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2009

The Iowa Orthopaedic Journal

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Published by the Residents and Faculty of the Department of Orthopaedics, The University of Iowa

Editors: Jonathan Donigan, M.D.
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THE IOWA ORTHOPAEDIC JOURNAL

2009 • Volume 29

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Ryan Ilgenfritz, M.D.

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INSTRUCTIONS FOR AUTHORS, 2010

<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 2010 edition is Monday, January 4, 2010.

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

Submit manuscripts and accompanying figures electronically to diana-johannes@uiowa.edu. It is essential to include:

1. **The original manuscript, double spaced, with illustrations and an abstract.** The corresponding author must be identified with mailing address, telephone/fax numbers and e-mail address. Manuscripts for accepted articles will not be returned.
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do not embed images in the document. 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.

Please refer to previous *Iowa Orthopaedic Journal* editions at the web address, given above and below, for previous examples of manuscript preparation.

Preparation of manuscripts: Manuscripts must be typewritten, 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: Drawings, charts and lettering should be done in black with white backgrounds. Put dates or initials in the legend, not in the figure. 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 JPP, Iowa City, Iowa 52242-1088 or by emailing diana-johannes@uiowa.edu.

EDITORS' NOTE

We are pleased and honored to present the 2009 edition of *The Iowa Orthopaedic Journal (IOJ)*. 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 inspired by the accomplishments of previous editors, especially those who worked on editions of the *IOJ* that have been published during our residency. In addition, several articles from previous *IOJ* editions have become staples of the Iowa Orthopaedic Residency and have set a high standard for our efforts in editing this year's *IOJ*.

The impact of the *IOJ* continues to increase with the availability of articles in an electronic format for free via PubMed. The number of retrieved *Iowa Orthopaedic Journal* articles is now more than 30,000 per month, with more than 1000 articles downloaded on average per day. We are excited about the exposure this is bringing to our department's journal, and we anticipate that the increasing readership will result in continued growth for the *IOJ*.

In this edition, as in years past, many of the articles have been written by our own faculty and residents. In addition, we have been fortunate to receive submissions from our respective medical school alma maters: Johns Hopkins University and The University of Miami. Submissions have also come from more remote locations, including two articles from The United Kingdom. This broad range of submissions has greatly enhanced the quality of this year's *IOJ*.

As is tradition, we would like to recognize the departing senior residents: Drs. Flint, Lyon, Mosqueda, Riley, Scordino, and Van Hofwegen. Through their intelligence and natural abilities they have given their fellow residents something to shoot for. Their patience and willingness to facilitate learning-by-doing while working with their junior residents has benefited us all. We sincerely thank them and wish them the best as they continue on to fellowship and the start of what will surely be remarkable careers.

Having just mentioned remarkable careers, it seems appropriate to introduce Dr. George El-Khoury, to whom this year's *Iowa Orthopaedic Journal* is dedicated. The effects of his work in the field of Musculoskeletal Radiology are tremendous and difficult to quantify, although a look through his 76 page CV gives you some idea. But his impact on the University of Iowa Orthopaedic Surgery residency can be attested to by every resident that has been fortunate enough to come through this program. His dedication to education and quality patient care have inspired us, starting with our one month rotations as interns, continuing through residency, and peaking during our time on the Musculoskeletal Oncology service as senior residents. He is a resource that we all rely on heavily, and when he is away, he is sorely missed. It has been our great privilege to learn from him.

The *Iowa Orthopaedic Journal* would not be possible without the help of Diana Johannes. Her hard work has been the motor driving the creation of this year's *IOJ*. She has spent countless hours organizing articles for review and publication. She has kept us on track in our efforts to produce the highest quality publication possible. She has



been a master proofreader, graphic artist, and organizer of all things, while at the same time continuing to serve admirably as Dr. Albright's administrative assistant. We sincerely thank her for her role in bringing this year's *IOJ* to fruition.

We would also like to thank our corporate sponsors who, in the midst of ongoing scrutiny of the role of industry in orthopaedics, have continued to provide integral educational support with integrity.

Finally, we would like to thank our faculty advisers, Drs. Joseph Buckwalter and Jose Morcuende. Their guidance and experience have made this edition possible. We are indebted to them for their input and leadership.

We hope that this year's edition of the *Iowa Orthopaedic Journal* lives up to the high standard set by our predecessors. As previous editors' notes have pointed out so well, the primary purpose of this journal is education, and we confirm that those who are privileged to participate in its production undoubtedly benefit the most.

Jonathan A. Donigan, M.D.
Ryan M. Ilgenfritz, M.D.

IOWA ORTHOPAEDIC JOURNAL EDITORS EMERITI

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GEORGE Y. EL-KHOURY, M.D. 2009 IOWA ORTHOPAEDIC JOURNAL DEDICATION



With great respect and admiration, the residents, faculty, and staff of the University of Iowa Department of Orthopaedics dedicate the 2009 *Iowa Orthopaedic Journal* to Dr. George Y. El-Khoury.

George El-Khoury was raised in the ancient city of Sidon, Lebanon. Of historical interest, the city of Sidon has been inhabited since at least 4000 BC, and perhaps longer. It is located approximately 60 km south of the capitol city of Beirut. Sidon was made famous by its defiance and

passionate struggle against conquer by Alexander the Great in 333 BC. Additionally, it was one of only two cities in Lebanon to have been visited by Jesus of Nazareth.

Dr. El-Khoury's mother was a pioneer and founded an elementary school to educate local children, as well as refugee youngsters. He attended the Evangelical School in Sidon, which was established by American missionaries. When he graduated from high school, he was accepted at the American University of Beirut where his father was working. He actually roomed with his father while attending the University; his mother supplied them with their meals. He earned his Bachelor of Science degree in Physics from AUB in 1965, graduating "With Distinction". His remarkable scholastic achievement during undergraduate studies secured him a scholarship as he pursued his medical education at the AUB.

During his medical education, George El-Khoury became intensely interested in the field of Radiology. Upon his graduation from medical school, he pursued a residency in Diagnostic Radiology at the American University of Beirut Hospital. One day during his first year of residency, he visited his sister's house in Sidon where he noticed a beautiful young lady with a cast on her arm. He rushed to examine her injury, and in the process, he successfully manipulated her wrist as well as her heart. The following year, George and Salam married. Today, after 40 years of marriage, they continue to be very much in love. George and Salam have two children, Joe and Hani. Joe completed his Orthopaedics residency at the University of Iowa program and is now a Pediatric Orthopaedic Surgeon at the University of Alabama at Birmingham. Hani is an Attorney in the Quad Cities, near Davenport Iowa.

Dr. El-Khoury began his career at The University of Iowa in 1971 as he further sought to advance his education with an additional residency in Diagnostic Radiology. After completion of his Residency in 1973, he returned to Beirut to take a position as Clinical Associate in Radiology at the American University of Beirut Hospital. As the clinical volume and complexity of our department here at the University of Iowa continued to grow, the need for a specialized Musculoskeletal Radiologist became very apparent. Fortunately, Dr. El-Khoury was persuaded to return to Iowa in October of 1975 as the Director of Musculoskeletal Radiology, a position that he still holds today.

When Dr. El-Khoury returned, the Iowa Department of Orthopaedics consisted of seven faculty members. Dr. Regi-

nald Cooper was the Chairman and there were 6 other staff surgeons: Drs. Ignacio Ponseti, Adrian Flatt, Michael Bonfiglio, Richard Brand, John Albright, and Bruce Sprague. Dr. Carroll Larson also remained on staff as Professor Emeritus, Drs. Stuart Weinstein and Joseph Buckwalter were both residents in our program at the time. Dr. El-Khoury was the only staff Musculoskeletal Radiologist, covering both Orthopaedics and Rheumatology. His division, as well as Orthopaedics, was housed in the Children's Hospital.

Over the past 33 years that Dr. El-Khoury has been a part of The University of Iowa he has developed his department tremendously. At the beginning of his career here, musculoskeletal imaging consisted of plain radiography, conventional tomography, and an occasional arthrogram or lipid myelogram. Today, the UIHC Musculoskeletal Radiology division is one of the largest and most technologically advanced in the United States. Dr. El-Khoury heads a team of four full-time faculty members that train four fellows each academic year. He has established the highest technology in all modern diagnostic imaging modalities such as MRI, Multi-dimensional CT, and ultrasound. Additionally, he and his colleagues perform diagnostic and therapeutic interventional procedures such as needle aspirations and core biopsies of bone and soft tissue lesions, osteoid osteoma radiofrequency ablation, as well as any variety of therapeutic injection that one could imagine.

Perhaps the most extraordinary feature about Dr. El-Khoury is his dedication to education. He has played an invaluable role as a mentor and teacher to students, residents, and faculty of the University of Iowa Orthopaedics department for the past 33 years. The medical students at the University of Iowa have voted Dr. El-Khoury as "Teacher of the Year" on numerous occasions.

Dr. El-Khoury's contribution to Orthopaedic resident education is irreplaceable. Beginning with a month long intern year rotation, Orthopaedic residents quickly learn that the expertise and amazing, thoughtful diagnostic abilities of Dr. El-Khoury embody what we hold as the essence of "Iowa Orthopaedics." This tremendous contribution becomes increasingly amazing as we progress through our training and tap further and further into the vast knowledge that he possesses. He constantly makes himself available for consultation both within the University, as well as from referring physicians. He is the "go-to guy" when challenging patient presentations are encountered in our clinics. A classic line that we all add to our vernacular is "Well, I'm not sure what this is ... why don't we go talk to Dr. El-Khoury." This is an invaluable service that only Dr. El-Khoury can provide.

It is our honor and great pleasure to dedicate the 2009 *Iowa Orthopaedic Journal* to Dr. George El-Khoury. What Dr. El-Khoury has contributed to the University of Iowa Department of Orthopaedics is impossible to quantify, and difficult to put into words. Working with and learning from him is a true privilege and we, as a department, are forever indebted to him for his service. Thank you, Dr. El-Khoury.

Ryan M. Ilgenfritz Jonathan A. Donigan
Joseph A. Buckwalter Jose A. Morcuende
Paul G. Etre

2009-2010 DEPARTMENT OF ORTHOPAEDICS AND REHABILITATION SCHEDULE OF LECTURESHIPS AND CONFERENCES

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

2009 Senior Residents Day

June 5-6, 2009

Marc R. Safran, M.D.

Professor, Department of Orthopaedic Surgery
Associate Director, Sports Medicine
Stanford School of Medicine
Redwood City, California

Paul Tornetta III, M.D.

Professor and Vice Chairman
Department of Orthopaedic Surgery
Boston University School of Medicine
Director of Trauma, Boston Medical Center
Boston, MA

*2010 to be arranged. Contact Linda Croy, (319) 353-7660

Iowa Orthopaedic Alumni Association Meeting

September 17-19, 2009

Dr. Freddie Fu, University of Pittsburgh

Dr. Michael Bonfiglio Visiting Professor

Dr. Scott Dye, San Francisco

Dr. Michael Bonfiglio Visiting Professor

Dr. Martha Murray, Children's Hospital in Boston,

The Ruth Jackson Society Lecturer

Dr. Lauris C. Kaldjian, The Van Olst Ethics Lecturer

Director, Program in Bioethics and Humanities

Associate Professor, Department of Internal
Medicine

UI Carver College of Medicine

*2010 to be arranged. Contact Peggy Stover, (319) 356-2332

25th Annual Hawkeye Sports Medicine Symposium

December 4-5, 2009 (speakers to be announced)

Marriott Hotel and Conference Center
300 East 9th Street, Coralville

*Speakers to be announced. Contact Kris Kriener, (319) 353-7954

Carroll B. Larson Shrine Memorial Lecture

April 10-11, 2009

Dr. John Flynn

Children's Hospital of Philadelphia

*Spring 2010 to be arranged. Contact Nancy Love, (319) 356-1872

Ponseti Clubfoot Treatment Symposium

October 16-17, 2009

*Speakers to be arranged. Contact Gloria Yorek, (319) 356-3469

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

Department of Orthopaedics

| | |
|-------------------------------------|--|
| Christina Ward 2008-present | Arthur Steindler 1912-1949 |
| Heather Bingham 2008-present | Theodore Willis 1917-1918 |
| Phinit Phisitkul 2008-present | Joseph Milgram 1926-1932 |
| Nicolas O. Noiseux 2007-present | Ernest Freund 1932-1936 |
| Robert Yang 2007-present | Thomas Waring 1932-1939 |
| Erika Lawler 2006-present | James Vernon Luck 1936-1939 |
| John E. Femino 2005-present | Ignacio Ponseti 1946-present |
| Joseph D. Smucker 2005-present | Eberly Thornton 1946-1952 |
| Jin-soo Suh 2004-2005 | Robert Newman 1948-1956 |
| Neil A. Segal 2004-present | Michael Bonfiglio 1950-1995 |
| Brian Wolf 2003-present | Carroll Larson 1950-1978 |
| Michael O'Rourke 2003-2007 | Adrian Flatt 1956-1979 |
| Sergio Mendoza 2003-present | Reginald Cooper 1962-present |
| Jose Morcuende 2001-present | Howard Hogshead 1964-1965 |
| Annunziato Amendola 2001-present | Maurice Schnell 1964-1965 |
| Joseph Chen 2000-present | Richard Johnston 1967-1970, 1998-present |
| Todd McKinley 1999-present | Donald Kettelkamp 1968-1971 |
| R. Kumar Kadiyala 1998-2004 | Gerald Laros 1968-1971 |
| Leon Grobler 1996-1999 | Richard Stauffer 1970-1972 |
| Brian Adams 1993-present | John Albright 1971-present |
| Charles Saltzman 1991-2005 | Doug Mains 1972-1973 |
| John Callaghan 1990-present | Bruce Sprague 1972-1979 |
| David Tearse 1989-2000 | Richard Brand 1974-2002 |
| Ernest Found 1987-present | Mike Mickelson 1976-1981 |
| Lawrence Marsh 1987-present | Stuart Weinstein 1976-present |
| Curtis Steyers 1985-2006 | Thomas Lehmann 1978-1987 |
| James Nepola 1984-present | Joseph Buckwalter 1979-present |
| Fred Dietz 1984-present | William Pontarelli 1980-1984; 1999-2004 |
| James Weinstein 1983-1996 | Charles Clark 1980-present |
| Barbara Campbell 1982-1984 | William Blair 1980-1997 |



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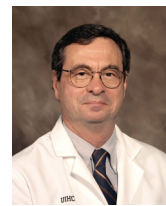
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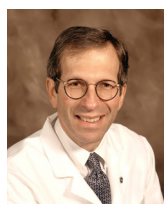
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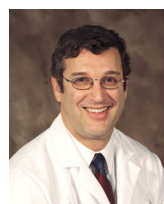
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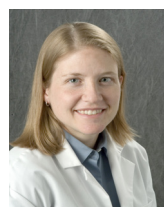
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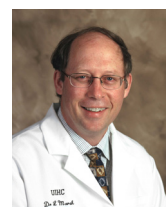
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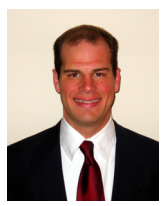
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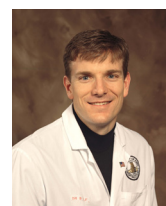
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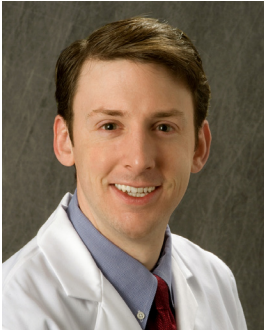


Dr. Brian Wolf



Dr. Robert Yang

2009 GRADUATING ORTHOPAEDIC RESIDENTS



John H. Flint, M.D.

John H. Flint was born in Modesto, California, the fourth of five children. His family enjoyed outdoor activities such as backpacking in the Sierras and the Coastal Range. When John turned 12, he and his family moved to Delaware where he completed middle school and

high school. He then attended, and graduated Summa Cum Laude from Brigham Young University in zoology with a minor in chemistry. After his first year of college he served a two year mission for his church in Sao Paulo, Brazil.

John then attended The University of Virginia School of Medicine in Charlottesville, Virginia. Between his first and second years of medical school he met his wife Regan while completing the Government Relations Internship Program in Washington, D.C. through the American Medical Association. As part of this program he interned at the National Highway Traffic Safety Administration working on the creation of educational materials regarding ten common medical conditions that affect older drivers.

Near the end of medical school, John and Regan were blessed with their first child, Harrison. During residency the Flint family added two more children, Tanner, now 3 years old, and Audrey, now one month old.

John dedicated a portion of his time during residency as a fellow with the Washington Health Policy Fellowship Program through the AAOS. As a fellow, he had the opportunity to lobby in Washington, D.C., advocating on behalf of orthopaedic patients, orthopaedic research, and fixing the sustainable growth rate. As a part of this program he also wrote several articles for the 'AAOS Now' magazine and created a website on aaos.org to educate residents regarding advocacy and the academy. He continues to be active with this group in promoting advocacy issues.

After completing residency, John will pursue an upper extremity fellowship at Triangle Orthopaedics in Raleigh/Durham, North Carolina, training in shoulder, elbow and hand surgery. Then he and his family will move to Flagstaff, Arizona, where he has taken a job with Flagstaff Bone and Joint.

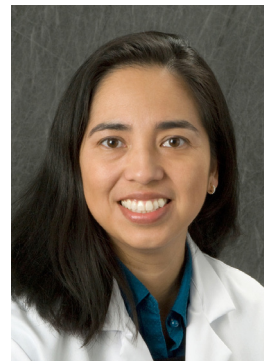


Craig Lyon, M.D.

Craig was born in Aurora, Illinois, and grew up in Sugar Grove, Illinois, with his twin brother and older sister. He attended Augustana College to play basketball with the dream of being an NBA small forward. During his freshman year someone pointed out that he was a six

foot white guy, so he decided to shift his focus to a career in track. He managed to win a national championship in high jump before suffering a serious foot injury which derailed his professional track career.

Somewhere along the line he decided orthopedic surgery would be a good fallback career since professional sports didn't seem to be working. He attended Rush Medical College in Chicago, Illinois. During residency he and his wife Shaunna were blessed with one son, Bradley. After residency Craig will be practicing general orthopedics in Lake Geneva, Wisconsin.



Teresa Mosqueda, M.D.

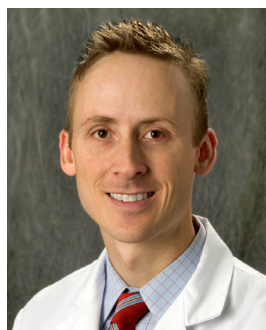
Teresa was born in Orange, California—the third of four children of a cement foreman and homemaker. She was the first in her large extended family to graduate from college and is the first doctor in the family. She left southern California to attend the University of the Pacific in Stockton, CA. She ran cross-

country during her freshman year, then transferred to San Diego State University where she completed her degree in kinesiology with an emphasis on athletic training. Teresa kept busy during her undergraduate career completing an athletic training internship and becoming a Certified Athletic Trainer, working part-time as an Athletic Trainer for the San Diego Chargers team physician, and working part-time for a local hand surgeon.

She then made the trek back north to attend medical school at the University of California, Davis. Here she was fortunate to find mentors in George Rab and Michelle James, both of whom encouraged her to pursue orthopaedic surgery. At the advice of George Rab, she

came to the University of Iowa during her fourth year of medical school to complete a sub-internship on the foot and ankle service. Despite telling Dr. Rab, “I’m from Southern California, what makes you think I would like Iowa?”, she discovered that he was indeed correct—she did like Iowa. Despite the hazards of driving a rear-wheel-drive truck in the winter, she has thoroughly enjoyed her five-year stint in Iowa City and now considers herself a “naturalized” Iowan.

Teresa will be packing up and heading west to Sacramento, to complete a fellowship in pediatric orthopaedics at the University of California, Davis/Shriners Hospital of Northern California. She is entertaining the idea of moving back to the Midwest after her fellowship.



Jaren Riley, M.D.

Jaren was born in the mountains of Gunnison, Colorado, to Fred and Sharyn Riley and grew up in the western U.S., living in Colorado, Seattle, and Utah. A two-year mission in Brazil taught him who he was and set his future goals. Upon his return to the U.S., he finished

his bachelor’s degree in psychology at the University of Utah. During the summer before coming to Iowa, Jaren met and instantly fell in love with Jessie Evans, and after a lengthy courtship of three months they married and moved to Iowa together.

Jaren loves the people of Iowa, their honesty, hard work, and integrity. He is grateful to have remained a Hawkeye throughout medical school and residency. Residency has tested his mental and physical capacities, and strengthened his love for his family. During the years in Iowa, he and Jessie were blessed with an angelic daughter, Aspen, and a rambunctious son, Porter. A second son is expected in May.

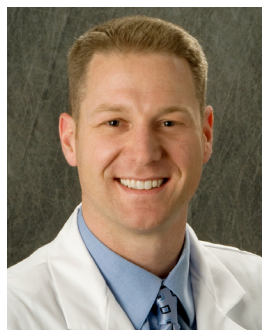
Next year, Jaren will return to the mountains of Utah. He looks forward to continuing his education in pediatric orthopedics when he finds the time along with climbing, fishing, and skiing. He credits any success in life to his wonderful wife, parents, and children.



Joseph Scordino, M.D.

Joe Scordino is originally from Binghamton, New York. He met his wife, Sarah, during medical school. He has one child, Siena, who is the apple of his eye. Joe and Sarah will be moving to Damariscotta, Maine next year where Joe will join a general orthopaedic practice. He has

thoroughly enjoyed his five years here at the University of Iowa.



Christopher Van Hofwegen, M.D.

Chris Van Hofwegen moved around a bit as a youngster, but for the most part he is an Iowan. After attending high school in Spencer, he went to Northwestern College in Orange City, Iowa. There he met Lisa, his wife, during a botany class. Ap-

parently studying flora wasn’t exciting enough to divert his attention from more stimulating surroundings. In any case, he spent much of his time the next four years playing basketball, studying, and trying to get into medical school. After graduation, he finally asked Lisa for a date. Unfortunately, she had begun medical school in Seattle and he had begun medical school in Iowa City. Thankfully, she accepted his delayed invitation.

Two years later they were married. Six years later they had their first child, Gabriel. Two years after that, almost to the day, they had their second, Calvin.

Next year their plan is to transition to the Hughston Clinic in Columbus, Georgia, for Chris’s sports medicine fellowship. Their final plan is still somewhat undecided, but they will likely land in a locale where snow does not predominate for the winter months.

Chris would like to thank his wife, family and friends for their support during residency. Ultimately it would not have been possible without them all.

2009 GRADUATING FELLOWS

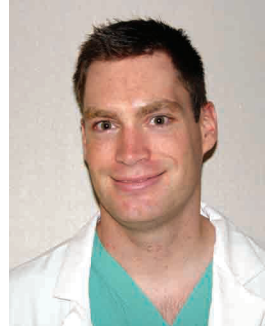


***Kristopher Aalderink,
M.D.***

Kristopher was born and raised in Western Michigan. He grew up in a Spartan household, an endless sea of “green and white,” as both of his parents had graduated from Michigan State University. Feeling rebellious following graduation from

high school, he and his twin brother succumbed to the dark side and attended the University of Michigan in Ann Arbor. He received his undergraduate degree in microbiology from the University of Michigan. He went on to attend the University of Michigan Medical School, where he met his wife, Monica. He then completed his orthopaedic surgery residency at Henry Ford Hospital in Detroit, MI.

Following the birth of their son, Lucas, Kris and Monica left Michigan for the great state of Iowa, for a one-year sports fellowship. This summer Kris will be moving with his family to southwest Florida, where he will join a private-practice orthopaedic group, practicing sports medicine and napping beneath the palm trees and sunny skies.



Allan Hammond, M.D.

Allan is in the orthopaedic department from January through June of 2009 for a Foot and Ankle Fellowship. He chose the Iowa fellowship program because it complemented his interest in lower extremity sports, reconstructive and trauma surgery, because of the unprecedented

arthroscopy laboratory opportunity, because of the notable history of the Iowa orthopaedic program, and the Canadian connection through Dr. Ned Amendola. Last but not least, he is here because his wife has family locally, and loves the Iowa City area.

Allan’s interests and hobbies include free-diving and scuba, even though there are somewhat limited possibilities locally, photography (both above and under water), wilderness hiking, and travel to remote places for all of the above.

NEW ORTHOPAEDIC FACULTY

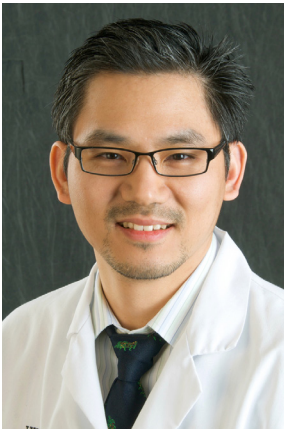


Heather Bingham, M.D.

Heather Bingham joined the University of Iowa Orthopaedics and Rehabilitation department in 2008 as the fourth physiatrist on the faculty.

She is originally from Utah and completed her bachelor's degree at Brigham Young University. She attended the University of Texas Southwestern Medical School at Dallas, graduating in 2004.

She completed her residency in Physical Medicine and Rehabilitation at the Mayo Clinic in 2008. Her clinical interests include spinal cord injury, EMG, neuro-rehabilitation, and ultrasound-guided procedures.



Phinit Phisitkul, M.D.

Phinit was born and raised in Bangkok, Thailand. He received his medical degree from Chulalongkorn University and completed his residency in orthopaedics at the Phramongkutklao Hospital and College of Medicine. He came to the University of Iowa Hospitals and Clinics and completed two fellowships: One in sports medicine (2004) and another in foot and ankle

surgery (2006). He then returned to Thailand and spent two years in academic practice at the Phramongkutklao Hospital and College of Medicine.

After accepting a position as a clinical assistant professor at the University of Iowa Hospitals and Clinics, he first spent several months in fellowships in foot-and-ankle endoscopy in Sheung Shui, Hong Kong, and in Amsterdam, The Netherlands. His clinical focus is on orthopaedic foot and ankle surgery.

Phinit's wife, Kantima, is currently in the first year of a nephrology fellowship at the University of Texas at Houston. It is hoped she will join the Internal Medicine Department at the University of Iowa Hospitals and Clinics as a hospitalist in 2010. Phinit and Kantima have a four-year-old son, Pat, who was born in Iowa. Pat enjoys everything in Iowa City and is also a big Hawkeye fan.



Christina Ward, M.D.

Although she is not new to the University of Iowa, Christina M. Ward, MD joined the faculty in October 2008 as Associate Professor specializing in hand surgery. She grew up in Lawrence, Kansas, and received her undergraduate degree from Grinnell College in Grinnell, Iowa. While at Grinnell, she met her husband, Nathan Lueck. After

completing medical school at Washington University in St. Louis, she began her orthopaedic residency at the University of Iowa. After a brief hiatus to care for her new daughter, Aleia, she completed her hand surgery fellowship at the University of Iowa in fall 2008. Christina and her family are enjoying their time in Iowa City while her husband completes his residency in the Department of Pathology.

