minnesota with strong, reputable academic departments in physical medicine and rehabilitation also enjoy the benefits of improved access to physical medicine and rehabilitation physicians and improved care of the neurologic and musculoskeletal conditions they treat. Efforts to bolster the Department of Orthopaedics and Rehabilitation at the University of Iowa could improve

patient access to rehabilitation physicians available at a tertiary care center. Iowa also has one of the largest percentages of citizens over the age of 65, at 14.9 percent, ranked fourth in the nation. Most citizens over the age of 65 are eligible for Medicare and are more likely to suffer from conditions such as osteoarthritis, stroke, osteoporosis, spine pain, and general debility. Psychiatrists are specifically trained to treat these types of conditions.

CONCLUSIONS

Examination of the number of psychiatrists per capita population served indicates that more psychiatrists are needed in Iowa. Further recruitment efforts should be tailored toward residents completing physical medicine and rehabilitation residency training programs in other midwestern states. Recruitment of psychiatrists to Iowa is essential to improve Iowa's ability to provide comprehensive rehabilitative medical care to patients with neuromusculoskeletal conditions including stroke, spinal cord injury, spinal pain and injury, musculoskeletal deconditioning, osteoporosis, and trauma. There may still remain significant challenges in the retention of Iowa psychiatrists due to low Medicare reimbursement and the high percentage of patients over the age of 65. These factors are now causing a scarcity of physical medicine and rehabilitation services but could develop into a public health crisis "perfect storm" in the years to come.

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OUTPATIENT PAIN REHABILITATION PROGRAMS

Joseph J. Chen, M.D.

ABSTRACT

Outpatient pain rehabilitation programs that include an interdisciplinary approach have been shown to be effective treatments for patients with chronic pain. The objectives of this article are to describe the common interdisciplinary pain rehabilitation programs available, the appropriate indications for use, the components of typical pain rehabilitation programs, the short-term and long-term success rates, the costs of attending these programs, and the significant societal costs of those patients who do not complete these programs and do not return to work.

HISTORY OF OUTPATIENT PAIN REHABILITATION PROGRAMS

The origins of the outpatient pain rehabilitation program date to the 1960s when Lidstrom, Zachrisson, and Forsell developed the "Swedish Back School." The goal of this back school was to reduce pain and prevent recurrence of low back pain. This program was a simple collection of four group sessions lasting only 45 minutes over 12 weeks' duration. Topics included biomechanics, ergonomics, exercises, and skill acquisition. The components of this program were supervised by either medical or paramedical professionals. In 1980, Mayer and Gatchel developed a more modern Functional Restoration Program. This program was more medically directed with an interdisciplinary approach to pain management geared toward patients with chronic disabling occupational musculoskeletal disorders. Much has been written about these programs. The Cochrane Database of Systematic Reviews evaluation of physical conditioning programs that include a cognitive-behavioral approach indicated there was moderate support for these programs being effective in the treatment of chronic back pain.

WHY USE A PAIN REHABILITATION PROGRAM?

In acute pain syndromes, symptoms are generally associated with a well-defined organic cause. Whether these are bony, ligamentous, or neurological causes, these injuries can easily be identified on physical examination or with diagnostic imaging. Pain relief generally occurs following resolution of the acute injury. Pain rehabilitation programs are not effective in these cases. In contrast, the etiologies of chronic pain syndromes are not as well understood. Possible mechanisms range from persistent scar tissue around nerve roots, neuropathic pain, central spinal sensitization, improper balance of serotonin or norepinephrine receptors, to psychogenic causes. Psychological and social factors may be part of initiating chronic pain, or may arise secondary to chronic musculoskeletal conditions.

Single-modality treatments including physical therapy, medications, or chiropractic manipulation are rarely helpful in these chronic conditions. The inadequate understanding of the complexity of chronic pain often leads to both under-diagnosis and over-diagnosis. Multiple medical and surgical consultations result in substantial health care costs. The patient's fear and immobility can then lead to depression, loss of physical stamina, increased ill-health perception, and further fear of worsening pain.

THE CHRONIC PAIN REHABILITATION TEAM

The pain rehabilitation team consists of several health care providers. Most programs include physical and occupational therapists, psychologists, and nurses along with pain physicians. Other programs may also utilize medical social workers, vocational rehabilitation counselors, and recreational therapists. Physical therapists are essential to educate patients on improving biomechanics, posture, flexibility, strength, and conditioning. Occupational therapy improves a patient's ability to perform activities of daily living and home-making tasks. Occupational therapists can also create an environment that may simulate a worker's job duties. The ability for a patient to bridge work and recreational activities should also be addressed by a physical therapist, an occupational therapist, recreational therapist, vocational counselor or even a medical social worker.

Perhaps the most important team member is the health psychologist. He or she often employs cognitive behavioral therapy to help rehabilitate the patient. Cogni-

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tive behavioral therapy includes structured techniques to help patients identify and change maladaptive thoughts and behaviors, or catastrophization. Acquisition of these skills is essential to allow patients to combat their problems independently. The methods psychologists employ to teach patients these skills include operant conditioning, assertiveness training, stress management, relaxation training, goal setting, pacing, positive coping strategies, and moderation in activities. The goals of cognitive behavior therapy include improved sense of mood and control, reduced patient interference with physical and social activities, enhanced self-reliance, and reduced inappropriate health care service utilization.

Other important team members include a medical social worker to evaluate community resources and provide appropriate resource assistance. Rehabilitation nursing can provide medication management, education, and nurse case management services. Vocational rehabilitation specialists are able to assist and explore vocational training options. The physician may provide a leadership role in coordinating the team's activities and educating patients, but is generally better suited to play as small a role as possible after diagnosis. By having a patient first utilize their own knowledge of their chronic pain and coping mechanisms, patients learn more self-reliance. In addition, using non-physician team members to briefly evaluate any persistent complaints can distance patients from reliance upon physicians to treat each and every flare-up of chronic pain. Typically, medical directors are physical medicine and rehabilitation physicians, psychiatrists, anesthesia pain physicians, or orthopaedic surgeons with an interest in pain management.

HOW IS CARE DELIVERED?

All patients enrolled in an outpatient pain rehabilitation program should receive an individual treatment plan even if therapies are delivered in a group setting. Some inpatient pain rehabilitation programs are used solely for detoxification from opiate medications, which can occur within one to two weeks. Typical outpatient pain rehabilitation programs last for two to 12 weeks or longer. These sessions may include half-days, daily sessions, weekly sessions, and/or monthly sessions. Contact hours range from three to 280 hours for such programs. Guzman reported that programs with over 100 hours of professional contact tended to have better outcomes than those with less than 30 hours of contact.

Therapies can be delivered in individual or group settings. Turner-Stokes showed either individual therapy or group therapy to be effective delivery mechanisms for cognitive behavioral therapy. Group therapy sessions may allow additional peer group support and encouragement. Group therapy also helps participants understand

that many others are experiencing the same problems with pain, activities of daily living, work interference, and recreational interference. In addition, Turner-Stokes concluded that members of the health care team working together can help maintain staff morale, as a lone psychologist or physician may feel isolated and frustrated when treating these complex chronic pain patients. Use of multidisciplinary teams in the treatment of chronic diseases such as diabetes and obesity is emerging and can be modeled from chronic back pain programs.

DO OUTPATIENT PAIN REHABILITATION PROGRAMS WORK?

Large meta-analyses indicate that outpatient pain rehabilitation programs offer clear benefits over conventional pain management in terms of mood, disability, interference with activities, pain behavior, reduction of pain intensity, decreased inappropriate use of health care, and return to work. A recent study in the Cochrane Database of Systematic Reviews by Heymans examined the use of back schools for non-specific low back pain.⁴ They reviewed a total of 19 randomized controlled trials consisting of 3584 patients and concluded that "There is moderate evidence suggesting that back schools, in an occupational setting, reduce pain, improve function and return to work status, in the short and intermediate term, compared to exercises, manipulation, myofascial therapy, advice, placebo, or waiting list controls, for patients with chronic, recurrent low back pain." There is also evidence that multidisciplinary treatments reduce symptoms, pain intensity, medication and health care provider use, and improve quality of life.⁵ Van Tulder noted improvements not only in physical parameters such as range of motion and flexibility but also in behavioral health parameters including anxiety, depression, and cognition.

SUMMARY OF SHORT-TERM BENEFITS

Short-term benefits of multidisciplinary pain treatment programs include pain reduction as well as improved flexibility, trunk strength, tolerance, self-perceived health status, pain related disability, and mood. Shirado also used a back school approach to treat 182 patients with chronic low back pain (LBP). Patients rated their pain on a 1-10 point scale as a 6.2 on average before the program, which decreased to an average of 2.8 after the program. Pain improved in 141 patients (81 percent), did not change in 27 (15 percent), and worsened in seven (four percent). Statistically significant improvements were achieved in finger-floor distance, trunk muscle strength, and endurance. Compliance with an exercise program significantly correlated with clinical results. Lemstra conducted a randomized controlled trial of 79 patients with fibromyalgia. Thirty-five patients completed

the intervention arm, and 36 control patients completed the no-treatment arm of the study. The intervention group had significant improvement in self-perceived health status, pain intensity, pain-related disability, depressed mood, and days and hours in pain. However, they had no change in nonprescription or prescription medication use or work status.

EFFECTS OF OUTPATIENT PAIN REHABILITATION PROGRAMS ON RETURN TO WORK

As a part of the Cochrane Database of Systematic Reviews, in 2002 Schonstein et al. reviewed 18 randomized controlled trials on work conditioning, work hardening, and functional restoration for workers with back and neck pain. They reviewed all randomized controlled trials that focused exclusively on injured workers, intended work outcomes, and availability of modified duties. The authors concluded that "Physical conditioning programs that include a cognitive behavioral approach can reduce the number of sick days lost at 12 month follow-up by an average of 45 days (95 percent confidence interval from -3 days to -88 days) when compared to general practitioner usual care or advice, for workers with chronic back pain." All of these studies included subjects with a capacity to return to pre-injury jobs with their pre-injury employer.

EXERCISE AND WORK

Taimela et al. studied 125 patients who had participated in a 12-week low back rehabilitation program and asked about pain and disability 14 months following treatment. They concluded that recurrences were fewer among those who maintained regular exercise habits after treatment. Work absenteeism was less among those who were physically active. Exercises are beneficial after treatment, but those with less favorable outcomes are also less likely to participate in exercise after treatment.

LONG-TERM SUCCESS OF OUTPATIENT PAIN REHABILITATION PROGRAMS

Patrick performed a 13-year follow-up study of 26 patients who had completed a chronic pain rehabilitation program at the University of Iowa Spine Center. The authors found that patients had maintained their treatment gains of decrease in pain intensity, decrease in pain interference, and improved mood. The patients had general health levels comparable to similar age-matched peers except for more pain and lower physical functioning. More than half of the sample was employed. Of those not employed, few reported that their unemployment was due to pain.

OTHER BENEFITS

Linton studied 185 patients with back or neck pain at risk for developing long-term disability who volunteered to participate.⁸ One hundred and fifty-eight patients completed a study in which each patient was randomized to one of three treatment arms. Those patients who completed a cognitive behavioral group program either with or without a physical therapy intervention had fewer health care visits and fewer days of sick leave than those who completed minimal treatment.

PROGRAM COSTS

Program costs vary throughout the country. Typically these costs depend on the length of the program and the program intensity. Usual charges include some physical therapy, psychology, and physician charges. These costs range from \$13,000 to \$30,000.

Reimbursement by third party payors for participation in these programs is varied. For those patients whose chronic pain is causally related to a specific work injury, workers compensation typically will pay for this treatment. Convincing third party payer administrators of the short-term and long-term benefits of a comprehensive pain rehabilitation program can be challenging, but medical directors can cite recent research studies on chronic pain rehabilitation programs as noted above. For those chronic pain patients who are working-age adults and have not attained eligibility for Medicare, their commercial insurance company typically pays for these programs based on how their contract pays for other physical therapy and/or psychotherapy charges.

Much of the challenge in chronic pain lies with patients who do not have insurance. These patients typically are not employed by large companies offering group health insurance coverage. If they are self employed and unable to work, they usually have no other source of income. When chronic pain patients are eligible for government health care benefits such as Medicaid, the reimbursement to a pain rehabilitation program can be significantly lower than that of other payors. Each state's Medicaid coverage differs in their management of physical therapy, psychotherapy, and physician reimbursement. However, those patients who are uninsured and unemployed because of their chronic pain are those patients who need these programs most desperately. Uninsured and unemployed patients create significant cost to society because of lost productivity and excessive unnecessary medical costs associated with diagnosing and treating chronic musculoskeletal pain.

TABLE 1
Comparison of Program Completers and Noncompleters

Utilization of:	Program Completers	Program Noncompleters
Surgery	2.3%	12.2%
New physician visits	20.8%	40.7%
>31 visits	3.4%	19.1%

From Proctor et al., *Arch of PM&R* 2005 86; 1509-15.

COSTS OF NOT ATTENDING

Proctor et al. tried to study the health care costs of those patients who failed to complete a pain rehabilitation program. He studied a large prospective cohort of 1137 patients who completed a multidisciplinary pain rehabilitation program and compared that group with a cohort of 303 program noncompleters. Researchers used a structured telephone interview of post-treatment outcomes performed one year after the program. The non-completers had more medical comorbidities including diabetes, cardiovascular conditions, hypertension, GI problems, cancer, and asthma. However, the work status of completers indicated that 90.4 percent of completers were able to return to work compared to only 48.7 percent of noncompleters. In addition, 84 percent of completers continued to work after one year compared to only 41 percent of noncompleters. Thirty-seven percent of treated patients returned to the same employer versus 16 percent of the noncompleters. Thirty-four percent of the completers even returned to their same pre-injury job compared to 18 percent of noncompleters. Other significant findings indicate that noncompleters had significantly increased health care utilization compared to completers. Noncompleters were seven times more likely to have had surgery in the same area. Noncompleters were also seven times more likely to have more than 31 additional health care visits in the next year (Table 1). Noncompleters were seven times less likely to have returned to work at the end of the year and 9.7 times less likely to have returned to any type of work. The authors concluded that, “Noncompleters had poor socioeconomic outcomes in the year after discharge from treatment especially on work status and health utilization outcomes. These outcomes are of great relevance to societal, medical and indemnity costs and to future worker productivity.”

PREDICTORS OF A GOOD OUTCOME

The goal of the medical director of a pain rehabilitation program is to predict those patients who are most likely to improve with the least amount of cost. However, it can be difficult to predict who will respond to a comprehensive pain rehabilitation program and who

will not. Van der Hulst reviewed published studies that were mainly descriptive or exploratory in nature. Consistent evidence was found for the predictive value of pain intensity, as a higher pain intensity correlated with a worse outcome. Several work-related parameters including high satisfaction with work and coping style (more active coping better than passive) correlated with better outcomes. Bendix, at the Copenhagen Back Center Functional Restoration Center, compared 816 patients treated in a functional restoration program with 144 patients who completed a shorter outpatient program and 51 patients who had no treatment. He found that younger age, fewer days of sick leave, connection to the work force, and decreased back pain intensity were significantly correlated with a better outcome at one year after entry into the study in all groups. Back muscle endurance, sports activity, activities of daily living scores, and vibrations were of importance in some outcome parameters after functional restoration. Smoking also positively correlated with disability pension.

CONCLUSION

Physicians need to be aware that outpatient pain rehabilitation programs are clinically effective and cost effective. Approaches to utilizing interdisciplinary teams to assist patients with chronic pain conditions can be helpful to the physician as well the entire health care team. Although the initial cost for a patient to participate in a pain rehabilitation program may be high, the cost to society of not attending such a program through lost productivity and excessive health care utilization is likely significant.

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RANDOMIZED SURGICAL TRIALS AND “SHAM” SURGERY: RELEVANCE TO MODERN ORTHOPAEDICS AND MINIMALLY INVASIVE SURGERY

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ABSTRACT

Surgical techniques are constantly changing and evolving, though research trials supporting the value of a specific surgical intervention are often limited by the lack of a legitimate control group. In surgical trials, the use of a placebo, or a “sham” surgery, is controversial. This article explores the debate regarding the use of sham surgeries and summarizes the few surgical studies that have used them. Arguments for and against their use in research are presented.

INTRODUCTION

In general, new surgical procedures are developed by a single surgeon or a small group of surgeons. These individuals then employ the new procedure on their patients, observe the results, and report them either as prospective or retrospective studies. This approach does not allow comparison of one procedure with others, or with a sham procedure, or (in most instances) with nonoperative treatment. Acceptance of new procedures is based on their perceived value relative to previously accepted treatments. This process can be powerfully influenced by the enthusiasm, skill, and prominence of the surgeon reporting the results and by their selection of patients for treatment. Reitsma observed that “In a climate where surgeons introduce experimental techniques without formal research preceding such innovations, surgical research is an ill-defined and elusive entity.”¹⁶

The gold standard of clinical research is the double-blind randomized placebo-controlled trial, yet very few surgical procedures are subjected to this form of investigation.^{1,18} Studies that are done in other fashions are

often criticized for failing to provide the true answer regarding the usefulness of a surgical procedure. In a randomized controlled trial there is a control group to which other treatment arms are compared. The control group is treated with a placebo in most medical specialty studies and pharmacology studies. However, in surgical trials, the use of a placebo, or a “sham” surgery, is controversial. In particular the question arises: When is it ethical, if ever, to perform sham surgery? The purpose of this article is to review the debate regarding the use of sham surgeries and summarize the few surgical studies that have used them. Arguments for and against their use in research will be presented.

BACKGROUND

The field of surgery has advanced at an unbelievable pace over the last several decades. No one would have believed 50 years ago that you could remove tumors from the brain using computer guidance, replace joints with titanium implants through three-inch incisions, or change a person’s vision with the use of a laser. Advances in surgical equipment and technology have been driving the advances in surgery. The art and practice of surgery began as a way to save lives in critical situations. However, today the vast majority of surgical procedures are done on an elective basis to improve quality of life. Traditionally, surgeries to treat acute or chronic disease have been accepted based on retrospective cohort analyses that are compared to historical nonoperative series. Sham surgery controlled trials have not been encouraged or performed regularly. A placebo controlled trial was inconceivable at the inception of surgery, as surgical intervention was performed only in “life or death” situations, and this remains true for some cases today. For example, one would not consider a sham surgery controlled trial involving irrigation and debridement of an infected joint.

THE PLACEBO EFFECT AND SHAM SURGERY

The problem for most surgical studies is determining how much of the effect of surgery is from the procedure itself and how much is placebo effect. As opposed to using a nonoperative control group, the benefit of using a sham surgery control in surgical trials is that sham surgery equalizes the placebo effect of surgery.

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Beecher first described the placebo effect of surgery in a classic paper following a randomized trial of internal mammary artery ligation versus a sham operation for angina pectoris back in 1959.^{9,17} The placebo response for surgery mimics that seen for other therapeutic interventions, accounting for up to 35 percent of the response.¹⁰ Part of the placebo effect is thought to be due to the surgeon-patient relationship.^{9,10} Equalizing as many variables as possible for the patient's treatment experience allows for the best understanding of the direct effect of the surgical procedure itself.

There are several core ethical principles at stake at the center of the debate regarding the use of sham surgery in surgical trials. In 1947, the Nuremberg Code put forth a statement regarding the appropriate practice of research on human subjects.¹⁹ The Nuremberg Code decreed that all research should avoid any unnecessary physical or mental suffering, and the degree of risk to be taken should never exceed the humanitarian importance of the problem to be solved by the experiment.¹⁹ In 1964, the Declaration of Helsinki reiterated many of the principles of the Nuremberg Code and expounded on them. This included the statement that the "concern for the interests of the subject must always prevail over the interests of society and science."²⁰ Finally, in the Belmont Report of 1979, the National Commission for the Protection of Human Subjects put forth the three basic principles of respect for persons, beneficence, and justice.¹⁵ This commission recognized the difficulty of balancing the importance of advancing science against the risks and benefits to study participants, stating there is "difficulty of making precise judgments" regarding the risk/benefit ratio of research protocols.

Certainly, trying to balance the benefit of sound study design, elimination of placebo effect, and truly studying a surgical procedure is valuable. However, making a non-therapeutic incision on a subject's skin definitely infringes upon the concept of "do no harm." Also, the risks of surgery are not benign. They include the possibility of bleeding, infection, antibiotic treatment to prevent infection, and the risk of undergoing an anesthetic. How do we balance these risks against the tremendous advantage of a sham controlled study designed to answer socially important scientific questions?

There have been very few sham controlled surgical trials to date. In 1959, Cobb published a study showing no difference in improvement between patients undergoing internal mammary artery ligation versus a sham operation for treatment of angina pectoris.¹⁷ In recent years, two studies were done to evaluate the intracranial implantation of fetal neural cells for Parkinson's disease.^{3,4} These studies had some of the study patients randomized to a sham operation that re-

quired simulating all aspects of the surgery, including the drilling of burr holes on the skull under anesthesia. In the field of orthopaedics, Moseley et al. in 2002 evaluated the effectiveness of arthroscopic surgery for arthritis of the knee.¹ In this study, one group received a full arthroscopic debridement, one group underwent arthroscopic lavage with irrigation fluid alone, and the last group had three one-centimeter sham incisions but no actual procedure performed. This study concluded that arthroscopic surgeries done for advanced arthritis were no more effective than the sham operation.