The 2009 Michael Bonfiglio Award for Student Research in Orthopaedic Surgery

The 2009 Iowa Orthopaedic Society Medical Student Research Award for Musculoskeletal Research

As has been our tradition, the University of Iowa Department of Orthopaedics and Rehabilitation, along with the Iowa Orthopaedic Society, sponsor 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 medical convocation and consists of a plaque and a stipend. It is awarded to a senior medical student in the Carver College of Medicine who has done outstanding orthopaedic research during his or her tenure as a medical student. The student has an advisor in the Orthopaedic Department; however, the student must have played a major role in the design, implementation and analysis of the project. He or she must be able to defend the manuscript in a public forum. The research project may have been either a clinical or basic science project, and each study is judged on the basis of originality and scientific merit. The winner presents their work at the spring meeting of the Iowa Orthopaedic Society, as well as at a conference in the Department of Orthopaedics and Rehabilitation.

The second award is the Medical Student Research Award for Musculoskeletal Research. This award is for students in the Carver 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 \$2000 stipend, \$500 of which is designated as a direct award to the student, and \$1500 of which is designated to help defray continuing costs of the project and 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 selection committee, consisting of the president of the Iowa Orthopaedic Society (Dr. Tim Gibbons), as well as members of the Orthopaedics and Rehabilitation Department (Dr. Charles R. Clark, Dr. Joseph A. Buckwalter, Dr. Morcuende, Dr. Femino, and Dr. Wolf) recommended that Krishna S. Iyer, M1, receive the 2009 Michael Bonfiglio Student Research Award. Krishna's award was based on his project, "Biomechanical Modeling to Predict Those at Risk of Developing Painful Knee Osteoarthritis". His advisors were Dr. Donald Anderson and Dr. Neil Segal, and his co-investigators were Thomas D. Brown, M.D., Jennifer Baker and James C. Torner.

The selection committee recommended that The Medical Student Research Award be given to William Shyy, M2, for his research titled, "Etiology of Congenital Idiopathic Clubfoot: A Candidate Gene and Genechip Mapping Dual Approach in the Search for a Causal Gene." 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



From left to right: Charles R. Clark, M.D., Michael Bonfiglio Professor of Orthopaedic Surgery; Neil Segal, M.D., advisor to Krishna Iyer; Krishna Iyer, M1, winner of the Michael Bonfiglio Award for Student Research in Orthopaedic Surgery; Donald D. Anderson, M.D., Ph.D., advisor to Krishna S. Iyer; William Shyy, M2, winner of the Iowa Orthopaedic Society Medical Student Research Award for Musculoskeletal Research; Jose Morcuende, M.D., Ph.D., advisor to William Shyy; Joseph A. Buckwalter, M.D., Department Chair, Department of Orthopaedics and Rehabilitation.

CERAMIC ON CROSSLINKED POLYETHYLENE IN TOTAL HIP REPLACEMENT: ANY BETTER THAN METAL ON CROSSLINKED POLYETHYLENE?

John J. Callaghan, M.D.^{+,*,**} and Steve S. Liu, M.D.^{*}

ABSTRACT

The authors evaluated the use of ceramic femoral heads on crosslinked polyethylene bearing couples versus metal on crosslinked polyethylene couples in a consecutive series of hips performed by a single surgeon over a one year interval. Ceramic femoral heads and more extensively crosslinked polyethylene were used more commonly in the younger aged patients with utilization of ceramic heads in patients average age 50.2 versus 63.9 for metal heads, and utilization of more extensively crosslinked polyethylene in patients average age 54.1 versus 77.2 years for patients receiving less extensive crosslinked polyethylene. The authors explain the cost effectiveness of this approach where the difference in cost is approximately 36%.

INTRODUCTION

Following the work of Semlitsch and coworkers⁶ which demonstrated a 20:1 reduction in wear with alumina ceramic on polyethylene versus chrome cobalt on polyethylene bearing surfaces in a wear simulator, the use of alumina ceramic-polyethylene couples in total hip replacement became popular in Asia and Europe. The potential reason for this improvement with alumina ceramic heads included the superior lubricating properties (more wettable, hence better able to maintain lubricant on the surface), the hardness of the surface and the relative inertness of the material. These characteristics could potentially provide a decrease in the coefficient of friction at the bearing surface, less susceptibility to

third body wear and scratching of the surface and less biologic response to any debris generated by ceramic wear particles⁶ In clinical practice there have been some encouraging reports with ceramic polyethylene bearing surface couples in total hip replacement. Oonishi and coworkers⁴ in 1989 reported a 0.1 mm per year head penetration rate with alumina ceramic femoral heads compared with a 0.25 mm per year rate with metal femoral heads. We reported a series of 32 millimeter modular femoral heads mated to gamma irradiated in air polyethylene at 17 to 21 years with a 0.034 mm per year rate of head penetration.⁹ Wroblewski et al.¹¹ reported a head penetration rate of 0.019 mm per year with a 22.225 mm alumina ceramic femoral head—chemically crosslinked polyethylene bearing surface at 17 year follow-up. These results encouraged the senior author to use ceramic femoral heads with crosslinked polyethylene at the bearing surface in patients he considered to be at a relatively high risk for accelerated wear. This study evaluates the usage trends of various bearing surface couples of a single surgeon practice over a one-year period. The authors hypothesized that the most expensive bearing surface couples would be utilized in the patients at higher risk for wear.

MATERIALS AND METHODS

We evaluated 133 consecutive primary total hip replacements performed by a single surgeon (JJC) over the course of a one-year interval (June 2007 to June 2008). A 5 megarad remelt gamma irradiated (Marathon, DePuy, Warsaw, Indiana) or a 7.5 megarad remelt gamma irradiated (Altrx, DePuy, Warsaw, Indiana) polyethylene was utilized in all cases. These were coupled with a metal (Articulaze, DePuy, Warsaw, Indiana) or ceramic (Articulaze Delta Ceramic, DePuy, Warsaw, Indiana) femoral head with diameters of 28 mm, 32 mm, or 36 mm in all cases except one. The remaining case was 26 mm metal head (Bantam Femoral Head, DePuy, Warsaw, Indiana). All acetabular and femoral components were cementless porous coated devices. The age, sex, and body mass index (BMI) of the patient cohort are summarized in Table I as are the head material and polyethylene treatment.

⁺The Lawrence & Marilyn Dorr Chair

^{*}University of Iowa, Iowa City, IA

^{**}VA Medical Center, Iowa City, IA

One author (JJC) has received funding from DePuy (Warsaw, IN).

Each author certifies that his institution has approved the reporting of these cases, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

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TABLE 1
Summary of Entire Cohort

| | Total Hips (n = 133) | % |
|---------------------------|----------------------|-------|
| Head Material: | | |
| Metal | 70 | 52.6% |
| Ceramic | 63 | 47.4% |
| Polyethylene Liner | | |
| 5 megarad | 19 | 14.3% |
| 7.5 megarad | 114 | 85.7% |
| Age (years) | | |
| Mean | 57.4 | |
| Median | 59 | |
| Range | 17 - 94 | |
| Avg Age Males | 56.1 | |
| Avg Age Females | 58.6 | |
| Sex | | |
| M | 64 | 48.1% |
| F | 69 | 51.9% |
| BMI | | |
| Mean | 32.2 | |
| Median | 31.2 | |
| Range | 19.1 - 57.9 | |

We evaluated the usage trends of the various bearing couples in terms of the patient demographics of age, sex and BMI. In addition, a cost analysis was performed based on the manufacturer's list price of the various components.

RESULTS

The demographics of the patients who underwent primary total hip arthroplasty during the time interval studied along with the distribution of patients receiving the various bearing surface materials (heads and liners) are listed in Table 1. The distribution of femoral head material utilized versus demographics are listed in Table 2. The distribution of polyethylene type versus demographics are listed in Table 3.

In regards to age, the younger patients received the more costly ceramic femoral heads ($p < 0.0001$ t-test) with the average age of patients with ceramic heads 50.1 years versus 63.9 years for patients with chrome cobalt femoral heads. Likewise in regards to age, the younger patients received the more costly 7.5 megarad gamma radiated remelt crosslinked polyethylene (average age 54.1 years) rather than the 5.0 megarad gamma radiated remelt crosslinked polyethylene (average age 77.2 years), $p < .001$ (Tables 2 and 3). Older patients received a greater percentage of 36 mm heads and younger patients received a greater percentage of 28 mm heads (TUKEY's multiple comparisons $p = 0.0005$). Males tended to receive heads of larger diameters ($p =$

TABLE 2
Comparison of Femoral Head Components

| | Metal Heads (n = 70) | % | Ceramic Heads (n = 63) | % |
|------------------|-------------------------|-------|---------------------------|-------|
| Head Size | | | | |
| 26 mm | 1 | 1.4% | | |
| 28 mm | 16 | 22.9% | 14 | 22.2% |
| 32 mm | 34 | 48.6% | 36 | 57.1% |
| 36 mm | 19 | 27.1% | 13 | 20.6% |
| Age | | | | |
| Mean | 63.9 | | 50.2 | |
| Median | 65 | | 52 | |
| Range | 17 - 94 | | 19 - 69 | |
| Sex | | | | |
| M | 24 | 34.3% | 40 | 63.5% |
| F | 46 | 65.7% | 23 | 36.5% |
| BMI | | | | |
| Mean | 32.9 | | 31.4 | |
| Median | 31.6 | | 30.3 | |
| Range | 19.1 - 57.9 | | 19.3 - 46.8 | |

TABLE 3
Comparison of Polyethylene Components

| | 5 megarad (n = 19) | % | 7.5 megarad (n = 114) | % |
|-----------------|-----------------------|-------|--------------------------|-------|
| Cup Size | | | | |
| 46 mm | 1 | 5.3% | | |
| 48 mm | 1 | 5.3% | 4 | 3.5% |
| 50 mm | | | 9 | 7.9% |
| 52 mm | 10 | 52.6% | 63 | 55.3% |
| 54 mm | 4 | 21.1% | 16 | 14.0% |
| 56 mm | 2 | 10.5% | 20 | 17.5% |
| 60 mm | | | 2 | 1.8% |
| 70 mm | 1 | 5.3% | | |
| Age | | | | |
| Mean | 77.2 | | 54.1 | |
| Median | 80 | | 57 | |
| Range | 23 - 94 | | 17 - 74 | |
| Sex | | | | |
| M | 4 | 21.1% | 60 | 52.6% |
| F | 15 | 78.9% | 54 | 47.4% |
| BMI | | | | |
| Mean | 29.4 | | 32.6 | |
| Median | 29.6 | | 31.6 | |
| Range | 20.3 - 43.3 | | 19.1 - 57.9 | |

0.009 Fisher Exact). Males tended to receive 7.5 megarad polyethylene more often than females ($p = 0.01$ Chi Square test). This was the case even though the average age of males was similar to the age of females (56.1 vs 58.6, respectively). When 5.0 megarad polyethylene was used, the surgeon was more likely to use a large (36 mm) diameter head because this polyethylene was used in the older age group of patients ($p < .0001$). The ceramic femoral heads were more commonly mated with the 7.5 megarad polyethylene (Chi Square test $p < 0.0001$).

The list price for a 36 mm ceramic head mated with a 7.5 megarad remelt crosslinked polyethylene liner is \$4,619.88 compared to the price of a 36 mm metal femoral head mated with a 5.0 megarad remelt crosslinked polyethylene liner is \$3,391.53. Hence, the ceramic-7.5 megarad remelt crosslinked polyethylene articulation cost 36% more than the metal-5.0 megarad remelt crosslinked polyethylene articulation.

DISCUSSION

Wear simulator studies as well as long term clinical studies have demonstrated the potential benefit in wear reduction of a ceramic femoral head on polyethylene bearing surface couple in total hip arthroplasty.^{4,6,7,9} This potential benefit has been attributed to the wettability, hardness, and inertness of the alumina ceramic material.⁶ The concerns over the use of ceramic femoral head on polyethylene versus metal on polyethylene bearing surfaces are the increased cost of materials and the potential for femoral head fracture.^{1,10} The present study evaluated the usage of ceramic femoral heads on crosslinked polyethylene and metal heads on crosslinked polyethylene at the articulating surface of primary total hip replacements performed by a single surgeon over a one year interval. This study was intended to analyze whether the more costly ceramic heads as well as a more costly crosslinked polyethylene were utilized in the patients at higher risk for wear.

As hypothesized, the ceramic femoral heads were utilized in the younger patients (average age 51.1 years versus 63.9 years for the metal heads). Likewise, the more extensively crosslinked material was utilized in the younger patients with an average age 54.1 years for the 7.5 megarad material versus 77.2 years for the 5.0 megarad material. The ceramic heads were most commonly mated with the 7.5 megarad polyethylene and both were more commonly utilized in males. Long term follow up studies of total hip replacement patients have documented increased polyethylene wear, determined by femoral head penetration, in younger patients as well as in males versus females.⁵ Body mass index did not correlate with the use of any specific bearing couple. Hence the more expensive ceramic head on more extensively crosslinked polyethylene was more commonly utilized in the younger more at risk population for increased wear and the threshold to use the more expensive bearings was lower in the more, at risk for wear, male population. The ceramic head-more extensively crosslinked bearing couple was used at a 36% increased expense using list price figures. This represents an increase of \$1,225.

Bozic et al² have calculated that an incremental cost in total hip arthroplasty of a new technology in a 50 year old of \$2,000 would need a 19% reduction in 20

year survival over an older technology. Conversely, an alternative bearing that added only \$500 to the cost of a conventional total hip arthroplasty could be cost-effective in a population of patients over the age of 65 years, even if it were associated with only a modest reduction in the revision rate. At least in terms of a marked reduction in wear demonstrated with a ceramic on polyethylene bearing surface both with gamma in air polyethylene, 0.034 mm/year⁷, and crosslinked polyethylene, 0.019 mm/year⁹, compared to the best studies demonstrating 0.1 mm/year⁵ with metal on gamma in air polyethylene and 0.03 mm/year with metal on crosslinked polyethylene,³ it appears to be a reasonable cost effective strategy to use ceramic on crosslinked polyethylene in the younger aged population as was utilized in this study when one considers the cost increase would probably be one half or less of the \$1,225 increase we calculated using list prices. Especially with the most recent reports of less than 0.004% fracture rates with ceramic heads⁸ and the hope that the newer alumina zirconia heads may further lower this rate, any catastrophic consequences of fracture including the inferior results with revision of these fractures because of the debris may be close to eliminated.¹

The authors recognized that a limitation of this study is the inability to definitely measure any cost effectiveness of our strategy because of the limited data on revision rate comparisons of these two bearing surface couple option in total hip replacement. With the evidence available however, the senior author continues to use ceramic head-extensively crosslinked polyethylene in the patients at higher risk for wear in his total hip arthroplasty procedures.

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COMPONENT VERSION IN MODULAR TOTAL HIP REVISION

Michael A. Kopec, B.Sc., Aaron Pemberton, M.D., Joseph C. Milbrandt, Ph.D., D. Gordon Allan, M.D. FRCS(C)*

ABSTRACT

Morphologic changes of the proximal femur make revision total hip arthroplasty challenging. Metaphyseal retroversion and diaphyseal varus are common in this scenario. Twenty-one total hip revisions using a modular femoral prosthesis were examined by obtaining three radiographs (A/P, surgical lateral, and true lateral of the femur) to assemble CAD models for determining the range of modular component positioning. An average of femoral neck anteversion was observed. Seventeen of 21 cases (81%) had retroverted metaphyseal segments ($-23.2^{\circ} \pm 17.4^{\circ}$) and/or varus stems ($-32.1^{\circ} \pm 13.0^{\circ}$). Neck anteversion averaged $21.4^{\circ} (\pm 10.0^{\circ})$. One of 21 cases (5%) resulted in component orientation similar to a non-modular prosthesis. Modular components provide options to accommodate proximal femoral remodeling not afforded by monobloc stems in total hip revision surgery.

INTRODUCTION

The benefits of modular femoral prostheses in total hip replacements have long been debated.¹⁻⁶ Modular stems provide the advantage of intraoperative flexibility to deal with the distorted femoral anatomy often encountered in revision surgery. Notable drawbacks of some designs include taper fretting/corrosion, and increased technical difficulty. Clinically, several investigators have noted satisfactory results with modular implants in both primary and revision scenarios.⁷⁻¹¹ In revision surgery, independent neck and stem placement allows for adjustment of the rotational alignment of the components into configurations not available in common single stem revision implants. The surgeon is thus better equipped

to deal with patients who have suffered from extensive bone loss, bony remodeling, periprosthetic fractures or developmentally atypical anatomy.

To our knowledge, the degree to which surgeons take advantage of rotational alignment configurations afforded by modular femoral stems has never been assessed. The present study quantifies the magnitude and direction of modular femoral components occurring in total hip revision surgery (Acumatch M-Series, Exactech Inc. Gainesville, FL, USA).

MATERIALS AND METHODS

Radiographs were obtained for twenty-one modular revision THAs in 21 patients that were performed over a thirty-month period by the senior author. Patient ages ranged from 37 to 87 years and indications for revision included twelve patients with aseptic loosening, four cases of sepsis, four periprosthetic fractures, and one mechanical device failure. Each patient had a well-fixed stem at his or her last clinical radiographic evaluation.

The Implant and Instrumentation: The AcuMatch M-Series (Exactech Inc. Gainesville, FL, USA) is a three-piece modular stem. Each component is compatible with all others such that any neck segment can be used with any size metaphyseal segment and with any size diaphyseal component. Rotational alignment of each segment is also independent. The stem is placed in a canal prepared by reaming, while the metaphysis is machined using a special reamer and guide whose location is controlled by the reamed canal.

In each case an M-series modular femoral stem with a curved distal stem was implanted. Diaphyseal diameters ranged from 13mm to 19mm with lengths between 200mm and 300mm. Metaphyseal segments were sized between 21mm extra small and 29mm small. Likewise, all femoral heads were 28mm in diameter with neck lengths ranging from -5mm to $+10\text{mm}$. Neck segment sizes ranged from -5mm with high offset to $+30\text{mm}$ with standard offset.

Surgical Technique: The femur was prepared with sequential flexible reamers until the cortex was engaged. The metaphysis was machined using the "basket" guide aligned with the reamed femoral canal accommodating the existing shape of femur at that level.

Implant Trialing and Placement: Trialing was used to determine the size and rotation of the implanted

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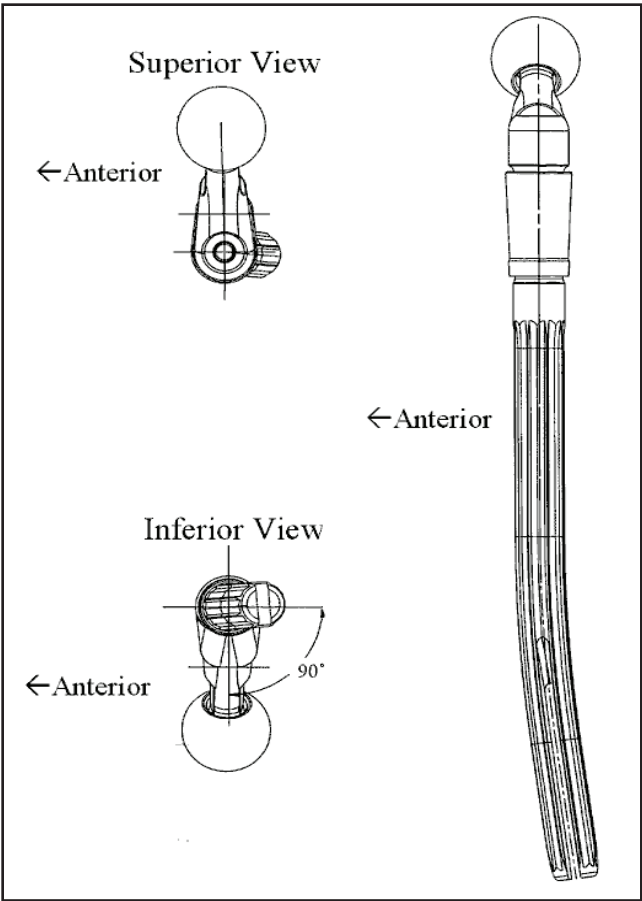


Figure 1. Implant with zero version.

component. The diaphyseal and metaphyseal trials were inserted together, although still able to be rotated about one another. The metaphyseal segment was positioned into the proper rotational orientation to conform to the bony metaphysis. The trial neck was applied and the locking bolt secured, fixing the orientation of the components. This construct was used as a template to assist in judging insertion of the definitive implants in a way that corresponds to the inner geometry of the bony architecture, recognizing that added adjustment can be performed with final insertion.

A diaphyseal component, 1 mm larger than the reamed canal, was introduced, engaging the sharp stem flutes to ensure rotational stability. A clothespin stem was used to reduce stress distally. The titanium plasma coated metaphyseal component with dual female tapers was introduced using an inserter that facilitates positioning and locking of the segments. The orientation of the femoral neck component (available in several lengths and two different offsets) was determined by the surgeon, and was typically 10 to 15 degrees of anteversion. Greater anteversion was required when persistent posterior instability was present.

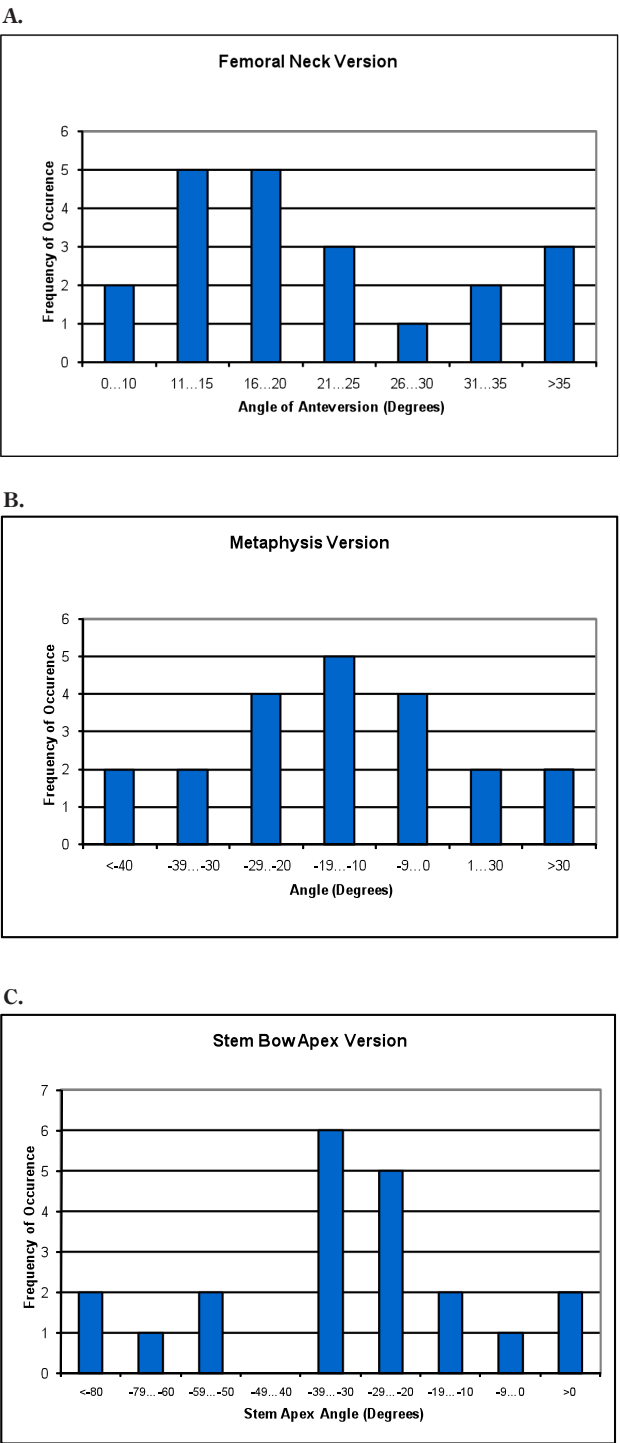


Figure 2. Distribution of neck (a), metaphysis (b), and stem bow (c) orientations.

Radiographic Analysis: Positioning of the modular femoral components was evaluated by obtaining an anterior/posterior and two lateral radiographs (true lateral of femur and surgical lateral of hip) for each patient. The radiographs from each case were retrospectively reviewed to determine the magnitude and orientation of the rotation of the components.

The surgical lateral view was used to assess the degree of anteversion of the femoral neck via the method described by Ghelman.¹² Three dimensional solid models of the individual implant components were assembled using Unigraphics (EDS Corporation, Plano, Texas), a commercial software package for computer-aided design (CAD). The individual components depicted by the CAD system were then rotated to mimic the alignment seen in the A/P radiograph. The model was then compared to the two lateral radiographs and adjustments were made to reconcile the three views. When the alignment of the model matched all three radiographs, the angle between the centerline of the neck segment and the center of the metaphyseal flare was measured. A measurement of 0° between the neck centerline and metaphyseal flare represents a version of zero. The angle between the centerline of the neck segment and the apex of the distal stem bow was also measured, with a measurement of 0° representing zero version. A component with zero version is shown in Figure 1. With the neck anteversion established, the orientation of all components relative to the planes of the body could be assessed.

Two-tailed t-tests with unequal sample variances (student's test) were used to assess statistical significance, which was assumed to exist at $p < 0.05$.

RESULTS

An average of $21.4^\circ \pm 10.0^\circ$ (S.D.) of femoral neck anteversion was observed in our series. This value falls close to that which has been recommended by several investigators.¹³⁻¹⁵ The metaphyseal segments averaged $35.0^\circ \pm 40.6^\circ$ version from the coronal plane. Likewise, an average of $36.6^\circ \pm 18.0^\circ$ of version was measured between the sagittal plane and the apex of the stem bow. In only one case were the components oriented in the configuration shown in Figure 1. The distributions of neck, metaphysis and stem bow versions are shown in Figure 2.

As seen in Figure 3, the majority of the metaphyseal segments faced posteromedially (17/21, $\theta = -23.2.1^\circ \pm 17.4^\circ$ S.D.), with two facing anterolaterally ($n = 2$, $\theta = 149^\circ \pm 8.59^\circ$), and two facing anteromedially ($n = 2$, $\theta = 20.9^\circ \pm 16.4^\circ$). The anterolateral group, which was composed of two patients with complex periprosthetic fractures was significantly different from both the anteromedial ($p < 0.05$) and posteromedial ($p < 0.01$) groups

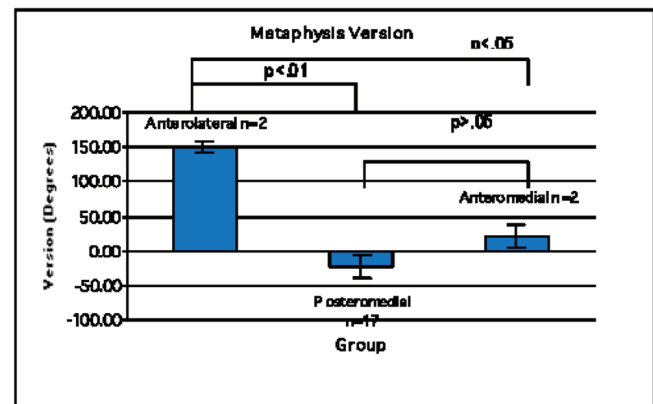


Figure 3. Metaphysis version from coronal plane by group.