The Parkinson's sham surgery trials and the Moseley knee arthroscopy study stimulated several commentaries on the ethics of sham surgery in research.^{2,5,6,7} Macklin identifies the fact that sham surgery has no potential benefit for the patient and violates the principle of minimizing harm to the patient as one of the major ethical issues presented by sham surgery use in surgical research.^{2,15,19,20} The declaration of Helsinki states that "every patient, including those of the control group—if any, should be assured of the best proven diagnostic and therapeutic method."²⁰ To avoid this additional and nontherapeutic risk to the patient, the sham surgery could be thrown out and a control group who receives nonoperative or less risky management could be used. In contrast, Stock disagrees with the argument that no clinical benefit is gained by participants who receive a sham operation.²⁴ They receive pain medicine, frequent attentive follow-up, exercise programs, counseling, and the placebo effect of surgery.

MEDICAL VERSUS SURGICAL RESEARCH

According to Miller, a distinction should be made between the ethics of clinical research and the ethics of daily medical care.⁸ Sham surgery controls have been criticized since they counter the basic tenet of medicine to "do no harm." However, this is not treating these surgical trials for what they are: Research. Miller suggests that it is not fair to impart the ethics of daily clinical medicine to research trials, and offers that sham surgeries should be viewed in the same spectrum as additional blood draws, radiographs, lumbar punctures, and biopsies - all things done regularly in accepted medical trials every day. Others counter that sham controls are different from medical placebo controls due to their substantial additional risks that are unique to surgery, such as anesthesia, bleeding, infection, and additional pain.²² An additional harm is done to patients as well. The patient, having just undergone an operation, also must then be actively deceived. One author, who happens also to be a surgeon, has suggested that the physician who performed the operation must then be removed as much as possible from the postoperative care of the patient

to eliminate the need for the surgeons to participate in this deception.²²

SHAM SURGERY: RISKS AND BENEFITS

The next major issue concerns finding the appropriate balance between the risks and benefits of research involving sham surgery. Some authors argue that the risk of sham operations cannot be justified regardless of the benefit, but many others agree that the risk/benefit ratio requires extremely careful analysis on a case-by-case basis.^{6,8,11,22,23,24,27} Several factors contribute to this analysis. London and Kadane suggest closely examining the importance of the sham control.²⁴ If there is acknowledged debate regarding the best treatment for an illness and if that debate centers on no treatment versus surgical treatment, then a sham surgery could be justified. For instance, these authors did not feel that there was evidence to support sham surgery in the Moseley knee arthroscopy trial because a previous study had already shown no benefit of lavage over placebo.²⁴

In addition, there may be substantial differences in the risks involved in various sham operations, as is the case with the Parkinson's trial and the knee arthroscopy trial mentioned previously. One required creating burr holes in the cranium, while the other used three one-centimeter stab incisions about the knee. One could argue that making an extraneous skin incision is little riskier than bronchoscopy, endoscopy, multiple blood draws, or other invasive procedures readily accepted in other trials.⁸

Moreover, the societal benefits of sham controlled trials could be great. Sham surgery has the potential benefit of saving society from the financial burdens of unproven operations.²³ For instance, the Moseley study concluded that knee arthroscopy for advanced arthritis, performed between 5000 and 6500 times a year at a cost of approximately \$5000 per procedure, was no more effective than placebo.¹ Testing the efficacy of expensive surgical and medical interventions with sham controls, as in the Moseley study, could have a dramatic impact on future medical costs. Lastly, sham operations may be the only option to truly determine whether a benefit from surgical intervention truly exists.

SURGICAL TRIALS: INFORMED CONSENT

The third major issue for sham surgeries involves enrolling and consenting patients for participation. The informed consent procedure for trials that involve sham operations is imperfect. Regardless of the detail in which patients are counseled that sham surgery may be performed, the "therapeutic misconception" still exists for many patients who are desperate for treatment.⁸ This was a significant issue for the stem cell research

trials done for Parkinson's disease, which is a terminal illness. However, the Parkinson's patients may be no less desperate than cancer patients consenting for placebo controlled drug therapy trials that are an accepted part of cancer chemotherapy research.

Another important issue is dealing with the very sensitive nature of human subject experimental research among the general public. Media attention to both the Moseley knee arthritis study, as well as the recent political debate regarding stem cell research such as the Parkinson's disease trial, has raised public awareness about the use of human subjects in research. Leeds has advocated that social aspects of sham surgery should be explored since there is an "inherent aversion" to sham operations in the general public.²⁶ Such education efforts would potentially include forums that bring forth opinions of physicians, former subjects in sham controlled trials, and representatives of the public to show that the medical community is concerned about public opinion regarding sham operations. Numerous operative interventions are becoming relatively routine and accepted based on minimal or shaky evidence of patient improvement. Every measure necessary should be taken to explore the appropriate use of potentially invaluable sham-controlled analyses.

Taking all these factors into account is necessary to determine the usefulness of and justification for placebo-controlled surgical trials. Emmanuel and Miller have suggested that one of four criteria should be met before placebo-controlled trials are required from a scientific standpoint.²⁵ These conditions are: A high placebo response rate, a condition that is chronic with a waxing/waning course, a condition for which existing therapies are only partly effective or have serious side-effects, or a relatively infrequent condition.

APPLICATION TO ORTHOPAEDIC RESEARCH: MINIMALLY INVASIVE SURGERY

Abundant possibilities exist in the field of orthopaedic surgery for such research. We like to believe that the surgical procedures we perform on patients offer a better outcome than that of nonoperative treatment or older surgical techniques. Depending on the condition, the true results of operative treatment are perhaps debatable; such uncertainties are more prevalent than we care to think about. Orthopaedics, as much as any other discipline in medicine, is driven by forces from technology and industry. Much of the focus in recent years has centered on less invasive procedures. Such well-established and successful interventions as total hip replacement, rotator cuff surgery, total knee replacement, shoulder stabilization surgery, and others are being done through surgical approaches that mini-

mize skin incisions. The advocates of these procedures cite decreased recuperation time, decreased morbidity, decreased pain, and fewer days of hospitalization as advantages of these procedures. Since these techniques are newer than more traditional and more extensive open techniques, comparable long-term results are not available. In addition, the traditional techniques continue to evolve and improve as well.

It would be advantageous to directly compare results of minimally invasive surgery to more traditional techniques. The ideal way to do this would be a randomized blinded clinical trial to remove patient and surgeon bias that might affect outcomes. There are significant difficulties with such a trial, however. First, the surgeon must believe there is a real question to be answered and that one treatment is not better than the other, commonly referred to as clinical equipoise. Secondly, increasing numbers of patients today are interested in the potential benefits of minimally invasive surgery. Naturally, if you ask a patient if they would prefer three one-centimeter incisions and to go home the same day as surgery, versus a four-inch incision and a stay overnight in the hospital, most patients will opt for the former. Optimally, this could be tested through a blinded randomized trial with all patients receiving the same skin incisions, regardless of surgical technique used. This would blind the patient, the clinician doing the follow-up, and others to the exact method used. Indications for surgery would need to be standardized and every effort made to eliminate selection bias for a trial of this nature. Minimally invasive surgeries have a significant learning curve and many surgeons select technically easier cases on which to use these techniques. Such bias must be eliminated to truly understand how these new and old techniques compare. The obvious obstacle to this kind of design is that extra skin incisions would be placed on patients who are really undergoing the minimally invasive procedure. Does this additional incision truly put them at greater risk? This is unclear, but a human subjects' office would likely have a hard time with this design. However, as we move forward with better research in the surgical specialties, issues such as these should be tackled if we truly want to decipher what is ultimately best for patients.

SUMMARY

Given the ethical background reviewed above, the field of orthopaedic surgery would benefit from further surgical trials that incorporate some element of sham surgery. Conferences around the globe abound with symposia debating the merits of various surgical techniques, mostly centered on how "invasive" a procedure appears. These debates center around some of the most commonly performed orthopaedic procedures, such as

rotator cuff repairs, shoulder stabilization, and hip and knee replacements. The means to providing answers are available, but come at the cost of sham incisions and sham surgery. Many years ago such surgical research eliminated a common surgical intervention, internal mammary artery ligation, from the treatment algorithm for chest pain. One can only imagine what other surgical interventions we might change with further such research today.

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CONCOMITANT IPSILATERAL FEMORAL NECK AND FEMORAL SHAFT FRACTURE NONUNIONS: A REPORT OF THREE CASES AND A REVIEW OF THE LITERATURE

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ABSTRACT

Ipsilateral femoral neck and femoral shaft fractures are rarely reported in the literature and represent a diagnostic and treatment challenge. Due to the possibility of missing a nonunion at either site, we recommend a high clinical suspicion and careful radiographic examination of both fracture sites. Because the development of nonunion at both sites is exceedingly rare, we report three cases of concomitant ipsilateral femoral neck and shaft nonunions that were treated by the senior author (KAE). Two patients were treated with a Pauwels osteotomy and a blade plate for the femoral neck nonunion and a reamed retrograde intramedullary nail for the shaft. One patient was treated with an antegrade reamed cephalomedullary intramedullary nail. All three patients' fractures united at a mean of 4.6 months and they are currently pain free and without physical limitations.

INTRODUCTION

To the best of our knowledge, ipsilateral femoral neck and shaft fractures treated surgically that have gone on to develop nonunions at both fracture sites have only been reported in the English literature six times in the last 25 years.^{1,2} These six cases are reported as complications of larger case series, and there was no discussion of treatment for the ipsilateral femoral neck and shaft nonunions.^{1,2}

Ipsilateral femoral neck and shaft fractures usually occur in multiply injured, younger patients from high velocity injuries. Retrospective reviews have demonstrated that femoral neck fractures in the setting of femoral shaft fractures may be missed in as many as 19-31 percent

of femoral shaft fracture presentations.^{3,4} Four methods for fixation of femoral neck and shaft fractures have received attention in the literature: (1) Initial prompt fixation with multiple cancellous screws for the femoral neck and an extra-articular retrograde intramedullary nail for the femoral shaft; (2) A cephalomedullary nail; (3) Antegrade intramedullary nailing with cancellous lag screws, and; (4) Plate fixation of the femoral shaft with lag screw fixation of the femoral neck. Due to the lack of randomized trials, it is unclear which method of fixation leads to fewer complications. Since the patient population is relatively young, successful treatment of the initial injury and subsequent treatment of ipsilateral lower extremity nonunions is important to avoid significant cumulative impact on quality of life.

Ipsilateral femoral neck and femoral shaft nonunions may present difficult diagnostic and treatment challenges. Diagnosis can be difficult because of referred pain and standard radiographic imaging limitations secondary to the presence of hardware. Furthermore, treatment is complicated by the previous hardware, and difficulty in selecting optimal methods secondary to the lack of literature on the topic.

We present three patients who sustained ipsilateral femoral neck and femoral shaft fractures that went on to nonunion at both sites, and a review of the literature on this topic. The purpose of this case series is to raise awareness of these ipsilateral femoral neck and shaft nonunions and to report our experience with them.

Case 1

A 38-year-old female fell from four stories and sustained the following injuries: a Pauwels-C femoral neck fracture, an ipsilateral 3A open right femoral shaft fracture (Figure 1), a 3A open right humeral shaft fracture, an LC-1 pelvic ring injury, and a right patella fracture. At the time of presentation, the femoral neck fracture was open reduced and stabilized with a dynamic hip screw and two-hole side plate, and the femoral shaft fracture was treated with a reamed retrograde femoral nail prior to patella fixation. The humerus fracture was also treated with irrigation and debridement and open reduction with internal fixation at the same surgery. At surgery there was noted to be bone loss at the femoral fracture site.

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Figure 1. An anteroposterior radiograph of the femur fractures of patient 1.

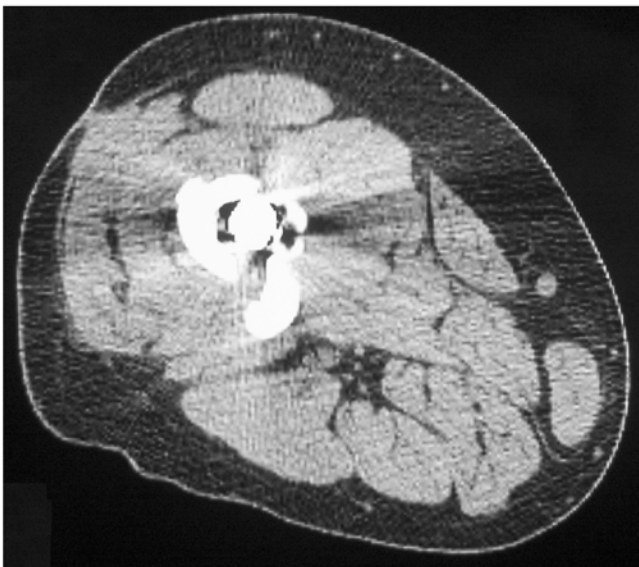


Figure 2. An axial cut of the thigh demonstrating the nonunion of the femoral shaft in patient 1.

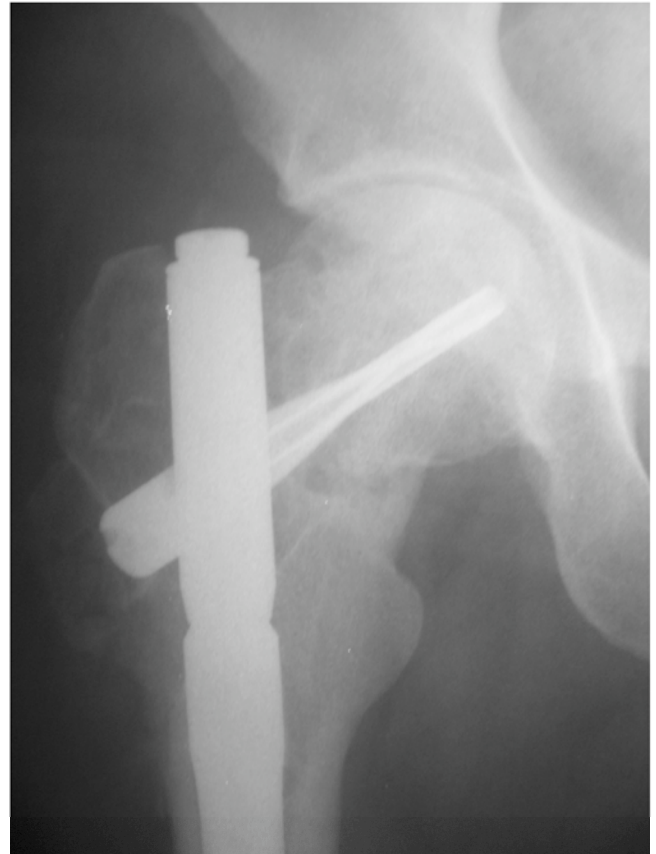


Figure 3. An anteroposterior view of the proximal femur showing fixation with a cephalomedullary device with acceptable femoral neck shaft angle in patient 1.

The patient's postoperative course was unremarkable, and she was kept on protected weight bearing.

Six months after her original surgical procedures she complained of pain in her right thigh. Radiographs and CT scan (Figure 2) of the right hip and femur demonstrated nonunions of the femoral neck and shaft. Workup for infection was negative. She was neither a diabetic nor a smoker.

The patient underwent removal of existing hardware and exchange nailing of her femur with a locked, antegrade intramedullary nail with a cephalomedullary spiral blade (Figure 3) (Synthes, Paoli Pa). In addition, a mixture of cancellous bone graft with bone marrow aspirate and BMP-2 (Infuse® bone graft, Medtronic, Philadelphia, PA) impregnated collagen sponges was placed after opening the fracture sites. The patient was initially given instructions to be toe-touch weight bearing.

At six months the patient had three of four cortices healed in the femoral shaft and radiographic evidence of a healed femoral neck fracture. She had no complaints and was functioning well with regard to activities of daily living.

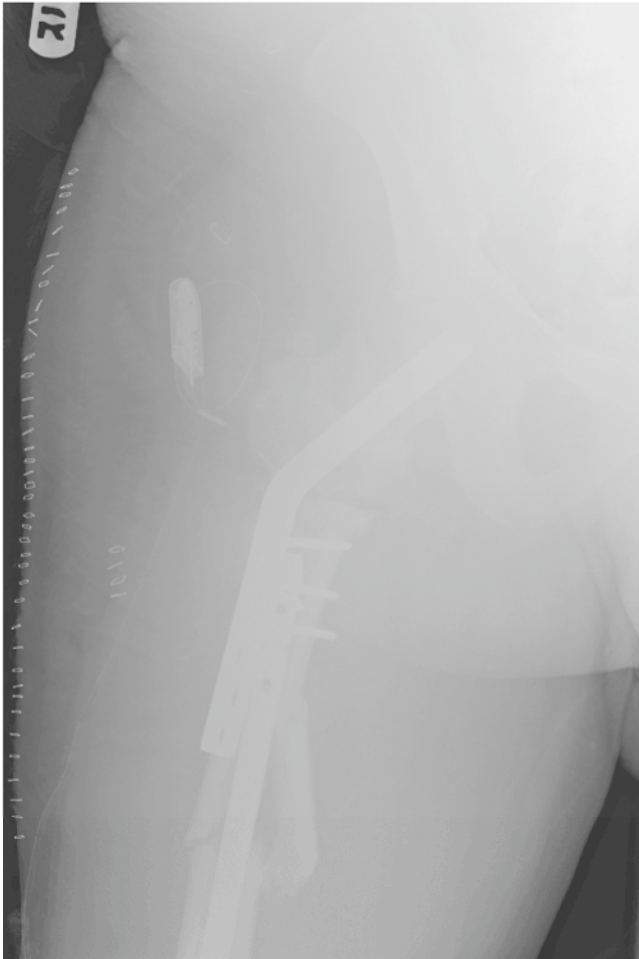


Figure 4. Radiograph demonstrating the Pauwels osteotomy with blade plate fixation and retrograde femoral nail after nonunion was diagnosed in patient 2.

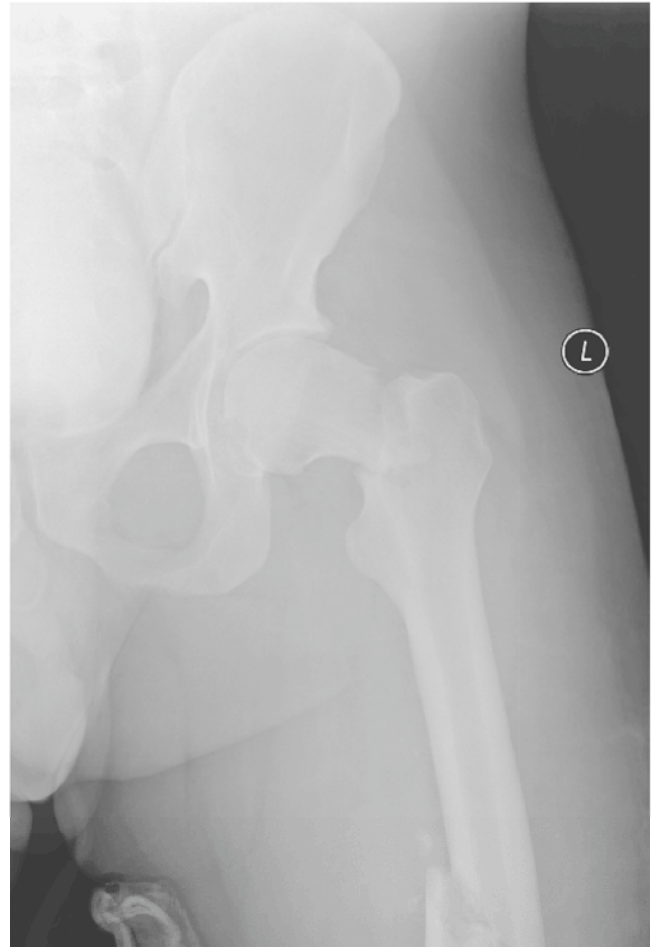


Figure 5. An anteroposterior radiograph of the proximal femur showing ipsilateral femoral neck and shaft fractures in patient 3.

Case 2

A 37-year-old male was struck by a motor vehicle while riding a motorcycle and sustained the following injuries: Closed ipsilateral right femoral neck and shaft fractures and a right open extra-articular calcaneus fracture. The patient was treated elsewhere with a reamed, antegrade cephalomedullary nail with a derotational screw for both femur fractures. The calcaneus fracture was treated with repeat irrigation and debridement and casting.

Six months after his original injuries, the patient presented to the senior author and described severe pain in his right thigh and groin that confined him to a wheelchair. Radiographs demonstrated nonunions of both the femoral shaft and neck fractures with intact hardware. The femoral neck had fallen into varus alignment.

At revision surgery, the hardware was removed and, due to the varus neck alignment, a Pauwels osteotomy

was performed to restore anatomic alignment. A 30° wedge of bone was removed from the lateral cortex, and a 130° blade plate was inserted under fluoroscopic imaging. Next, a reamed retrograde nail was inserted and locked in compression. Autogenous graft from the bone wedge was placed around the osteotomy site, and an implantable bone stimulator was used. Postoperative anteroposterior radiographs show the Pauwels osteotomy, blade plate, and retrograde nail (Figure 4).

The patient was made foot-flat weight bearing and discharged from the hospital on postoperative day four. At five months, radiographs confirmed union at both sites and the patient was advanced to full weight bearing. The patient did complain of a leg length discrepancy that measured two centimeters. The leg length discrepancy was successfully treated with a shoe lift.

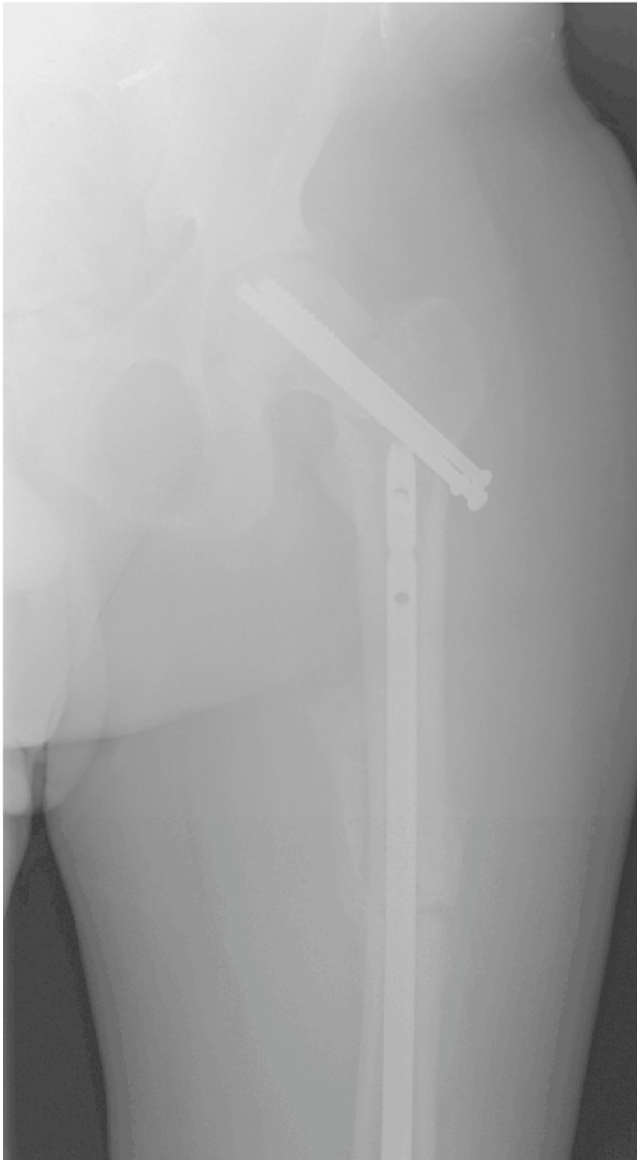


Figure 6. An anteroposterior radiograph of the proximal femur demonstrating possible nonunion of the femoral neck and femoral shaft in patient 3. The radiograph also shows varus malposition of the femoral neck.



Figure 7. A CT coronal reconstruction showing a nonunion of the femoral neck and shaft in patient 3.

Case 3

A 30-year-old male with a neuromuscular condition was struck by a motor vehicle while riding a motor scooter. He sustained the following injuries: A displaced Pauwels-C left femoral neck fracture (Figure 5), a 3A open left femoral shaft fracture, a left open radius and ulna fracture, and a left tibia fracture. The femoral neck fracture was treated elsewhere with three cannulated screws and the femoral shaft was treated with a reamed retrograde femoral nail.

At two months follow-up, the patient still had hip and thigh pain, and there were minimal radiographic signs of bone healing at either site. After four months of treatment with a bone stimulator, the pain did not improve and there was no sign of healing. Plain radiographs demonstrated that the hip had fallen into varus malalignment and that the cannulated screws were backing out (Figure 6). Computed tomography (CT) scan was obtained which confirmed ipsilateral nonunions of the neck and shaft of the femur (Figure 7).

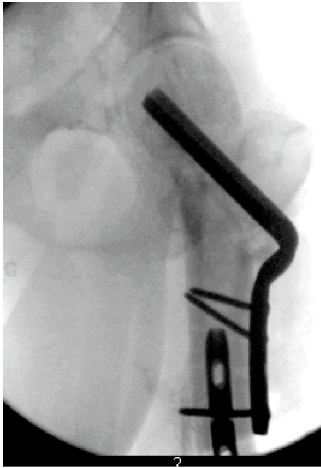


Figure 8. This radiograph demonstrates the Pauwels osteotomy with blade plate fixation and retrograde femoral nail in patient 3.

Seven months after the patient's initial surgery, the patient was taken to the operating room and the cannulated screws, as well as the intramedullary nail, were removed. Again, because of the neck malalignment, a Pauwels osteotomy with removal of a 40° bone wedge was performed, followed by placement of a 130° blade plate (Figure 8). Autogenous bone graft from the removed wedge was then placed in the osteotomy site. Next, a reamed retrograde femoral

nail was inserted across the shaft nonunion. After irrigation, a bone stimulator was placed with leads to both the osteotomy site and femoral shaft. The patient was placed on foot-flat weight bearing status.

At ten weeks the patient was without pain and there was radiographic evidence of fracture healing. The patient was advanced to 30 pounds weight bearing. At three months there was abundant callus at the shaft and the patient was advanced to weight bearing as tolerated. During healing, as the neck fracture settled into a stable position, the blade plate appeared to advance into the foveal region on radiographs. However, the patient had no groin or thigh pain. Nine months after surgery for the ipsilateral nonunions, the patient was without pain and full weight bearing. Due to concern regarding the position of the blade plate, the plate was removed. The patient tolerated the procedure well and seven months after the removal of hardware was without pain and was back to pre-injury status.

DISCUSSION

Ipsilateral femoral neck and shaft fractures usually occur in young patients who sustain multiple injuries from high energy trauma. The reported number of femoral shaft fractures that have accompanying femoral neck fractures is thought to range between 2.5 to six percent.^{5,8} Five to 43 percent of femoral neck fractures go on to nonunion, and the reported rate for femoral shaft nonunion is two to ten percent.^{1,4,9-11} The incidence of ipsilateral femoral neck and shaft fractures that go on to nonunion is not known.

It is possible that ipsilateral femoral neck and shaft fractures are more likely to go on to nonunion than isolated femoral neck or femoral shaft fractures for two

reasons: (1) Ipsilateral injury is more likely to be a high energy injury, and thus may have increased vascular disruption, and (2) The free segment between the femoral neck and shaft fractures may create more motion at the proximal and distal fracture sites than would be encountered at an isolated femur fracture site. Other injury and patient factors increase the likelihood of ipsilateral injuries progressing to nonunion, such as smoking, significant soft tissue disruption, use of unreamed small-diameter intramedullary nails for the femoral shaft fracture, and prolonged delay in weight bearing.^{2,12} Each of our patients had risk factors for the development of nonunion: Open fracture, bone loss, and smoking. In addition, all of the patients sustained multiple trauma and numerous fractures. Each, however, healed all the fractures sustained other than the ipsilateral femoral neck and shaft fractures.

Nonunions of ipsilateral femoral neck and shaft fractures are rare. A review of the literature over the past 25 years only mentions six cases of treated ipsilateral femoral neck and shaft fractures that both went on to nonunion. Ideally, initial management would decrease the number of nonunions that occur with these fractures. In 1987, Swiontkowski reviewed 20 case series comprising 176 cases that implemented 60 different methods of treatment.⁴ Since 1987, the number of methods of treatment and devices for internal fixation have increased. Determining the best method for fixing these combined fractures at presentation continues to be supported more by subjective reasoning than by scientific data due to the lack of controlled studies. Currently, lag screw fixation of the femoral neck fracture and reamed intramedullary nailing of the shaft is the preferred method of fixation for the initial injury.^{2,13} However, antegrade intramedullary nailing with a cephalomedullary device, or plating of the femur fracture are also possibilities depending on fracture characteristics and surgeon preference. The priority when approaching these combined fractures should be anatomic reduction and stabilization of the femoral neck fracture, since delayed or inappropriate treatment of the femoral neck fracture can lead to avascular necrosis of the femoral head in a young individual. Additionally, prompt internal fixation decreases non-orthopaedic complications, particularly in the pulmonary system, in multiply injured trauma patients.¹⁴

Six to eight months may pass before a potential delayed union can be considered a nonunion, owing to the protracted length of time that femoral shaft and femoral neck fractures require to heal.¹⁵ Clinical diagnosis of ipsilateral femoral neck and shaft nonunions is challenging since the patient may be experiencing referred pain from one of the nonunion sites that masks the pain from the second nonunion site. Additionally,

the hardware in place may decrease radiographic visibility of a nonunion. The lack of a specific definition of a nonunion and the above factors specific to ipsilateral femoral neck and shaft fractures may necessitate the use of an intraoperative exam.

After the ipsilateral nonunions have been diagnosed, there is very little in the literature to guide treatment. Of the previous six ipsilateral femoral neck and shaft nonunions, five appear in a case series by Watson et al. and one is published in a case series by Wiss et al.¹² The article by Wiss et al. does not state how the ipsilateral nonunions were treated. The five ipsilateral nonunions in the case series by Watson et al. were treated in the following ways: Two were treated with a long hip screw and a plate, one was treated with a hip screw and a reamed retrograde nail, one was treated with a blade plate and a reamed retrograde nail, and the last one was treated with a hip screw and an exchange nail. The exchange nailing failed and had to be converted to a compression plate.

Due to the small number of patients in this series and the small number of patients reported in the literature, we cannot make any specific recommendations on the ideal choice of fixation for ipsilateral femoral neck and shaft nonunions. We do recommend correcting any malalignment of the femoral neck with a Pauwels osteotomy. If femoral neck varus is present, we recommend first performing the osteotomy with correction and provisional fixation of the osteotomy site. At this point, either a long side-plate that extends beyond the shaft nonunion site may be applied and fixed with further soft tissue dissection, or an intramedullary nail may be placed. We would recommend that a retrograde intramedullary nail that overlaps the proximal plate be used, especially in cases in which an intramedullary nail is already in place. This allows for a less invasive approach to the femoral shaft nonunion. Exchange nailing in the face of femoral shaft nonunion has been shown to be successful in 78.3 percent of cases.¹⁶ For younger individuals, we recommend treating both the femoral neck and femoral shaft nonunions during the same surgical setting to eliminate the need for a second surgery and decrease rehabilitation time. If two implants are used, one for each nonunion site, the devices should overlap in order to prevent a stress riser. If infection is suspected as a cause of the nonunion, appropriate preoperative labs (erythrocyte sedimentation rate, C-reactive protein, and white blood cell count), should be obtained. In addition, intraoperative cultures should be obtained and the patient treated appropriately postoperatively.

Intertrochanteric osteotomy is used in the treatment of femoral neck nonunions in order to convert the principally shear forces acting on the fractured femoral neck into compressive forces. At no time is the nonunion site

exposed. Healing of the nonunion is purely due to alteration in the biomechanical forces at the femoral neck. The technique relies on careful preoperative planning and meticulous attention to surgical detail. Good quality biplanar radiographs are essential. Classically, the amount of the wedge resection is based on the angle the fracture line makes with the femoral shaft. The operation is performed at the intertrochanteric level. A 30 to 60° wedge is removed from the lateral cortex and the osteotomy site fixed with a 95 to 120° blade plate, depending on the size of the wedge removed. The blade should enter the proximal fragment two centimeters proximal to the osteotomy site, and its tip should lie in the inferior quadrant of the femoral head.¹⁷ Patients should be kept partial weightbearing for six to 12 weeks until fracture and osteotomy site unions have occurred.

Marti et al. reported on 50 patients treated with an intertrochanteric abduction osteotomy of Pauwels.¹⁸ The authors treated all patients less than age 70 with this operation, regardless of the presence of femoral head necrosis. Eighty-six percent of their patients healed their femoral neck fractures. Seven patients went on to hip arthroplasty, but only three of these were performed for persistent nonunion.

Anglen reported his series of 13 patients ages 18-59 who underwent intertrochanteric osteotomy for femoral neck nonunion.¹⁷ Twelve of the 13 patients united radiographically and clinically. Good functional results, as measured by SF-36 testing, were seen in 11/13 patients.

In the case of elderly patients with limited mobility who have ipsilateral femoral neck and shaft nonunions, our treatment would change. We would consider a hip arthroplasty, either hemi- or total, depending on the patient's functional status following successful healing of the femoral shaft with an intramedullary nail. Allowing for healing of the femoral nonunion prior to implantation of a hip prosthesis allows the orthopaedic surgeon to perform a standard primary hip arthroplasty. Our opinion is that preoperative labs to rule out infection, as well as intraoperative cultures, should be undertaken prior to implantation of the hip prosthesis in these cases.

Treatment for ipsilateral nonunions should be dictated by the characteristics of the nonunions. When femoral neck varus malalignment is present, an osteotomy is usually required to achieve union. This, however, will limit the type of instrumentation that may be utilized. However, with careful planning and meticulous care, patients with nonunions of the femoral neck and shaft can be successfully treated with good outcomes.

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NEUROGENIC ATROPHY OF THE MEDIAL HEAD OF THE GASTROCNEMIUS PRESENTING IN A TOE WALKER: A CASE REPORT

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INTRODUCTION

In the adult population, equinus deformity is frequently accompanied by an underlying etiology, such as a neurologic disorder, trauma, poliomyelitis, muscular anomaly, diabetes, or vascular malformation.^{1-4,6-12,14} Often these patients present secondary to the aesthetics of an altered gait, difficulty with ambulation, problems with shoe wear, or pain resulting from repetitive pressure on the forefoot. We present a unique case of an adult female toe walker with bilateral neurogenic atrophy of the medial head of the gastrocnemius, which has not previously been reported in the literature.

CASE REPORT

A 46-year-old female presented with a 10 year history of tight calves, left side worse than right. Her primary complaint was that despite extensive stretching and yoga, she was unable to walk flat on her feet. Over the ensuing years, she developed increasing calf pain when ambulating long distances. She denied any childhood history of toe walking. She could recall no specific injury and had no history of trauma, diabetes, or neurologic illness.

On standing, the absence of muscle bulk on the medial aspect of her calves was visualized (Figure 1). She also stood with equinus deformity bilaterally, but with a more notable deformity on the left versus the right. On single- and double-leg stance, the medial head of the gastrocnemius was notably absent with the lateral head well defined. She was able to perform heel raises with no evidence of weakness. Ambulation revealed a steady gait with a normal base; however, she was unable to achieve a flat foot during stance phase on both sides. She had a normal neurovascular exam. Further inspection revealed atrophy of the medial head of the gastrocne-

mius bilaterally. Hamstrings were supple. At the location of the proximal head of the medial gastrocnemius, thick fibrous tissue was palpated bilaterally.

She was evaluated by a neurologist whose consultation revealed a normal clinical exam. A lower extremity nerve conduction test was normal. An MRI revealed diffuse marked fatty atrophy of the medial heads of both gastrocnemii with no evidence of nerve entrapment or attenuation (Figure 2).

We elected to perform a gastrocnemius release. Preoperative exam following administration of anesthetic revealed that, despite complete musculoskeletal relaxation, her ankles were unable to reach a neutral position secondary to medial soft tissue restraint. A six-centimeter incision was made over the medial head of the gastrocnemius, bilaterally. The medial head was isolated. On inspection, a severely atrophic and scarred residual muscle belly was noted. The medial head was then divided in its mid-portion. Gross inspection showed fibro-fatty tissue present throughout the medial head. Histology revealed atrophic skeletal muscle and fibroadipose tissue, consistent with neurogenic atrophy (Figures 3 and 4). Following release, an intraoperative examination confirmed passive positioning of the ankle above the neutral position bilaterally. On follow-up, she noted painless plantigrade ambulation with full return of lower extremity strength and mobility.

DISCUSSION

Equinus deformity secondary to multiple factors, including neuromuscular disorders, diabetes, trauma, and musculoskeletal deformities, has been identified as an etiology for toe walking.^{1-3,6,8-10,12-13} In addition, previous reports of equinus deformity secondary to hemangioma of the calf have been published.^{1-3, 5-14} However, isolated atrophy of the medial head of the gastrocnemius has not been described based on our literature review. This particular patient had experienced calf pain and tightness for ten years. She denied any history of significant medical problems or trauma, and she did not recall any diagnosis of a musculoskeletal anomaly. The gastrocnemius is innervated by the tibial nerve, which enters the muscle in its proximal aspect. This particular patient had no evidence, either clinically or radiographically, of constriction of the tibial nerve, nor was there evidence of a central lesion. Following failed conservative treat-

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Figure 1. Standing photograph shows the equinus deformity, left worse than right. In addition, note the marked atrophy of the medial head of the gastrocnemius bilaterally.



Figure 2. T1-weighted MRI of the right lower leg showing marked diffuse fatty atrophy with thickening of the deep fascia.

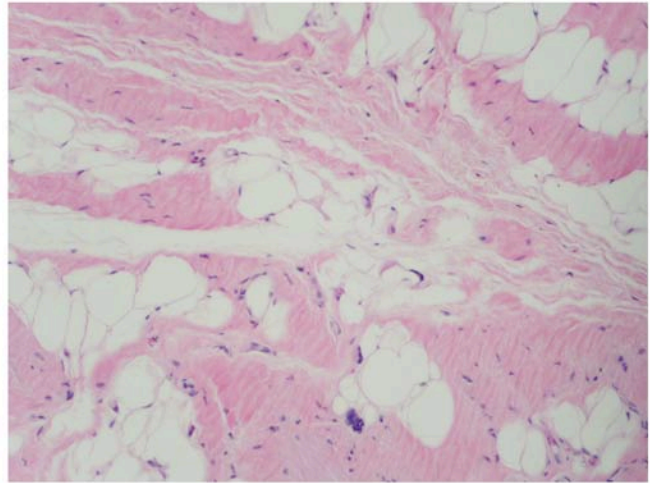


Figure 3. Histologic section taken from the right residual medial gastrocnemius revealing shrunken atrophic muscle fibers surrounded by fibroadipose tissue.

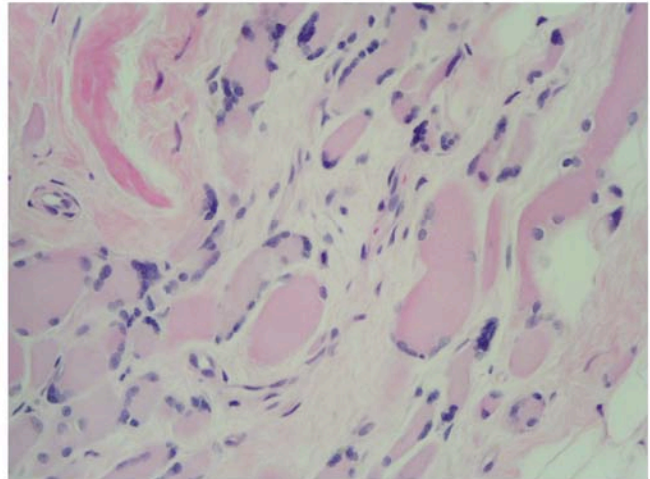


Figure 4. Histologic section highlighting variably mixed myofibers with crowded peripheral nuclei.

ment, division of the constricted residual gastrocnemius resolved her pain and improved her ambulation. For patients presenting with an uneventful history and new onset equinus deformity, isolated neurogenic atrophy of the gastrocnemius should be considered.

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DISLOCATION OF THE POSTERIOR TIBIAL TENDON: A LITERATURE REVIEW AND PRESENTATION OF TWO CASES

Nicholas R. Goucher, M.D., Michael J. Coughlin, M.D., and Ronald M. Kristensen, M.D.

ABSTRACT

Dislocation of the posterior tibial tendon has rarely been reported in the English literature. The most common mechanism is a traumatic injury. We present two patients with a traumatic dislocation. One patient was delayed in presentation to the treating physician by seven months. The second patient presented within one week. Both underwent surgical stabilization with repair of the torn retinaculum and deepening of the groove posterior to the medial malleolus. They have both returned to their pre-injury level of activity without any recurrence of dislocation.

INTRODUCTION

Traumatic dislocation of the posterior tibial tendon is a rare occurrence with only 32 cases reported in the English literature. These cases are often delayed in diagnosis, having undergone prior treatments for ankle sprains,^{1,3} tendinitis,⁴ or subtalar dislocation.⁵ Physical examination and a careful history remain the most reliable methods for diagnosis, but the diagnosis can be easily overlooked upon presentation following acute injury. The most common mechanism is a traumatic injury in which the foot is inverted and either dorsiflexed or plantarflexed with a violent contraction of the posterior tibial tendon. At surgical exploration, findings include a tear or avulsion of the flexor retinaculum,^{1,5,6,8,14,15,16,17} a shallow retromalleolar groove,^{1,2,7,16} elevation of the retinaculum from the tibia in a "retinacular-periosteal sleeve,"^{4,10} or a lax retinaculum.^{8,9,11,12,13} Patients typically present to the treating physician with prolonged medial ankle symptoms refractory to conservative treatment. Surgical stabilization has been successful, and most patients return to full function.

The posterior tibial tendon is the most superficial structure coursing behind the medial malleolus. It is held within the retromalleolar groove by a strong fibro-

osseous tunnel and the flexor retinaculum originating from the tip of the medial malleolus and inserting into the calcaneus (Figure 1). The flexor digitorum longus, flexor hallucis longus, and the posterior tibial neurovascular bundle are deeper structures and do not appear to be involved in the dislocation. Tearing of the fibro-osseous tunnel and flexor retinaculum allows the posterior tibial tendon to dislocate anteriorly over the medial malleolus (Figure 2).