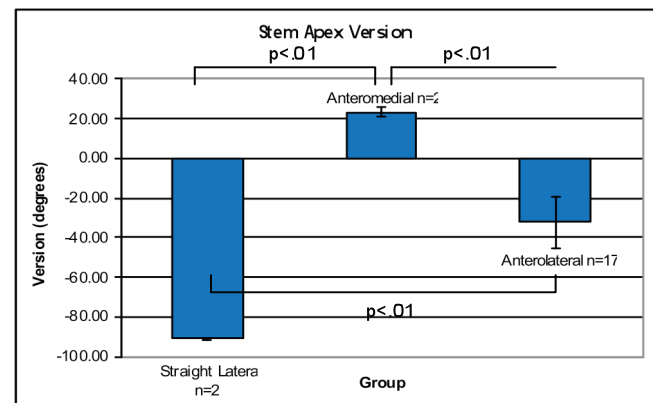


Figure 4. Stem bow version from sagittal plane by group.

indicating that such revisions seem to require a distinct set of component orientations. The two patients in the anteromedial group were admitted for infection and a periprosthetic fracture, and neither appeared to have undergone extensive remodeling.

The most common stem apex orientation was anterolateral ($n = 17$, $\theta = -32.1^\circ \pm 13.0^\circ$ from sagittal plane) followed by anteromedial ($n = 2$, $\theta = 4.8^\circ \pm 17.5^\circ$) and straight lateral ($n = 2$, $\theta = 85^\circ \pm 0^\circ$). Each group was significantly different from the others ($p < 0.05$). Figure 4 depicts the neck and stem bow version from the sagittal plane for the directional groupings. The presence of the latter two groups indicates a deviation from the normal bow of the femur, which is directed posteriorly and medially.

Figures 5, 6 and 7 illustrate three specific cases in which rotational alignment has been significantly altered from that shown in Figure 1. Figure 5 shows a patient whose metaphyseal segment has been seated in marked anteversion in accordance with the geometry of the residual proximal femur. Here 40° of femoral neck anteversion (the most of any revision) was required to avoid

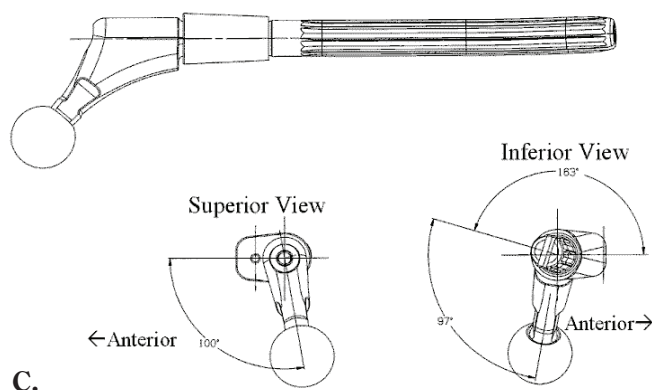
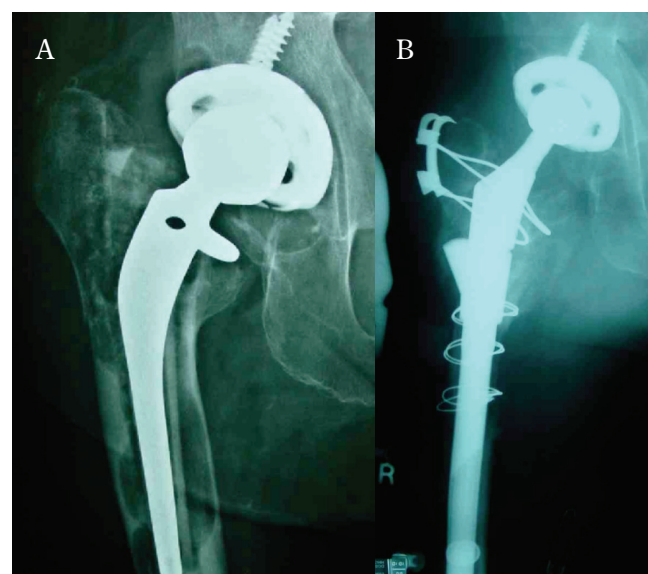


Figure 5. Pre (A) and Postoperative (B) A/P radiographs and corresponding model (C) showing insertion of the metaphyseal segment in anteversion necessitated by a fracture of the greater trochanter and proximal femur, as well as extensive osteolysis. Metaphysis shows 100° version between itself and the centerline of the femoral neck, and is now anteverted 141° from the coronal plane. Apex of stem faces 34° lateral of straight anterior.

posterior instability. Figure 6 represents a distal stem segment implanted with the stem bow facing laterally to correspond to the bow of the native femur. Figure 7 depicts an instance of a metaphyseal segment implanted in marked retroversion from metaphyseal remodeling.

DISCUSSION

In only one case of twenty-one implantations was neck, metaphysis, and diaphysis orientated similarly to a one-piece stem (metaphysis facing straight medially and apex of stem bow facing anteriorly), indicating that neck and metaphysis version often needed to be established independently from stem placement. The large variances and multiple directional groupings observed suggest that the independent positioning of components afforded by

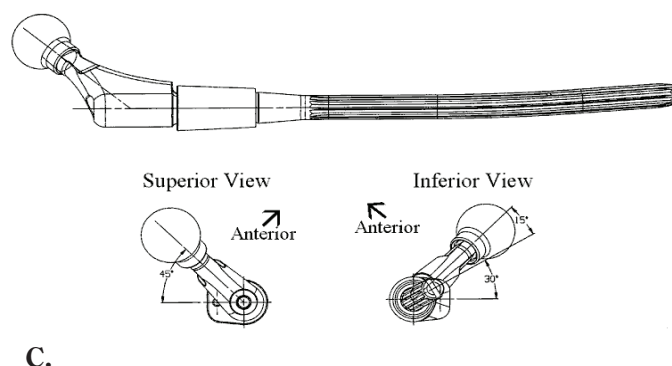
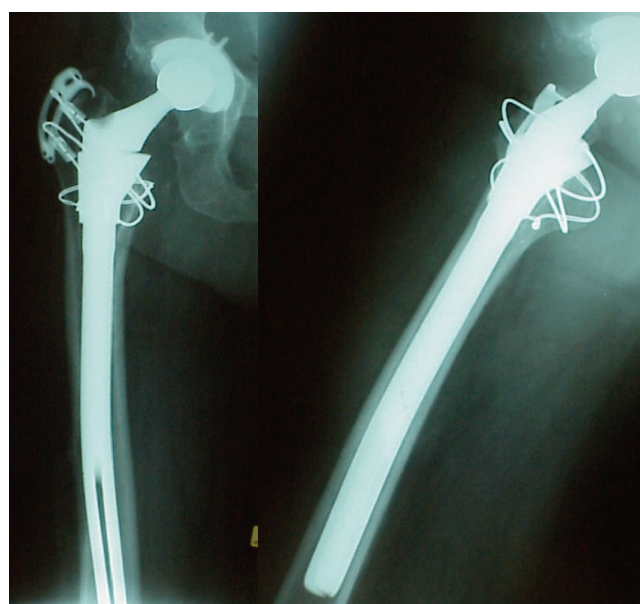


Figure 6. A/P radiograph (A), lateral radiograph (B) and corresponding model (C) demonstrating lateral placement of distal stem bow. Metaphysis is rotated 45° from the centerline of the neck and is seated in 30° of retroversion. Apex of Stem bow faces straight laterally.

a modular stem is beneficial during revision surgeries when extensive bony remodeling, periprosthetic fractures, and atypical anatomy may hinder proximal femoral fixation of single stem implants. Such fixation has been previously noted to be of paramount importance to clinical success.^{16,17}

The most common metaphyseal orientation was posteromedial (81% of cases) indicating that many of the patients had undergone substantial metaphyseal remodeling into retroversion, which was often secondary to gross loosening prior to revision surgery. Bony remodeling of the proximal femur into retroversion has been postulated to occur as a result of posteriorly oriented torsional loads encountered during activities such as stair climbing, and has been noted in the literature in both cemented and press fit implants.^{18,19}

Had noncemented single stem implants been implanted in many of the patients in the present study, a

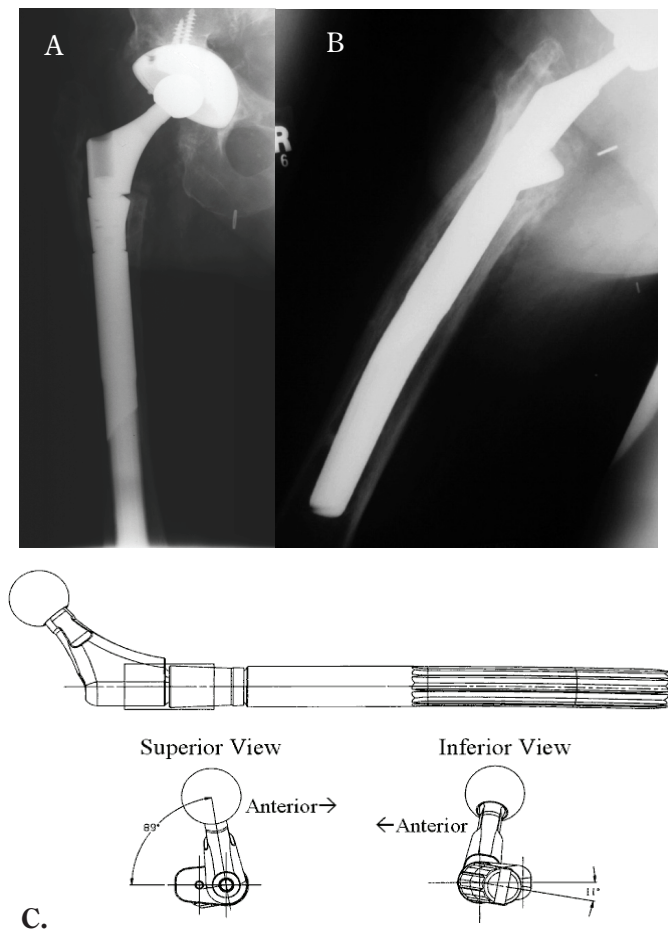


Figure 7. A/P radiograph (A), lateral radiograph (B) and corresponding model (C) depicting implantation with metaphyseal segment seated in marked retroversion and distal stem segment in standard position. Metaphysis is rotated 89° from neck centerline and now faces nearly straight posterior in 78° of retroversion. The stem apex faces 4° lateral of straight anterior.

tradeoff would have to be made between the femoral stem version that offered the best fixation and that which offered the best joint stability. Moreover, a compromise that places fixation as paramount and consequently deviates from optimal neck version has been observed to shift the location of peak stress on the femur, inducing larger bending moments on the anterior and posterior aspects of the proximal femoral shaft.²⁰ The increased stresses could potentially induce micromotion and jeopardize fixation over time.

The majority of distal stem segment apices faced anterolaterally; this finding is consistent with the bow of the natural femur, which is in both the lateral and anterior directions. Migration of total hip arthroplasties into varus has long been seen as an indicator of aseptic loosening.²¹⁻²⁴ The presence of six hips (28.6% of cases) with greater than 50° version in the anteromedial direction suggests significant varus remodeling of the proxi-

mal femur as a result of loosening and varus migration of the primary arthroplasty. As was the case with the establishment of metaphysis version, the intraoperative flexibility allowed by independent stem placement may permit stem positioning that more closely approximates the native femur, and perhaps enables the surgeon to utilize a highly modular prosthesis with a curved stem in situations where implantation of a straight cylindrical stem would have required extended trochanteric osteotomy.²⁵ Although, as of late, there have been several reports of good to excellent union rates in revision THA using extended trochanteric osteotomy,²⁶⁻²⁸ there still persists the risk of non-union, trochanteric fragment escape, fracture of the proximal femur, and the need for an extensively porous coated stem of a potentially uncommon length and diameter. Additionally, Noble has reported a 73% decrease in torque to failure in a cadaveric study comparing the torsional strength of the native femur to that of one which contained an implant and had been osteotomized and repaired.²⁹ The reduced torsional strength may be significant clinically when weighting the use of a modular stem versus an extensively porous coated stem and extended trochanteric osteotomy, since patients who undergo extended trochanteric osteotomy will need to remain non-weight-bearing for a longer time and avoid extensive abductor muscle activity longer than undergoing revision surgery with a modular prosthesis.

We conclude that during difficult revision surgeries, rotational alignments that deviate from those offered by single stem implants are both necessary and quite common. It can, therefore, be inferred that stem modularity has both tangible and quantifiable benefits during total hip revision especially when attempting to fit the implants to the residual bony anatomy.

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DOES FUNCTIONAL IMPROVEMENT FOLLOWING TKA CORRELATE TO INCREASED SPORTS ACTIVITY?

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ABSTRACT

Improved TKA designs and surgical techniques have allowed surgeons to not only treat the pain associated with osteoarthritis but also to restore function. The present study analyzed whether the increase in physical activity of patients following surgery is associated with their level of functional and objective improvement. An activity questionnaire was utilized to collect pre- and post-operative information from 355 patients (417 knees). Corresponding functional and objective assessments were collected using the Knee Society rating system. Overall, a mean 48 point (range, -44 to 97 points) improvement in Knee Society function score showed moderate correlation to a 2.5 point (range, -40 to 57 points) increase in weighted activity score ($R = 0.362$). There was less of a correlation between the mean objective score increase of 49 points (-32 to 84 points) and change in activity level ($R = 0.194$). There were 29% of the patients who showed no change in activity level. These results suggest that change in activity level is more closely associated with improved function than changes in objective measures. With more than 52% of TKA patients reporting increased activity scores, further studies are needed to as-

sess longer-term effects of activity levels on the durability of these prostheses.

INTRODUCTION

Total knee arthroplasty (TKA) has been shown to provide excellent short- and long-term outcomes in individuals who are largely sedentary.¹⁻⁴ Recently, there has been more attention to patients achieving more functional outcomes and participating in various sporting activities after total knee arthroplasty. This is still an ill-defined area with some orthopaedic surgeons recommending only sedentary activities and other surgeons allowing certain low impact sports.^{5,7} Typically, higher impact sports have not been recommended after TKA. However, it is generally accepted that some level of exercise is beneficial and ideally, the return of function and relief of pain provided by TKA will lead to increased exercise and an overall healthier lifestyle. It remains unclear whether improved functional and objective outcomes correlate with an increase in activity level.

Part of the difficulty of analyzing the effects of differing activity levels on knee replacement outcomes is that there is no validated method to analyze these activity levels. The Knee Society functional score describes basic activities such as use of a cane and walking up and down steps.⁸ There have been a few recent studies that have described functional results of patients with total knee arthroplasty. For example, Noble et al. reported on the functional results of 257 knee patients.⁹ They found that 48% of the patients did not report a functional limitation while participating in activities. In another recent report, 72 high activity knee replacement patients were compared to sedentary TKA patients and found similar clinical and radiographic outcomes at a mean follow-up of 7 years.¹⁰ The authors analyzed patients with an activity scale which was made up of two components; patient activities and impact of activity levels based on Knee Society and American Association of Hip and Knee Surgeons (AAKHS) recommendations. This activity score lacked any information on the duration of sports participation. There are a few other activity scores that have been utilized, but most are qualitative and have not been validated. For example, the UCLA score is a 10-point scoring system based on a general question about activity participation. It has been recommended

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Each author certifies that his or her institution has approved the human protocol for this investigation and that all investigations were conducted in conformity with ethical principles of research.

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TABLE 1
Impact scores for each activity listed on the sports activity questionnaire

| Impact Score = 1 | Impact Score = 2 | Impact Score = 3 |
|------------------------|-------------------------|-------------------|
| Aerobics | Ice Skating | Baseball/Softball |
| Badminton | Roller/Inline Skating | Basketball |
| Bicycling (road) | Skiing (cross country) | Football |
| Bicycling (stationary) | Skiing (downhill) | Gymnastics |
| Bowling | Tennis (singles) | Handball |
| Croquet | Weight lifting/machines | Hockey |
| Dancing | | Jogging |
| Farming | | Lacrosse |
| Fencing | | Martial Arts |
| Gardening | | Racquetball |
| Golf | | Rock Climbing |
| Hiking | | Soccer |
| Horseback Riding | | Squash |
| Horseshoes | | Volleyball |
| Rowing/Canoeing | | |
| Shooting/Hunting | | |
| Shuffleboard | | |
| Speed Walking | | |
| Swimming | | |
| Tennis (doubles) | | |

that this score can be adjusted based on a visual analog scale and the surgeons assessment of the frequency and intensity of activity.¹¹

This study evaluated changes in activity levels following TKA by asking a number of questions: 1) Can a weighted activity score (adding temporal and duration components, and other new recommendations) be easily utilized for TKA patients?; 2) Does functional improvement correlate to an increase in this weighted activity score?; 3) Does objective improvement predict changes in weighted activity score?; 4) What are the activity levels of patients relative to functional and/or objective outcome?; and 5) Do various clinical or demographic factors influence the weighted activity score and objective functional outcomes?

MATERIALS AND METHODS

A group of 417 total knee arthroplasties were assessed for clinical and radiographic follow-up at three institutions between August 1, 2006 and August 1, 2007. The primary purpose of this study was to analyze the weighted activity score for these patients and correlate these to objective and functional outcomes. The activity survey was utilized a cross-sectional assessment of patients who were returning for follow-up for a minimum of 12 months following TKA. All patients who enrolled in this study had Institutional Review Board approval from each center.

There were 162 men and 255 women who had a mean age of 69 years (range, 35 to 95 years). The group consisted of only patients with primary osteoarthritis and excluded any patients with osteonecrosis or post-traumatic arthritis, rheumatoid arthritis or other diagnoses. Patients had a mean body mass index of 31 (range, 17 to 51). Patients were followed for a mean of 36 months (range, 12 to 116 months).

Patients were evaluated with a new weighted activity questionnaire which can be found in Appendix I. A previously reported questionnaire included a listing of activities, frequencies of the activity participation per week, month, and years, and a series of patient-related questions that had to do with activity level, competitiveness, and satisfaction.¹⁰ The activities were then given scores of 1 to 3 points based on a previous Knee Society survey. Activity scores were calculated using frequency times weighted points. The new weighted activity score utilizes all of these questions with some small modifications, but added further information concerning time of involvement per day. In addition, changes were made for the stratification of the sports on the 3-point scale to reflect recent recommendations based on impact level.¹² Table 1 provides the weighted score for each of the sports. Sports listed by the patient on their survey in the "Other" category were assigned a weighted score based on the surgeon assessment of impact level and

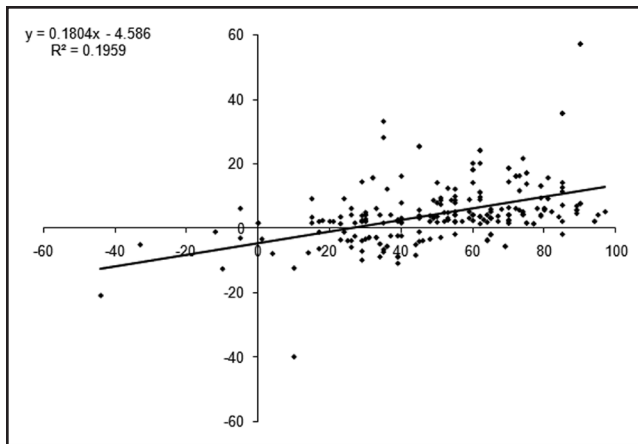


Figure 1. There was a moderate, positive correlation between the increase in Knee Society functional score and the increase in weighted activity score. This figure shows the change in functional score on the x-axis and change in activity score on the y-axis, excluding those patients who had relatively no change in activity level.

whether they recommend the activity for their patients. Patients were administered pre- and post-operative activity questionnaires and the change in weighted activity score was determined for each patient.

All the knees were evaluated using the Knee Society objective and functional scores.⁸ As previously noted, the activity questionnaire was also used to collect data concerning patient satisfaction using a Likert 10-point scale.¹³ Various demographic variables were collected for all of the patients which included age, gender, body mass index, Charnley class,¹⁴ as well as American Society of Anesthesiologists (ASA) classification.

All of the data for weighted activity scores, as well as demographic data and Knee Society objective and functional scores and satisfaction indices, were collected using a Microsoft Access Database (Microsoft Corporation, Seattle, Washington). Data was exported to SPSS version 13.0 software (SPSS Incorporated, Chicago, Illinois) for statistical analysis. An initial power analysis indicated our sample size was sufficient to answer our primary research questions at a power of 80% ($\alpha = 0.05$) for an effect size of 0.2 for the correlation coefficients assessed. All correlations were assessed by Spearman's rank coefficient. Linear regression analysis was used to analyze the correlation of change in functional and objective outcomes and the corresponding change in weighted activity score. Based on initial survey results suggesting a large proportion of patients reporting no change in activity level, we re-assessed the linear correlations after excluding patients who had less than plus or minus one point change in their activity scores. In addition to evaluating the change in scores, we also compared the final outcomes based on post-operative Knee Society objective and function scores with the final weighted scores. In order to assess which demo-

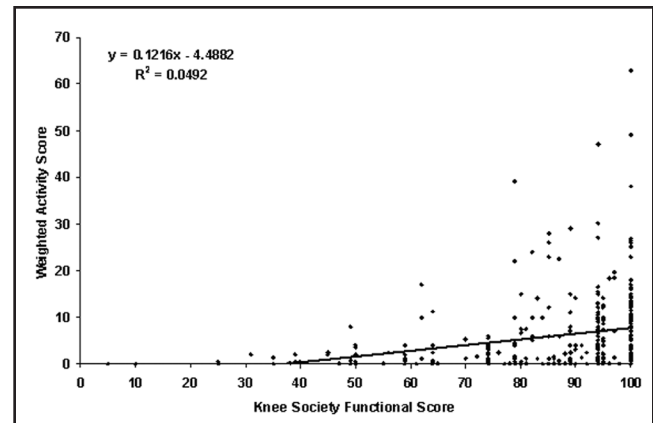


Figure 2. Patients who had higher functional scores were consistently more active than their counterparts who had lower scores.

graphic factors may have affected the weighted activity score as well as the functional and objective outcomes, we conducted a stepwise regression analysis including age, gender, BMI, Charnley class, and ASA classification as potential predictors of change in activity and final activity scores. Additionally, the data was stratified by each of these variables and a Chi-square analysis was used to compare the proportions of patients who had a decrease in activity level, no change, or an increase in activity level.

RESULTS

Overall, the Knee Society function score increased by a mean of 48 points (range, -44 to 97 points) from pre-operative assessment to final follow-up. The mean pre- and post-operative function scores were 40 points (range, 0 to 86 points) and 88 points (range, 5 to 100 points), respectively. The corresponding increase in weighted activity score was 2.5 points (range, -40 to 57 points) with a mean activity score of 6.2 points (range, 0 to 63 points) at final follow-up. Linear regression analysis showed that the increase in weighted activity level had a direct positive correlation with the increase in functional improvement ($R = 0.362$, $p < 0.001$). The linear model of the best fit relationship for the change in weighted activity level as a function of the increase in Knee Society function score showed that every 10 point increase in function score was predictive of a 1.2 point increase in weighted activity score. When excluding the large number of patients who showed no or limited change (between plus or minus one point) in their weighted activity score, the correlation coefficient improved to 0.443 (Figure 1). This subset of patients had a mean increase in weighted activity score of 4.6 points (range, -40 to 57 points).

The increase in weighted activity level also had a positive correlation with the 49 point (range, -32 to 84 points)

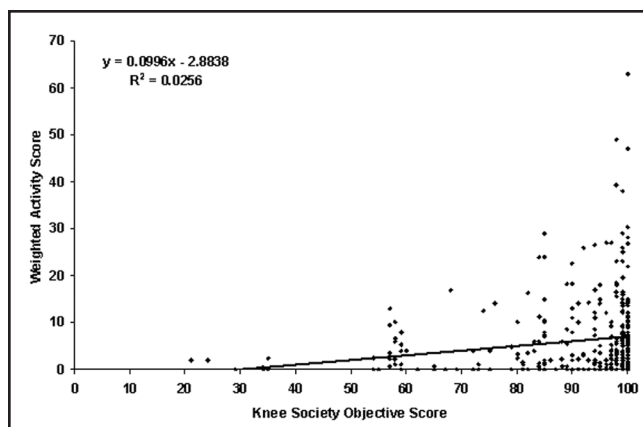


Figure 3. This graph shows a linear model for comparing the Knee Society score and a weighted activity score that assesses frequency, duration, and impact of sports participation.

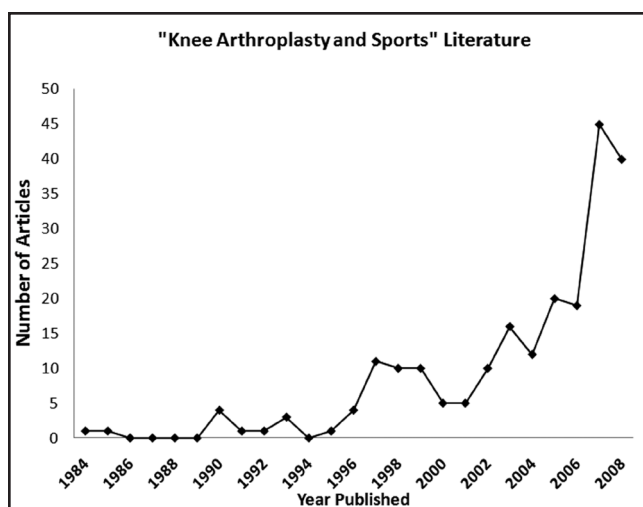


Figure 4. This graph shows the increasing number of studies related to sports activity following total knee arthroplasty, especially in the past five years.

increase in Knee Society objective scores. Although the R value was statistically significant for this relationship ($p < 0.001$), the correlation of 0.194 was less than that of the correlation between the functional score and the weighted activity level.

The assessments of the correlation between the Knee Society functional and objective outcomes to the final weighted activity scores are provided in Figures 2 and 3.

The stepwise linear regression analysis indicated that Charnley class, age, and gender were the best predictors of change in activity level following surgery (see Table 2). BMI and ASA classification were shown to not be significant predictors in this multi-variate analysis. A large number of patients (29%) did not change their activity level. Table 3 provides a stratification by demographic factors and the number of patients who decreased, had

TABLE 2
Demographic Predictors of Increased Activity Level Following TKA

| Data | Coefficient | Std. Error | P-Value |
|----------------|-------------|------------|---------|
| Constant | 10.917 | 2.57 | |
| Charnley Class | -1.497 | 0.449 | <0.001 |
| Age | -0.0884 | 0.037 | 0.018 |
| Gender | 1.552 | 0.758 | 0.041 |

no change, or increased their sports activity following TKA.

DISCUSSION

There has been a tremendous interest in activity levels and return to sports and higher functioning total knee replacements (Figure 4). This is reflected in the nearly tripling of publications concerning “total knee arthroplasty and sports” when comparing the number of publications in the most recent five year period (2004 to 2008, $n = 136$) with the preceding five years period (1999 to 2003, $n = 46$). In fact, the studies from the 2004 to 2008 period represent over 60% of the published sports related TKA reports to date. This interest served as one of the justifications for this study which attempted to understand how to grade the activity levels of TKA patients and how well improvement in functional and objective outcomes predicted increases in activity level following surgery.