Case 1

A 28-year-old recreational athlete presented seven months after sustaining a twisting injury to her left ankle while running downhill. She initially was unable to ambulate. Radiographs obtained following the initial injury were normal, and she was treated conservatively. She was later able to compete in a triathlon without difficulty. Several weeks after the triathlon, she developed pain along the medial ankle and was injected with a corticosteroid without relief. An MRI was obtained six months following her initial injury that demonstrated posterior tibial tendon inflammation with increased intra-substance signal and edema in the distal medial tibia and plafond. The posterior tibial tendon was not dislocated. She presented to the treating physician (RMK) seven months following her injury. On examination, she had a clinically subluxable posterior tibial tendon. She reported mild medial ankle pain with rest and severe pain with activity. She underwent surgical exploration with partial excision of the torn portion of the posterior tibial tendon, groove deepening along the course of the posterior tibial tendon, and repair of the flexor retinaculum as illustrated in Figure 3. Her postoperative course consisted of partial weight-bearing at one week in a CAM (controlled ankle motion) boot plus range-of-motion exercises. She progressed to full weight-bearing six weeks following surgery with a removable ankle brace. Swimming and biking activities were initiated for cross training. At four months following surgery, she complained of pain only with running. On physical examination, she had slightly decreased ankle range of motion (dorsiflexion decreased 5° and plantar flexion decreased 10°) and normal strength. At final follow-up 13 months following surgery, she had resumed competing in triathlons without difficulty. Her strength and range of motion had

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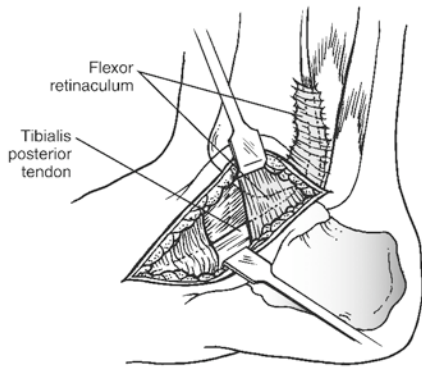


Figure 1. Posterior tibial tendon within flexor retinaculum and fibro-osseous tunnel.

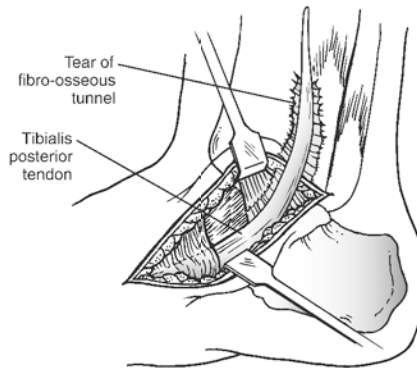


Figure 2. Tear of flexor retinaculum and fibro-osseous tunnel allows anterior dislocation of the posterior tibial tendon.

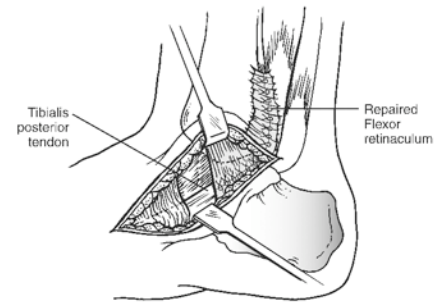


Figure 3. Repair of flexor retinaculum and fibro-osseous tunnel with relocation of the posterior tibial tendon.

returned to normal, and she experienced no recurrence of tendon subluxation.

Case 2

A 37-year-old male orthopaedic surgeon was waterskiing when he fell forward from his skis. He experienced some pain along the medial aspect of his ankle and could not continue waterskiing. Ten minutes later, he twisted his ankle a second time, felt a pop and noted a significant amount of medial ankle pain and swelling (Figure 4). He presented two days later to the treating physician (RMK) with left ankle pain isolated to the medial malleolar region. On examination, the posterior tibial tendon could be displaced anteriorly. An MRI was obtained which demonstrated that the posterior tibial tendon was dislocated anteriorly (Figure 5). He underwent surgical exploration one week following the injury (Figure 6). A groove-deepening procedure was performed (Figure 7) followed by repair of the flexor retinaculum (Figure 8). The tendon remained located with intra-operative range of motion of the ankle. He did not undergo physical therapy. At six months follow-up he has had no recurrent subluxation and has skied multiple times without pain. On physical examination, he has lost 5° of active dorsiflexion and has normal plantar flexion. His strength has returned to pre-injury level.

DISCUSSION

Ouzanian and Myerson¹ have reported the largest clinical series with seven cases involving dislocation of the posterior tibial tendon. They presented six traumatic dislocations and one that occurred following multiple cortisone injections over an 18-month period. The average length of time to diagnosis was nine months, illustrating the common delay in presentation with this condition. The patients underwent various conservative treatment modalities without success, and all eventually required operative treatment. Only two patients had MRI findings

consistent with a dislocated posterior tibial tendon. Upon surgical exploration, an inflamed posterior tibial tendon was encountered in three of seven patients with a torn, avulsed, or redundant retinaculum. The retro-malleolar groove was also noted to be shallow in four of the seven cases. Operative treatment consisted of retinacular repair in four cases and recreation of the retinaculum using local tissue in three cases. Two patients had a groove-deepening procedure. At final follow-up, five patients were asymptomatic, one was improved, and one had continued difficulty.

Bencardino et al.⁸ reported on the MRI findings of seven cases of posterior tibial tendon dislocation. The mechanism of injury was acute ankle dorsiflexion in two and major trauma in five. There were three medial malleolar fractures. In one patient, the diagnosis was made prior to MRI examination. MRI demonstrated a dislocated tendon in five patients and subluxation in two. One tendon demonstrated a partial tendon tear. The retromalleolar groove was shallow in one, slanted in one, and normal in five. The retinaculum was disrupted in two and avulsed from the tibia in five. Only two patients underwent surgery for their tendon dislocation in this primarily radiographic study. The authors concluded that MRI was a valuable tool for diagnosis and surgical planning for patients suspected of having a posterior tibial tendon dislocation.

In the English literature, 15 other series reported a total of 18 more cases of dislocation of the posterior tibial tendon. A tear in the flexor retinaculum or its avulsion from the tibia was noted in seven series for a total of eight cases.^{2,5,6,14,15,16,17} A lax retinaculum without tear was noted in a total of four patients, one in each of four series.^{9,11,12,13} Two series reported on one patient each with an elevated "retinacular-periosteal sleeve."^{10,14} A shallow groove was reported at surgical exploration in three series,^{2,7,9} and in one case demonstrated by computed tomography.¹⁶ Three series reported a normal retromal-



Figure 4. Swelling and ecchymosis around the medial ankle region.

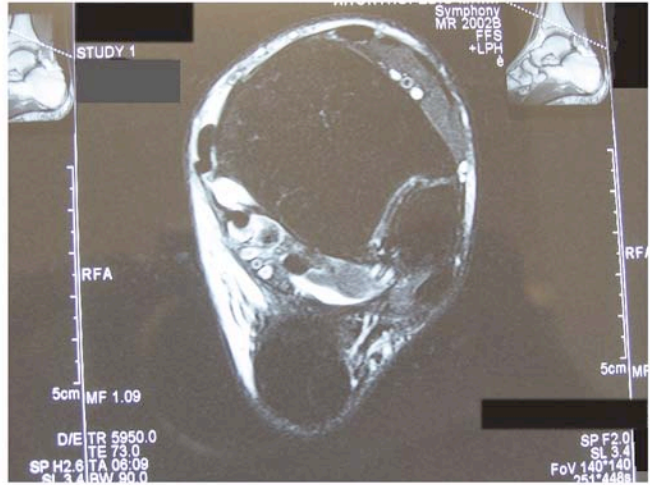


Figure 5. Axial MRI demonstrating anterior dislocation of the posterior tibial tendon.



Figure 6. Posterior tibial tendon dislocation.

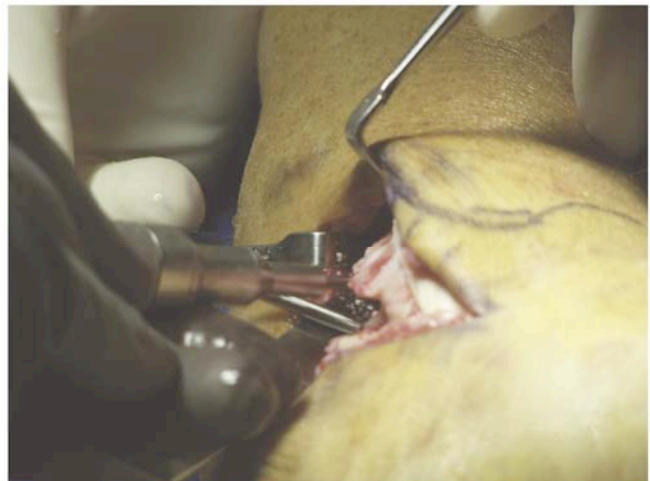


Figure 7. Deepening of the retromalleolar groove.

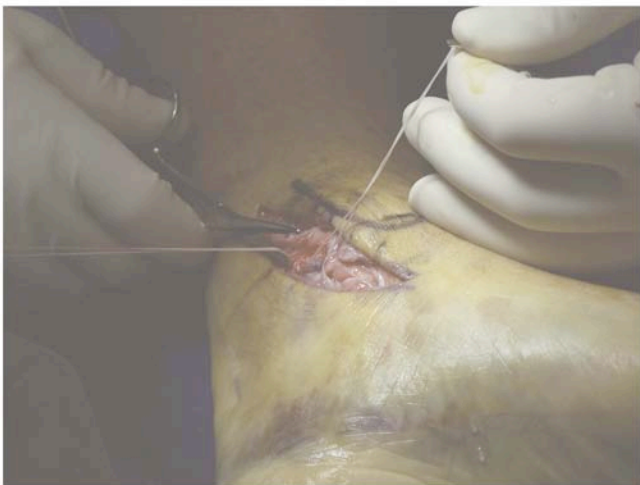


Figure 8. Repair of the flexor retinaculum.

leolar groove at the time of surgical exploration,^{4,6,15} while the rest did not mention the groove.

Plain radiographic examination was reported in ten series representing 11 patients.^{2,4,6,9,11,13,15-17} Ten of the 11 plain radiographs were reported as normal. One patient had a small fleck of bone near the medial malleolus representing an avulsion fracture.² MRI was also used in several series to aid in evaluation of the extremity.^{3-5,9,11,17} Two of the six patients who underwent MRI examination had a normal reading despite later confirmation of dislocation of the posterior tibial tendon on surgical exploration, demonstrating that MRI can miss a dynamic posterior tibial tendon dislocation that may be relocated at the time of the exam. Computed tomography was used twice in the literature.^{3,16} Rolf et al. reported one case of dislocation of the posterior tibial tendon that was documented by CT and ultrasound.³ In this study, there was no mention of the architecture of

the retromalleolar groove on CT. A study by Soler et al.¹⁶ also mentions the use of CT. In their study, the authors report the anatomic variations of the retromalleolar groove in 25 cadaveric specimens as measured on plaster molds made of the specimens. The variation in width of the groove was large in this series, ranging from six to 15 millimeters in width and 1.5 to four millimeters in depth. Based on these cadaveric findings, the authors concluded that the patient had a sulcus that was less than normal size when measured on the CT scan images. Perlman et al. performed tenography of the posterior tibial tendon in their series and demonstrated a dislocated posterior tibial tendon in both of the cases presented in their report.²

There is no strong agreement in the literature on what is the best method of treatment. Simple flexor retinacular repair was made in six series^{3,5,6,10,14,15} versus a complex reconstruction with a periosteal sleeve (one series of one patient),¹⁶ an Achilles tendon flap (two patients from two different series),^{3,17} or suture anchor repair (two patients in two different series).^{4,11} There were four series in which the authors felt there was a shallow retromalleolar groove; however, groove deepening procedures were performed in two other series where no mention of the depth of the groove was made.^{2,7,9,12,13,16} Soler et al. reported that the retromalleolar groove was hypoplastic at the time of surgical exploration, but the authors did not perform a groove deepening procedure and instead reconstructed the flexor retinaculum with a periosteal sleeve held in place with sutures through bone tunnels.¹⁶ In two of the remaining series in which a groove-deepening procedure was performed, a burr was used once⁷ and an osteotome and curette were used once.¹² Perlman et al. performed a groove-deepening procedure by sliding a cortical bone slot graft posteriorly 1.5 cm to hold the relocated tendon in place.² Sharon et al. similarly used a cortical graft from the tibia anterior to the retromalleolar groove to maintain reduction of the posterior tibial tendon.¹³ Healy et al. elevated a cortical periosteal flap that was held open by a local cancellous bone graft obtained by deepening the retromalleolar groove in one patient.⁹ All reported good or excellent results with resumption of pre-injury level of activity.

CONCLUSION

Dislocation of the posterior tibial tendon is an uncommon injury rarely reported in the English literature with only 32 cases since 1968. The first described case was by Martius on himself when he fell from a balloon in 1874.¹⁸ Presentation to the diagnosing physician is often delayed, with the patients having undergone conservative treatment for various incorrect diagnoses. Conservative treatment is uniformly unsuccessful in the

literature. Surgical stabilization by relocating the tendon and repairing or reconstructing the flexor retinaculum, with or without groove deepening, has been shown to be highly successful, with most patients returning to their pre-injury level of function. In our two patients, one presented late at seven months following injury with the initial diagnosis of a sprained ankle. The second patient was an orthopaedic surgeon; he made his own diagnosis and referral on an acute basis. They have both since returned to full function, with one competing in triathlon events. We do recognize that the two new cases presented in this report are of relatively short follow-up. Finally, MRI and other imaging modalities can help to establish the diagnosis, but have been negative in some series.^{4,8,9} A careful history and thorough physical examination remain the mainstay of diagnosis. Delay in diagnosis and treatment did not appear to have a deleterious effect on patient outcome in our case, nor did it adversely affect patients reported in the literature. Posterior tibial tendon dislocation should be considered in a patient with chronic medial ankle pain following injury with normal radiographic examination.

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PROXIMAL TIBIOFIBULAR SYNOSTOSIS AS A SOURCE OF ANKLE PAIN: A CASE REPORT

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ABSTRACT

We report the case of a 61-year-old man who presented with ankle pain of unknown etiology. The actual cause for his pain was missed during his two initial visits when only ankle radiographs were taken. During his third visit, a full-length tibia film revealed a proximal tibiofibular synostosis. He successfully underwent a fibular osteotomy with complete symptomatic relief. A literature review of this topic is presented.

INTRODUCTION

Post-traumatic proximal tibiofibular synostosis is an extremely rare condition that to our knowledge has been reported only a few times in the literature with varying presentations. As far as we know, there are no cases in the literature where the patient presented with ankle pain entirely due to this condition and was successfully managed with a simple osteotomy. We present one such case here along with a literature review of this topic.

CASE REPORT

A 61-year-old man presented with complaints of right ankle pain of 11 years' duration that was worse after walking a few hundred yards and was completely relieved by rest. He had broken his tibia 12 years prior to presentation and the fracture had healed uneventfully with conservative treatment. For almost a year after the fracture had healed, the patient was totally asymptomatic, but then his ankle started to ache on exertion. He was seen twice, in 1999 and 2002, at his local hospital where

ankle radiographs did not reveal any abnormalities. Therefore, he was referred to the author for a second opinion. Clinical examination was entirely normal except for pain and discomfort in his ankle during the push-off phase of walking. A full-length tibia radiograph taken at that time showed a proximal tibiofibular synostosis with a normal ankle joint (Figure 1), which was further confirmed on MRI scan (Figure 2). Following a literature search to find the various treatment modalities for this condition,^{1,2,3,4} he successfully underwent fibular osteotomy. Several centimeters of fibula were excised at the junction of the middle and distal thirds of the fibula. The patient remained symptom free at one year follow-up.

DISCUSSION

Although there are a few reports of distal tibiofibular synostosis in the literature, an isolated post-traumatic proximal synostosis presenting with ankle pain has never been reported.^{5,6} Rahm reported the first recorded case of proximal tibiofibular synostosis in a 43-year-old female in 1924.⁷ His patient was asymptomatic, and the only major complaint at presentation was unilateral genu valgum for which she successfully underwent a corrective osteotomy. Similar to Rahm's case, most cases of proximal tibiofibular synostosis may be totally asymptomatic, found incidentally on routine radiographs. Alternatively, such synostoses may be due to multiple hereditary exostoses, or may present with unusual symptoms such as intermittent peroneal neuropathy.⁸

The proximal tibiofibular joint is a synovial joint whose primary function is dissipation of torsional loading applied at the ankle joint and absorption of lateral tibial bending movements.⁹ The fibular malleolus maintains intimate contact with the lateral surface of the talus in all positions of the ankle joint so that dorsiflexion and plantar flexion at the ankle joint produce rotation of the fibula around its own axis.¹⁰ Experimental studies by Ogden have shown that as the obliqueness of the joint inclination increases, the surface area and mobility of the tibiofibular joint decreases, which has some effect on the progressive dorsiflexion of the ankle.¹¹ Frick et al. analyzed the effects of iatrogenic tibiofibular synostosis on lower extremity growth, alignment, and function in children. He concluded that synostosis may interfere with the normal motion that occurs between the tibia and fibula during weight-bearing, which may potentially

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Figure 1. Full-length AP and lateral radiographs of the tibia and fibula showing a mature proximal tibiofibular synostosis.

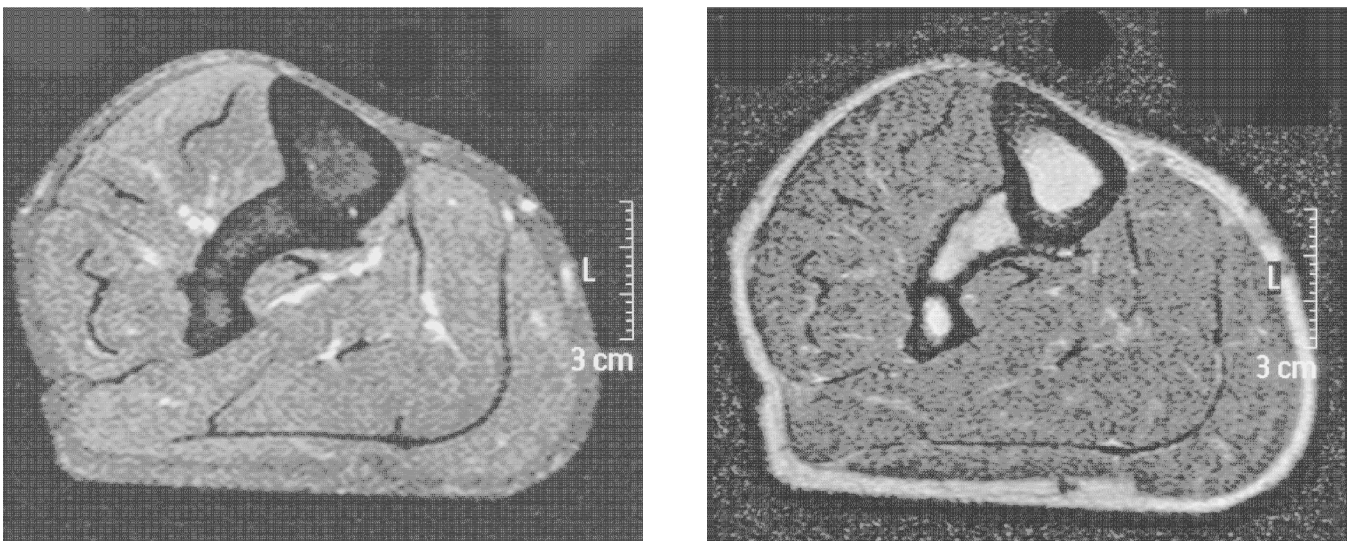


Figure 2. Axial MRI view (T1 and T2 images) showing a solid bony bridge between the tibia and fibula at the junction of its proximal and middle thirds.

lead to persistent ankle pain.⁶ Such pain is found to be more pronounced during the push-off phase of walking due to failure of the normal downward and lateral motion of the fibula that usually occurs during maximum weight bearing and stress, which can sometimes lead to a stress fracture of the fibula.⁵

If a synostosis is present from birth or occurs before closure of the physis, it is always associated with at least one deformity, such as distal positioning of the proximal tibiofibular joint, leg length discrepancy, bowing of the fibula, or valgus deformity of the knee.¹² The absence of all of these anomalies in our case, along with a history of trauma, supports a post-traumatic etiology, and suggests that the synostosis occurred after physal plate closure. The post-traumatic form probably arises from soft tissue damage with bleeding across the interosseous membrane leading to new bone formation. The tibia and fibula share three joints: the superior, middle (formed by the interosseous membrane), and inferior tibiofibular joints. In a manner similar to the radius and ulna in the upper extremity, these two bones act as a single unit. Thus, any disruption of normal anatomy at one end can affect the function at the other end. Failure to recognize this basic principle led to the missed diagnosis of synostosis on two occasions, when only ankle radiographs were taken.

A literature search for various treatment modalities for this condition shows that a synostosis usually does not require treatment, especially if the ankle has good motion.^{3,5,11,12} Symptom relief is obtained either by excision of the synostosis or by fibular osteotomy, and should be done only after the synostosis has matured. Resection of several centimeters of the fibular shaft at the junction of the middle and distal thirds of the fibula helps to reduce the mechanical stress on the proximal tibiofibular joint coming from the ankle joint. The danger zone for fibular osteotomy is 70 to 150 mm from the fibular head, where peroneal nerve branches to the extensor hallucis longus tendon could be injured. Some surgeons have tried interposing muscle or Silastic material along with bone wax to prevent recurrence after excision of the synostosis itself, but recurrence rates are still high.^{3,4} Achieving perfect hemostasis is the key to success in these cases. Adjunctive post-operative single fraction low dose (800 Gy) irradiation may reduce recurrence rates.¹ Symptomatic tibiofibular synostosis can sometimes be treated successfully with custom-molded shoe orthotics.²

CONCLUSION

To conclude, post-traumatic tibiofibular synostosis is a rare condition that may present with persistent ankle

and lateral knee pain due to failure of normal downward motion of the fibula during weight bearing. This case illustrates the importance of considering the tibia and fibula as a single unit when dealing with persistent ankle and knee problems. Also, the presence of a synostosis should alert the surgeon to look for various abnormalities that are usually associated with this condition. An MRI scan is essential to rule out the possibility of a neoplastic process and to confirm the extent of the synostosis and its relation to the neurovascular structures. A simple fibular osteotomy gives excellent symptomatic relief with minimal complication.

Competing Interests

On behalf of all the authors, I hereby declare that there is no competing interest as far as this manuscript is concerned.

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CORRECTION OF GENU RECURVATUM SECONDARY TO OSGOOD-SCHLATTER DISEASE: A CASE REPORT

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ABSTRACT

Complications secondary to Osgood-Schlatter disease are rare, and there have been few reports on their treatment. Partial growth arrest of the proximal tibial physis as a result of Osgood-Schlatter disease has been infrequently described. Genu recurvatum from partial physal arrest can cause cosmetic deformity, instability, pain, and weakness. We report a case of genu recurvatum secondary to Osgood-Schlatter disease treated successfully with proximal tibial osteotomy and distraction with a Taylor spatial frame.

CASE REPORT

A 15-year-old boy presented with right knee pain and deformity. He had a several year history of anterior knee pain directly over an enlarged tibial tubercle, related to playing football. He had no history of trauma or infection. Over the preceding year, his symptoms had been worsening and his knee began to feel increasingly unstable. He also noticed right knee hyperextension. He reported a significant growth spurt during the previous year. He had an older brother with similar symptoms, who had been diagnosed with Osgood-Schlatter disease.

Physical examination revealed no deformity in the coronal plane; however, in the sagittal plane he had obvious recurvatum of his right knee with approximately 20 degrees of hyperextension. His knee range of motion had been shifted 20 degrees into extension. He lacked 20 degrees of flexion compared to the normal side. By block exam, his affected leg was 1.5 centimeters short. There was no deficit in total range of motion. Ligamentous exam of both knees was normal.

Scanogram of the lower extremities revealed a 1.6-centimeter leg-length discrepancy with the left (unaffected) leg longer. Radiographs revealed normal coronal alignment; however, the lateral view showed recurvatum of 17 degrees with obvious anterior slope of his tibia (Figure 1). His posterior tibial angle, as described by Paley and Tetsworth,¹⁵ measured 107 degrees (normal 77-84).

Due to persistent symptoms despite bracing, surgery was elected. The deformity was corrected gradually with the Taylor spatial frame. The frame was applied first so as to mimic the deformity (Figure 2). The osteotomy was performed percutaneously with a Gigli saw just below the tibial tuberosity. Over the next month, his deformity was corrected with daily changes in strut length pre-calculated by the computer program. After one month of correction, his frame was maintained during the consolidation phase until osteotomy healing was complete (Figure 3). During this time the patient was able to perform range of motion and strengthening exercises (Figure 4). During the consolidation phase he acquired a superficial pin tract infection that resolved after removal of the pin and a short course of antibiotics. Follow-up radiographs revealed correction of the genu recurvatum, equal leg lengths, and a healing osteotomy site. At final follow-up, he had returned to playing football and had symmetric full range of motion of the knee.

DISCUSSION

Osgood-Schlatter disease is characterized by pain, swelling, and enlargement of the proximal tibial tubercle at the site of attachment of the patellar tendon. The disease was first described in 1903 by Osgood and a few months later by Schlatter. It occurs in preadolescent children, usually in boys between 11 to 15 years of age and girls 8 to 13 years of age. It is more common in boys.

The etiology of Osgood-Schlatter disease is not known. Avascular necrosis (AVN), systemic disease, endocrinopathy, structural changes in the patellar tendon, and traumatic avulsion of the cartilage have all been proposed as etiologic theories. In 1975, Ogden and Southwick, through gross and histologic studies, found that Osgood-Schlatter disease appears to be an inability of the developing secondary ossification center to withstand tensile forces, resulting in avulsion of segments of

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Figure 1. (a) Lateral radiograph and (b) long-leg lateral radiograph showing the anterior tibial slope causing a severe recurvatum deformity

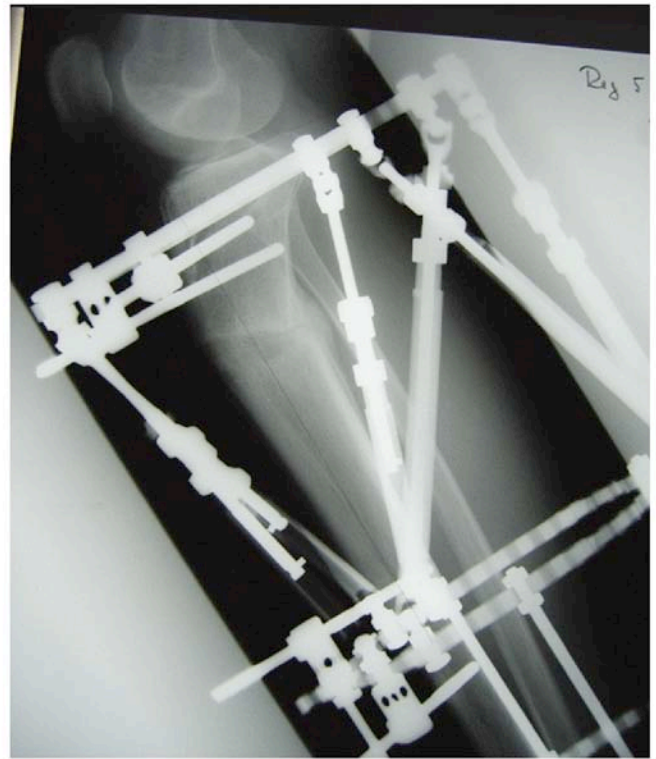


Figure 3. After the correction, the frame is neutral.

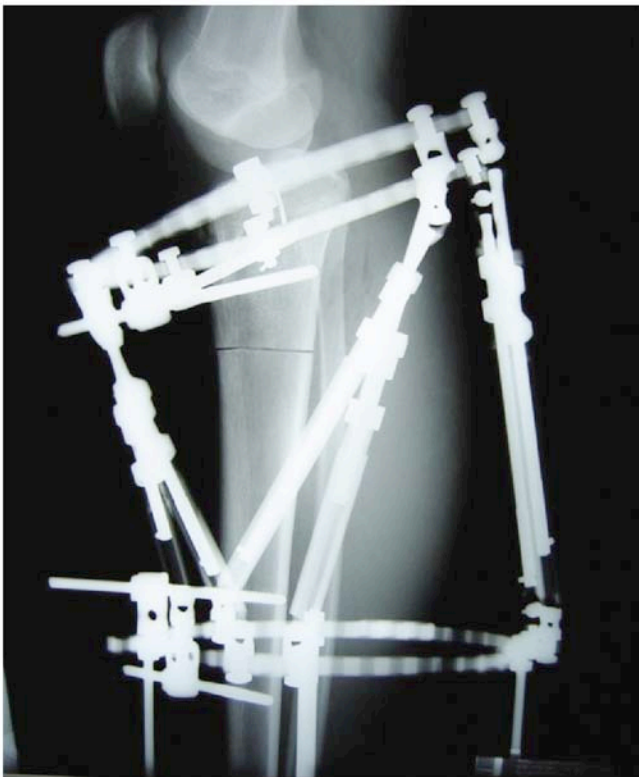


Figure 2. The fixator is applied so as to mimic the deformity. The proximal and distal rings are orthogonal to their respective segments. Note the percutaneous Gigli saw osteotomy just below the tubercle.



Figure 4. Use of a 2/3-diameter ring proximally allows full knee flexion.

the ossification center and eventual formation of extra bone between the fragments.¹² AVN appears an unlikely etiology in light of several studies showing that there is excellent blood supply to the anterior, lateral, and medial surfaces of the tuberosity. In addition, the disease does not display the remodeling seen with avascular necrosis.⁴ It is now believed that Osgood-Schlatter disease is caused by repetitive microtrauma to the proximal tibial tubercle from the contracting quadriceps mechanism during a growth period when the tibial tubercle is susceptible to strain. The symptoms of Osgood-Schlatter disease usually resolve without treatment or with simple conservative treatment such as restriction of activities or cast immobilization for three to six weeks. In 1990, a review of the natural history of untreated Osgood-Schlatter disease found that 76 percent of patients had no limitation of activity.⁷ Surgery, although rarely indicated, may be considered if symptoms are persistent or severely disabling. Surgical treatment options include tibial sequestrectomy, insertion of bone pegs into the tibial tuberosity, or excision of an ununited tibial tuberosity.¹¹

Complications of Osgood-Schlatter disease are rare. Ogden and Roberts reported on complications of Osgood-Schlatter disease with or without treatment. These included subluxation of the patella, patella alta, nonunion of the bony fragment to the tibia, and premature fusion of the anterior part of the epiphysis with resulting genu recurvatum.¹¹ In 1981, patellar tendon avulsion was reported as a complication of Osgood-Schlatter disease.² Pseudarthrosis between the patellar tendon ossicle and the tibial tuberosity was diagnosed with histologic examination in a patient with symptoms of Osgood-Schlatter disease.¹⁷ An association between avulsion fractures of the tibial tuberosity in adolescents and Osgood-Schlatter disease has also been reported. Nimityongskul, Montague, and Anderson in 1988 presented a series of eight patients with tibial tuberosity avulsion fractures; six of the patients had prodromal symptoms prior to injury.¹⁰ Ogden suggested a relationship between the development of Osgood-Schlatter disease and subsequent acute avulsion of the tibial tuberosity. He presented 14 patients with physeal fractures of the tibial tuberosity; nine of them had pre-existing Osgood-Schlatter disease.¹³

Genu recurvatum as a complication of Osgood-Schlatter disease is rare, and few cases have been reported. An extensive Medline search revealed five reported cases. A sixth case was reported by Pappas in 1984; however, this case was a recurvatum deformity in a patient with Osgood-Schlatter disease who had also undergone tibial wire traction and spica casting for treatment of two femoral fractures, and thus had several potential causes of recurvatum.¹⁶ Risk factors for physeal arrest

of the proximal tibia include unrecognized trauma, tibial traction, Osgood-Schlatter disease, and prolonged immobilization. It was noted that more than half of Pappas' patients with recurvatum deformity had previous injury and half had been treated with tibial traction.¹⁶ In 1952, Stirling first described premature fusion of the anterior tibial physis as a complication of Osgood-Schlatter disease.¹⁸ In 1965, Jeffreys reported a case of Osgood-Schlatter disease resulting in enough recurvatum deformity to require correctional osteotomy.⁶ Zimble reported a case of recurvatum deformity from physeal arrest as a possible complication of Osgood-Schlatter disease. In this case, they successfully corrected a 20-degree recurvatum deformity and a 10-degree valgus deformity with a proximal tibial osteotomy and an autogenous iliac crest bone graft.²¹ In 1991, two cases of tibial recurvatum were reported by Lynch and Walsh, who recommended the need for regular screening for this rare complication of Osgood-Schlatter disease.⁹

Injuries to the proximal tibial physis are very rare, with a reported incidence of between 0.5 and 3.1 percent of all epiphyseal injuries.¹⁶ Angular deformities related to such injuries are also rare. The maturing physis is most susceptible to injury, and adolescent patients have been reported to have the highest incidence of physeal injuries. The tibial tubercle, with its subcutaneous position, is subject to direct trauma that may arrest the growth of the anterior part of the tibial physis resulting in genu recurvatum.^{5,19} The most commonly reported complication is angular deformity and leg-length discrepancy.

Treatment options include acute and gradual correction techniques.^{1,3,8,16} Although opening wedge osteotomies with bone graft can correct angular deformity and some shortening, the technique is exacting and risky. Circular external fixation allows for an infinitely adjustable correction that can be obtained gradually and fine-tuned as the correction progresses. The over-all time to healing is similar to opening wedge techniques, and full weight bearing is allowed from the outset. In addition, the frame allows the knee to be free for range of motion. We believe this is an excellent treatment option for many deformities of the proximal end of the tibia that would benefit from opening wedge techniques. It is well tolerated by patients, extremely accurate, and safe.

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PAROSTEAL OSTEOSARCOMA OF THE THUMB METACARPAL: A CASE REPORT

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ABSTRACT

A 60-year-old man presented with increasing swelling of his right thumb, duration one year. Imaging studies demonstrated a bone-forming lesion extending from the dorsal cortex of the thumb metacarpal and involving the underlying medullary canal. Incisional biopsy yielded the diagnosis of parosteal osteosarcoma. The differential diagnosis for and rarity of parosteal osteosarcoma arising in the tubular bones of the hand are discussed.

INTRODUCTION

Osteosarcomas are rare in the distal extents of the appendicular skeleton. Parosteal osteosarcoma, a typically well-differentiated subtype of osteosarcoma, is exceedingly rare in the hand.^{1,4} More commonly, benign neoplasms and pseudotumors arise in the hand and are mistaken for parosteal osteosarcoma.^{5,7}

CASE REPORT

This 60-year-old man was referred to the orthopaedic oncology clinic due to an enlarging mass in his right thumb over the preceding year. He experienced no pain from the mass and recalled no prior injury to his thumb or hand. He had no significant medical co-morbidities or medical history.

On physical examination, diffuse swelling was palpable around his right thumb metacarpal. It was not tender. His thumb was neurovascularly intact.

Imaging demonstrated a well-circumscribed bone-forming lesion associated with the dorsal cortex of the thumb metacarpal, but also involving the medullary space (Figures 1 and 2). Incisional biopsy demonstrated parosteal osteosarcoma with woven bone in a fibrous

stroma, including nuclear atypia characteristic of a low-grade osteosarcoma (Figure 3).

The lesion was widely resected and the thumb reconstructed with a vascularized fibular autograft, which continues to function well four years later (Figure 4). There has been no recurrence or metastasis after the resection.

DISCUSSION

Only six cases of parosteal osteosarcoma have previously been reported to arise from tubular bones in the hand.^{1,4} However, a number of non-malignant mimicker lesions are often confused with osteosarcomas. These include florid reactive periostitis,⁷ bizarre parosteal osteochondromatous proliferation or Nora's lesion,⁵ myositis ossificans,⁶ and ossified hematoma.⁶

Distinguishing a parosteal osteosarcoma from these alternate benign lesions prior to treatment is critical. Wide excision of parosteal osteosarcoma is often curative, but the most successful attempt at this is usually the primary excision. While two of the previously reported hand parosteal osteosarcomas arose in phalanges and were successfully treated with digital amputation,¹ two of the three previously reported cases of parosteal osteosarcoma in metacarpals underwent complicated treatment courses secondary to initial misdiagnoses.^{3,4} One ended in hand amputation,³ and the other resulted in lung metastasis following three resections for local recurrences.⁴

The features that helped to distinguish this lesion from possible benign mimickers were manifold. Many of the benign entities arise following antecedent injury of some sort, but such a history was lacking in this case. The lack of a radiographically zonal organization with peripheral density and central lucency was also helpful, although this feature is less distinguishing in the hand than in juxtacortical lesions associated with other long bones. The appearance of the lesion closely associated with, but not involving, the underlying cortical bone in its peripheral regions is highly suggestive of parosteal osteosarcoma. This feature is often termed the "string sign." Medullary involvement as determined by three-dimensional imaging also makes most benign entities less likely. Histopathologically, the presence of malignant-appearing osteoblasts weaving seams of irregular osteoid is best interpreted as osteosarcoma.

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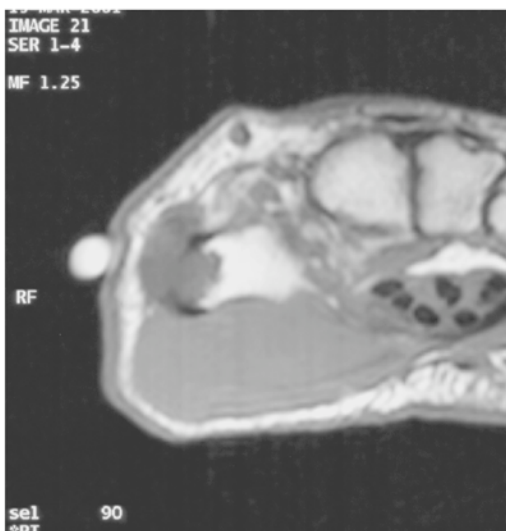
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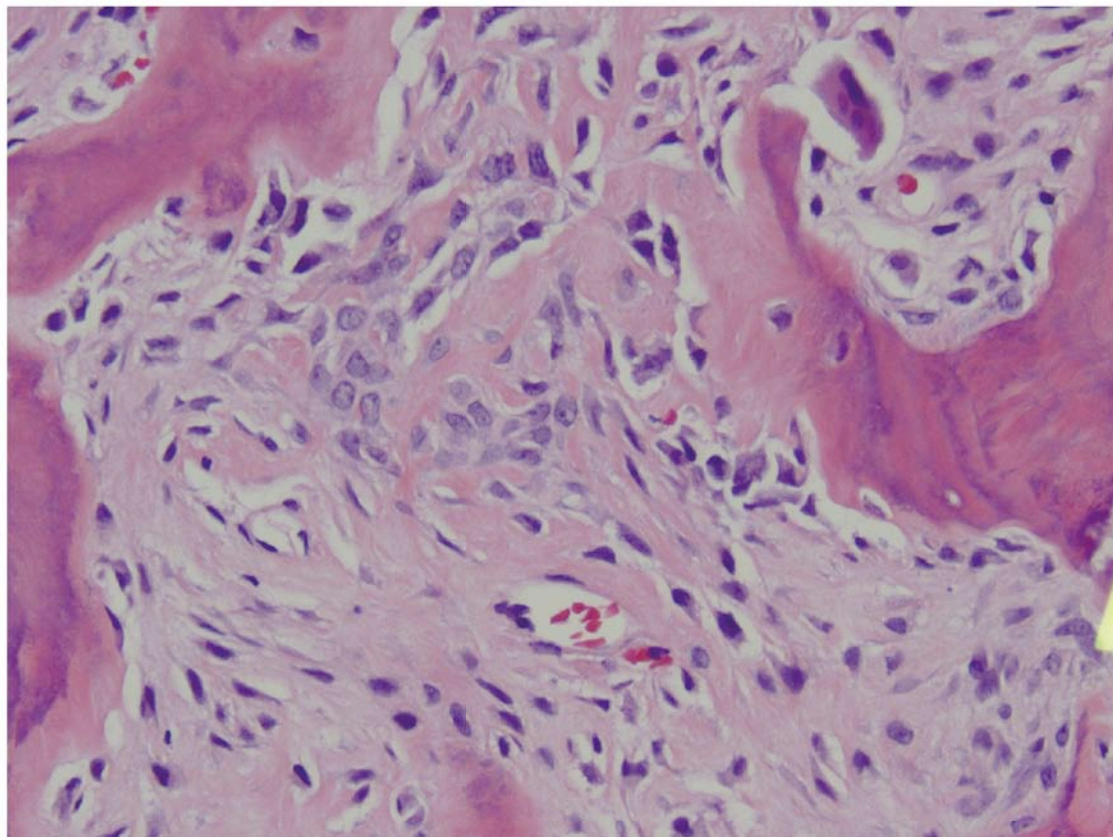
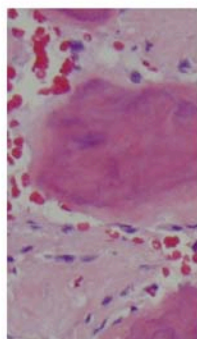
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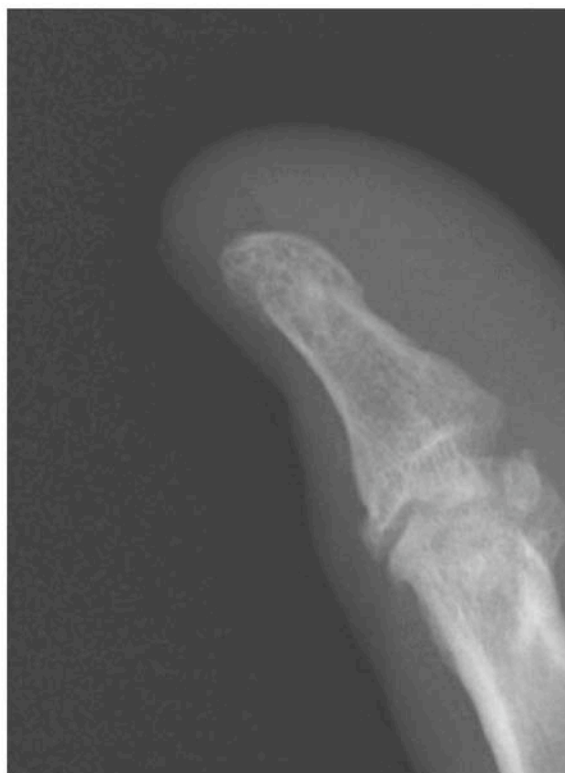
Figures 1A and 1B. Anteroposterior (A) and lateral (B) plain radiographs of the right thumb showing a bone-forming lesion arising from the dorsum of the thumb metacarpal. The lateral radiograph demonstrates a "string sign" with tumor growth abutting but not disrupting periosteum, which suggests a diagnosis of parosteal osteosarcoma (black arrow).