The limitations of the present study include that a small percentage of patients (less than 1%) who came in for follow-up chose not to participate in this study. However, it is likely that this small number of patients would not have changed the results significantly. Another limitation was that the follow-up for most of the patients in this study was short term. Patients with follow-up as short as one year were included because our primary question was not related to implant survival, but rather was assessing whether there was a correlation between improvement in functional and objective outcomes and increases in activity level. A separate statistical analysis showed that time following surgery was not significantly correlated with sports activity for our cohort; however, it remains unclear whether the correlations in this study would be valid for patients at longer follow-up.

In a few recent studies, it has been shown that a large percentage of TKA patients return to sporting activities. Bradbury et al.¹⁵ studied 160 TKA patients and found that 75% returned to sports activity with 20% participating in high impact sports such as tennis. Bock et al.¹⁶ studied 167 TKA patients and found 80.4% returning to sports activity with some of them to high activity sports such as cycling (18%). In another study by Bauman et al.,¹⁷

TABLE 3
Change in Weighted Activity Score Stratified by Demographic Variables

| Group/Stratification | Points Change (range) | Decrease (%) | No Change (%) | Increase (%) | P-value* |
|----------------------|-----------------------|--------------|---------------|--------------|----------|
| Gender | | | | | |
| Men | 3.6 (-21 to 57) | 34 (0.21) | 40 (0.25) | 88 (0.54) | 0.295 |
| Women | 1.9 (-40 to 25) | 44 (0.17) | 80 (0.31) | 131 (0.51) | |
| < 60 years old | 4.9 (-12.5 to 57) | 14 (0.17) | 12 (0.14) | 59 (0.69) | <0.001 |
| > 60 years old | 1.9 (-40 to 35.5) | 64 (0.19) | 108 (0.33) | 160 (0.48) | |
| BMI Classification | | | | | |
| Obese | 2.6 (-40 to 57) | 40 (0.19) | 63 (0.3) | 109 (0.51) | 0.888 |
| Non-obese | 2.4 (-21 to 20) | 38 (0.19) | 57 (0.28) | 110 (0.54) | |
| ASA Classification | | | | | |
| 1 | 4.0 (-4 to 25) | 4 (0.36) | 0 (0) | 7 (0.64) | 0.004 |
| 2 | 3.1 (-40 to 57) | 31 (0.14) | 60 (0.27) | 130 (0.59) | |
| 3 | 1.8 (-12.5 to 35.5) | 41 (0.23) | 60 (0.33) | 81 (0.45) | |
| 4 | -2.9 (-8.5 to 0.8) | 2 (0.67) | 0 (0) | 1 (0.33) | |
| Charnley Class | | | | | |
| A | 3.8 (-21 to 33) | 29 (0.18) | 22 (0.14) | 107 (0.68) | <0.001 |
| B | 3.7 (-40 to 57) | 14 (0.12) | 34 (0.28) | 72 (0.6) | |
| C | 0.2 (-12.5 to 12.3) | 35 (0.25) | 64 (0.46) | 40 (0.29) | |
| Overall | 2.5 (-40 to 57) | 78 (0.19) | 120 (0.29) | 219 (0.53) | |

*P-value is Chi-square analysis of group stratifications and the numbers of decrease, no change, and increase.

a cross-sectional survey using the UCLA activity score was used to assess the level of 184 TKA patients who had a mean age of 69 years (range, 41 to 88 years). The survey was only given to patients who had a minimum of one year follow-up. Patients showed sustained, moderate activity levels with a median UCLA score of 6 points (range, 3 to 8 points). As patients increasingly are interested in participating in sports activity following surgery, it is important to have tools to evaluate their activity and its correlation with outcomes.

It was previously shown by Konig et al. that there was a need for separate functional and objective ratings following TKA.¹⁸ They reported that between two and five years following surgery functional scores declined, whereas objective scores plateaued. They showed that pain had a significant but low correlation with walking distance ($p = 0.027$, $r = 0.13$). Although age ($p < 0.00001$), BMI ($p = 0.0025$), and pre-operative patient category ($p < 0.005$) were significant predictors for functional scores in a multiple-regression, none of these correlated with the knee score. The present study showed similar results with relatively poor correlation between change in activity and change in objective measures compared to a higher correlation between change in activity and functional score.

Although there was a moderate correlation between change in activity and change in function score, it should be noted that there was a large variation in the final activity scores for patients who had similar function scores. This suggests the need for an additional outcome measurement that is a function of activity level. The need for an activity component for a rating system is further indicated by the increasing demand of patients to participate in sports. Validation of any scoring system can be a very complex one, and it is hoped that this work may serve as a step towards the validation of both of these scoring systems.

ACKNOWLEDGMENT

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FRACTURED CEMENT SPACERS—A REPORT OF TWO CASES

Rajesh Botchu, R. Anwar, KJ Ravikumar

INTRODUCTION

Cement spacers are being increasingly used for revision arthroplasties. A fracture of the spacer is likely to occur due to fatigue failure unless a hard shell composed of an inert material structurally supports the spacer. We report two cases of failures of the cement spacers, which we believe occurred due to insufficient strength in the articulating cement mould.

CASE 1

A 79 year-old-man attended the accident and emergency department due to severe pain in the hip. He felt a crack in his hip as he bent down to pull a sock up his leg in the sitting position. He underwent a first stage revision about six weeks ago for an infected total hip replacement and an antibiotic loaded cement hip spacer was used to maintain the joint space.

On examination, the left leg appeared shortened and externally rotated. The movements were significantly painful. The distal neurovascular status was entirely satisfactory. The scar over the lateral aspect of the hip had healed well with no local signs of infection and the inflammatory markers were within normal limits. A radiological examination revealed a fracture of the cement spacer at the level of the spacer neck (Figure 1).

Subsequently, a second stage revision was performed. A fracture was found at the level of the junction of the neck and the stem of the spacer. The integrity of the rest of the spacer mould appeared well preserved.

CASE 2

A 76-year-old lady was presented with a history of severe pain following a first stage revision of her infected total hip replacement performed four weeks ago. An articulating antibiotic loaded mould of polymethylmethacrylate (PMMA) cement (Alomed) was used as a spacer for the inter-revision period. The immediate post operative recovery was normal. Full weight bearing

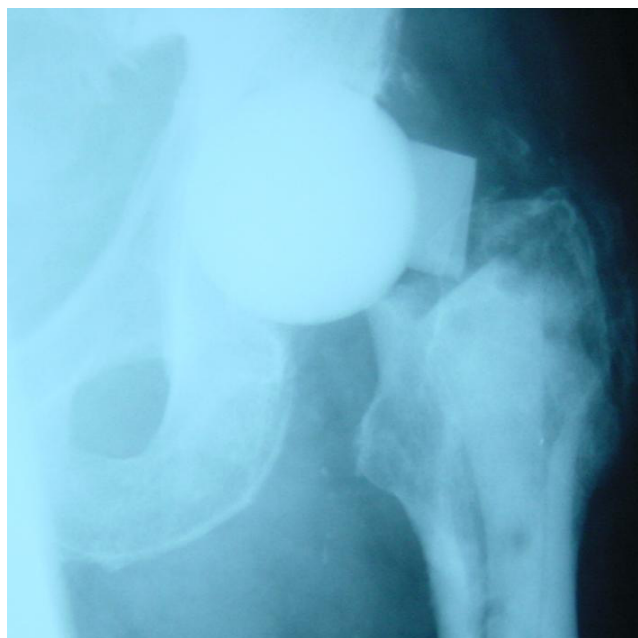


Figure 1. AP view of the left hip showing a fracture of the cement spacer at the level of the neck of the cement spacer mould (Case 1).

mobilisation was commenced shortly after the revision. However, spontaneous onset of severe pain in the hip caused significant restriction of mobility. There was no history of any direct or indirect trauma.

On examination, the leg appeared externally rotated and shortened. The movements of the hip produced severe pain. Examination of the distal leg including the neurovascular status did not reveal any abnormality. The patient remained afebrile throughout, and the inflammatory markers showed a downward trend. A radiological examination of the hip suggested a fracture of the cement spacer mould (Figure 2).

The patient, therefore, underwent a second stage revision after removal of the spacer and showed an uneventful recovery. The level of the break in the spacer and its overall appearance were very similar to that in case I (Figure 3).

DISCUSSION

A methylmethacrylate bone cement spacer keeps the tissue planes intact and prevents soft tissue contracture during the interoperative period of a two-stage revision. More recently, many commercial moulded designs have been introduced that resemble the actual joint

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Figure 2. AP view of the left hip showing a fracture of the cement spacer at the level of the neck of the cement spacer mould (case II).

prostheses, in shape and size. These moulded spacers provide intramedullary support to the weak femur and enable local antibiotic delivery, as well as permit limited mobilization of the patient.¹ It has been shown that if a spacer is used, the patients are almost free of pain and mobile with good leg control, spending two-thirds of the treatment period at home.²

However, the mechanical resistance offered by these cement moulds to the weight bearing forces is unknown. Schoellner et al in their study on fabricated moulds showed an average failure load 1550 N on being loaded at 20N/s in a craniocaudal direction.³

O'Connor and colleagues,⁴ in their invitro study on bone cement, found that there are two specific foci where the magnitude of the strain in the cement mantle approaches values that could lead to early fatigue failure of the cement. These two regions with highest (greater than 1,000 microstrain) strains were the most proximal portions of the cement mantle and near the tip of the femoral component. Although these two regions are recognized areas of high strain and also common sites of cement debonding and cement mantle failure, the strain-gauge studies have shown that the magnitude of cement strains in the proximal portion of the cement mantle were highest especially during stair-climbing. The moulded articulating cement moulds are probably subjected to similar high strains at the level of the spacer neck.

Full weight bearing or excessive movement, as seen in the above two cases, puts the fragile cement insert under tremendous strain and this may lead to fatigue failure.

We, therefore, believe that a construct made of a high strength material should structurally support the



Figure 3. The fractured cement spacer mould as removed from the hip.

spacer and materials that weaken it must be avoided. One study has revealed that the fractures in the cement mantle of a proximal femoral prosthesis are seen by the addition of barium sulphate to render the cement radio-opaque.⁵ However, this needs to be investigated by further studies.

The moulded cement spacers should, therefore, be treated as just ordinary spacers aimed to maintain the soft tissue planes and length. Full weight bearing mobilisation should be avoided. Commercial designs of the cement spacers may be improved by the addition of a hard shell composed of an inert (non reactive) material with high tensile strength that can withstand weight-bearing forces.

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MID-VASTUS VS MEDIAL PARA-PATELLAR APPROACH IN TOTAL KNEE REPLACEMENT—TIME TO DISCHARGE

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ABSTRACT

Background

It has been shown before that when compared with the medial para-patellar approach, the mid-vastus approach for TKR results in less post-operative pain for patients and more rapid recovery of straight leg raise. As far as we are aware the post-operative length of stay of the two groups of patients has not been compared. We postulated that the reduced pain and more rapid recovery of straight leg raise would translate into an earlier, safe, discharge home for the mid-vastus patients compared with those who underwent a traditional medial para-patellar approach.

Methods

Twenty patients operated on by each of five established knee arthroplasty surgeons were evaluated prospectively with regard to their pre and post-operative range of movement, time to achieve straight leg raise post-operatively and length of post-operative hospital stay. Only one of the surgeons performed the mid-vastus approach, and the measurements were recorded by physiotherapists who were blinded as to the approach used on each patient.

Results

The results were analysed using a standard statistical software package, and although the mean length of stay was lower for the mid-vastus patients, the difference did not reach a level of significance ($p = 0.13$). The time taken to achieve straight leg raise post-operatively was significantly less in the mid-vastus group ($p < 0.001$).

Conclusion

Although this study confirms previous findings that the mid-vastus approach reduces the time taken for patients to achieve straight leg raise, when compared with the medial para-patellar approach, on its own it does not translate into a significantly shorter length of hospital stay.

In order to reduce the length of post-operative hospital stay with an accelerated rehabilitation program for TKR, a multi-disciplinary approach is required. Patient expectations, GP support, physiotherapists and nursing staff all have a role to play and the mid-vastus approach, in permitting earlier straight leg raising, significantly contributes to this.

INTRODUCTION

Total knee arthroplasty (TKA) is a very commonly performed, major orthopaedic procedure, and accounts for a large proportion of elective inpatient bed-days. The pressure to improve productivity and efficiency of orthopaedic units is seemingly inexorable and the reduction of post-operative inpatient stay is a constant target to help reduce the pressure on beds.

Inpatient stay and consequently the timing of discharge after TKA is influenced by a variety of pre-operative, operative and post-operative factors.¹ We wanted to know if a simple modification to the operative technique could significantly reduce the length of in-patient stay after TKA in this hospital.

Historically the medial para-patellar approach has been the most popular approach to the knee for TKA.² This involves making a sagittal incision in the quadriceps tendon proximal to its insertion into the patella. More recently the mid-vastus approach has gained in popularity.³ This does not involve disruption of the quadriceps

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TABLE 1

| Variable | Method | n | Mean | StDev | Minimum | Median | Maximum |
|-------------------------|--------|----|------|-------|---------|--------|---------|
| Length of hospital stay | MV | 20 | 7.3 | 1.9 | 5 | 7 | 11 |
| | MPP | 80 | 7.8 | 2.3 | 5 | 7 | 16 |
| Days to SLR | MV | 20 | 2.1 | 1.0 | 0.5 | 2 | 4 |
| | MPP | 80 | 3.2 | 1.8 | 0.5 | 3.5 | 8 |

tendon. An elegant study by White et al in 1999,⁴ showed that all other factors being equal, this approach led to reduced post-operative pain and analgesia requirements and a more rapid recovery of straight leg raise when compared to the medial para-patellar approach.

Post-operative length of stay of the two approaches has not been compared. We postulated that the reduced post-operative pain and more rapid recovery of movement with the mid-vastus approach would translate into an earlier, safe, discharge home for these patients compared with those patients who underwent a traditional medial para-patellar approach.

METHOD

In our prospective, blinded study, twenty consecutive patients operated on by each of five established knee arthroplasty surgeons were evaluated for several parameters. Each of the 100 patients had measurements taken for pre and post-operative range of movement, time taken to regain a straight leg raise and the number of post-operative days spent in hospital prior to discharge.

The exclusion criteria were dementia, patients who were unable to comply with having the measurements taken and those patients who were unable to undertake the standard post-operative physiotherapy regime. Patients, who had significant co-morbidities that might otherwise delay their discharge, or whose discharge was delayed by the time taken to set up appropriate home care packages, were also excluded.

The post-operative physiotherapy regime was the standard extension type regime employed in our institution. This involves incremental increases in the degree of flexion in the post-operative period. The aim is to achieve 90 degrees of flexion prior to discharge, although if steady improvement is being made patients can be allowed home before reaching this milestone. In these cases, more intensive, supervised physiotherapy is arranged on an out-patient basis.

All measurements and data were recorded on a standard pro-forma (Figure 1) by physiotherapists working on the elective orthopaedic unit. Although the physiotherapist recorded who the operating surgeon was in each case, they were blinded as to which approach was used on each patient.

MIDVASTUS v MEDIAL PARA-PATELLER STUDY.

Patient Reference label



PRE-OP ROM

POST-OP DAY 1ST ACHIEVED SLR am/pm

POST-OP DAY OF DISCHARGE

ROM ON DISCHARGE

Figure 1. Sample of patient reference label.

Out of the five study surgeons, one performed the mid-vastus approach in every case and the other four all used the traditional medial para-patellar approach.

The mid-vastus approach was performed according to the technique described by Engh et al. The distal portion of the arthrotomy is identical to the traditional medial para-patellar approach. When the superomedial pole of the patella is reached the arthrotomy turns medially to divide the vastus medialis obliquus in line with its fibres for not more than 4 cm. In this way the quadriceps mechanism is not violated.

In each case a tourniquet was used as was regional anaesthesia in the form of sciatic and femoral nerve blocks.

The results were analysed using the Minitab 14 statistics package.

RESULTS

The distribution of the post-operative length of stay (LOS) data was skewed to the right and therefore all analysis of variance tests and t-tests were performed

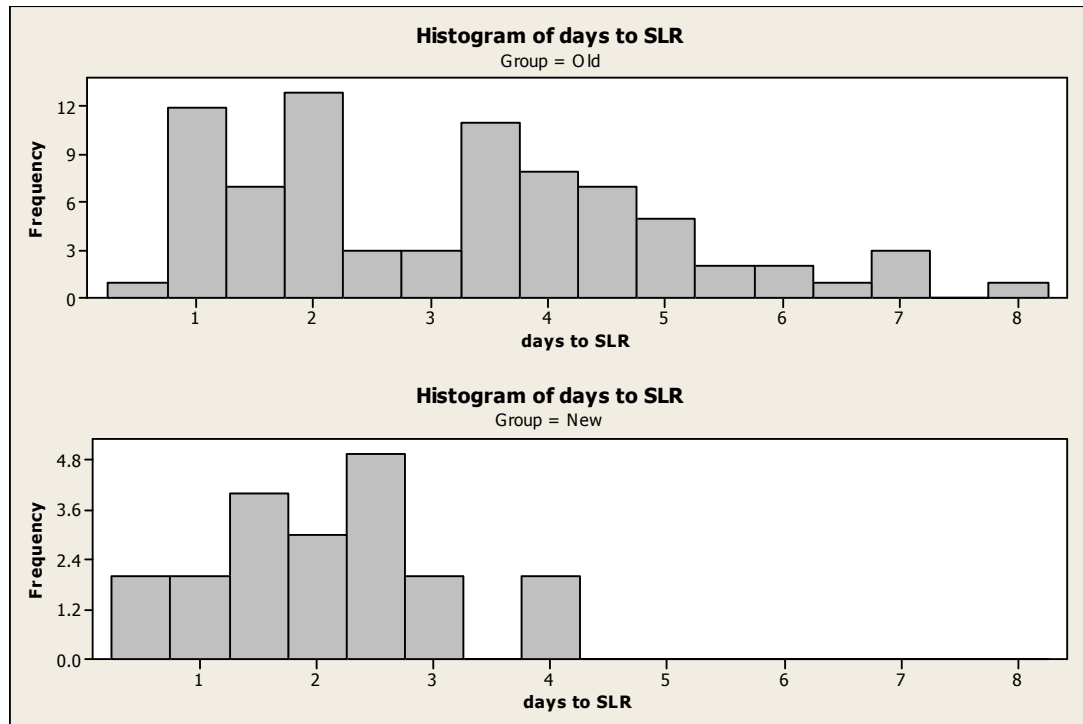


Figure 2. Days to straight leg raise. Old = medial para-patellar approach. New = mid-vastus, quadriceps spacing approach.

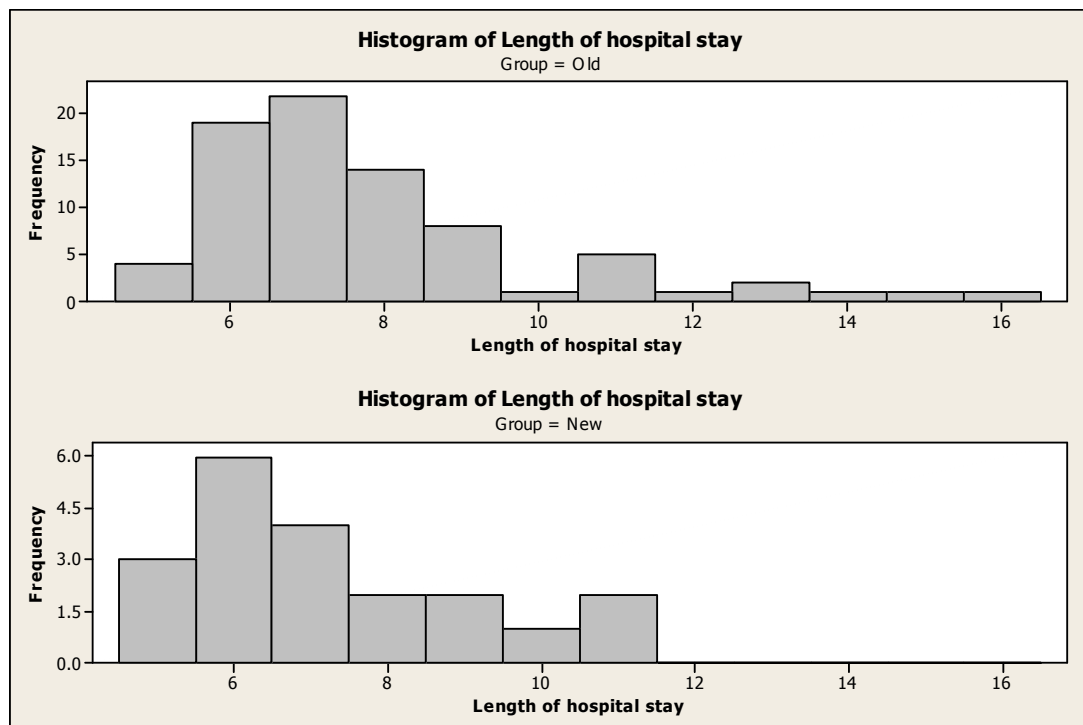


Figure 3. Old = medial para-patellar approach. New = mid-vastus, quadriceps sparing approach.

on log (LOS). The time to straight leg raise (SLR) data was reasonably symmetric and no transformation was required (Table 1 and Figure 2).

For the LOS there was no significant difference in means ($p = 0.24$ using two independent samples t-test on log (LOS)) and no significant difference in variances ($p = 0.82$ using Levene's test on LOS) (Figure 3). It can also be seen that the median LOS was identical for both approaches (Table 1).

For the time to SLR there was a significant difference in means ($p = 0.001$ using two independent samples t-test with unequal variances) and a significant difference in variances ($p = 0.006$ using an F-test). The estimated difference in means is 1.1 days (MPP-MV) with a 95% confidence interval of 0.5 to 1.7 days. There is 1.8 times more variation in time to SLR using the MPP approach than there is using the MV approach based on a comparison of standard deviations.

CONCLUSION

The purpose of this study was to see if employing the mid vastus approach for TKR significantly reduced time to discharge when compared to the medial para-patellar approach.

It has already been shown that the length of time a patient stays in hospital after undergoing a TKR is dependant on multiple factors. Crowe and Henderson⁵ showed that a single pre-operative physiotherapy education session reduced length of hospital stay from 10.5 to 6.5 days. The type of anaesthesia used can also affect length of stay. Wang et al.⁶ showed that although local nerve blocks generally wear off rapidly (within the first 18 hours) they do provide excellent analgesia allowing early mobilisation and an earlier discharge.

This study confirms the finding of White et-al that the mid-vastus approach significantly reduces the time taken to achieve a straight leg raise after TKR.

It also demonstrates the multi-factorial nature of rehabilitation and shows that by altering the approach alone, in our study at least, the length of hospital stay is not significantly reduced. If a significant reduction in post-operative length of stay is to be achieved then the whole episode needs to be addressed; from pre-operative patient information through surgical and anaesthetic technique to a robust discharge package involving physiotherapists, occupational therapists and general practitioners.

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POSTERIOR-STABILIZED VERSUS POSTERIOR CRUCIATE LIGAMENT-RETAINING TOTAL KNEE ARTHROPLASTY

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ABSTRACT

Posterior-stabilized and posterior cruciate retaining total knee arthroplasty prostheses have had high success rates, but it is unclear whether one design has superior outcomes. The purpose of the present study was to directly compare the outcomes of these two designs. Forty-five patients who received a posterior-stabilized prosthesis were compared to 46 consecutive patients who received a cruciate-retaining implant. At a mean follow-up time of 60 months (range, 49 to 69 months), the mean Knee Society knee scores improved from 42 points (range, 20 to 73 points) to 93 points (range, 39 to 100 points) for the cruciate-retaining group and from 38 points (range, 20 to 70 points) to 94 points (range, 60 to 100 points) for the posterior-stabilized group. The mean Knee Society functional scores improved from 36 points (range, 10 to 60 points) to 71 points (range, 15 to 100 points) for the cruciate-retaining group and from 32 points (range, 10 to 70 points) to 73 points (range, 32 to 100 points) for the posterior-stabilized group. The ranges of motion were 125° (range, 100 to 140°) and 118° (range, 87 to 135°) in the cruciate-retaining and posterior-stabilized groups, respectively, at final follow-up. Radiographic analysis revealed no radiolucencies that were progressive or were greater than 1 millimeter in length. There were no re-operations in either group. This study

did not conclusively demonstrate the superiority of one knee design over the other, suggesting that the choice of implant should be based on surgeon preference and existing pathology of the posterior cruciate ligament.

INTRODUCTION

Total knee arthroplasties have had excellent results, with multiple studies showing survival rates greater than 90% at follow-up times of 10 to 20 years.¹⁻⁶ Numerous prostheses have been developed to improve the durability and function of these procedures. However, there has been controversy regarding whether the posterior cruciate ligament (PCL) should be retained or removed during the procedure. Some potential advantages of cruciate-retaining prosthetic designs include preservation of bone, more normal knee kinematics, increased proprioception, femoral rollback on the tibia during flexion, and greater stabilization of the prosthesis, with the PCL preventing anterior translation of the femur on the tibia. Posterior-stabilized implants attempt to replace the role of the PCL with a polyethylene post and femoral cam that interact to prevent anterior translation of the femur on the tibia, while allowing femoral rollback during flexion. Potential advantages of these designs include a less technically demanding procedure, a more stable component interface,⁷⁻⁹ and increased range of motion.^{7,10,11}

Recent studies have shown high short- and mid-term success rates of both designs,¹²⁻¹⁶ but it is unclear whether one design has superior outcomes.¹⁷ The purpose of the present study was to directly compare the Knee Society knee as well as function scores, ranges of motion, radiographic outcomes, and complications of two larger cohorts of patients who received contemporary cruciate-retaining or posterior-stabilized prostheses.

METHODS

Fifty-four consecutive patients underwent total knee arthroplasty utilizing a posterior-stabilized prosthesis, and another group of fifty-three consecutive patients received a cruciate-retaining implant. All patients who had osteoarthritis, osteonecrosis, or rheumatoid arthritis and who were indicated for a total knee arthroplasty were invited to take part in a prospective study to follow their outcomes, and none of the patients declined. In the

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cruciate-retaining cohort, 1 patient passed away and 6 patients changed their addresses prior to the five-year follow-up visit, so their results were not included in the study. At the latest follow-up visit (mean follow-up time 17 months; range, 3 to 48 months), the patients who were lost to follow-up had mean Knee Society knee and function scores of 85 points (range, 52 to 100 points) and 78 points (range, 50 to 100 points), respectively. In the posterior-stabilized group, 3 patients passed away and 6 patients could not be reached at the five-year follow-up visit, so they were also excluded. At their last follow-up (mean follow-up time 29 months; range, 7 to 49 months), the mean Knee Society knee and function scores of the patients who were lost to follow-up were 85 points (range, 34 to 100 points) and 63 points (range, 45 to 100 points), respectively. No other patients were excluded. The patients were evaluated in the office one month after the procedure and annually thereafter. The ranges of motion, Knee Society scores,¹⁸ radiographic outcomes, and complications were assessed at each follow-up visit, and these were compared at the five year follow-up. This study received full institutional review board approval.

The patients who received cruciate-retaining arthroplasties consisted of 20 men and 26 women who had a mean age of 64 years (range, 40 to 77 years), a mean body mass index of 32 kilograms per meter squared (range, 26 to 43 kilograms per meter squared), a mean preoperative Knee Society knee score of 42 points (range, 20 to 73 points), and a mean preoperative Knee Society functional score of 36 points (range, 10 to 60 points). The patients who received posterior-stabilized arthroplasties consisted of 17 men and 28 women who had a mean age of 66 years (range, 45 to 81 years), a mean body mass index of 32 kilograms per meter squared (range, 23 to 47 kilograms per meter squared), a mean preoperative Knee Society knee score of 38 points (range, 20 to 70 points) and a mean preoperative Knee Society functional score of 32 points (range, 10 to 70 points).

All procedures were performed by two of the authors, who both used a standard median parapatellar approach. All surgeries utilized the Scorpio CR cruciate-retaining system or the Scorpio PS posterior-stabilized system (Stryker, Mahwah, New Jersey). Each author performed approximately half of the CR procedures and half of the PS procedures.

The patients were evaluated in the office one month, one year, and annually after the surgery. Knee Society scores,¹⁸ ranges of motion, and radiographs (weight-bearing anteroposterior and lateral views) were assessed at each follow-up visit. Radiolucencies were evaluated using the system of zonal analysis developed by the Knee Society.¹⁹

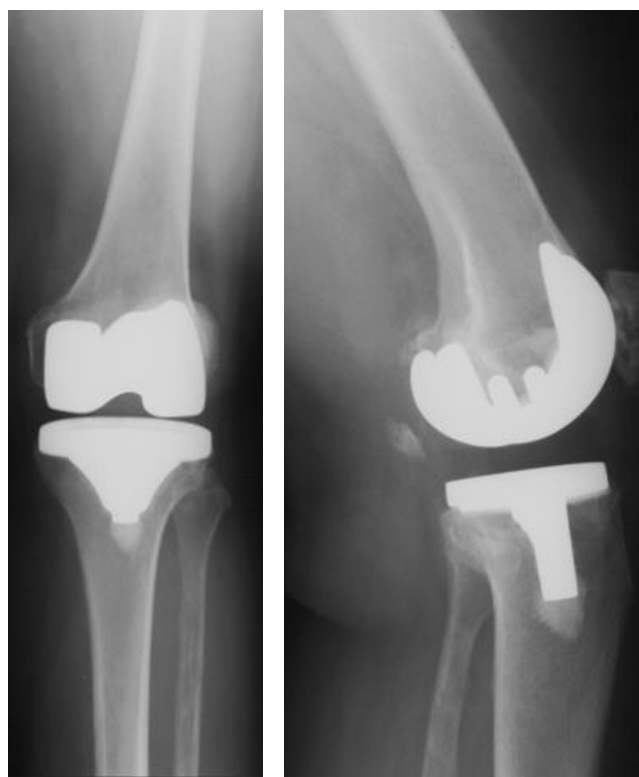


Figure 1. Anteroposterior (A) and lateral (B) radiographs of the knee of a 55 year old woman who received a cruciate-retaining prosthesis.

The Knee Society scores and ranges of motion of the two groups were compared with Student t-tests. All statistical analyses were performed using SigmaStat version 3.0 (SPSS, Chicago, Illinois).

RESULTS

At a mean follow-up time of 60 months (range, 54 to 69 months), the clinical scores of the two groups were similar, but the cruciate-retaining group had a higher mean range of motion. The mean Knee Society knee scores of the cruciate-retaining and posterior-stabilized groups were 93 points (range, 55 to 100 points) and 94 points (range, 60 to 100 points), respectively ($p=0.823$). The mean Knee Society functional scores were 71 points (range, 15 to 100 points) for the cruciate-retaining group and 73 points (range, 32 to 100 points) for the posterior-stabilized group ($p=0.565$). The mean ranges of motion were 125° (range, 100 to 140°) for the cruciate-retaining group and 118° (range, 87 to 135°) for the posterior-stabilized group. Figures 1 and 2 show examples of the two implants.

There were two incidents of postoperative knee pain in the cruciate-retaining group, but no revisions or reoperations in either group. Two 65 year old men who received cruciate-retaining prostheses began having per-

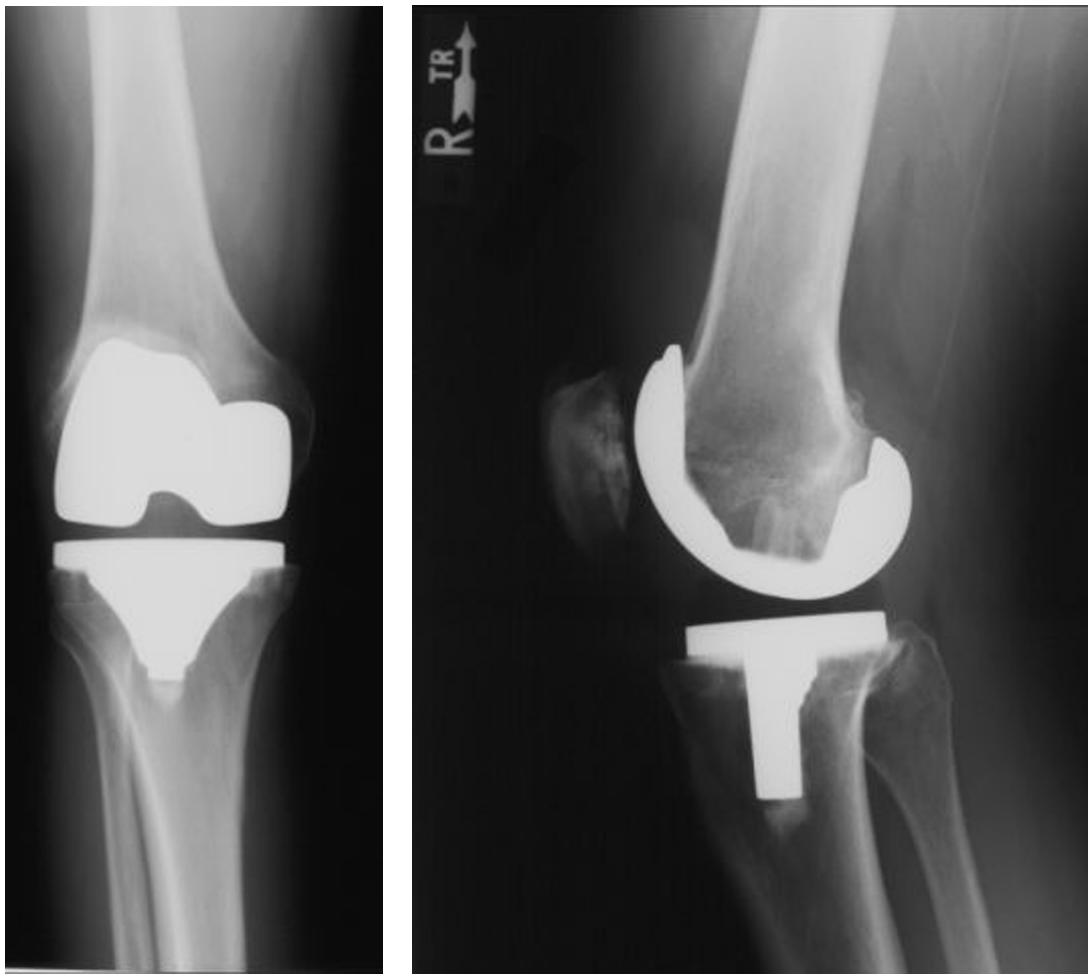


Figure 2. Anteroposterior (A) and lateral (B) radiographs of the knee of a 52 year old woman who received a posterior-stabilized prosthesis.

sistent pain in the operative knees, at one year and five years after the surgery, respectively, with no radiologic or physical abnormalities, and they have both received adequate pain relief with analgesic medications. The Knee Society knee scores of the three patients were 55 and 68 points, and the Knee Society functional scores were 80, and 65 points at follow-up times of 59 and 60 months, respectively.

Assessment of radiographs revealed no radiolucencies that were longer than one millimeter, and no progression of radiolucencies. There was one incidence of lateral patellar tilt in a 71 year old man who received a cruciate-retaining prosthesis, but he was doing well clinically, with Knee Society knee and functional scores of 100 and 80 points, respectively, and he did not desire any treatment. No other radiographic abnormalities were seen.

DISCUSSION

Despite the high success rates of total knee arthroplasties, there is still controversy regarding removal

versus retention of the PCL. Proponents of cruciate-retaining designs believe that it is important to retain as much of the original anatomy as possible, and that the PCL can continue to stabilize the knee during flexion. The posterior-stabilized designs utilize a tibial post and femoral cam to substitute for the PCL, which allows femoral rollback and attempts to prevent anterior movement of the femur. Many studies have compared the two types of prostheses, with mixed results. The present study was performed to directly compare the clinical results of both designs, made by the same manufacturer, at the 5 year follow-up to determine whether either prosthesis had a distinct advantage.

There were some limitations to this study. The patients were not randomized, although they were followed prospectively. Also, several patients in each cohort were deceased or could not be contacted for the five-year follow-up visit, although almost all of them were doing well one to four years after the procedure. Despite these limitations, this report demonstrates that both designs

had excellent clinical outcomes at a follow-up time of five years, with few differences between the two types of prostheses.

Several other studies have directly compared the two prosthetic designs, with mixed results. Maruyama et al.¹⁰ examined 20 patients who underwent bilateral total knee arthroplasties, with a posterior-stabilized implant in one knee and a cruciate-retaining implant in the other, and found that the clinical scores of the two implants were similar at follow-up times of 30 months, with greater flexion in the posterior-stabilized knees (131° versus 122° , $p < 0.05$). Yoshiya et al.⁷ performed a kinematic analysis of a cohort of 20 patients who underwent bilateral total knee arthroplasties with a posterior-stabilized implant in one knee and a cruciate-retaining implant in the other. The posterior-stabilized implant was more stable, with no anterior translation under weight-bearing conditions and femoral rollback with passive flexion, whereas, the cruciate-retaining prostheses did experience anterior femoral translation between 30° and 60° under weight-bearing conditions, indicating that the PCL might not be functioning. They also found a greater range of motion of the knees that had posterior-stabilized implants ($131^\circ \pm 12^\circ$ versus $121^\circ \pm 16^\circ$). Bolanos et al.¹⁷ examined 14 patients who had bilateral total knee replacements, with posterior-stabilized prosthesis in one knee and a cruciate-retaining prosthesis in the other knee, and found that Knee Society scores, isokinetic strength of the quadriceps and hamstring muscles, gait parameters, knee ranges of motion, and electromyographic waveforms during stair-climbing were similar for the two prostheses at a mean follow-up time of 98 months (range, 72 to 134 months). Tanzer et al.²⁰ examined two groups of 20 patients who were randomized to receive cruciate-retaining or posterior-stabilized implants and found no differences in Knee Society or radiographic scores at the two-year follow-up. The results of the present study support the previously-published data, by finding similar clinical scores in two larger patient cohorts, but in contrast to previous studies, it found that the cruciate-retaining knees had a significantly higher mean range of motion by 7° .

The present study shows a 100% survival rate of both posterior-substituting and cruciate-retaining knees at a mean follow-up time of 60 months (range, 48 to 69 months). The cruciate-retaining group had a slightly higher mean range of motion, in contrast to previous studies, which showed higher ranges of motion in posterior-stabilized knees, but this difference is likely not clinically important. The published evidence regarding PCL retention or substitution remains inconclusive, especially as some studies have found that the PCL appears to be nonfunctional in many patients who have

cruciate-retaining designs,^{7,21} and one study found no difference between a PCL-sacrificing and a PCL-substituting design. Kinematic and anatomic studies to elucidate the reasons for any differences between the two groups are indicated, and further follow-up will be necessary to evaluate long-term differences between the two groups. At this time, the choice of implant can be based upon surgeon preference and training, as well as the presence of any existing PCL pathology.

CONFLICT OF INTEREST STATEMENT

Three of the authors (FRK, MAM, CLB) are consultants for Stryker Orthopaedics. The other authors have no external sources of support. No company has had any role in the study design; the data collection, analysis, and interpretation; the manuscript preparation; or the manuscript submission.

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REVISION TOTAL KNEE ARTHROPLASTY FOR MAJOR OSTEOLYSIS

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William J. Maloney MD##, and John C. Clohisy MD**

ABSTRACT

Twenty-eight knees in 26 patients underwent revision TKA requiring surgical management of major osteolytic defects. Three groups of osteolytic defects were identified based upon the degree of implant stability and the magnitude of bone loss. Outcome measures included the Knee Society Clinical Rating Score (KSCRS), visual analog pain score, and radiographs. At a mean follow-up of 48 months, the average knee pain scores, range of motion, and KSCRS improved ($p < .05$). Ninety-six percent of the knees demonstrated clinical and functional improvement. Radiographs for 24 revision TKA's (86 percent) demonstrated component stability and incorporation of both cancellous and structural allografts. Revision TKA for major osteolytic defects may be effectively performed using a variety of bone grafting techniques. Both morselized and structural bone grafting, in combination with stemmed components was successful in managing revision TKA in the setting of major osteolysis. Significant improvement in clinical and

radiographic outcomes may be anticipated using these surgical techniques.

INTRODUCTION

Recent studies describing the indications for revision TKA surgery have identified polyethylene wear and associated osteolysis as factors in nine to 34 percent of primary TKA failures.^{5,17,35} While osteolysis has been linked to polyethylene wear, these studies have not specified the proportion of patients for whom major osteolysis was a primary cause of failure. Large osteolytic defects may occur in conjunction with both well-fixed implants and in the setting of aseptic loosening.¹¹ In addition, a number of factors including gender,^{5,32} implant design characteristics,^{18,22,28,29} polyethylene thickness,¹⁴ polyethylene sterilization method,⁵ component alignment,^{5,17} and method of implant fixation¹⁴ have all been noted to influence the incidence of osteolysis in TKA.

Although the development of periprosthetic osteolysis has been recognized as a significant complication of TKA,^{4,5,14,20,22,23,30,31,38} a limited number of published studies have presented either short or mid-term results of revision surgery for TKA failure associated with major osteolytic defects.^{3,8,9,11,19,26} The main purpose of this study was to retrospectively review the clinical and radiographic results of revision TKA performed in the setting of major osteolysis and to compare our results to the previous early and mid-term studies. Our secondary goal was to assess the surgical techniques utilized to address major osteolytic lesions encountered in revision TKA.

MATERIALS AND METHODS

Between 1997 and 2003, the two senior authors (WJM, JCC) performed TKA revision surgery with associated major osteolytic^{15,16} defects in twenty-six patients (28 knees). During this same period, the same surgeons performed a total of 222 TKA revisions and 677 primary TKA's. All 222 TKA revision cases were reviewed and 28 knees (13%) had major osteolysis. Inclusion criteria for this study included all visible radiographic osteolytic defects measuring $\geq 30\text{mm}^2$ in size^{15,16} on at least one radiographic projection (anteroposterior, lateral, or oblique radiographs) and in association with a clinically symptomatic/painful TKA, or, osteolysis with concurrent or impending mechanical loosening. The mean patient age at the time of surgery was 67.3 years (range, 52-78

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Each author certifies that his or her institution has approved the human protocol for this investigation and that all investigations were conducted in conformity with ethical principles of research, and that informed consent was obtained

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TABLE 1
Summary of Defects and Treatments

| Knees | Revision Implant Design | AORI Defects |
|-------|-----------------------------|-----------------------|
| 23 | stems/augments/CCK or Ps | Type 2 = 18; Type 3=5 |
| 2 | rotating hinge | Type 3 = 2 |
| 3 | polyethylene liner exchange | Type 2 = 2 |

years) with both genders equally represented (fourteen knees for both males and females). The mean body-mass index of patients preoperatively measured 33 kg/m² (range, 24 - 49kg/ m²). The patients were retrospectively reviewed under an IRB-approved institutional protocol.

Bone defects were classified following the Anderson Orthopaedic Research Institute (AORI) system of Engh and Ammeen¹⁰ and our patient treatment groups (1, 2 and 3) were, in part, derived from this classification system. In our cohort, we encountered three cases with major osteolysis associated with well-fixed implants. There is no appropriate classification category for this type of case in the AORI system.

Over the time course of this study, the two senior authors (WJM, JCC) had the same surgical strategies for knee revision cases. Major contained osteolytic defects were treated with impaction grafting, and the use of structural allograft was reserved for large uncontained structural defects. Table 1 shows a summary of the implants and defects in this study. All components were cemented at the component-bone interface of the tibial platform and keel, and the distal femoral metaphyseal surface. All failed components were revised with a stemmed revision implant which included a total of 44 revised components—25 tibial and 19 femoral components. The method of stem fixation for TKA revisions is outlined in Table 2. Utilization of cemented stem fixation was selected if host bone quality was determined to be suboptimal for supporting cementless fixation or combined with a large structural allograft, and was performed in 10 femoral revisions and 9 tibial revisions. The use of metallic augments in TKA revision was required in 17 femoral and 6 tibial revisions in this series.

The size, location, and treatment of osteolytic lesions in the 28 knees are summarized in Appendix 1. We defined treatment Group 1 patients as those requiring a revision TKA with standard revision implants (component stem extensions with or without the use of augments). This group included patients that required the use of augments and/or morselized allograft to reconstruct bone defects and not requiring the use of a structural allograft (see Figure 1). Twelve patients (43 percent) had large contained metaphyseal defects amenable to mor-

TABLE 2
Stem Fixation Methods in TKA Revisions

| Method of Stem Fixation | n |
|--|---|
| Cementless stems: tibial + femoral | 9 |
| Cemented stems: tibial + femoral | 6 |
| Cementless femoral stem + cemented tibial stem | 4 |
| Cementless tibial stem alone (no femoral revision) | 3 |
| Cemented tibia stem alone (no femoral revision) | 3 |
| (3 knees underwent liner exchange only) | |

selized cancellous allograft bone-grafting and a stemmed revision component. Five patients (18 percent) had extensive osteolytic defects (contained) involving both the metaphyseal and diaphyseal bone with an intact cortical rim and contained defect that would support a stemmed revision component and morselized impaction cancellous allograft. Treatment Group 2 was defined as any patient undergoing revision TKA of one or both component that required the use of a structural allograft to reconstruct either a tibial or femoral defect, or the use of a modular rotating hinge TKA. Eight knees (28 percent) had large uncontained metaphyseal defects that required structural allograft reconstruction and a stemmed component (see Figure 2). Treatment Group 3 was defined as those knees that had stable implants and had osteolytic defects that were managed with component retention, modular polyethylene liner exchange (same thickness liner used at revision), and impaction cancellous bone grafting and curettage of the osteolytic defect. Three patients (11 percent) had well fixed components and extensive metaphyseal and diaphyseal osteolysis with attenuated cortical bone that would not readily support conventional revision arthroplasty components. For these three patients, component revision would have directed either use of an extensive structural allograft or significant bone replacement with an oncology implant; impaction grafting with component retention was performed on patients in Group 3 (see Figure 3).

Patients returned for post-operative follow up at intervals of 4 weeks, 3 months, 6 months and 12 months during the first year after surgery, with annual clinical and radiographic follow up thereafter. Visual analog pain scores (0-10; 0=no pain, 10=severe pain) and Knee Society Clinical Rating Scores²⁵ were completed at each visit by self-administered patient questionnaires. Radiographic analysis included sequential standing anteroposterior radiographs, supine lateral radiographs, and tangential radiographs of the patella and was performed by an orthopaedic surgeon (JAK) not involved in the care of the patients. Serial radiographs were reviewed retrospectively for evidence of allograft incorporation, the presence of linear or focal osteolysis, and component

| Appendix 1. Size and Location of Major Osteolytic Defects (n=28 knees) | | | | |
|--|----------------|---|---------------------------------|--------------------------------------|
| Case | Type of Defect | Size of Defect | Location of Graft | Type of stem fixation |
| | (Engl/Parks) | 1- Contained metaphyseal (3-5 cm) 2- Contained metaphyseal with diaphyseal extension (>5 cm) 3- Uncontained metaphyseal(3-5 cm) 4- Uncontained metaphyseal with diaphyseal extension (>5 cm) | s- structural c- cancellous | |
| 1 | II | 1- Tibia | c- Tibia | Cemented |
| 2 | II | 1- Tibia | c- Tibia | Cemented |
| 3 | II | 2- Tibia | c- Tibia | Cementless |
| 4 | II | 1- Tibia | c-Tibia | Cementless |
| 5 | II | 1- Tibia | c-Tibia | Cementless |
| 6 | II | 1- Femur | c- Femur | Cementless femur; Cemented tibia |
| 7 | II | 2- Femur | c-femur | Cementless |
| 8 | II | 1- Tibia | c-tibia | Cementless |
| 9 | II | 1- Tibia | c-tibia | Cemented |
| 10 | II | 1- Tibia | c-tibia | Cementless |
| 11 | II | 1- Tibia | c- tibia | Femur- Cemented Tibia- Cementless |
| 12 | II | 1- F/T | c- Tibia | Cementless |
| 13 | II | 1- F/T | c- F/T | Cementless |
| 14 | II | 1- F/T | c- Tibia | Femur-Cementless Tibia- Cemented |
| 15 | II | 2- F/T | c- F/T | Cementless |
| 16 | II | 2- F/T | c- F/T | Cementless |
| 17 | III | 2- F/T | c- Tibia | Cementless |
| 18 | III | 4- F/T | s- Femoral head (F/T) | Cemented |
| 19 | III | 4- Femur | s- Distal fem allograft | Cemented |
| 20 | III | 3-Tibia | s- Femoral head (T) | Cementless |
| 21 | III | 4- Tibia | s- Posterior 1/3 Proximal Tibia | Cemented |
| 22 | III | 4- Tibia 2- Femur | s- Femoral head (T) | Cemented |
| 23 | III | 4- Femur | s- Femoral head (F) | Cemented |
| 24 | III | 4- F/T | s- Femoral head (F/T) | Femur- Cementless T- Cemented |
| 25 | III | 3-Tibia | s-Femoral head (T) | Cementless |
| 26 | None | 2- Femur | c- Femur | N/A |
| 27 | None | 2- Femur | c- Femur | N/A |
| 28 | None | 2- Tibia | c- Tibia | N/A |

Appendix 1. Data table summarizing the size and location of osteolytic defects in the 28 patients in this study.

stability. Osteolysis was defined as a radiolucent lesion that was a minimum of 5 mm² in width with loss of the trabecular pattern and a corticated margin that was not present on the preoperative or immediate postoperative radiograph.¹³ The criteria for graft incorporation and regression / resolution of lesions used in this study was similar to that used in previous studies.^{2,7,27,34,36} These criteria have been reported and described in the form of a bone graft incorporation scale² relative to total hip arthroplasty. Graft incorporation includes loss of the distinct border between the osteolytic defect and the surrounding bone, return of bone density in an area of

osteolysis to that of the surrounding bone, and development of a trabecular bone pattern in an osteolytic region previously devoid of bone. Patients rated their clinical improvement using an established grading system^{6,24} at most recent follow-up as being excellent, good, fair, poor, or worse.

Statistical analysis to compare the results of surgery in the four treatment groups was performed using Fisher's exact test and the Kruskal-Wallis test. Within each group, pre and postoperative analysis was performed using the Wilcoxon Signed ranks test for VAS pain and the paired t-test for range of motion and KSCRS.

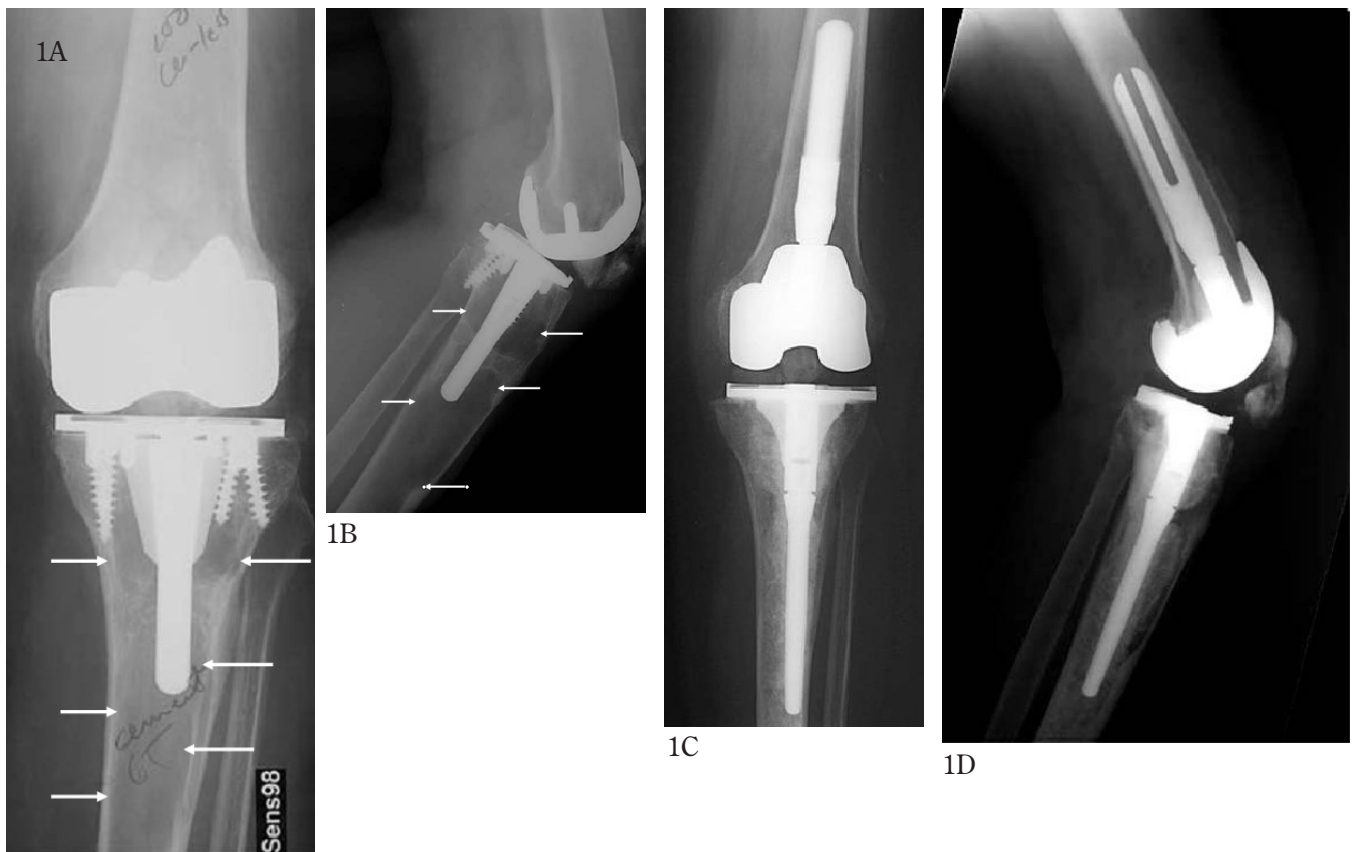


Figure 1. Preoperative AP (1A) and lateral (1B) radiographs of a Group 1 patient with a large periprosthetic contained osteolytic defect of the tibia (white arrows). The tibial polyethylene was nonmodular and had severe wear, requiring revision of all components. The components were revised (1C, 1D) and the contained defect was bone grafted with impacted morselized cancellous allograft (white arrows) using a cemented tibial stem.