Figures 2A and 2B. Magnetic resonance imaging of the right thumb metacarpal, demonstrating dorsal cortical destruction and both extramedullary and intramedullary involvement. The axial image in A is T1 weighted (TE 690, TR 14) and the coronal image in B is T2 weighted (TE 3456, TR 99.)



Figures 3A and 3B. Photomicrographs at medium (A) and high magnification (B) of the hematoxylin- and eosin-stained sections from an incisional biopsy of a parosteal osteosarcoma showing woven bone of variable degrees of maturity within a fibrous stroma that demonstrates nuclear atypia and variable cell morphologies consistent with parosteal osteosarcoma.



Figures 4A and 4B. AP and lateral radiographs of thumb at five-year follow-up after resection of low-grade osteosarcoma and fibular graft reconstruction.

TABLE 1
Reported Cases of Parosteal Osteosarcomas Arising in the Hand

Age/Gender	Tumor Location	Treatment Course	Outcome
40F	index middle phalanx	digital amputation	no recurrence or metastasis 2 years later
not reported	index middle phalanx	digital amputation	no recurrence or metastasis 3 years later
26M	R. long finger metacarpal	marginal excision after misdiagnosis wide excision of recurrence at 9 months hand amputation for recurrence at 2 months	no recurrence or metastasis 4 years later
53F	L. index metacarpal	marginal excision after misdiagnosis repeat marginal excision after recurrence at 9 years observation of recurrence at 2 years resection 3 years later	recurrence 6 years later with lung metastasis
47F	R. ring finger metacarpal	resection, extra-corporeal radiation, and reimplantation	no recurrence or metastasis 9 months later
60M	R. thumb metacarpal	resection and free-fibular reconstruction	no recurrence or metastasis 5 years later

The first two cases above are reported in reference 1, the third in reference 3, the fourth in reference 4, and the fifth in reference 2. The final case in the table is presented in this report.

Because of its rarity, parosteal osteosarcoma remains primarily a diagnosis to be excluded in the hand. However, the implications of this diagnosis and the fact that it can occur in the hand must be considered carefully in each case. This article documents the sixth reported case of parosteal osteosarcoma arising in the hand. This entity should continue to figure prominently in the differential diagnosis of surface bone-forming lesions associated with the tubular bones of the hand.

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INTRAOSSEOUS NEURILEMMOMA INVOLVING THE DISTAL TIBIA AND FIBULA: A CASE REPORT

Ryan M. Ilgenfritz, M.D., Kevin B. Jones, M.D., Nathan Lueck, M.D., Joseph A. Buckwalter, M.D., M.S.

ABSTRACT

Schwannoma, or neurilemmoma, is a benign nerve sheath tumor most commonly located in the soft tissue. Occasionally, Schwannomas involve osseous structures. Involvement of two adjacent long bones was not found in a review of the English language medical literature. We present the case of a neurilemmoma affecting both the distal fibula and tibia. Although rare, intraosseous neurilemmoma should be included on the differential diagnosis of painful, radiographically benign-appearing lesions arising in long bones.

INTRODUCTION

Schwannoma, or neurilemmoma, is a benign nerve sheath tumor most commonly located in the soft tissue. Occasionally, Schwannomas involve osseous structures. The rarity of osseous involvement leads to omission of Schwannoma from the initial differential diagnosis in the majority of cases. The diagnosis is often not even suspected until the histologic appearance is evaluated after excisional biopsy. Most cases with osseous involvement appear to be related to nerves entering bone through nutrient canals.¹ Schwannomas may also erode into adjacent bones from nerves in soft tissue locations. Involvement of two adjacent long bones was not found in a review of the English language medical literature. We present a neurilemmoma affecting both the distal fibula and tibia.

CASE REPORT

A 34-year-old female originally presented for evaluation of left foot pain of several years duration. Her symptoms began as pain along the medial side of the heel. She underwent an endoscopic medial plantar fasciectomy by a local podiatrist that provided a short period of relief. Soon thereafter, she developed pain laterally that led to endoscopic lateral plantar fasciectomy by the same po-

diatrist. Persistent hindfoot discomfort and new forefoot pain prompted the referral to our clinic.

Her pain was aching in nature and moderate in intensity. It was activity related and did not radiate proximal to the ankle. She also reported occasional sharp ankle pain related to participation in sports that had responded to short-term immobilization. She denied numbness and paresthesias. She had noticed a significant size difference between her feet, with the left being larger than the right. She denied any history of trauma to the left foot or ankle. Review of systems was negative for systemic complaints. Past medical history consisted of borderline personality disorder, bipolar disorder, sensorineural hearing loss, and Treacher Collins Syndrome, for which she underwent reconstructive facial surgery as a toddler.

Examination of her lower extremities revealed a proportional asymmetry in foot size, with the left being larger than the right. Left ankle circumference measured 1.5 cm greater than the right. No palpable masses were noted. The skin was normal. Moderate pes planus deformity was noted bilaterally, left greater than right. Her heel alignment was neutral. She was able to stand and walk on her toes and heels and had normal strength in all muscle groups. Subtalar and ankle motion were symmetric bilaterally. Sensation was intact to light touch throughout the sural, saphenous, deep peroneal, superficial peroneal, and tibial nerve distributions. Dorsalis pedis and posterior tibial pulses were strong and capillary refill brisk in the toes. The lateral plantar surface and the metatarsal heads were tender.

Anteroposterior, lateral, and mortise views of the left ankle demonstrated a lytic lesion of the distal, medial fibula at the level of the syndesmosis (Figure 1). The lesion had well-defined cortical margins with a smooth periosteal reaction proximally. Possible involvement of the lateral cortex of the tibia was also noted. These findings were considered incidental and not related to her pain. Accommodative foot wear and close follow-up was recommended.

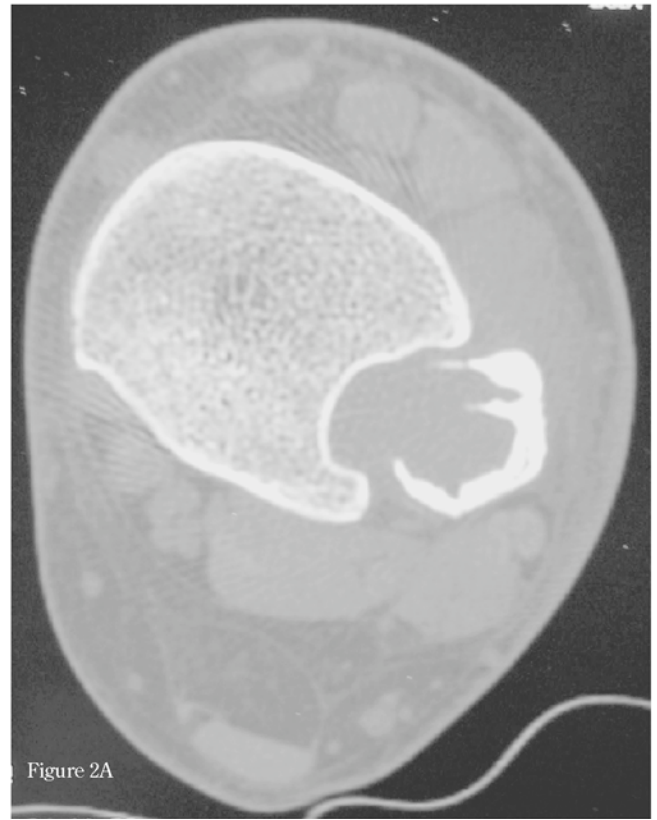
Two years later, her primary care provider became concerned that the size of the lesion within her distal fibula was increasing and referred her to us again. The aching ankle pain had returned for several months and was now accompanied by pain along the anterior border of the lateral malleolus extending proximal to the left ankle. The patient denied any trauma in the interim.

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Figures 1A-C. Anteroposterior (a), mortise (b), and lateral (c) views of the left ankle demonstrating a lytic lesion of the distal, medial fibula at the level of the syndesmosis that also appears to involve the lateral cortex of the tibia. The lesion has well-defined cortical margins with a smooth periosteal reaction proximally.



Figures 2A-B. Axial CT image (a) and coronal reconstruction (b) of the left ankle revealing destruction of the distal, medial cortex of the fibula and involvement of the adjacent lateral tibial cortex by an eroding soft tissue mass.

Physical exam now demonstrated less asymmetry in foot and ankle size. There was no evidence of neurovascular deficit. She was tender to palpation approximately 5 cm above the lateral malleolus, maximally along the anterior border of the fibula. Plain radiographs and a CT (Figure 2) obtained by the primary care provider demonstrated expansion of the lytic lesion in comparison to previous films. MRI revealed a lesion that was isointense to skeletal muscle on T1 weighted imaging and hyperintense and heterogeneous on T2 weighted imaging (Figure 3). Based on these findings, an excisional biopsy was scheduled. Diagnosis was uncertain, but aneurysmal bone cyst, giant cell tumor of bone, periosteal chondroma, both soft-tissue and intraosseous ganglia and cysts, and indolent pigmented villonodular synovitis were considered in the differential.

Intraoperatively, the lesion was identified between the tibia and fibula extending several centimeters proximal to the tibiotalar



Figures 3A-B. T1 (a) and T2 (b) sequence coronal plane MR images of the left ankle. The lesion appears isointense to skeletal muscle on T1 and hyperintense and heterogeneous on T2. These images also demonstrate soft tissue extension of the lesion across the syndesmosis abutting both the fibula and the tibia.

joint. The mass appeared to be extra-osseous and had eroded the adjacent cortices of the tibia and fibula. The superficial peroneal nerve was identified during dissection near the mass.

Gross pathologic examination revealed a mass of red-tan soft tissue measuring 3 x 2.5 x 1 cm. A portion of the tissue, which measured 2.2 x 0.4 x 0.8 cm, was cystic with a thick capsule. Sectioning revealed a mottled, yellow-tan, friable tissue with areas of cystic change. There was no osseous component apparent on gross examination.

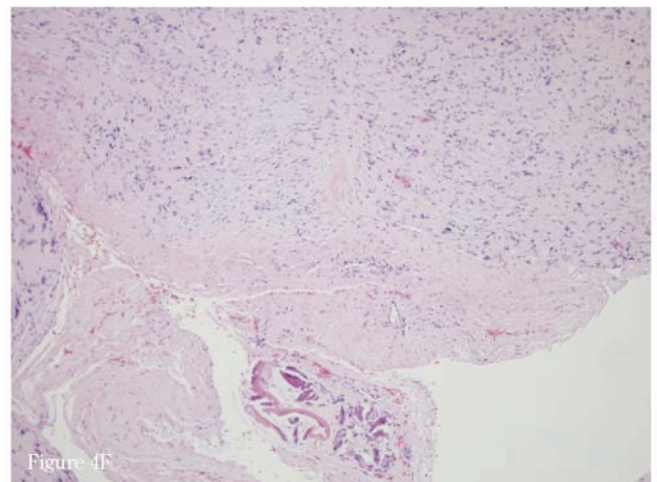
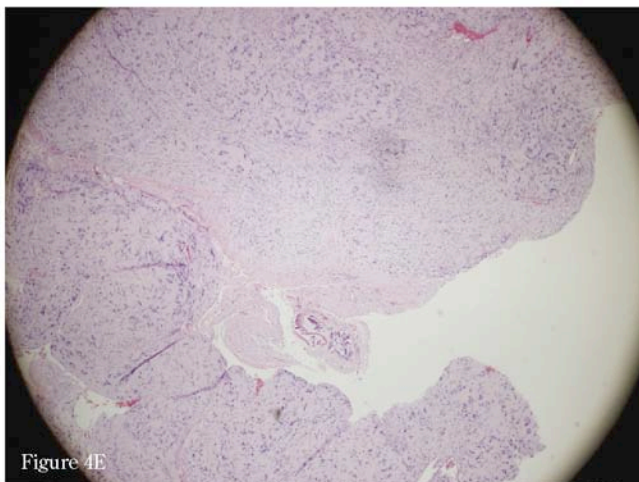
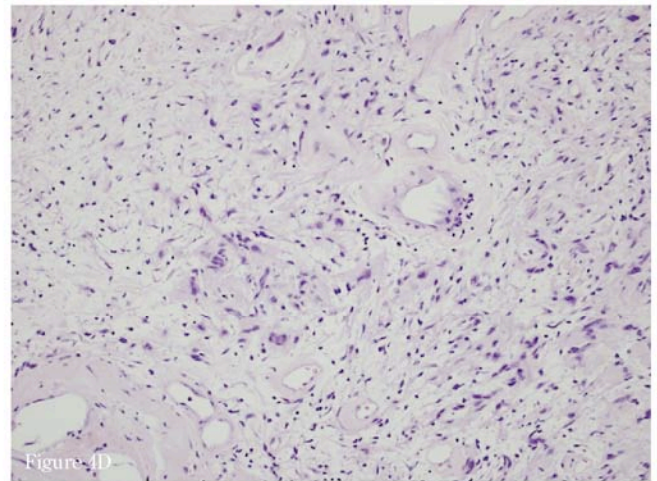
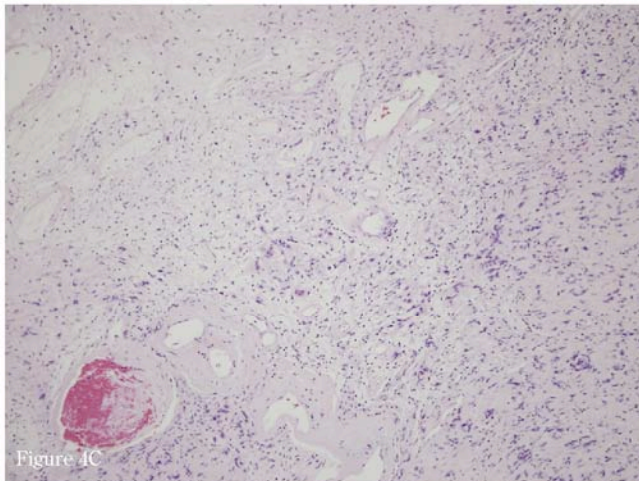
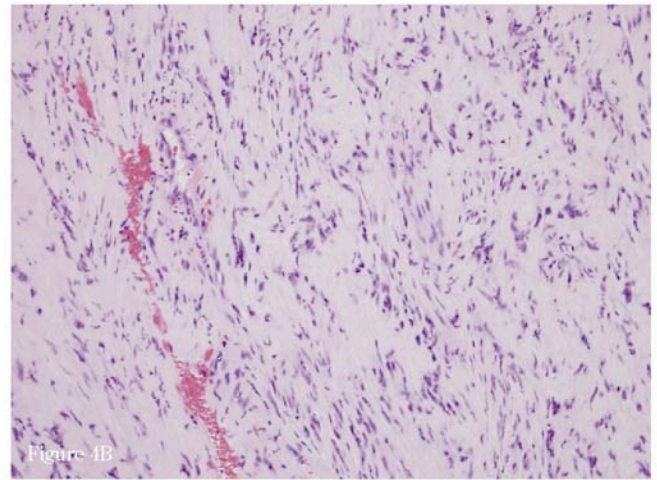
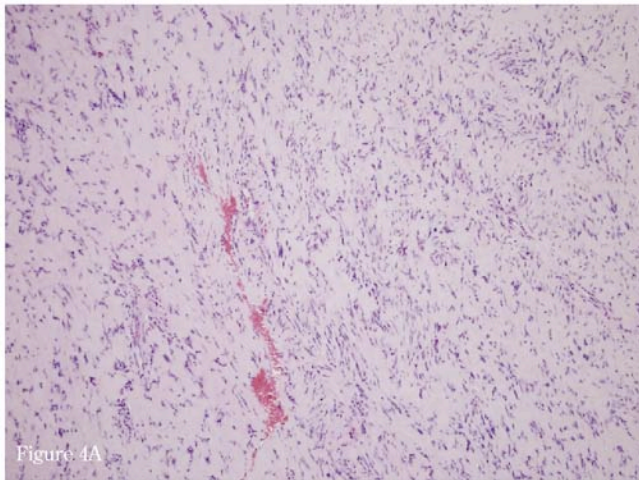
Microscopic sections revealed interlacing bundles of spindle cells with fibrillary cytoplasmic processes arranged in cellular areas (Figures 4A, 4B). Nuclear palisading and Verocay bodies were numerous. Also noted were areas of loosely arranged cells in a myxoid matrix with foci of cystic degeneration (Figures 4C, 4D). Thick walled vessels were also noted. Neither cellular atypia nor mitotic figures were seen. Small areas of osteoid component were found on microscopic examination (Figures 4E, 4F). The appearance was consistent with

the classic depiction of the Antoni Type A and B cells associated with a neurilemmoma or Schwannoma.²

The patient tolerated the excisional biopsy well and was placed in a walking boot for protection. Postoperatively, she experienced paresthesias and numbness across the dorsum of her foot, which resolved completely 4-5 months after the excision. No other evidence of neurovascular deficit was noted. She was transitioned out of the walking boot and at 6 months postoperatively had no limitation in her functional capacity. She retained full tibiotalar and subtalar joint motion, and there were no other complications. She continued to do well with no pain, neurovascular deficit, or evidence of radiographic recurrence at 27-month follow-up.

DISCUSSION

Neurilemmoma, or Schwannoma, is the least common of the benign peripheral nerve sheath tumors. Estimated incidence is approximately 1 in 40,000 individuals, usually presenting in the second to fifth decades of life. While most commonly solitary, multiple neurilemmomas are



Figures 4A-F. Photomicrographs of pathologic sections from the left ankle syndesmosis soft tissue mass reveal two distinct tissue components: 1) Cellular areas consisting of interlacing bundles of spindle cells with palisading nuclei; 100X (a) and 200X (b) magnification. 2) Areas of loosely arranged cells and thick walled blood vessels in a myxoid matrix with foci of cystic degeneration; 100X (c) and 200X (d) magnification. These components represent Antoni A and B tissues, respectively. An encapsulated margin and a single focus of metaplastic or reactive bone; 40X (e) and 100X (f) magnification.

known to develop in association with neurofibromatosis type 2.³ The presence of a solitary lesion has no association with gender or ethnicity.

Neurilemmomas arise from the myelinating Schwann cells within the nerve sheath. These lesions are slow-growing and displace the nerve fascicles. Thus, the most common presentation consists of a slow-growing soft tissue mass that is painful or produces paresthesias with percussion. Minor sensory loss can result, but motor weakness is rare. Surgical excision of symptomatic lesions seldom leads to chronic neurologic deficit. Occasionally, a minor sensory neuropraxia may be seen after excision and usually resolves completely with conservative treatment.

Diagnosis of neurilemmoma in soft tissue locations is often made by the MRI appearance alone. These lesions tend to be isointense to skeletal muscle on T1 weighted imaging and hyperintense and heterogeneous on T2 weighted imaging.^{4,5} The lesion commonly has an attenuated margin above and below that has been described in the literature as the "string sign".^{5,6}

When neurilemmomas affect osseous structures, they are often asymptomatic and on most occasions are discovered as an incidental finding. The typical radiographic appearance is of a benign, cyst-like defect centrally placed within the long bone and possessing a thin border of sclerosis.⁵ More frequent on the differential diagnosis of such osseous lesions are simple bone cyst, aneurysmal bone cyst, non-ossifying fibroma, benign fibrous histiocytoma, desmoplastic fibroma, fibrous dysplasia, chondromyxoid fibroma, and enchondroma. Intralesional calcification is rare and only complicates the differential diagnosis further when present.⁴

In the past, authors used the terms "intraosseous neurilemmoma" and "intraosseous neurofibroma" interchangeably, but they are now distinguished.¹ Intraosseous neurofibroma is rare outside of a primary diagnosis of neurofibromatosis type I, or Von Recklinghausen's disease.⁷ Moreover, it is usually periosteal in location. The majority have been reported in the mandible. In contrast, intraosseous neurilemmoma typically arises in association with a nerve that enters bone through a nutrient canal.⁸ Occurrence in most of the bones of the skeleton has been reported.^{1,4,9-19} In addition, these lesions are very infrequent in individuals with underlying neurofibromatosis.¹

In all of the reviewed cases in the literature, the diagnosis of neurilemmoma was not made until after histologic examination of tissue obtained during excision of the lesion. Microscopically, these lesions consist of two distinct histologies. The first, referred to as Antoni A, consists of compact spindle shaped cells with palisading Schwann cells, known as Verocay bodies, in

a fibrous background. The second, known as Antoni B, is loosely cellular with a myxoid matrix and frequent cystic degeneration and hemorrhage.² Some literature suggests further classification of these lesions based on the predominant tissue: Verocay-type neurilemmoma for those lesions that are predominantly composed of Antoni A tissue, and Antoni-type for those that are predominantly composed of Antoni B tissue.² While the majority of lesions contain both components, a predominance of Antoni B type tissue is thought by some authors to be an indicator of aggressiveness along the spectrum between neurilemmoma and malignant peripheral nerve sheath tumor.^{13,20}

In conclusion, we present a neurilemmoma that seems to have developed in an intraosseous location within the distal fibula. With progression of growth and complete erosion of the medial cortex of the fibula, the lesion extended across the syndesmosis to abut the lateral cortex of the distal tibia. Continued growth eventually led to pressure erosion of the lateral cortex of the adjacent distal tibia. Somewhat uniquely, this particular intraosseous neurilemmoma may have been the cause of the patient's foot pain symptoms via mass effect alone, rather than direct involvement with a peripheral sensory nerve. Although very rare, intraosseous neurilemmoma should be included on the differential diagnosis of painful, radiographically benign-appearing lesions arising in long bones.