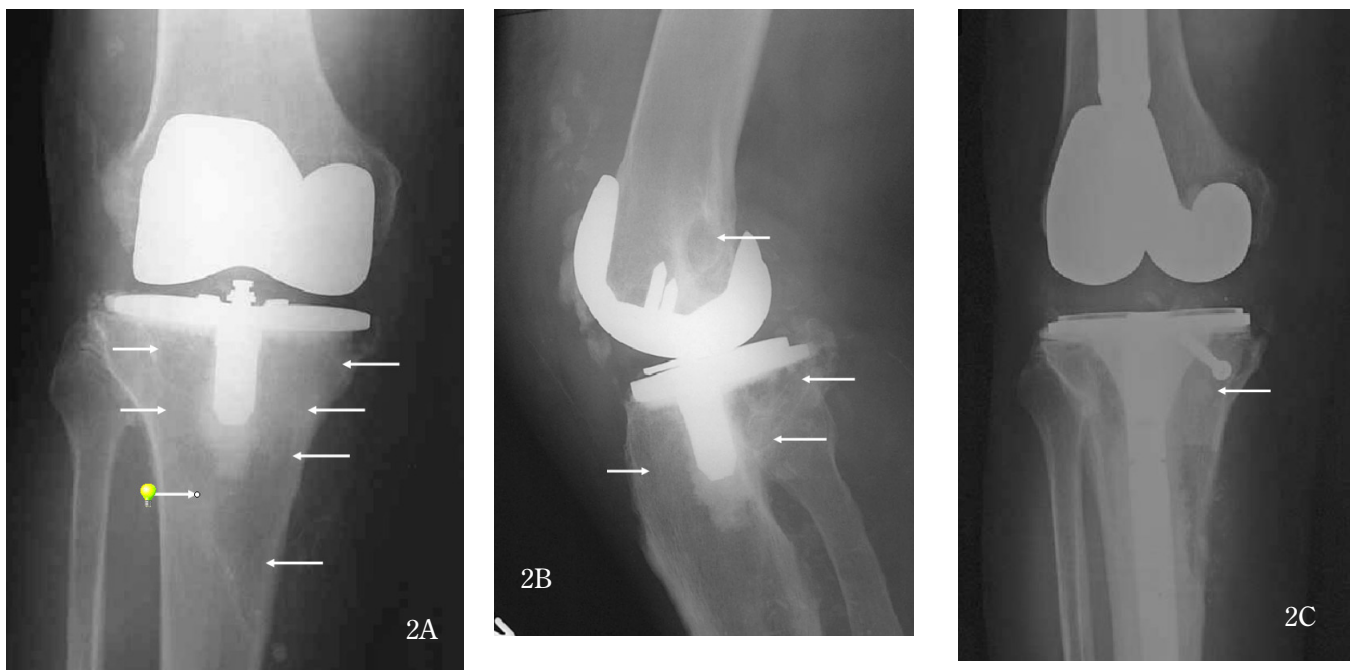


Figure 2. Preoperative AP (2A) and lateral (2B) radiographs of a Group 2 patient with a large periprosthetic noncontained osteolytic defect of the posteromedial tibia (white arrows). This defect was managed with a structural allograft (white arrows) to the proximal tibia (2C) and revision of components. A cemented tibial stem was implanted.

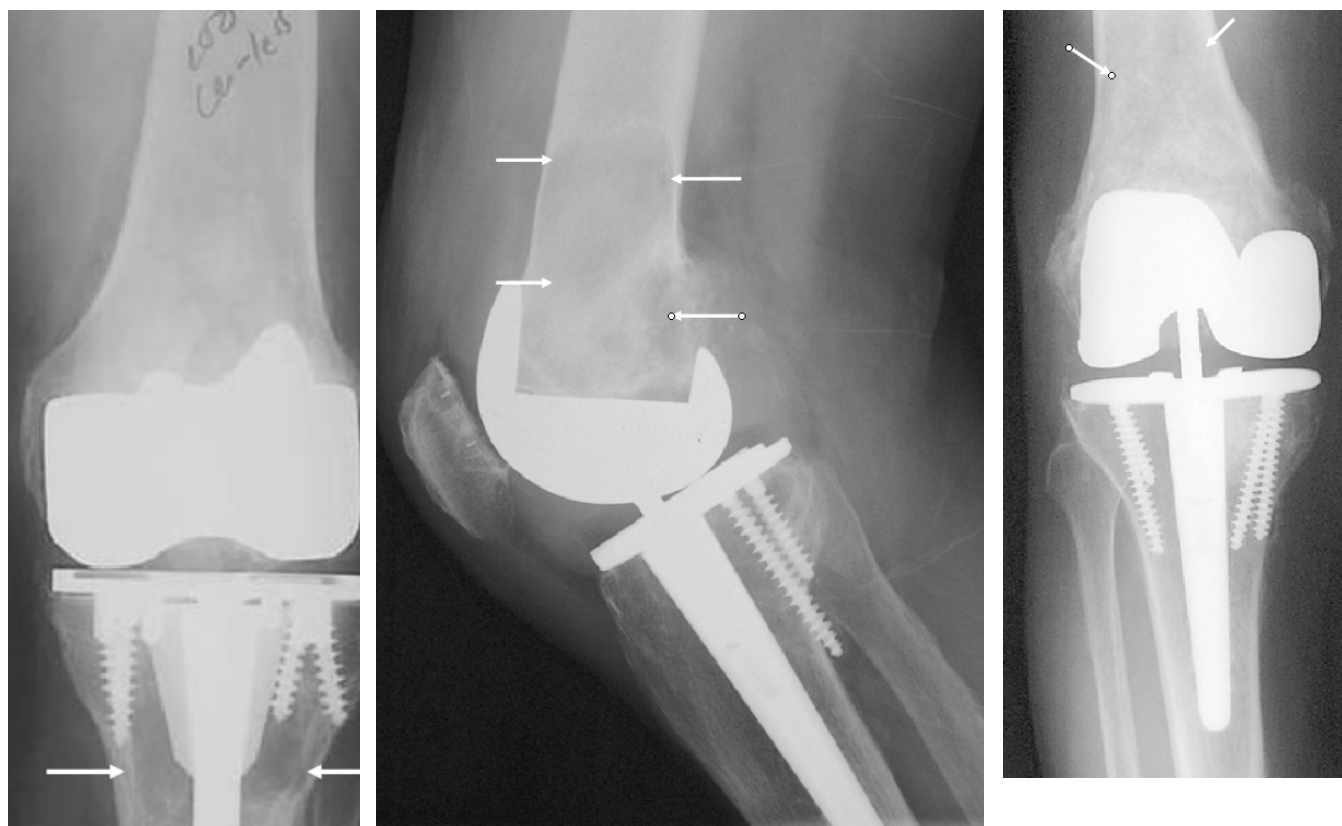


Figure 3. Preoperative AP (3A) and lateral (3B) radiographs of a Group 3 patient with a large periprosthetic contained osteolytic defect (white arrows) of the femur involving the distal femur. This patient was 84 years of age, participated in low-demand activities, with significant medical comorbidities. The components were retained with a modular polyethylene exchange and bone grafting (white arrows) of the large osteolytic defect of the distal femur was performed (3C, 3D). Allograft incorporation is demonstrated in the region of prior osteolysis, with loss of the definition of the prior osteolytic defect.

RESULTS

At a mean follow-up of 48 months (range, 24-96 months), none of the 26 patients were lost to follow-up, and average knee motion, pain, and function scores were significantly improved compared to preoperative values. When Groups 1, 2, and 3 were combined together for analysis of data, the VAS pain scores improved from a mean preoperative value of 6.9 to 1.8 points postoperatively ($p < .05$). The range of motion arc improved from an average of 97 degrees preoperatively to 110 degrees at most recent follow-up ($p < .001$). Mean knee flexion improved from 98 degrees (range, 40-120 degrees) preoperatively to 115 degrees (range, 75-142 degrees) postoperatively ($p < .05$). A Mean knee preoperative flexion contracture of 7 degrees (range, 0-30 degrees) improved to 1 degree (range, 0-10 degrees) postoperatively ($p = .06$). Knee Society Clinical scores improved from 39 to 84 points (55 point increase; $p < .001$), while Function scores improved from 46 to 69 points (23 point increase; $p < .001$). In 24 of 28 knees (86 percent) an improvement was noted in range of motion and Knee

Society Clinical Scores. One patient from Group 1 (3.6 percent) had a poor functional outcome secondary to periprosthetic infection and extensor mechanism failure following revision TKA (12 months postoperatively). One patient in Group 2 (structural femoral allograft) required a tibial revision for aseptic tibial component loosening at 18 months following the revision.

Radiographic evaluation revealed stable component fixation and graft incorporation in 24 of 28 knees. Two tibial components (revised in the left and right knee in the same patient from Group 1 (7.2 percent)) demonstrated radiographic progressive linear radiolucency at the tibial cement-bone interface without component subsidence at 3-year follow-up (both knees tibial revision with the use of a cemented stem). This patients Knee Society score is unchanged pre vs. postop score of 115, 121 respectively), indicating a fair result and the patient reported being probably improved. One patient in Group 2 required re-revision of a tibial component for aseptic loosening at 6-years postoperatively. This patient had a previous cementless stem with cemented

TABLE 3
Summary—Results of Groups 1, 2, and 3

| Group | N(knees) | PreROM | PostROM | PreKSC | Post KSC | PreKSF | Post KSF |
|-------|----------|--------|---------|--------|----------|--------|----------|
| 1 | 17 | 93 | 110* | 34 | 83* | 50 | 70* |
| 2 | 8 | 103 | 110 | 43 | 83* | 38 | 77* |
| 3 | 3 | 107 | 108.7 | 73 | 93 | 56.7 | 76.7 |

*p<0.05

Summary of mean results of Group 1 (component revision combined with morselized allograft) to the osteolytic defect, Group 2 (Tibial and femoral component revision combined with structural allograft reconstruction to the osteolytic defect), and Group 3 (Component retention with impaction grafting of osteolytic defects). PreROM = preoperative range of motion in flexion; PostROM = postoperative range of motion in flexion; KSC = knee society clinical; score; KSF = knee society function score.

fixation at the baseplate. The previous structural allograft on the femoral side was asymptomatic clinically and radiographically no signs of mechanical loosening were present. The remaining 24 knees (86 percent) had radiographically stable implants on most recent radiographic follow-up (minimum 24 months), and both structural and morselized cancellous allografts appeared were radiographically incorporated and stable. Seventeen knees (61 percent) had AORI Type II deficiencies and eight patients (29 percent) had Type III deficiencies. An additional three patients in this study (10 percent) had defects that could not be adequately classified using this system. Thus, we have developed a simple grouping of our results based upon the need for structural versus cancellous bonegraft, and retention versus revision of components.

Group 1 (Table 3)

Revision TKA components with morselized bone grafting (17 knees)

VAS pain decreased from an average of 7.25 to 1.33 points ($p<0.05$). Range of motion arc improved from an average of 93(range, 40-116 degrees) to 110 (range, 75-142 degrees) degrees postoperatively ($p=0.009$). Knee Society Clinical scores improved from 34 to 83 points ($p=0.001$). Knee Function scores improved from a mean of 50 to 70 points ($p=0.013$). Total Knee Society scores in Group 1 improved preoperatively from 84 to 152 points postoperatively ($p=.001$).

Group 2 (Table 3)

Component revision with structural allograft or rotating hinge implants (8 knees)

VAS pain improved from an average of 7.29 to 2.29 points ($p<0.05$). Range of motion arc in this cohort remained unchanged pre (103 degrees) versus postoperatively (110 degrees; $p=0.325$). Knee Society Clinical scores improved from an preoperative mean of 42.9 to 83.1 points postoperatively ($p=0.05$). Knee Society Function scores improved from 37.5 to 76.9 points ($p=0.012$).

Group 3 (Table 3)

Component retention with impaction grafting (3 knees)

VAS pain improved from an average of 6.0 to 0.33 points. Similar to group 3, the range of motion arc in Group 4 was unchanged pre (107 degrees) versus postoperatively (109 degrees). Knee Society Clinical and Function scores showed a trend in improvement from 73.0 to 93.0 points, and from 56.7 to 76.7 points, respectively.

At most recent clinical follow-up, 18 knees (64 percent) were associated with an excellent outcome, 8 knees (32 percent) a good outcome, and 2 knees were unimproved or poor—one knee had developed sepsis (poor) and another required tibial revision for aseptic loosening (unimproved). When an excellent and good outcome were combined, 96 percent of knees undergoing revision TKA in the setting of major osteolysis were associated with clinical improvement.

Statistical analysis assessing outcomes across treatment Groups 1,2, and 3 did not detect statistically significant differences with respect to changes in pain level ($p=0.97$), range of motion ($p=0.15$), Knee Society Clinical scores ($p=0.22$), or Knee Society Functional scores ($p=0.43$).

DISCUSSION

Engh et al.^{9,10} have described the AORI classification for bone deficiency based on the stability of the remaining metaphyseal bone to support a primary or revision TKA, and the need for augments or structural bonegraft. The AORI classification serves as a basis for our classification and treatment groups, yet does not address the use of morselized bonegraft in the scenarios of retained or revised components in revision TKA surgery. In our study, seventeen patients (61 percent) had Type II AORI deficiencies and eight patients (29 percent) had Type III deficiencies. An additional three patients in this study (10 percent) had defects that could not be adequately classified using the AORI system. For these patients,

TABLE 4
TKA Osteolysis Revision Studies

| Study/yr | n | Defects | Graft Type | Follow-up | Success | Comments |
|---|-----------|-----------------|--|------------------------------------|-----------------------------------|---|
| BLINDED (current study) 2007 | 28 | combined | Structural & cancellous | Mean 33 mo | 89% improved | Improved knee & function scores |
| Hockman 2005 | 24 | combined | Structural & cancellous | Min 5yr | 96% | Bulk better than cancellous |
| Lonner 2002 | 14 | Non-contained | Impaction Grafting | 6-40 months (mean 17 months) | 100% improved | 48 point improvement |
| Benjamin 2001 | 33 | Contained | Cancellous | 36 mo | 100% clinical and radiographic | Improved |
| Bradley 2000 | 19 | contained | Cancellous +/- Cement | 6-62 months Mean: 33 months | 100% improved | 87 point improvement (200 pt scale) |
| Van Loon 1999 | 18 | Combined | Structural & cancellous | Mean 38 mo. | 89% | 61 pt increase (200 pt scale) |
| Engh 1997 | 30 | Non-contained | Structural | 24-120 months (mean 50 months) | 87% success | 32 point improvement |
| Ghavazi 1997 | 28 | Non-contained | Structural | 24-132 months Mean: 50 months | 77 % improved | 29 point improvement |
| Engh, Parks, Ammeen 1994 | 25 | contained | varied | 2-6 yrs Mean: 41 months | 100% clinically improved | Mean post-op score: 86.3 Classification of defects described |

Summary and results of previous studies of revision TKA performed for osteolysis. The current study is listed at the top, in bold-face type.

the presence of extensive osteolysis beneath a well-fixed component directed management toward implant retention with a large volume of cancellous allograft, rather than management with either revision components, bulk structural allograft, allograft prosthetic composite (APC) reconstruction, or the use of a modular oncology prosthesis.

A number of management strategies can be considered when dealing with structural and non-structural bone deficiencies during revision arthroplasty surgery (Table 4), and have been described by other authors.^{3,11,12,19,26} Similar to our findings, these studies support the treatment of large osteolytic defects with revision stemmed TKA implants and both structural allograft and cancellous bone grafting. In addition, several authors have reported the results of particulate bone-grafting following revision total knee arthroplasty performed with or without cement.^{1,3,21,33,37,39,40,41}

In the current study, the management of osteolytic defects was dictated by the integrity of host bone structural support and whether defects were contained or uncontained. For patients with contained defects (Group 1), cancellous allograft was impacted into the osteolytic defect and revision components—with or without augments—were cemented at both the implant bone interface and cement was added within the metaphysis

along with either cementless or cemented stem fixation, depending on host-bone quality for stem fixation. It is our preference to use a diaphyseal engaging cementless stem with flutes and a clothes-pin design combined with generous cement at the metaphyseal-implant junction. This group of patients made up the majority of our TKA revisions. The selection of a cemented versus a cementless stem extension in this series was chosen based upon the patient's metadiaphyseal and diaphyseal bone quality, endosteal diameter, patient age, comorbidities, and the presence or absence of a structural allograft requiring support. In patients with suitable bone a cementless stem was selected. Cemented stems were typically chosen in older age patients with poor bone quality or large diameter canals > 21mm, and in whom reaming of an osteoporotic canal was considered unsafe.

For patients with uncontained defects (Group 2), structural allograft reconstruction of the segmental defect was performed using either femoral head (6 cases), proximal tibial (1 case) or distal femoral allograft (1 case), with surface and metaphyseal cementation of components. Cemented stem fixation was used for 6 of 8 patients due to inadequate host bone-stock available to support a diaphyseal-engaging cementless stem.

For the patients in Group 3, extensive osteolysis in both the metaphysis and diaphysis precluded the re-

removal of well-fixed implants in the setting of extensive metaphyseal and diaphyseal bone loss that would have required extensive bone replacement, either in the form of massive structural APC, or a modular oncology prosthesis. Instead of extensive bone replacement with revision components, we elected to retain the primary components, to perform cancellous allograft impaction into the osteolytic defect, and to exchange the polyethylene insert. These patients have continued to function well at recent follow-up.

This study is limited due to several factors. The relatively small number of patients included in this study (n=28 knees) and other recent series both reflects the relatively low incidence of major osteolysis as a primary indication for revision TKA and limits the ability to define statistically significant differences among treatment groups. Both the retrospective nature of this study and the small patient groups treated comprise a limitation of this study. Nonetheless, the majority of patients (86 percent) were significantly improved by the results of the surgery. Significant improvement was obtained in all groups with respect to VAS pain, clinical and functional scores following revision TKA. Of the remaining 3 patients (4 knees), periprosthetic sepsis (1 knee), aseptic tibial component loosening (1 knee), and radiographic recurrence of linear osteolysis (2 knees) occurred. The mean follow-up of 33 months is similar to other reported series. The use of cemented and cementless fixation methods is, in the authors' experience, representative of the population of TKA patients requiring revision for osteolysis, and thus is a common scenario encountered by surgeons performing revision TKA for osteolysis.

CONCLUSION

Revision TKA with selective bone grafting is effective in the management of major periprosthetic osteolytic defects. The results of this study indicate that substantial bone defects may be effectively managed with a combination of component retention or revision, and both structural and cancellous bone grafting during revision TKA. The use of both cementless and cemented stems to bypass bone defects reflects the heterogeneous defect and patient factors encountered in revision TKA surgery, and both stem fixation options are useful techniques. Group 1 knees are managed with standard TKA revision implants, augments, and morselized cancellous bone grafting. Group 2 knees are any TKA revision that requires structural allograft reconstruction. There may also be a subset of patients (Group 3 knees) for whom more conservative reconstruction (component retention, modular polyethylene liner exchange with impaction

allografting) is indicated. Careful surgical planning is essential to determine both optimal implant selection and bone graft requirements.

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CHARACTERIZATION AND PATHOLOGICAL CHARACTERISTICS OF SPONTANEOUS OSTEONECROSIS OF THE KNEE

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ABSTRACT

Objective: Spontaneous osteonecrosis of the knee affects patients typically over the age of fifty-five years. Evidence exists that this process may not be true necrosis. The purpose of this study was to characterize the demographic, radiographic, and pathologic features of this condition.

Materials and Methods: Twenty-one patients (twenty-two knees) consecutively treated for spontaneous osteonecrosis of the knee were studied.

Results: Only one of twenty-two specimens demonstrated evidence of bone necrosis. No specimens showed fat necrosis, marrow necrosis, fibrous change or appositional bone repair. Fourteen of twenty-two specimens (64%) showed significant osteopenia and fifteen of twenty-two specimens (68%) showed evidence of osteoarthritis.

Conclusions: This study demonstrated that spontaneous osteonecrosis of the knee is not an osteonecrotic condition and has been misnamed. Osteopenia and osteoarthritis may play a role in the pathogenesis of this disease.

INTRODUCTION

Spontaneous osteonecrosis of the knee (SPONK) is a condition that leads to knee pain in patients who are typically over 55 years of age. It usually affects one condyle of the knee and often leads to arthritic changes. Originally, it was proposed that this condition is caused by bone death or osteonecrosis.^{1,12} However, patients have

a different history, clinical course, and bony involvement than those with true osteonecrosis. True osteonecrosis typically occurs in younger patients (often less than 40 years), affects multiple joints and condyles, and is associated with risk factors such as corticosteroids and alcohol abuse.¹² SPONK most typically affects the medial condyle of the knee, is unilateral, and occurs in older patients with no osteonecrosis risk factors.⁶

The histopathology of SPONK lesions was initially thought to show signs of cell death.³ Recent work has shown that the cause of SPONK may be subchondral or stress fractures in osteopenic bone.¹⁵ SPONK may then be a misnomer and not true osteonecrosis.

The purpose of this study was to characterize the various demographic and radiographic aspects of SPONK. Another primary purpose was to qualitatively and quantitatively assess the histopathology associated with this disease.

MATERIALS AND METHODS

Selection of Subjects

Patients with SPONK were selected from a database of one hundred and sixty patients (285 knees) who underwent surgical intervention for a preoperative diagnosis of osteonecrosis of the knee. Institutional Review Board approval was obtained for this study. Patients diagnosed with spontaneous osteonecrosis of the knee were then identified based on clinical history and imaging data. Subjects over the age of fifty-five years with unilateral disease that primarily affected the medial femoral condyle, had no other joint involvement, and no history of risk factors for osteonecrosis were included in the study group (sixteen patients, sixteen knees). Five more patients with clinical variants of SPONK were later added to the study group; two patients were under fifty-five years of age, two patients exhibited lateral femoral condylar disease only, and one patient had bilateral knee disease. Before inclusion in the study group, each diagnosis of SPONK was confirmed by an examination of plain radiographs and magnetic resonance images. The final study group included twenty-one patients and twenty-two knees. The mean age for the group of spontaneous osteonecrosis patients was sixty-seven years (range, forty-two to eighty-one years) and sixty-two percent were women (thirteen of twenty-one patients).

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Clinical Evaluation

Patient hospital records were analyzed to obtain demographic data including age at time of presentation, gender, race, height, weight, corticosteroids, tobacco and alcohol use, comorbid diseases, symptom onset and duration, laterality of disease, and involvement of other joints. Alcohol and tobacco use were assessed qualitatively based on patient responses to a questionnaire. Corticosteroid use was assessed quantitatively. The total dosage was calculated by obtaining the duration of corticosteroid use, the average daily dose, and the maximum daily dose.

Radiographic Evaluation

Plain radiographic films, bone scans, and magnetic resonance images were reviewed for all patients. Anterior-posterior and lateral plain radiographs were used to assess lesion stage. Although a unique staging system for spontaneous osteonecrosis of the knee was proposed by Aglietti and associates in 1982, a modified version of Ficat and Arlet's criteria for osteonecrosis of the hip was chosen for this study (Table 1).⁷⁻¹⁰ According to this system, Stage I lesions have normal plain radiographs but can be identified by characteristic changes on magnetic resonance imaging and bone scintimetry. Stage II lesions demonstrate sclerotic or cystic change on plain radiographs, identified by radiodensities in the distal femur or proximal tibia. Stage III lesions exhibit subchondral collapse, as evidenced by the characteristic "crescent sign" on plain radiographs. Stage IV lesions reveal articular collapse, joint space narrowing, degeneration on both sides of the joint, and possible osteophyte formation. Stage IV disease is often indistinguishable from osteoarthritis on plain radiographs. When available, staging was conducted on two separate sets of radiographs, one obtained at the time of clinical presentation and the other obtained at the final visit before surgery.

Histological Examination

Hematoxylin and eosin-stained paraffin sections of the total knee arthroplasty (n = 13) and core decompression (n = 9) specimens were obtained and evaluated microscopically by one of us (EFM) in a masked manner. The location of the lesions for examination was carefully performed on macroscopic specimens obtained after total knee arthroplasty. Core decompressions included biopsies that samples the area of involvement based on x-rays and magnetic resonance imaging evaluation.

The bone and marrow for each specimen were evaluated in the following systematic manner: initially, the bone was analyzed qualitatively for osteoporosis, evidenced by thinning and depletion of trabeculae. The

bone itself was then analyzed for evidence of death, revealed by a generalized loss of lacunar osteocytes. Bone that demonstrated viable repair surrounding a dead core was tabulated as dead bone. By comparing the amount of dead trabeculae and the total amount of bone specimen, an actual percentage of dead bone was determined and recorded for each sample. Trabecular bone was also examined for evidence of microfracturing on a qualitative basis only.

The amount of appositional bone repair was determined by examining dead trabeculae surrounded by viable bone. This type of repair exhibits a dark seam of osteoid between the dead bony core and the surrounding viable bone. The percentage of dead bone that exhibited evidence of a reparative process was recorded.

Marrow was examined for fat necrosis, granulation tissue, fibrous tissue, edema, calcifications, and lipid cysts. Of those areas where marrow necrosis was evident, the tissue was differentiated into fat necrosis, granulation tissue, or fibrous tissue. Fat necrosis was identified by a loss of lipocyte nuclei and cell membrane blurring. Fibrous tissue was identified by the presence of fibroblasts and obvious fibrous organization. The percentage of each of these three tissue types of the total abnormal The presence of edema in the marrow space, as evidenced by an eosinophilic fluid occupying the space between lipocytes, was recorded. The degree of marrow edema was qualitatively assessed on a scale of zero to three, with zero representing no edema and three signifying extensive edema. Calcifications of fat necrosis within the marrow were readily identified by distinct areas of increased staining. Lipid cysts were identified as large, circular, membrane-bound structures in areas of obvious fat necrosis. The presence of these histological entities was recorded qualitatively.

The presence of osteoarthritis was assessed, based on the observation of articular cartilage fraying and reactive bone changes directly beneath the articular surface. Cases of osteoarthritis exhibited subcortical bone thickening, active bone formation with osteoid seams, and some focal areas of necrotic bone. Areas of bone necrosis and active repair secondary to osteoarthritic change were not included in the above categories.

The osteonecrosis pathological stage for each specimen was determined based on the system of Arlet and Durroux for osteonecrosis of the hip.⁴ Based on this classification system, Stage I lesions demonstrate a loss of normal hematopoietic marrow elements and evidence of edema only. Stage II lesions display obvious fat necrosis only. Stage III lesions reveal both marrow and bone necrosis. Stage IV lesions display necrosis, as well as marrow fibrosis and appositional repair.

TABLE 1

| | <u>True Osteonecrosis</u> | <u>SPONK</u> | <u>Mean</u> | <u>Our Study</u> | | |
|--------------------------------|--|-------------------|-------------|-------------------|-------|-----|
| Age | < 45 yrs | > 55 yrs | 67 | 20/22 | > 55 | 92% |
| Gender | M > F alcohol F > M SLE | F > M | | 13/21 | F > M | 62% |
| Unilateral | < 20% | > 95% | | 21/22 | | 95% |
| Affected Femoral Condyle(s) | Multiple | One | | 20/22 | | |
| Tibial Involvement | 22% | Less common | | 3/22 | | |
| Location of Bone | Diaphysis, metaphysis, and Epiphysis | Epiphysis only | | Epiphysis only | | |
| Risk Factor | Alcohol, Steroids, 80% | Rare | | 1/22 | | |
| Other Joint Involvement | 90% | Rare | | 0/22 | | |

RESULTS

The mean duration of symptoms prior to surgical procedures was eleven months (range of three to thirty-six months) for the group of spontaneous osteonecrosis patients. None of the spontaneous osteonecrosis patients had other large joints involved with symptomatic disease.

The laterality of disease was equivalent (eleven left knees and eleven right knees). The majority demonstrated lesions primarily in the medial femoral condyle (nineteen of twenty-two knees). Four knees (eighteen percent) showed evidence of disease in the lateral femoral condyle.

None of the spontaneous osteonecrosis patients had corticosteroid exposure greater than 2 grams for the previous ten years before the diagnosis. Three of twenty-one patients reported a history of heavy alcohol use (400 ml of ethanol per week for greater than one year.¹² Comorbid disease in the patients included one patient each with diverticulitis, Parkinson's disease, prostate cancer, hypothyroidism, polycystic kidney disease, lymphoma, polymyositis, chronic pancreatitis, hepatitis, and inflammatory bowel disease. There were no patients with systemic lupus erythematosus, sickle cell disease, diabetes, or documented coagulation disorders.

Three of twenty-two knees were graded as Stage I, eight (thirty-six percent) as Stage II, four as Stage III, and seven were judged to be Stage IV. One magnetic resonance image could not be located for examination, but a radiographic report was found that documented a visible lesion (Stage II). On magnetic resonance imaging, the presence and location of a low signal intensity

lesion as well as evidence of bone edema, subchondral fracture, and meniscal tearing were documented. Nine knees demonstrated characteristic low signal intensity lesions, and two knees exhibited signs of bone marrow edema in the affected condyle.

Nineteen of twenty-two specimens (eighty-six percent) were classified as normal bone with no evidence of bone marrow edema, marrow necrosis, or bone necrosis. Only two specimens (nine percent) in the group of specimens demonstrated evidence of bone marrow edema. None of the specimens demonstrated necrotic bone with repair. One specimen in the spontaneous osteonecrosis group showed evidence of necrotic bone. No marrow necrosis was observed in any specimens.

Twenty-one of twenty-two knees specimens (ninety-five percent) were categorized as Arlet and Durrux Stage 0. The one specimen that demonstrated necrotic bone was classified as Stage III because there was no repair noted. Fourteen of twenty-two specimens (sixty-four percent) demonstrated qualitative evidence of osteopenia and fifteen of twenty-two specimens (sixty-eight percent) demonstrated osteoarthritic changes. Figure 1 shows these common findings. No evidence of microfractures or subchondral fractures was seen.

DISCUSSION

While the clinical picture of spontaneous osteonecrosis of the knee has been well-characterized, the associated histopathology has received less scrutiny. The earliest report of spontaneous osteonecrosis provided only descriptive histologic data.² It was from this study

that the term "spontaneous osteonecrosis of the knee" originated. The present quantitative study of histology indicates that this term may not be entirely appropriate for this disease. Contrary to its classification as osteonecrosis, this disease does not seem to be associated with any appreciable amount of bone necrosis. Only one specimen from the twenty-two knees (four percent) demonstrated any evidence of bone death. In the present study, we characterized the clinical and radiographic data from twenty-two knees that were not dissimilar from previous studies. In this study, the greater majority of patients fell into typical categories for SPONK with only a few exceptions (2 patients <55, one with history of alcohol use, one bilateral knee). This has been what we have generally found; patterns that allow easy classification in most cases with occasional patients with one aberrant demographic variable (e.g., age less than 55 years, bilateral disease).

The results of this study further support the theory that SPONK is not caused by bone death but may be caused by osteoporosis and insufficiency fractures. This has been suggested by evaluation of magnetic resonance imaging scans^{11,13,14} and by evaluation of histological specimens.⁵ For example, Narvaez demonstrated three cases of insufficiency fracture of the medial femoral condyle and one of the medial tibial plateau in knees with SPONK. While our study revealed no histological evidence of fracture lines, osteopenia was evident in sixty-four percent of the specimens. A recent report has suggested that biochemical markers of bone turnover are elevated in SPONK.⁵ They found these markers in twenty-two patients with SPONK and compared these to twenty patients with osteoarthritis of the knee. In both diseases, markers were elevated which were indicative of increased bone turnover with deposition of collagen Type I more pronounced in SPONK knees.

Yamamoto and Bullough studied fourteen knees in patients who had operative treatment for SPONK.⁵ Their findings were similar to the present study in that osteonecrosis was not found to be the primary event. They only found localized evidence of osteonecrosis as a result of subchondral insufficiency fractures. Our study did not find any insufficiency fractures.

Our study had several limitations. This was a retrospective case series. The evaluation of histological specimens was also subject to sampling error. Assessments of osteopenia and osteoarthritis were not entirely ideal since only qualitative observations were made. However, any attempt to quantitate the degree of osteopenia in the specimens would be difficult because of the high prevalence of osteoarthritic changes. Nevertheless, despite these shortcomings, we can definitely conclude that necrotic bone is rarely, if ever, found in these lesions.

This study demonstrated that SPONK is not an osteonecrotic condition. Further work to more carefully evaluate the pathology of this condition and to determine the role of osteoporosis and insufficiency fracture in its etiology needs to be performed.

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COMPLIANCE-DEPENDENT LOAD ALLOCATION BETWEEN SENSING VERSUS NON-SENSING PORTIONS OF A SHEET-ARRAY CONTACT STRESS SENSOR

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ABSTRACT

Piezoresistive array pressure sensors are widely used in orthopaedic research to determine contact stress distributions across articular joint surfaces. Experience with such sensors has shown there can be inaccuracies in how the sensor perceives applied load, depending on the material stiffnesses between which it is compressed experimentally, versus in calibration. A study was undertaken to quantify the relationship between load perception of one such sensor design (Tekscan) and the stiffness of the materials between which it is compressed. A three-dimensional finite element model of a 3x3 sensel portion of the sensing matrix was formulated, along with a layer of compression test material on each side of the sensor. The elastic modulus of the test material was varied across the range representative of cartilage (12 MPa) to hard plastic (10 GPa). Using the computed contact pressure results between contacting surfaces of the sensor layers, the percentage of load passing through the active conductor intersections was determined. The results revealed that with increase of the elastic modulus of the material between which the sensor was compressed, the percentage of load on the active conductor intersections increased monotonically. The highest sensitivity of perceived loading to test material modulus (0.1%/MPa) was seen at the low end of the modulus range. The more compliant the test material, the more the sensor layers conformed around each other's geometric incongruities, the larger the true contact areas, and the higher the fraction of the total load that passed through the intermediate (non-sensing) regions between the conductors.

INTRODUCTION

Piezoresistive array pressure sensors are commonly used in orthopaedic research, to determine contact stress distributions across articular joint surfaces. The physical layout of the (periodic) sensing elements of these transducers is such that differing fractions of the regionally applied loading can potentially pass through non-load-sensing portions between sensing elements of the transducer, depending on the stiffnesses of the test material surfaces between which the transducer is compressed. It is often impractical to calibrate the transducer between loading platens whose stiffnesses identically match those of the actual compression test material surfaces of interest experimentally. Moreover, in some experiments (e.g., osteochondral defect repair studies¹) sites of greatly differing stiffness come into and out of contact. Need therefore exists to appreciate the influence of compression material surface stiffness on the load perceived by the sensing elements of the transducer.

In the widely-utilized form manufactured by Tekscan (Boston, MA), these sensors can be as thin as 0.1 mm, and consist of a matrix of conductive strips in rows and columns, printed on separate layers of Mylar film. Lines of piezoresistive ink are applied over each conductive strip in the sensing area, leaving visibly ink-free spaces between them. Two such Mylar layers are adhered together around the edges, so that the piezoresistive ink-coated conductors face each other perpendicularly. The entire sensing area can be viewed as divided into squares centered on the intersections between ink covered conductors. Each of these squares is referred to as a sensel, of which as little as 10% of whose area is occupied by the intersection of the orthogonal conductors. When the sensor is positioned between contacting surfaces, each conductor intersection acts as a variable resistor, whose resistance is dependent on the instantaneous local compression of that sensel. Lead wires connect each row and column to a computer that records resistance values for all conductor intersections in the sensor.

To allow conversion of sensel resistance to load or pressure, calibration is necessary. Typically, the sensor is placed between two flat platens made of synthetic materials, such as rubber, plastic, or metal. Then, various known loads are applied across the sensor. Intui-

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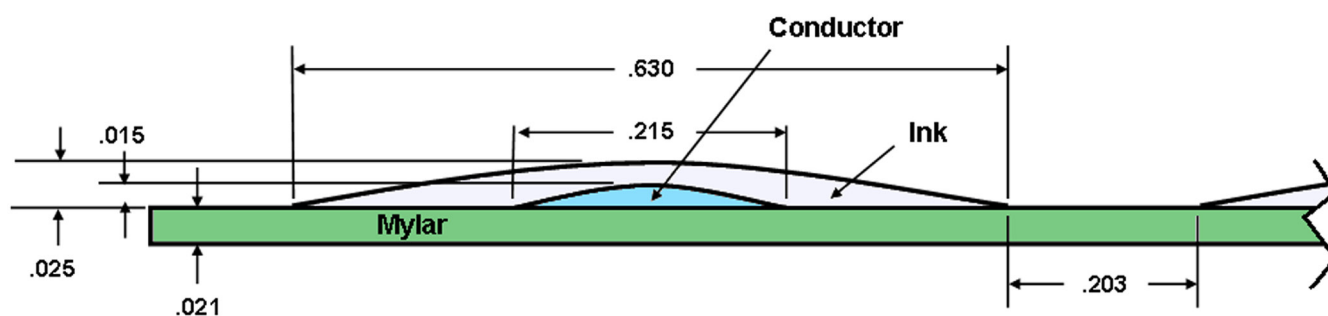


Figure 1. Cross-sectional dimensions (mm) of one ink-covered conductor strip, printed periodically on Mylar substrate.

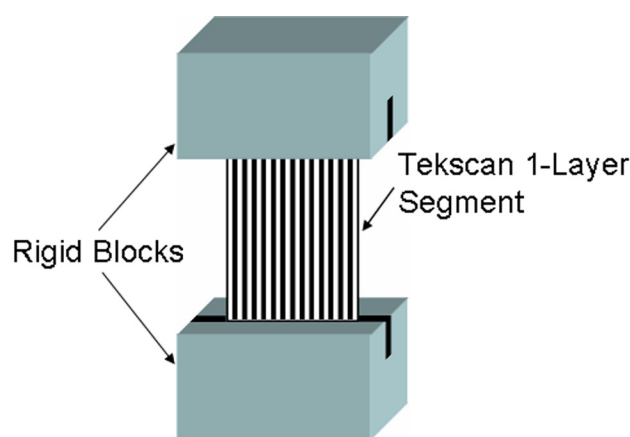


Figure 2. Setup for tensile test used to determine material properties, showing one layer of the sensor bonded to rigid blocks to be clamped in an MTS machine.

tively, the load perceived by the sensor should depend on the properties of the test material compressing it. This is an important relationship to quantify, since final results from the experiment (e.g., cartilage-on-cartilage compression) depend heavily on sensor calibration accuracy. In this study, a finite element (FE) analysis was undertaken to determine the force distribution within a Tekscan sensor, as a function of the stiffness of the surface between which it is compressed.

METHODS

An FE model of a (repeating) section of a Tekscan ankle sensor (Model 5033) was created and analyzed using ABAQUS software. Geometry (Figure 1) was determined from a single layer of a Tekscan sensel matrix, assessed using a measuring microscope. Material properties were found by performing staged tensile tests, parallel to the conductors, on one layer of the sensor matrix from five different sensors, using an MTS machine. To do this, a segment from one layer of each sensor matrix was removed and bonded on each end to two metal blocks (Figure 2) in turn clamped into the MTS machine. A

first tensile test determined the elastic modulus of the intact layer. Then, the piezoresistive ink was dissolved with acetone, while preserving the conductors intact, at which point a second tensile test was performed on the remaining segment (i.e., Mylar + conductor). Lastly, after subsequently removing the conductive strips the Mylar film was tested alone. This tensile test sequence was repeated for all five specimens. All (tangent) modulus evaluations were at a strain level of 2%. Since one layer of the sensor array can be considered as a unidirectional fiber-reinforced composite, the rule of mixtures²

$$E_{Composite} = E_1V_1 + E_2V_2 + \dots + E_nV_n$$

was used to estimate each component material's modulus, where E_i and V_i represent the elastic modulus and volumetric fraction of each i 'th component of the composite. With this approach, the moduli of Mylar, piezoresistive ink, and conductive strips were found to be 2.9 GPa, 3.68 GPa, and 0.77 GPa, respectively. Poisson's ratio was assumed to be 0.35 for all three materials.

The FE model consisted of three units of a (periodic) section of the Tekscan sensor, with three ink-covered conductors attached to a Mylar strip on bottom and three lying perpendicular on top (Figure 3). A layer of compression test material 1.5 mm thick (nominal articular cartilage thickness) backed each side of the Tekscan segment. The model was formulated as a contact problem, with frictionless interaction between the contacting layers. The outermost surfaces of the test material layers were constrained in all directions except for the top surface, which was free to move vertically. The model was driven by a vertical load of 16 N (1.78 N/sensel) applied to the top-most rigid surface, causing compression of the sensor. This load was based on the 80th percentile stress (2.55 MPa) from a recent study where six cadaver ankles at 0° flexion had been subjected to a 600 N axial load, representing one body weight.³ The test material properties were varied from representative of cartilage (12 MPa modulus,⁴ 0.42 Poisson's ratio⁵) up to representative of hard plastic (10 GPa).

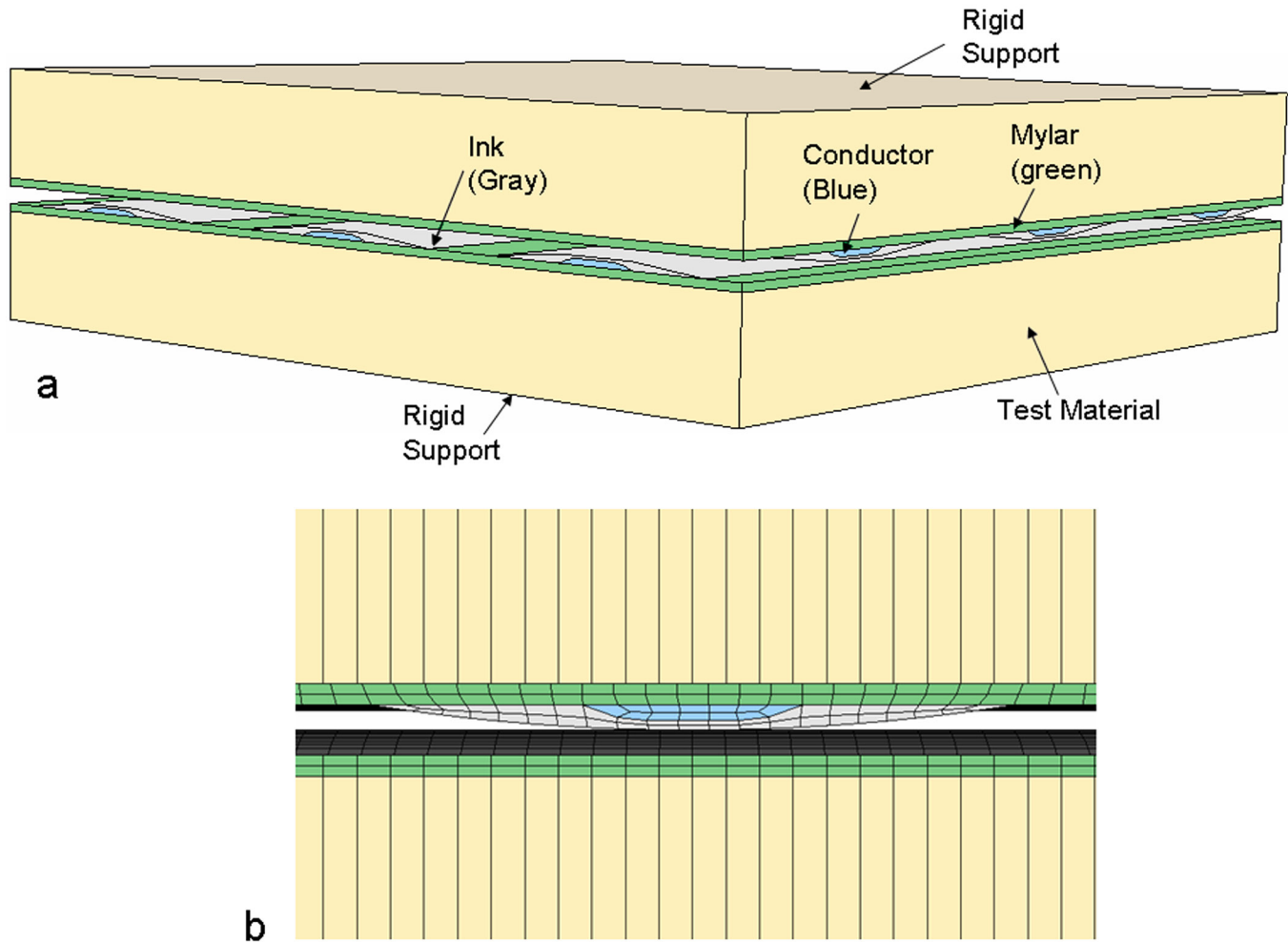


Figure 3. (a) Finite Element model of a segment of a Tekscan ankle sensor showing three ink-covered conductors on bottom, and three lying perpendicular on top, with a test material backing on each side. (Not shown to scale) (b) FE zoning of the cross section for one sensel.

The force transmitted through the region directly between the top and bottom intersecting conductors was determined for each case, using the ABAQUS contact pressure results. The middle sensel was analyzed, to minimize end condition effects. The region of elements on the bottom sensor layer directly between the middle column and row conductor intersection was isolated, as shown in Figure 5. The percentage of force on the middle sensel conductor intersection, relative to the force passing through the overall middle sensel, was calculated.

To confirm adequacy of the FE zoning, a preliminary comparison was done versus Hertzian contact stresses. Using similar zoning, homogeneous material properties were assigned to the model. A load of two N per sensel (18 N total) was applied in the same manner as in the Tekscan sensor FE model. The (homogeneous) material

elastic modulus was varied from 500 MPa to 5000 MPa. Hertzian contact equations for two perpendicular cylinders⁶ were used to determine the theoretical pressure at the center of each contact area. Hertzian analytical vs. ABAQUS-calculated pressure values had discrepancies ranging from 1.6% to 4.3%, with an average of 2.6%.

The FE model was then validated by performing a corresponding physical force vs. displacement compression test on a sensor. In this test, a sensor was compressively loaded between rigid parallel platens in an MTS machine. To simulate this situation, the test material was removed from the total FE model, leaving just the sensor. The outermost surfaces of the sensor-only model were then rigidly constrained. The FE-predicted compressive load/displacement behavior was in very reasonable agreement with the experimental measurements (Figure 4).

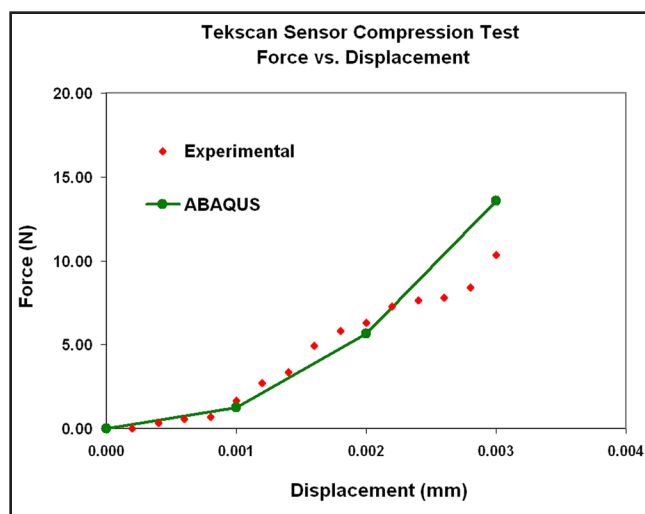


Figure 4. Force vs. displacement relationship comparing the FE model response and experimental response of a Tekscan 5033 sensor in a compression test.

RESULTS

A series of model trials was then run, spanning test material elastic modulus range from 12 MPa to 10 GPa. Figure 5a shows the computed contact pressure distribution on the bottom contact surface of the sensor segment when the test material had a modulus of 10 GPa. The nine contact patches were small in area, and the force transmission was concentrated through the conductor intersections. Figure 5b shows the contact pressure distribution when the test material had a modulus of 12 MPa, in which case the nine contact patches were very large, with diffuse contact pressure, and with substantial load transmission through the regions between the conductor intersections.

Figure 6 shows fractional load transmission changes for test material modulus between 12 MPa and 10 GPa. The percentage of force over the middle sensel active sensing region ranged from 8.5% (for a 12 MPa test material) to 96.4% (for a 10 GPa test material). The relationship reveals that with increase of test material elastic modulus between which the sensor is compressed, the force on the active conductor intersection monotonically increases, with greatest sensitivity (~1% perceived load change per 10 MPa of test material modulus change) occurring at the (cartilage-representative) low end of the range considered.

DISCUSSION

The purpose of this study was to quantify how the sensor's perception of applied loading would change due to variation in the stiffness of the surfaces between which it was compressed. With more compliant materials, such as cartilage, the top sensor layer was able to conform to the curvature of the ink/conductor complex on the bottom layer. This resulted in a much larger contact area, with less load passage through the active intersection. By contrast, stiffer test materials resulted in small contact area, with almost all of the load going through the active intersection. Since the pressure sensor reads the electrical resistance only at the sensing sites (i.e., directly between the intersecting conductors), any load passing outside of the intersecting region would not be accounted for in the sensor output data. This makes it evident that the sensor results will be compromised when there is a mismatch between the moduli of the materials between which the sensor is calibrated, versus those between which it is used experimentally. Fortunately, as a practical matter,

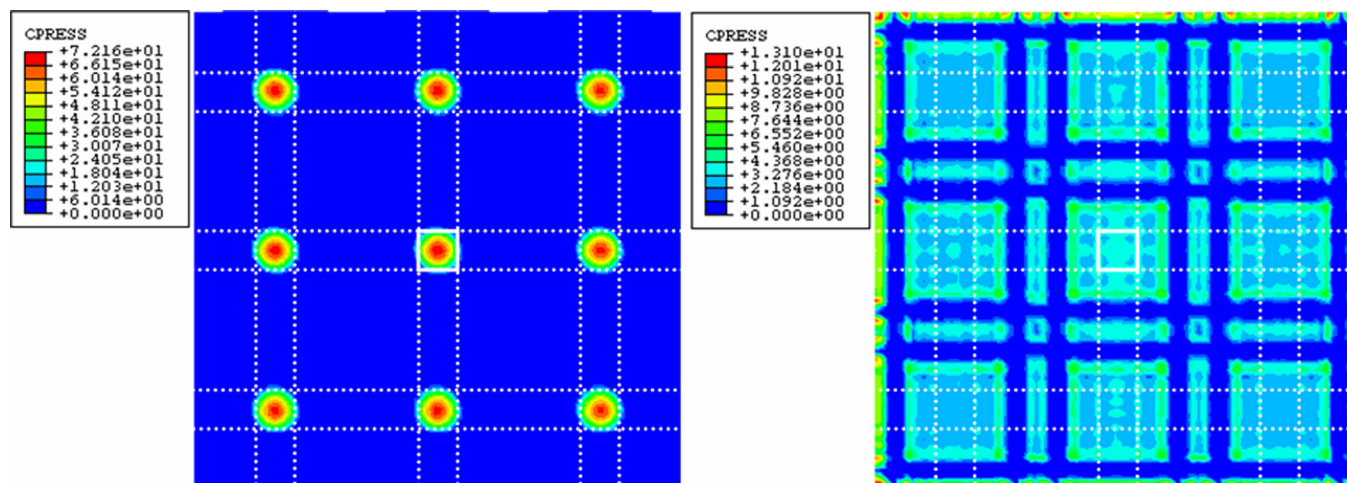


Figure 5. ABAQUS images showing the contact pressure distribution on the top of the bottom layer in the sensor with a regional applied load of 2.56 MPa, for a test material with an elastic modulus of (a) 10 GPa, representing hard plastic and (b) 12 MPa, characteristic of cartilage. (Color scales are different) Dotted lines show the conductor traces. The white square shows the active conductor intersection in the middle sensel that was isolated to determine the force distribution.

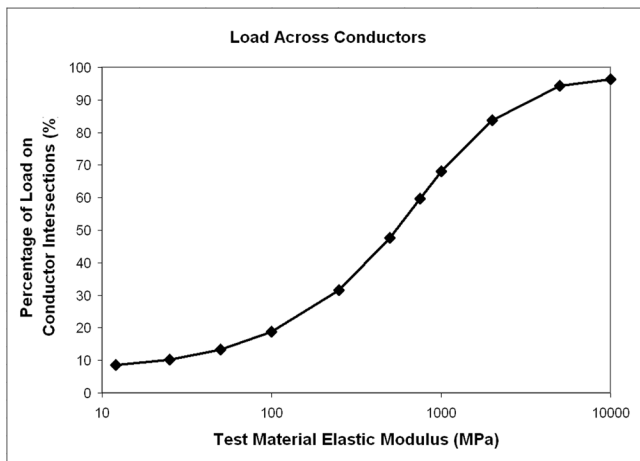


Figure 6. The semi-log relationship between the stiffness of the contact material and the fractional force distribution over the sensel active conductor intersection at an applied load of 16 N (1.78 N/Sensel).

for most usages in orthopaedic research, the magnitude of this compromise does not appear to be severe. In even the most sensitive region (12 MPa, representative of cartilage-on-cartilage contact), an “error” of 1% per 10 MPa of modulus discrepancy would not be problematic, since even for relatively severe levels of cartilage degeneration the effective elastic modulus changes are only on the order of a few MPa.⁷ It therefore should suffice for most purposes to have performed calibrations between synthetic surfaces nominally matching cartilage modulus, with a scaling step to register recovery of the aggregate load applied to the specimen.