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SECONDARY ANEURYSMAL BONE CYST OF THE PATELLA: A CASE REPORT

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ABSTRACT

A 20-year-old man presented to our clinic with pain and swelling in the right knee of one year's duration. Biopsy of the patella revealed an aneurysmal bone cyst secondary to a giant cell tumor. He was treated by curettage and bone cement to fill the defect. The rarity of this lesion in the patella and its treatment modalities are discussed.

INTRODUCTION

We present a case of an aneurysmal bone cyst secondary to a giant cell tumor in a 20-year-old patient, at an unusual site - the patella. He was treated by curettage of the lesion and bone cement to fill the cavity. A review of the literature reveals only one other case of a secondary aneurysmal bone cyst of the patella.

CASE REPORT

A 20-year-old college student presented to our orthopaedic outpatient department with complaints of pain in the right knee of three years' duration, and swelling of the right knee for one year. He also had fevers in the evenings and loss of appetite for three weeks. There was no history of weight loss or exposure to tuberculosis.

On examination, the patella appeared bigger and more prominent on the right side compared to the left. There was no localized warmth, but the patella was notably tender. In addition, there was a palpable bony thickening of the patella. No synovial thickening or knee joint effusion was noted. His knee range of motion was 0 to 110 degrees with pain at terminal flexion. There was no ligamentous laxity.

Laboratory studies revealed a hemoglobin of 13.5 gm/percent and white blood cell count of 13,000 cu.mm. Inflammatory markers were within the normal limits; his erythrocyte sedimentation rate was 18, C-reactive protein was negative, and alkaline phosphatase was 286 units. Mantoux test was non-reactive.

Radiographs of the right knee showed multiple lytic lesions in the patella (Figure 1). Core biopsy of the patella was done. The histology was consistent with an aneurysmal bone cyst. The patient then underwent curettage of the lesion using a high speed burr through a window made on the medial aspect of the patella. The material was sent for formal histopathological examination. The cavities in the patella were packed with bone cement (Figure 2). The biopsy showed an aneurysmal bone cyst with multiple giant cells confirming the diagnosis of aneurysmal bone cyst secondary to giant cell tumor.

DISCUSSION

Aneurysmal bone cyst (ABC) is an expansile cystic lesion, often occurring in the second decade of life,¹ with a slightly increased incidence in women. It constitutes one to six percent of all primary bone tumors. Long bones are the most often affected, but the spine is involved in 30 percent of patients with ABC.

ABCs, although benign, can be locally aggressive. The etiology of this condition is not definitively known, although most believe it is a vascular malformation within the bone. The proposed theories for the origin of this malformation are that it either occurs *de novo*, when it is called primary ABC, or secondary to tumors or trauma, when it is called secondary ABC. Secondary ABCs can be seen associated with giant cell tumor (GCT), chondroblastoma, osteoblastoma, or osteosarcoma. Recent studies have identified chromosomal abnormalities suggesting that the tumor, once thought to be a reactive process, may actually be a neoplasm.² This case is unusual in that it identifies an ABC occurring at a rare site (the patella) and secondary to a giant cell tumor (a lesion which also occurs rarely in the patella).

ABCs are usually painful, so late presentation as a pathological fracture is less common than with unicameral bone cysts.³ Although both conventional radiology and MRI are useful for diagnosing ABCs, biopsy is often needed to confirm the diagnosis. In this patient, initial

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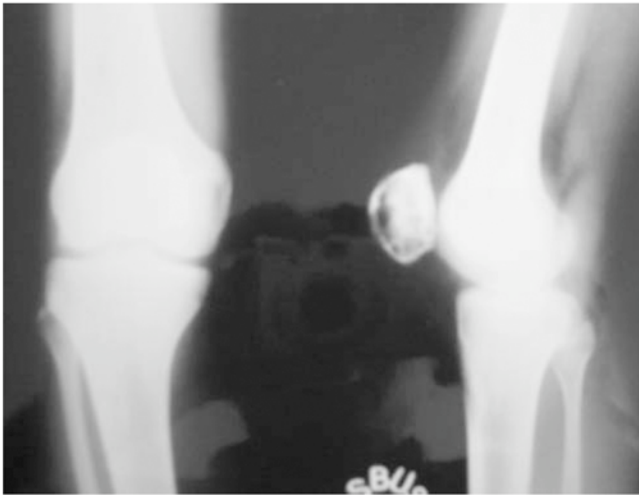


Figure 1A



Figure 1B

Figure 1. Radiographs of the right knee (1A) and magnified view of the patella (1B) revealing lytic lesions in the patella.

radiographs showed multiple lytic lesions in the right patella. At the time of presentation, our differential diagnoses included tuberculosis, bone cyst, or giant cell tumor. However, the ESR was normal and the Mantoux test was not reactive. We then performed a core biopsy of the patella which showed features suggestive of an aneurysmal bone cyst.

The mainstay of treatment of ABCs is intralesional curettage with locally applied adjuvants such as liquid nitrogen or phenol.⁴ Other options include en bloc dissection or selective arterial embolization. The recurrence



Figure 2A

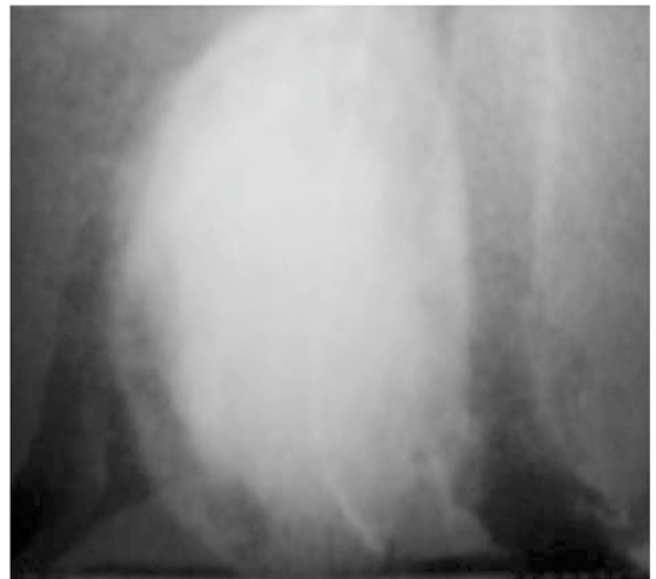


Figure 2B

Figure 2. Post-operative radiographs of the knee (2A) and magnified view of the patella (2B) after curettage and placement of bone cement.

following curettage of an ABC secondary to GCT has been reported as 2 to 25 percent. Young age and open physes are associated with an increased risk of local recurrence.⁵

We followed the patient for two years with radiographs of the right knee. There was no evidence of local recurrence at the end of two years, but the patient still requires longer follow-up.

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SPONTANEOUS SEPTIC ARTHRITIS CAUSED BY *BURKHOLDERIA CEPACIA*

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ABSTRACT

We describe the first reported case of a spontaneous septic arthritis caused by *Burkholderia cepacia*, the organism responsible for onion skin rot. The source of infection was most likely from hematogenous spread, as the patient's blood cultures were positive for *B. cepacia*. Treatment involved arthroscopic irrigation and drainage of the affected shoulder. Despite post-operative resolution of this immunocompromised patient's shoulder symptoms, he was unable to survive the *B. cepacia* bacteremia. Our report not only describes the case but also reviews the difficulty in treating *B. cepacia* infections.

INTRODUCTION

Burkholderia cepacia (*B. cepacia*), formerly known as *Pseudomonas cepacia*, is an aerobic, catalase-positive, gram-negative rod that was first isolated in 1950 as the responsible agricultural pest for onion skin rot.¹ Since that time, the bacteria has been identified as an opportunistic pathogen, commonly colonizing cystic fibrosis patients. In these patients, colonization with *B. cepacia* leads to worsening lung function and an increased mortality rate.² Highly transmissible strains have caused infections between cystic fibrosis patients

and asymptomatic non-cystic fibrosis carriers, as well as patients with chronic granulomatous disease.^{3,4}

B. cepacia is an extremely resilient species which can survive harsh environmental conditions with minimal nutritional needs.⁵ The bacterium's large genome, twice the size of *Escherichia coli* (*E. coli*), allows for this tremendous adaptability and inherent resistance to multiple antibiotics.⁶ This article describes the first reported case of spontaneous septic arthritis with *B. cepacia* from hematogenous spread.

CASE REPORT

We present the case of a 65-year-old white man with a history significant for recurrent angioimmunoblastic T-cell lymphoma and an allogenic stem cell transplant complicated by graft versus host disease. He was maintained on the immunosuppressive medications mycophenolate mofetil and tacrolimus following his transplant. In the three months preceding his presentation for septic arthritis, the patient had been admitted on four occasions for *B. cepacia* bacteremia. No source of infection had been isolated despite an extensive infectious disease work-up. For this particular hospital stay, he was admitted with a diagnosis of hyperkalemia. On hospital day two, the orthopaedic surgery service was consulted for increasing left shoulder pain and limited range of motion.

There was no prior history of trauma, similar symptoms, injections, or surgery to the left shoulder. The patient stated that his shoulder pain was localized, had an insidious onset, and was not accompanied by any other symptoms. Pertinent physical exam findings demonstrated a temperature of 99.7° F and no palpable effusion, erythema, or warmth. There was pain with passive range of motion of the shoulder including abduction, forward flexion, and rotation. Active range of motion was 30 degrees of forward flexion, 90 degrees of abduction, 45 degrees of external rotation, and internal rotation to the lumbar spine. Neurovascular examination of the extremity was normal.

Initial laboratory results included a correcting hyperkalemia and a leukocyte cell count of 4,000 cells per microliter, an erythrocyte sedimentation rate of 84, and a C-reactive protein of 7.7. Radiographs of the left shoulder only showed degenerative joint disease in the glenohumeral joint (Figure 1). A tagged white blood cell

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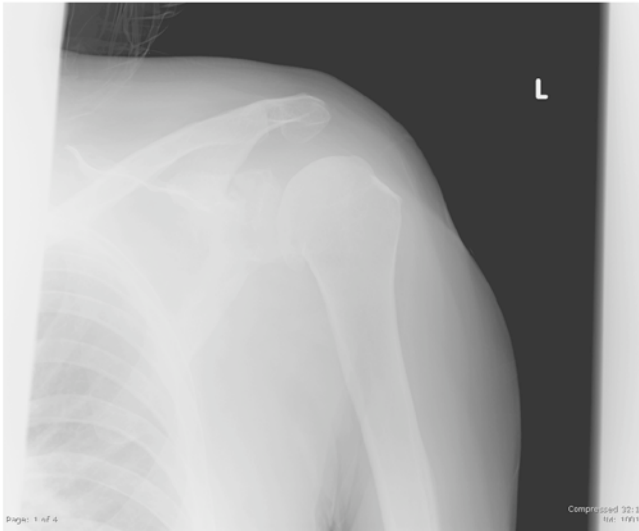


Figure 1. The patient's left shoulder AP radiograph showed generalized osteoarthritis.

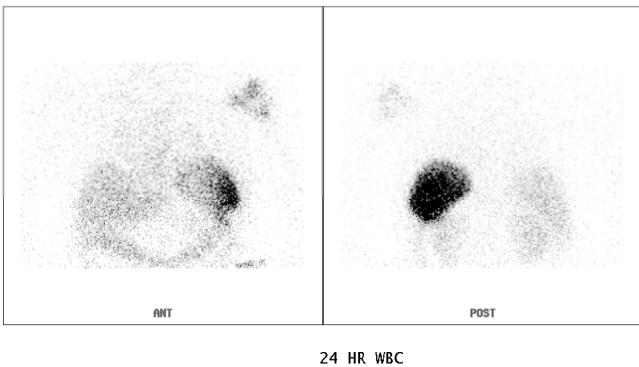


Figure 2. A tagged white-blood-cell scan demonstrated increased uptake in the patient's left shoulder.

scan obtained as a part of the patient's general infectious disease work-up demonstrated marked uptake in the left shoulder (Figure 2). Arthrocentesis of the left shoulder revealed frankly purulent joint fluid with a nucleated cell count of 121,000 cells per microliter.

The patient was taken to the operating room for arthroscopic irrigation and debridement of the left shoulder. A temporary drain was placed in the left glenohumeral joint and was removed post-operatively, after 48 hours of minimal drain output. Admission blood cultures eventually grew *B. cepacia*, as did the final cultures from the shoulder. Both sets of positive cultures demonstrated identical antibiotic sensitivities. Following the recommendations of infectious disease consultants, the patient was treated with ceftriaxone.

Despite surgical management of the septic shoulder (with relief of symptoms) and culture-sensitivity based intravenous antibiotic therapy, the patient continued to have persistent *B. cepacia* bacteremia. He was re-admit-



Figure 3. An MRI obtained two months after surgical management, despite resolution of shoulder symptoms, reveals chronic inflammation and avascular necrosis of the humeral head on this coronal oblique T2 image.

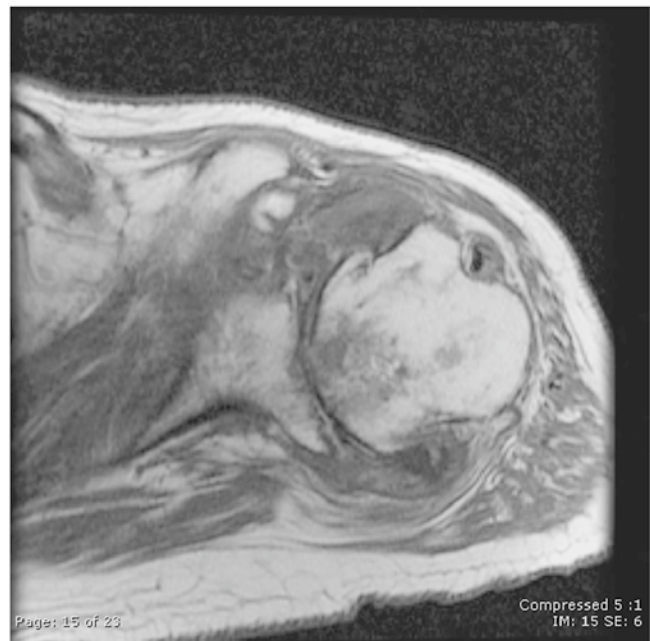


Figure 4. Axial T1 image from same shoulder MRI highlights the degenerative joint destruction and the avascular necrosis of the humeral head.

ted to the oncology service twice after discharge following his shoulder infection. Diagnostic investigations including multiple transesophageal echocardiograms, colonoscopy, lymph node biopsy, and CT scans of the

thorax, abdomen, and pelvis failed to reveal a source for infection. In spite of a benign shoulder exam, an MRI of the shoulder was performed two months after surgery. This study showed inflammatory changes and avascular necrosis of the humeral head, but no evidence of recurrent fluid collection or osteomyelitis (Figures 3 and 4).

Despite careful medical management and multiple consulting services, the patient eventually succumbed to the *B. cepacia* bacteremia and died. An autopsy was performed and attributed his death to persistent bacteremia with multi-system organ failure secondary to lymphoma. No other obvious sites of infection or abscess were discovered at autopsy. Interestingly, the patient lived on a farm with a well water supply. While this water supply tested negative for *B. cepacia* on two separate occasions, it was still presumed that the patient's habitat was somehow the source for his persistent infection with *B. cepacia*.

DISCUSSION

Burkholderia cepacia is a hardy bacterium that can survive in otherwise inhospitable environments. Studies have demonstrated that it is capable of living for over a year in a 10% iodine solution and can use penicillin as its only energy source.^{7,8} Transmission of the species occurs through physical contact with patients or aerosolized droplets.⁹ Nosocomial infections have involved direct patient inoculation with contaminated solutions with resulting *B. cepacia* bacteremia.¹⁰ Once acquired, the species is very difficult to eradicate. Even if patients receive aggressive treatment with culture-sensitive antibiotics, there is typically minimal clinical improvement. For example, cystic fibrosis patients rarely have reduction in the number of bacteria in sputum samples.¹¹ Only two immunocompetent patients have been reported to succumb to fatal *B. cepacia* infections.^{12,13}

Burkholderia cepacia possesses multiple virulence factors within its genome, particularly for antimicrobial resistance.⁶ The bacteria's genomic material has transposable elements and is divided into one to four circular replicons. This arrangement has a high likelihood for recombination events and increased genetic diversity.¹⁴ Structural features that contribute to *B. cepacia*'s multi-drug resistance are β -lactamase proteins, antibiotic efflux pumps, and an outer membrane ten times less permeable than that of *E. coli*.^{14,15} The bacteria also produce acyl-homoserine lactones, which are small signaling proteins that diffuse to neighboring cells and affect gene transcription. These signaling proteins allow the bacteria to rapidly respond to environmental changes, increasing their virulence.⁶

There have only been two previous reports in the English literature of *Burkholderia cepacia* isolated from

joint cultures. Both were from direct inoculation following a joint injection with *B. cepacia*-contaminated steroid solution from multi-use vials.^{16,17} The first case described was in a 58-year-old female with an ankle septic arthritis following an injection with contaminated methylprednisolone.¹⁶ The septic joint responded to intravenous gentamicin and serial aspirations. After 17 days of treatment, the patient was walking and recovered uneventfully. Matteson described a second case in a 72-year-old female with a septic knee one week after an intra-articular injection of steroid.¹⁷ The bacteria proved exceptionally difficult to eradicate from the joint despite multiple aspirations and operative debridements over a 60-day period.

The patient in our report had no prior injections or surgeries on the infected left shoulder joint. To our knowledge, this case is the first reported in the English literature of a spontaneous *B. cepacia* septic arthritis. With other pathogenic bacteria, the most common etiology of septic arthritis is hematological seeding of the synovial joint membrane.¹⁸ Considering the positive blood cultures in our patient, the most likely etiology for his septic arthritis is hematologic spread. No source was ever found to account for the patient's persistent bacteremia. Nevertheless, our infectious disease service recommended antibiotic treatment for non-vegetative endocarditis after resolution of his septic shoulder, as others have reported *B. cepacia* endocarditis.¹⁹ A theoretical consideration for an additional endovascular source involves the spleen. For instance, in a murine model, *B. cepacia* has been isolated in the spleen 35 days after initial infection.²⁰

Patients with chronic diseases and on immunosuppressive therapy have long been known to have an increased risk for septic arthritis. These patients represent a diagnostic and treatment challenge for orthopaedic surgeons. A high index of suspicion is required for diagnosing septic arthritis in the immunocompromised patient, since they may have only mild symptoms or an atypical presentation. Fever and an elevated leukocyte count may not be present and symptoms may only include pain or decreased range of motion. While most cases of septic arthritis are caused by gram positive organisms, immunocompromised patients are also at increased risk for infection with gram negative bacteria.¹⁸ Other rarer causes of septic arthritis, such as mycobacterium and fungi, must also be considered.

SUMMARY

We present the first case of a hematogenously spread septic arthritis caused by *Burkholderia cepacia*. This hardy bacterium is very difficult to eradicate and will typically colonize infected patients. Orthopaedic surgeons should be suspicious for this potentially fatal pathogen

in the care of immunocompromised patients and patients with cystic fibrosis or chronic granulomatous disease. Finally, consultation with an infectious disease service should be considered, as *B. cepacia* is naturally resistant to multiple antibiotics. Patients may require complex multi-antibiotic regimens with regular follow up.

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MULTIFOCAL SKELETAL TUBERCULOSIS: A REPORT OF THREE CASES

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ABSTRACT

Tuberculosis of the bone is a well-recognized clinical condition that can be diagnosed and managed by physicians and orthopaedic surgeons, often with an excellent outcome. However, the occurrence of multifocal skeletal involvement in immunocompetent patients is rare, even in countries where tuberculosis is endemic. Patients with multifocal skeletal tuberculosis may present with multiple vague somatic symptoms. We report three cases of multifocal skeletal tuberculosis in non-immunocompromised patients. All three patients were effectively treated with antituberculous drugs.

INTRODUCTION

Tuberculosis of the bone, constituting 10 to 20 percent of all tuberculosis, is a well-recognized clinical condition that is easily diagnosed and managed by physicians and orthopaedic surgeons with an excellent outcome. However, the occurrence of multifocal skeletal involvement is exceptional, constituting less than five percent of all bony tuberculosis, even in countries where tuberculosis is commonplace. Tuberculosis with multiple-bone involvement is extremely unlikely in immunocompetent patients and in those with normal pulmonary findings. Nevertheless, since patients with multifocal skeletal tuberculosis may present with vague multiple somatic symptoms, orthopaedic surgeons should maintain a high degree of suspicion in order to diagnose this condition. Multifocal skeletal tuberculosis must be considered in the differential diagnosis in the presence of multiple destructive skeletal lesions. Furthermore, this condition

may mimic malignant disease both clinically and radiologically. Radiographs should be done as a first screening test, while bone scan may help to detect multiple bone involvement at an early stage. CT scans may be useful to demonstrate the extent of the lytic lesions, while biopsy confirms the diagnosis. We report three cases of multifocal tuberculosis in non-immunocompromised patients. All three patients were effectively treated with antituberculous drugs.

Case 1: A 19-year-old engineering student presented to us with complaints of diffuse pain over the back, chest, and right hip region of six months' duration. He gave a history of decreased appetite and significant weight loss. There was no history of night sweats, chronic cough, or exposure to tuberculosis. On examination, he had tenderness over the upper thoracic spine, the thoracolumbar junction, the sternum, and the right sacroiliac joint. There was no paraspinal swelling or spasm. The peripheral blood count was normal. His erythrocyte sedimentation rate (ESR) was 54mm and Mantoux test was non-reactive. Radiographs of the thoracolumbar spine, chest, and pelvis were normal. Isotope scan showed an increased uptake in T1, T2, T9 through L2, the right sacroiliac joint, and the sternum (Figure 1). CT scan showed destruction of the involved vertebral bodies, the right sacroiliac joint, and the sternum (Figure 2). Biopsy of the sternal lesion showed a granulomatous lesion suggestive of tuberculosis.

Case 2: A 41-year-old executive came to our outpatient department with complaints of pain over the mid and low back, the right side of the chest, the left hip region, and the right first metatarsophalangeal (MTP) joint of eight months' duration. There were no constitutional symptoms of tuberculosis. On examination, he had tenderness over the mid-thoracic spine, thoracolumbar junction, and left sacroiliac joint. Paraspinal spasm was present, but there was no paraspinal swelling. His ESR was 38mm. Radiographs showed lytic lesions in the first MTP joint (Figure 3), and the T7 and T8 vertebral bodies. A bone scan showed increased uptake in T7, T8, L2, the left sacroiliac joint, the right fourth and fifth ribs, and the right first MTP joint. His CT scan showed lytic lesions in the left ilium in addition to lesions at T7, T8, and L2 (Figure 4). His Mantoux test was positive, showing a 14 x 15 mm area of induration at 48 hours. Biopsy of the first metatarsal head confirmed tuberculosis.

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CASE 1

Figure 1. CT scan of the spine showing lesions at T9, T10, and L2.

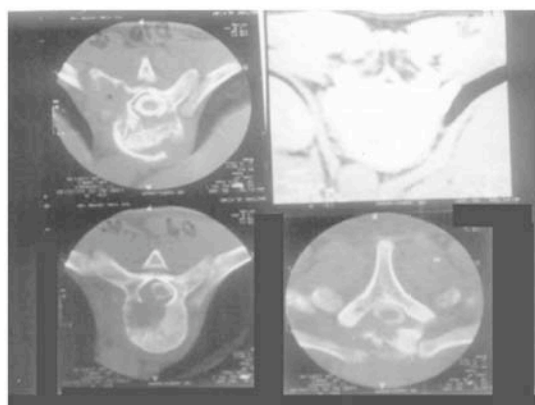


Figure 1

Figure 2. CT scan of the chest showing a lesion in sternum.

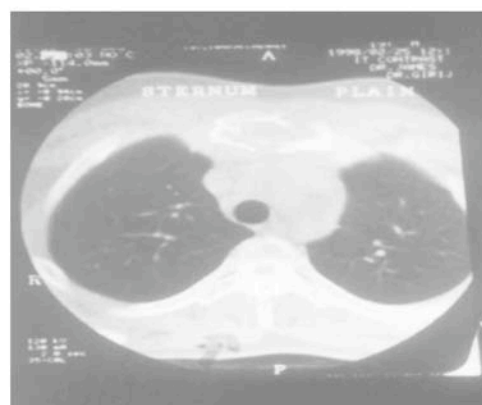


Figure 2

CASE 2

Figure 3. Radiograph of the right first metatarsophalangeal joint reveals a lytic lesion.



Figure 3

Figure 4. CT scan of the pelvis reveals lytic lesions in the left ilium.



Figure 4

CASE 3

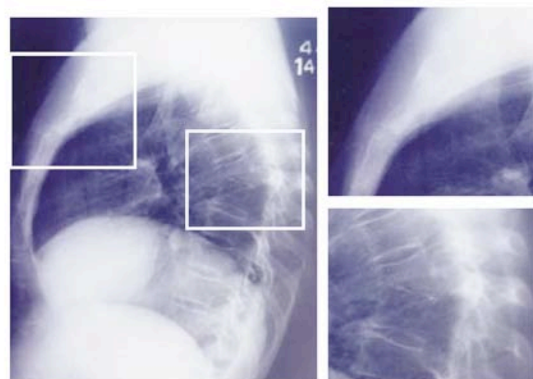


Figure 5. Lateral radiograph of the chest and thoracic spine with lytic lesions visible at T6 and T7 as well as the sternum.

Case 3: A 55-year-old housewife presented with pain in the upper back and left hip region and a discharging sinus over the sternum of five months' duration. On examination, there was gibbus at T6 and T7, as well as tenderness at the left sacroiliac joint and a discharging sinus over the sternum. Her ESR was 93mm and Mantoux test was strongly positive. Radiographs showed erosive lesions in the sternum and left sacroiliac joint and loss of the intervertebral space between T6 and T7 (Figure 5). Tuberculosis was confirmed by biopsy of the sternal lesion.

Treatment Course

Enzyme-linked immunosorbent assay (ELISA) testing for the human immunodeficiency virus (HIV) was done for all three patients and all were negative for the presence of HIV. All three patients were treated conservatively with bracing and antituberculous drugs. They had two months of intensive therapy with four drugs: isoniazid, rifampin, ethambutol, and pyrazinamide, followed

by four months' treatment with isoniazid and rifampin. Follow-up CT scan after 18 months showed resolution of all lesions in all the patients.

DISCUSSION

Tuberculosis of the bone is a relatively common clinical condition, constituting 10 to 20 percent of all tuberculosis. It can occur at any age and at almost any site of the body. In the spine, the thoracolumbar region is the most commonly affected. The multifocal skeletal form of tuberculosis is exceptional even in endemic countries, representing less than 5 percent of all bony tuberculosis.¹ The multifocal skeletal form is usually seen associated with pulmonary tuberculosis. A suppressed host immune response also predisposes to multifocal tuberculosis. Tuberculosis with multiple bone involvement is exceedingly rare in non-immunocompromised patients and in those with normal pulmonary findings.

In the first patient, we initially suspected leukemia based on his history and clinical examination and because one of his first-degree relatives had died of leukemia. However, his peripheral blood count was normal. Following his isotope scan and CT scan, our differential diagnoses included bony secondary metastases, multiple myeloma, or hyperparathyroidism. However, the bone marrow aspiration, serum electrophoresis, and parathyroid hormone assay were normal. The final diagnosis was confirmed by biopsy of the sternum which showed a granulomatous lesion suggestive of tuberculosis.²

In the second patient, based on his clinical findings and bone scan, we considered multiple myeloma, multiple secondary metastases, and multifocal tuberculosis in the differential diagnosis. Bone marrow aspirate, serum electrophoresis, and urine testing for Bence-Jones proteins were negative. Biopsy of the first metatarsal head confirmed tuberculosis.

For the third patient, the diagnosis of tuberculosis was more obvious with a sternal sinus and thoracic spine lesions with deformity. Tuberculosis was confirmed by biopsy of the sternal lesion.

Approximately 50 percent of patients with bone and joint tuberculosis have negative findings on chest X-ray.³ We feel that the difficulty in diagnosing multifocal skeletal tuberculosis is due to both the generalized somatic symptoms at presentation, and the non-specific physical findings and radiologic results, all of which give rise to a large differential diagnosis. Therefore, physicians should maintain a high degree of suspicion for tuberculosis if a patient presents with multiple somatic symptoms, particularly if the patient is from an area where tuberculosis is endemic. Multifocal skeletal tuberculosis must be considered in the differential diagnosis of multiple destructive skeletal lesions. This condition may mimic malignant disease both clinically and radiographically.⁴

The mainstay of treatment of spinal tuberculosis is conservative management with bracing and anti-tuberculosis drugs. Surgery is needed only if there is a neurologic deficit or spinal instability. These lesions respond rapidly to anti-tuberculosis drugs and quiescence is evidenced by the return of bone density to normal, as illustrated in these three cases.

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THE TOXINS OF WILLIAM B. COLEY AND THE TREATMENT OF BONE AND SOFT-TISSUE SARCOMAS

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ABSTRACT

In 1891, William B. Coley injected streptococcal organisms into a patient with inoperable cancer. He thought that the infection he produced would have the side effect of shrinking the malignant tumor. He was successful, and this was one of the first examples of immunotherapy. Over the next forty years, as head of the Bone Tumor Service at Memorial Hospital in New York, Coley injected more than 1000 cancer patients with bacteria or bacterial products. These products became known as Coley's Toxins. He and other doctors who used them reported excellent results, especially in bone and soft-tissue sarcomas.

Despite his reported good results, Coley's Toxins came under a great deal of criticism because many doctors did not believe his results. This criticism, along with the development of radiation therapy and chemotherapy, caused Coley's Toxins to gradually disappear from use. However, the modern science of immunology has shown that Coley's principles were correct and that some cancers are sensitive to an enhanced immune system. Because research is very active in this field, William B. Coley, a bone sarcoma surgeon, deserves the title "Father of Immunotherapy."

Each year in the United States approximately 5000 people die from bone and soft-tissue sarcomas.^{1,2} These deaths occur despite innovative techniques in surgery, new chemotherapeutic drugs, and the sophisticated delivery of radiotherapy. Therefore, in an attempt to reduce this death rate, new treatment modalities are being investigated. One such treatment modality is immunotherapy. Immunotherapy is based on the idea that a



Figure 1. William B. Coley (1862-1936) from *Trans Am Surg Assoc* 54(1936):415. Courtesy of the Welch Library of the History of Medicine.

patient's immune system can be stimulated or enhanced to attack the malignant tumors. The first systematic study of immunotherapy for the treatment of malignant tumors was begun in 1891 by William B. Coley (1862-1936), a bone sarcoma surgeon (Figure 1). Coley injected streptococcal organisms into a cancer patient in order to cause erysipelas and stimulate the immune system. The patient's tumor disappeared, presumably because it was attacked by the immune system. This experiment began Coley's life-long study of immunotherapy. For the next 40 years, he treated hundreds of patients with inoperable bone and soft-tissue sarcomas using immunotherapy. His work was widely publicized and discussed. He was in the ideal location to carry out his work as the Chief of the Bone Sarcoma Unit at Memorial Hospital in New York, America's first cancer hospital, and his work was supported by the first cancer research grant, which he helped establish.

Not only is Coley known as the "Father of Immunotherapy," he also became the model for the present-day clinician-scientist. First he had inspiration: He was deeply moved by the death of his very first patients due to wide-

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spread metastatic bone sarcoma. Second, motivated by this inspiration, he combed the literature to find ideas about what might be an effective treatment for cancer. Some reports suggested that having an infection might cause tumor regression. Third, following his study of the literature, he developed a theory for treatment. He began to inject patients with bacteria and bacterial products and noticed that some tumors disappeared. Finally, he regularly published his work. During his life, Coley's work was often severely criticized, and, at times, he was completely dismissed by the scientific community. This occurred because his methods of treatment and patient follow-up were not consistent, and many colleagues could not believe his good results. However, Coley persisted. Thanks to recent discoveries in immunology, we are now convinced that some of his observations were correct, and that his theories may have much to offer us today.

William Coley was born in 1862 to a very old Connecticut family. He went to college at Yale and graduated from Harvard Medical School in 1888. He then joined the staff of the New York Hospital as an intern on the surgical service. One of his first patients in 1890 was Bessie Dashiell, a 17-year-old girl who had a swelling in her hand which was diagnosed as a malignant bone tumor, most probably a Ewing's sarcoma in her metacarpal. Despite a forearm amputation, she died of widespread metastases within ten weeks. This rapid spread of a lethal cancer had a profound effect on Coley. He was determined to find an effective treatment. During a review of the records of New York Hospital, Coley learned about a patient who, seven years previously, had had an inoperable malignant tumor in his neck that seemed to disappear after he developed erysipelas. The patient was discharged, apparently without evidence of a residual tumor. Coley personally searched for this patient by combing the tenements of Lower Manhattan. After weeks, he finally found the patient, a German immigrant named Stein, and he had no evidence of residual cancer.

Mr. Stein's seemingly miraculous cure contrasted with Bessie Dashiell's rapid death and inspired Coley to scour the literature looking for other patients who had cancer remission due to a concurrent bacterial infection. He was aware of anecdotal theories of the beneficial effect of fever on malignant tumors. For example, Didier noted in 1725 that patients with syphilis developed very few malignant tumors.³ Sir James Paget had also mentioned that an infection may cause a regression in certain tumors.⁴ In addition to these anecdotes, Coley was able to find specific examples in the literature. For example, in 1867, the German physician Busch reported that a malignant tumor had disappeared when the patient contracted erysipelas. The cause of erysipelas, a streptococcal organism, was not known until 1881.⁵ Then, in



Figure 2. Drawing of Coley's first bone sarcoma case treated with his toxins. Courtesy of *Annals of Surgery*/Lippincott.

1888, Bruns intentionally injected a cancer patient with the streptococcus organism to induce erysipelas, and he noticed the shrinkage of the malignancy.⁶ Coley was able to find approximately 47 cases in the literature documenting the beneficial effect of infections on tumors.

Coley was convinced that having a severe infection could cause cancer to regress. It took a great deal of courage, but in 1891 he injected his first patient with streptococcal organisms and noticed the shrinkage of a malignant tumor. This encouraged him to treat two other patients with long-bone sarcomas (Figure 2). The injections appeared to be quite dangerous, and two of his patients died of infection. However, there was some observable shrinkage of their malignant tumors. He published his first work describing these three patients in 1891 (Figure 3).⁷

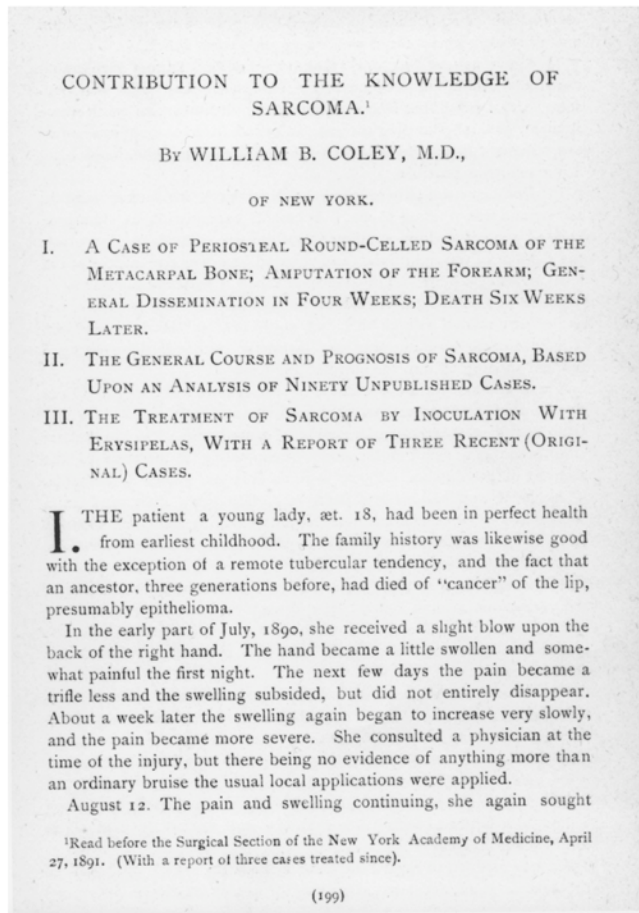


Figure 3. Title page to Coley's first article of 1891 describing his toxins. Courtesy of *Annals of Surgery*/Lippincott.

Because of the danger of live streptococcal organisms, Coley continued his treatments using a heat-killed streptococcal organism combined with a second organism that we now call *Serratia marcescens*. This concoction became known as Coley's Toxin. By 1893, he had tried his toxin on ten patients, most of whom did well.⁸ By 1916, he had documented 80 more cases in a monograph.⁹ By the end of his career, he had written over 150 papers on this subject and treated almost 1,000 cases. He mainly used his toxins on patients with inoperable bone and soft-tissue sarcomas, observing that this treatment was far less effective on other types of cancer such as melanomas and carcinomas. Beginning in 1899, Parke Davis & Company had begun to prepare the toxins so they were available for all physicians. They were widely used for the next 30 years.¹⁰

As a result of his widely used treatment, as well as the fact that he was publishing his work, Coley was much in the public eye. Early in his career he received small donations from the Rockefeller family to help with his

research, and in 1902 he arranged a large grant from the Huntington family that supported him and other cancer researchers. This endowment was the first in the United States designated specifically to study cancer.¹¹

Despite Coley's high profile, his work came under criticism because of inconsistencies. First, although Coley described hundreds of favorable responses to his toxins, his patient follow-up was poorly controlled and poorly documented. Second, there were 13 different preparations of the toxins, and some of these were more effective than others. Third, Coley used various methods of administration. Some toxins were given intravenously, others intramuscularly, and some were injected directly into the tumor. Therefore, many doctors who used Coley's Toxin did not get the same good results that he did, and some noticed no effect at all. Some critics went so far as to call him a charlatan. As early as 1894, the *Journal of the American Medical Association (JAMA)* issued a severe criticism of the use of these toxins:

*There is no longer much question of the entire failure of the toxin injections, as a cure for sarcomata and malignant growths. During the last six months the alleged remedy has been faithfully tried by many surgeons, but so far not a single well-authenticated case of recovery has been reported.*¹²

Despite JAMA's claim, however, some physicians had success with Coley's Toxin. Yet many of those doctors looked askance at Coley because of his personal belief, held long after the idea had been generally dismissed, that cancer was caused by microorganisms. Coley held this belief until the end of his career.

Additional controversies surrounding Coley's work reflect a field struggling to stabilize its understanding of how to treat cancer. For example, James Ewing, perhaps the most famous cancer pathologist in the country, was a leading opponent of Coley's work. This was a particular problem for Coley because Ewing was Medical Director of Memorial Hospital, and for many years was Coley's boss. Their memos to one another reflect constant interpersonal animosity. Ewing himself had become a fanatical supporter of radiation therapy for the treatment of all bone tumors and repudiated any other theories for the treatment of cancer. Ewing therefore refused Coley permission to use his toxins at Memorial Hospital. This was ironic, because Coley had more experience than any other surgeon in the country in treating the small round blue cell sarcoma that still carries Ewing's name.

In addition, by 1920 Coley's work ran into serious resistance from the Bone Sarcoma Registry. This registry, established by E. A. Codman, who had invited Ewing

and Joseph Bloodgood from Johns Hopkins to join him, was the first cancer registry of any kind.¹³ Its role was to standardize the diagnosis and treatment of all forms of bone cancer by collecting cases from all over the country. The cases would be evaluated by Codman, Ewing, Bloodgood, and other prominent bone specialists. Coley had a great deal of difficulty having some of his cases accepted by the registry, despite being the leading bone tumor surgeon in the country. Members of the registry believed the toxins were ineffective. In fact, during the 1920s, both Codman and Bloodgood insisted that the excellent responses reported by Coley were often because the patients had the wrong diagnoses.

Thus, his work gradually fell out of favor. By 1952, the Park Davis Company no longer produced Coley's Toxin, and, in 1962 the Food and Drug Administration refused to acknowledge Coley's Toxin as a proven drug.¹⁴ Thus, in 1962 it became illegal to use Coley's Toxins for the treatment of cancer.

Despite the downward spiral of Coley's treatment ideas, they never completely died. He himself remained undeterred, holding on to his belief in his toxins until the end of his career in 1933. He was not alone. In fact, by the early 1930s, a few doctors had changed their minds and were willing to accept that the toxins might be beneficial. In 1934, *The Journal of the American Medical Association* reversed its position and agreed that Coley's Toxin might be of value:

*It appears, that undoubtedly the combined toxins of erysipelas and prodigiosus may sometimes play a significant role in preventing or retarding malignant recurrence or metastases; occasionally they may be curative in hopelessly inoperable neoplasms; . . . The Council has, for these reasons, retained Erysipelas and Prodigiosus Toxins-Coley in New and Nonofficial Remedies, with a view to facilitating further studies with the product.*¹⁵

In a symposium held in 1935, Codman, apparently seeing evidence of the toxin's benefits, reversed his position and suggested that Coley's treatment might have some value after all.¹⁶ Also, a controlled study done in 1962 showed a dramatic response in 20 of 93 cancer patients.¹⁷ Further acceptance of his ideas was brought about by Coley's own children. His son Bradley (1892-1961), also an orthopaedic surgeon, succeeded him as the head of the Bone Tumor Service at Memorial Hospital. Bradley Coley's major textbook on bone tumors was published in 1948, and while advocating surgery as the main treatment for bone sarcomas, he supported the use of Coley's toxin as adjunctive therapy.¹⁸ He believed that it would be of value in preventing micro-metastasis. His daughter, Helen Coley Nauts (1907-2001), became

a cancer researcher and devoted her life to the study of her father's toxins. She tabulated every patient he treated and reviewed all his notes. She published 18 monographs and tabulated over 1000 of his cases and noticed that in 500 of these there was near-complete regression.¹⁹

Nowadays, orthopaedic oncologists do not use Coley's Toxins for the treatment of bone and soft-tissue sarcomas. However, because many of these tumors are lethal, treatment options may one day be supplemented by immunotherapy. Since Coley's death, the field of immunology has developed into a sophisticated specialty. Scientists are studying the effect on tumors of such factors as tumor necrosis factor (TNF), interferons, streptokinase and many other cytokines, all related to the immune system.²⁰ Indeed, vaccines are being developed for the treatment of numerous types of cancer, particularly colon cancer and melanoma.²¹ One form of immunotherapy which is consistently effective is the installation of BCG bacilli into the bladder to treat superficial bladder cancer.

William Coley's intuitions were correct: Stimulating the immune system may be effective in treating cancer. He was a model of the clinician-scientist, treating patients and using his practice to initiate research and build theories. But he was a man before his time, and he met with severe criticism. Despite this criticism, however, Coley stuck with his ideas, and today we are recognizing their potential value.

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