ACKNOWLEDGMENTS

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IA-FEMESH: ANATOMIC FE MODELS—A CHECK OF MESH ACCURACY AND VALIDITY

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ABSTRACT

Musculoskeletal finite element (FE) analysis is an invaluable tool in orthopaedic research. Unfortunately, the demands that accompany anatomic mesh development often limit its utility. To ease the burden of mesh development and to address the need for subject-specific analysis, we developed IA-FEMesh, a user-friendly toolkit for generating hexahedral FE models. This study compared our multiblock meshing technique to widely accepted meshing methods. Herein, the meshes under consideration consisted of the phalanx bones of the index finger. Both accuracy and validity of the models were addressed. Generating a hexahedral mesh using IA-FEMesh was found to be comparable to automated tetrahedral mesh generation in terms of preprocessing time. A convergence study suggested that the optimal number of hexahedral elements needed to mesh the distal, middle, and proximal phalanx bones were 3402, 4950, and 4550 respectively. Moreover, experimental studies were used to validate the mesh definitions. The contact areas predicted by the models compared favorably with the experimental findings (percent error < 13.2%). With the accuracy and validity of the models confirmed, accompanied by the relative ease with which the models can be generated, we believe IA-FEMesh holds the potential to contribute to multi-subject analyses, which are pertinent for clinical studies.

INTRODUCTION

Computational models of joint anatomy and function provide a means for biomechanists, physicians, and physical therapists to understand the effects of repetitive motion, acute injury, and degenerative diseases. Moreover, such models may be used to improve the design of prosthetic implants. Musculoskeletal finite element (FE) analysis has proven an invaluable tool in orthopaedic-related research. While it has provided significant biomechanical insight, the demands associated with modeling the geometrically complex structures of the human body often limit its utility. The majority of the analyses reported in the literature refer to a single, or 'average,' bone geometry, although in many cases anthropometric variability should not be neglected. Individualized models are important for future development of this field, as they offer a means of correlating mechanical predictions with clinical outcomes. The challenge is that most biological structures are dauntingly complex and few commercial FE software programs are geared toward modeling anatomic structures. To ease anatomic mesh development, we developed IA-FEMesh,¹ a user-friendly toolkit for generating hexahedral FE models.

There are two broad types of mesh generation schemes—routines for structured and unstructured meshes.^{2,4} The techniques for generating structured grids are based on rules for geometrical grid-subdivisions and mapping techniques. Structured grids, as the name implies, have a clear structure and can be recognized by all interior nodes of the mesh having an equal number of adjacent elements. The techniques used to generate them produce triangular or quadrilateral elements for two-dimensional analyses, and tetrahedral and hexahedral elements in three-dimensions. Structured meshing algorithms generally involve complex iterative smoothing techniques that attempt to align elements with boundaries or physical domains. Where non-trivial boundaries are required, "block-structured" techniques can be employed which allow the user to break the domain up into topological blocks. Structured grid generators are most commonly used when strict elemental alignment is mandated by the analysis code or is necessary to capture physical phenomenon. Unstructured mesh generation, on the other hand, relaxes the node valence requirement, allowing any number of elements to meet at a single node. Triangle and tetrahedral meshes

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are most commonly thought of when referring to unstructured meshing. While there exists some overlap between structured and unstructured mesh generation technologies, the main feature that distinguishes the two approaches is the unique iterative smoothing algorithm(s) employed by structured grid generators. While free-form meshing schemes using tetrahedral elements are widely employed, it is well known that hexahedral elements would, in many cases, be more effective for analysis.

IA-FEMesh¹ is based on a multiblock approach. The objective of this study was to address the accuracy, validity, and quality of the models generated via the building block approach provided by IA-FEMesh. Moreover, we compared the resulting mesh definitions to both hexahedral and tetrahedral meshes generated via commercial software packages. For this study, the phalanx bones of the index finger were used to develop and test the methodology; the phalanx bones are small and have regions of high curvature, which tested the capabilities of IA-FEMesh to capture these anatomical features.

METHODS

Specimen

A cadaveric arm (female, age = 74) was obtained from the Anatomy Gifts Registry in Hanover, Maryland. Computed tomography (CT) images were obtained on a Siemens Sensation 64 CT scanner (matrix = 512x512, FOV = 172mm, KVP = 120, Current = 94mA, Exposure = 105mAs) with an in-plane resolution of 0.34mm and a slice thickness of 0.4mm. Following image acquisition, the data was processed using BRAINS2 software^{5,6}. The images were resampled to 0.2mm isotropic voxels and spatially normalized such that the vertical plane of the frame was aligned superiorly/inferiorly in the coronal view, vertically aligning the third metacarpal. The CT images were manually segmented⁷ to isolate the phalanx bones of the index finger and the respective bony surface representations were exported in STL format as triangulated surfaces (Figure 1a). These surfaces formed the foundation for the respective mesh definitions.

Mesh Generation using IA-FEMesh

The first step toward meshing the bones was to define building block structures for each of the bony surface definitions. For example, the initial building block for the distal bone was defined by the bounds of the surface (Figure 1b). This block was then edited to better mimic the surface geometry. This was done by subdividing the block and repositioning the block vertices closer to the surface geometry (Figure 1c). Once the structure was defined, mesh seeding was assigned to the blocks

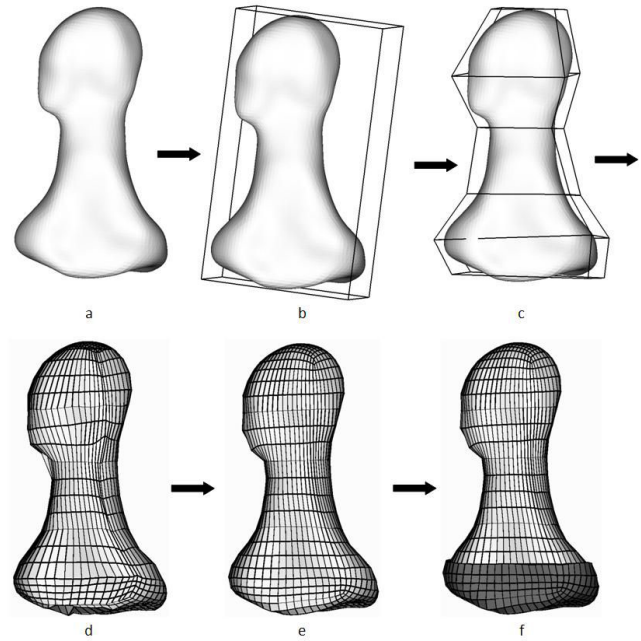


Figure 1. An example of the meshing techniques used on the distal phalanx bone. IA-FEMesh initiates with (a) a surface representation and (b) an initial building block is defined based on the bounds of the surface. This block is then (c) subdivided into multiple building blocks and edited to match the surface geometry. Mesh seeding is applied and projected onto the surface to create (d) an initial, unsmoothed hexahedral mesh. This mesh is (e) smoothed using Laplacian smoothing. Then (f) a uniform articular cartilage layer is extruded.

based on an average element length. The mesh was then projected onto the surface (Figure 1d) and smoothed to accommodate distorted elements caused by areas of high curvature (Figure 1e). A detailed description of IA-FEMesh is described by Grosland and colleagues.¹

Model Accuracy

Prior to implementing any FE model, it is important to ensure that the FE mesh used to partition the domain of interest is of sufficient spatial resolution to provide the desired degree of accuracy. This process consists of progressively increasing the mesh resolution to the point where the mesh is adequately refined such that the solution does not change appreciably with additional mesh refinement. In other words, the mathematical solution has converged. Consequently, a convergence study was performed for each of the phalanx bones of the index finger under consideration.

A hexahedral mesh of each phalanx bone was generated in IA-FEMesh as described previously. Various levels of mesh refinement were considered; this was accomplished by varying the average element length between 0.25mm and 2.0mm. For simplicity, the bone was considered an elastic, isotropic material with an

elastic modulus of 2.0GPa and Poisson's ratio of 0.35. A 40N (grasp strength⁸) point load was applied at the phalanx head, while the proximal end of the bone was fixed in all directions. All analyses were performed using ABAQUS/Standard (Version 6.7-1; Hibbit, Karlsson & Sorensen, Inc, Pawtucket, RI). The ideal mesh was determined when the von Mises stresses converged; the stresses were monitored at the distal end, mid shaft, and proximal end of each bone at regions away from the boundary and loading conditions where high stress concentrations occur.

Comparing Meshing Techniques

Mesh development via IA-FEMesh was compared to conventional meshing techniques afforded by commercial (MSC/PATRAN, Version 2005 r2; MSC Software Corporation, California, USA) and open-source (NETGEN, Version 4.3) software. This allowed for a direct comparison of the multiblock meshing technique to methods that are widely accepted and utilized. Several factors were considered including the time to generate the mesh. This time did not include the time to segment the CT image or generate the surface definition, since each mesh initiated with the same surface.

Additionally, element types (hexahedral and tetrahedral) were compared with respect to the required mesh density and the mesh quality. Note, NETGEN does not allow the user to assign a given mesh density, but instead defines refinement on a scale of "very coarse" to "very refined." In terms of mesh quality, the number of zero volume and distorted elements, as defined by ABAQUS, were investigated. In addition, the ability to capture the anatomical geometry, specifically at the articulations and areas of high curvature, and the resultant von Mises stress distributions were studied.

Contact Analysis

The distal interphalangeal (DIP) joint, due to its small size, was the focus of our contact analysis/validation studies. Subject-specific material properties were assigned to the middle and distal phalanx bone meshes using the established relationship between apparent density and the modulus of elasticity.⁹ A Poisson's ratio of 0.35 was assigned to all bony elements.

In addition to the bones, the articular cartilage was modeled for contact analysis. Due to the size of the joint space, the cartilage could not be readily defined from imaging data. Therefore, the cartilage was created based on the underlying bone mesh, by extruding the cartilage elements a given distance. This resulted in a uniform cartilage layer (two layers of elements) 0.25mm thick. Figure 1f shows an example of the distal phalanx bone

and the corresponding articular cartilage hexahedral mesh for the DIP joint. The cartilage was considered as an elastic, isotropic material with a modulus of elasticity of 12.0MPa and a Poisson's ratio of 0.42.

The middle bone was fixed in all directions (x,y,z) at the proximal-most nodes; the distal bone was loaded with respect to the anatomical center of rotation of the DIP joint. Initially, a 10N compressive follower load was applied while the distal bone was free to translate and rotate. This translational and rotational freedom allowed the bone to settle in the most natural position. Once the bone settled, the distal bone was fixed in the x and z translations, as well as all rotations. A compressive force was applied until the maximum loading was obtained. The maximum load was defined by the load at which the solution failed to converge based on the given boundary conditions.

Model Validity

To validate the FE contact models, biomechanical testing of the corresponding specimen was conducted. The bones of the index finger were dissected of all soft tissues with the exception of the ligaments and articular cartilage. The ligaments were originally kept intact to aid joint stability. Once joint malalignment had been accounted for, the ligaments were removed to accommodate pressure sensitive film within the joint space.

A custom fixation device was used to anchor the bones for quasi-static loading using an MTS 858 Mini Bionix II system and gimbal that allowed for axial loading, abduction/adduction, and flexion/extension. A custom lockable XZ table was employed to adjust for slight malalignments prior to applying large loads. Note that the loading and boundary conditions described above for the FE analysis mimicked those applied experimentally.

The distal bone was fixed in the gimbal and the middle bone was fixed and attached to the XZ table. A pre-load was initially applied, allowing the joint to settle in the neutral position and account for any mal-alignments. Once settled, the XZ table was locked, allowing no translation upon further loading. The specimen load was released to insert pressure film in order to capture the contact area. This study used both super low pressure film (0.5-2.5MPa) and low pressure film (2.5-10MPa). Axial compressive loads of 25N and 50N were applied. This process was repeated three times for each load. The pressure film was scanned using an HP Scanjet 4070 Photosmart scanner and the contact area was measured using ImageJ (Version1.40g; Research Services Branch, National Institute of Mental Health, Bethesda, MD).

TABLE 1

Based on the convergence study, the ideal number of elements and nodes for each phalanx bone, as well as the average element length used to obtain the ideal meshes

| Finger Bone | Number of Nodes | Number of Elements | Average Element Length (mm) |
|------------------|-----------------|--------------------|-----------------------------|
| Distal Phalanx | 4200 | 3402 | 0.625 |
| Middle Phalanx | 5952 | 4950 | 0.75 |
| Proximal Phalanx | 5544 | 4550 | 1.0 |

RESULTS

Table 1 summarizes the number of nodes, number of elements, and average element length that was deemed optimal for each bone based on the convergence study.

Meshing Technique and Element Comparison

Using IA-FEMesh it took approximately six minutes to generate a hexahedral mesh of the proximal phalanx bone. This was comparable to NETGEN, which allowed the same bone to be meshed in four minutes via tetrahedral elements. PATRAN, however, required significantly more time. Table 2 summarizes the mesh generation time for each meshing technique and element type, in addition to the resulting element quality.

The mesh generated using IA-FEMesh resulted in fewer distorted hexahedral elements (i.e., 10%), as compared to the model created in PATRAN (16.58%, including one zero volume element). Both hexahedral meshes had more distorted elements (angles less than 45° or greater than 135°) than the tetrahedral mesh, mainly along the edges of the bone.

Overall, the meshes had similar stress distributions, as shown in Figure 2. The tetrahedral meshes required considerably more elements to obtain smoother stress distributions in comparison to the hexahedral meshes.

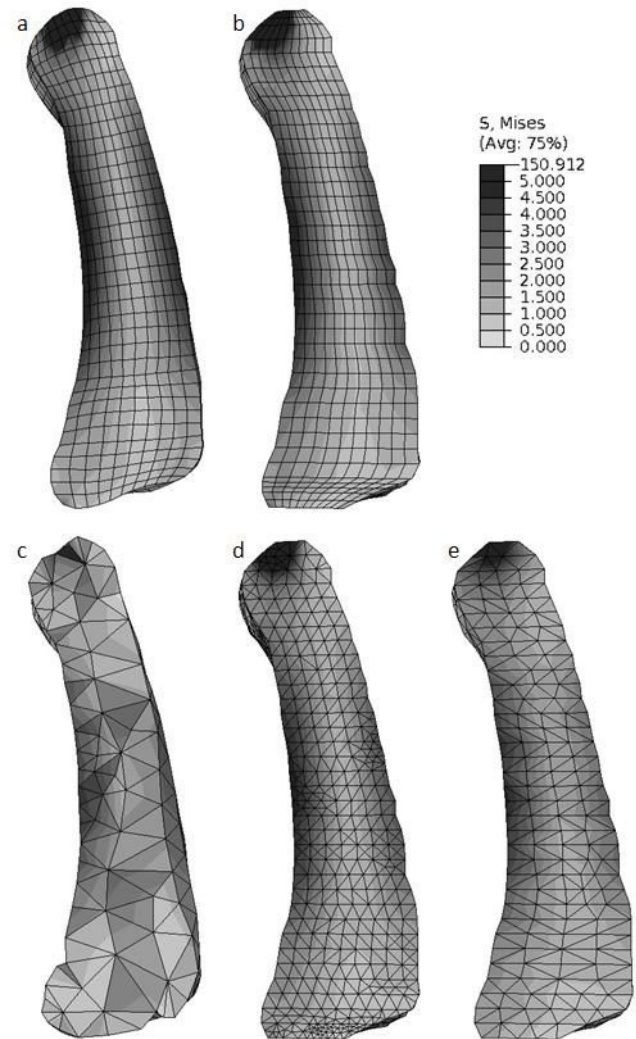


Figure 2. The von Mises stress distribution for the various meshing techniques: (a) IA-FEMesh and (b) PATRAN hexahedral mesh, (c) NETGEN tetrahedral mesh (moderate), and PATRAN (d) tetrahedral mesh, and (e) tetrahedral mesh (2.0 mm). Meshes have an average element length of 1.0 mm unless stated otherwise.

TABLE 2

The number of nodes and elements in each mesh and the corresponding average element length as well as element quality and mesh generation time

| Meshing Software | Element Type | Average Element Length (mm) | Number of Nodes | Number of Elements | Distorted Elements | Zero Volume Elements | Mesh Generation Time (min) |
|------------------|--------------|-----------------------------|-----------------|--------------------|--------------------|----------------------|----------------------------|
| IA-FESMesh | Hex | 1 | 5544 | 4550 | 455 | 0 | 6 |
| PATRAN | Hex | 1 | 6552 | 5434 | 901 | 1 | 330 |
| PATRAN | Tet | 1 | 11366 | 52835 | 228 | 0 | 330 |
| PATRAN | Tet | 2 | 1724 | 7506 | 55 | 0 | 330 |
| NETGEN | Tet | — | 808 | 2457 | 0 | 0 | 1 |

Note: Hex = C3D8, Tet = C3D4 element types in ABAQUS

TABLE 3
The resulting contact area for the experimental data and the finite element model

| Load (N) | Contact Area (mm ²) | | |
|----------|---------------------------------|----------|-----------|
| | Pressure Film | FE Model | Error (%) |
| 25 | 12.36 | 10.73 | -13.17 |
| 50 | 15.61 | 15.03 | -3.69 |

This is most noticeable in the mesh generated using NETGEN; the stress distribution is not as smooth for this coarse mesh. Additionally, IA-FEMesh and NETGEN provided the most geometrically accurate meshes with the ability to capture the articulating surface and areas of curvature; whereas the geometry defined using PATRAN did not capture the articulating surface, but instead a flat surface was generated. For contact analysis, the geometry of the articulating surface is crucial.

Contact Analysis

Table 3 summarizes the experimental and computational contact areas (and the corresponding percent error) for the DIP joint at the 25N and 50N compressive loads. Figure 3 illustrates the contact area predicted via the FE analysis. As compared to the experimental findings, the FE model underestimated the contact area for both loading conditions. As the load increased from 25N to 50N, the percent error decreased from 13.17% to 3.69%. These values are similar to the error values reported by Harris et al.¹⁰ and Liao et al.¹¹ They have shown that Fuji film percent error ranges from 8-36% for contact area measurements.

DISCUSSION

Mesh Comparison

The time to generate an accurate finite element model is crucial when considering subject-specific models. IA-FEMesh enabled geometrically accurate hexahedral meshes to be readily developed (approximately six minutes). This was considerably less time intensive than traditional methods such as PATRAN, which proved time consuming and laborious. Meshing algorithms such as NETGEN are capable of rapidly generating a mesh, but are limited to tetrahedral elements. Moreover, NETGEN has limited control over the level of mesh refinement. The meshing technique utilized by NETGEN requires the meshes to be optimized and due to the curvature of the bony surface and the increased number of elements, NETGEN could not optimize a more refined mesh. The bony geometry proved challenging for PATRAN as well. PATRAN relies on a series of segmented contours, as

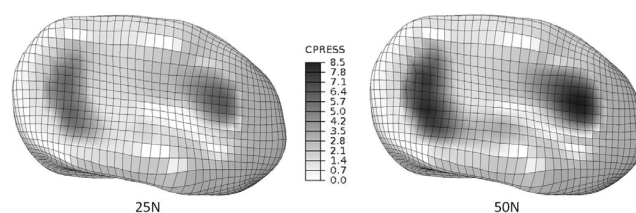


Figure 3. The finite element predicted contact pressure for the distal interphalangeal joint at 25N and 50N loads.

opposed to the surface representation, as its structural input. Consequently, the plane in which the contours were defined played a significant role in the outcome of the mesh. Herein, the contours were defined axially, and as a result yielded poor surface definitions under these conditions. Had the models generated by PATRAN been considered for contact analysis, the contours would have been exported in another plane (e.g., coronal). That being said, the palmar and/or dorsal side of the mesh would have then lacked fidelity. Consequently, both IA-FEMesh and NETGEN benefit from relying on the bony surface representation to generate the mesh.

It should be noted that as the geometric complexity increases, the time required to generate the building block structure in IA-FEMesh will increase, thereby adding time to the meshing process. Tetrahedral algorithms, however, would not be influenced significantly. That being said, the time to mesh the same model via traditional hexahedral methods would also likely increase substantially, thus making IA-FEMesh a favorable alternative for hexahedral mesh definitions. To date, no attempt has been made to optimize the number of building blocks necessary for meshing a given structure. Future studies will investigate, for example, the fewest number of blocks required to mesh a bone. Moreover, our long-term goal is to automate the building block definitions, thereby further reducing the time devoted to establishing the building block structures.

The mesh generated using IA-FEMesh resulted in fewer distorted hexahedral elements as compared to the model created in PATRAN, however both hexahedral meshes had more distorted elements than the tetrahedral meshes. This was expected, since tetrahedral elements are less sensitive to distortion.¹²

When comparing the stress distributions for the various models, the hexahedral meshes yield a smooth stress distribution as compared to the tetrahedral mesh definitions. A tet mesh oftentimes results in an irregular pattern of elements, with considerable variation in element shape. And, as is true with elements in general, as the element shape deviates from ideal, numerical integration problems arise and inaccuracies are introduced. It takes approximately five times more tetrahedral elements (~27,000) than hexahedral elements (~5,000)

to obtain a similar distribution. Due to the mesh refinement limitations imposed by NETGEN, a suitable mesh contour was not achieved.

Contact Analysis

This work was an extension of a previous study conducted by Gassman.¹³ Therein, the phalanx bones were treated as rigid bodies and the articular cartilage was modeled with eight-noded continuum elements with an elastic modulus of 12.5MPa and Poisson's ratio of 0.42. Axial loading was applied using point loading, ranging from 5N to 25N. The loading conditions resulted in contact areas ranging from approximately 5mm² to 25mm² for the DIP articulation. This study utilized continuum elements throughout with subject-specific material properties and showed similar results, predicting contact area ranging from 10.7 to 15.0mm² for the DIP joint with compressive loads of 25N and 50N, respectively.

The percent error for the DIP joint loaded under compression to 25N and 50N was 13.17% and 3.69%, respectively. Harris et al.¹⁰ and Liao et al.¹¹ have shown that the percent error for Fuji film when measuring contact area can range from 8-36%. Our results fall within and below this reported error range. We believe that our results could be further improved upon with slight modifications. For example, the choice of pressure sensitive film (super low pressure and low pressure films) may have influenced the outcome. For example, ultra low films may have been preferable to capture contact pressures as low as 0.2 MPa.

As with any mathematical or computational model, assumptions were made. For example, in the absence of imaging data detailing the cartilage, this model assumed a uniform cartilage thickness over the articular surface; when in actuality there is variation over the articulation. Consequently, this may too influence the resulting contact of the joint. Despite these assumptions, the results were in agreement with the experimental findings, thereby establishing confidence in the validity of the mesh.

CONCLUSION

Finite element modeling is an invaluable tool for biomechanical research. Until recently, the process of generating accurate hexahedral meshes for contact analysis was time consuming and labor intensive. This study found that IA-FEMesh is capable of generating anatomically accurate hexahedral meshes of the human phalanx in significantly less time than a traditionally used commercial mesh generator; in addition, the time is comparable to tetrahedral meshing techniques such as NETGEN. Since IA-FEMesh allowed for easy mesh generation, it was utilized to create meshes for contact analy-

sis of the distal interphalangeal joint. Moreover, these models were validated experimentally using pressure sensitive film. Therefore, IA-FEMesh has been shown to be a user-friendly meshing software that efficiently generates accurate finite element models comparable to the labor intensive traditional meshing techniques.

ACKNOWLEDGMENTS

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COMPARISON OF TWO DIFFERENT ANESTHESIA TECHNIQUES FOR TOURNIQUET PAIN WITH THE USE OF FOREARM TOURNIQUET

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ABSTRACT

Purpose

The purpose of this prospective, randomized study was to compare the effectiveness of two different anesthesia techniques for tourniquet pain in minor surgeries of the hand with the use of the forearm tourniquet.

Methods

In group 1, the area under the tourniquet was anesthetized circumferentially using a cream composed of 5% lidocaine and 5% prilocaine (Emla® Astra). In group 2, the area under the tourniquet was anesthetized with a ring-type infiltration of the skin and subcutaneous tissues using 50% diluted Citanest solution using 22 G × 3 1/2" size spinal needle (Sujia®) with three injections.

Results

There were no statistically significant differences between the means of the two groups with respect to both tests (p value = 0.18 [t-test], p = 0.951 [Mann-Whitney test]). Tourniquet related anesthesia technique discomfort was higher in group 2 (p = 0.001).

Conclusions

The tourniquet placed at the distal forearm is an effective, safe, and useful technique for hand surgery. Anesthesia using Emla cream is equally effective and less disturbing than using the injection technique (subcutaneous ring anesthesia).

INTRODUCTION

A pneumatic tourniquet is usually employed during surgery of the hand to provide a bloodless field. The use of a pneumatic tourniquet is often complicated by the development of tourniquet pain. Various methods have been used to prevent this complication, but most have proved unsatisfactory. The purpose of this prospective, randomized study was to compare the effectiveness of two different anesthesia techniques for tourniquet pain in minor surgeries of the hand with the use of forearm tourniquets.

MATERIALS AND METHODS

The study was performed at Ankara Education and Research Hospital between 02/14/2006 and 05/14/2007. One hundred cases in 92 patients subjected to hand surgery enrolled in this prospective, randomized study (Table 1). They all gave informed consent to participate, and ethical approval from our institution was obtained. For testing the efficiency of the anesthetic agents to the tourniquet pain, a control group was chosen. Twenty-four volunteers accepted to have an inflated tourniquet over their forearm. The volunteers who could not

TABLE 1

Patients' age and sex, the procedures, tourniquet pressure, tourniquet time, HLVAS scores.

| | |
|---|--------------------|
| Number of cases | 100 |
| Number of patients | 92 |
| Male/ Female | 30/62 |
| Mean age (range) in years | 41.5 |
| Mean tourniquet time (range) | 13.335 min. (5-29) |
| Mean tourniquet pressure (range) (mmHg) | 226.47 (200-260) |
| Mean VAS score (range) | 3.05 (0-100) |
| Procedures: | |
| Carpal tunnel release | 29 |
| Tumor excision | 16 |
| Ganglion excision | 15 |
| Trigger finger release | 15 |
| Trigger thumb release | 11 |
| Phalanx or metacarp fracture osteosynthesis | 8 |
| Foreign object removal | 5 |
| Removal of implant | 1 |

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Figure 1. The figure is demonstrating the application of the cream (EMLA®). We applied the cream 1 gr per cm² centimeters proximal to the distal wrist crease routinely. The amount of the cream was evaluated as the multiplication of the diameter of the forearm (where the tourniquet would be inflated) and width of the tourniquet (10 centimeters).

tolerate the tourniquet for 13.3 minutes were excluded from the control group. Subjects with a high risk of cardiovascular disease, malignancy, local infection, uncontrolled hypertension, psychotic disorder, local circulation disorder, lactation, coagulation disorder, skin problems or an allergy to local anesthetic agents, systolic arterial pressure more than 160 mmHg, or under 16 years of age were excluded. Before the operations all the patients were tested as if they would take a general anesthesia. Intravenous hydration was performed for all the patients using a 0.9% NaCl solution. For the patients with bilateral pathology, the second hand was operated on after the first operation wound was healed.

TECHNIQUE

Premedication with 10 mg oral diazepam (Diazem®) was performed in all patients 1 hour before surgery. Because of the hypotensive effect of diazepam, this drug was given to the patients whose blood pressures were normal. Before tourniquet inflation the surgical site was anesthetized by local infiltration using diluted 2% prilocain HCl (Citanest®). Median, ulnar, and digital blocks were also used if necessary. Median nerve blocks were applied at the level of the wrist, and ulnar nerve blocks were applied at the level of the elbow (between the tip of the olecranon and the medial epicondyle). Digital blocks were applied at the level of the metacarpophalangeal joint. Using a computer-generated randomization sequence, patients were randomly allocated into two groups. In group 1, the area under the tourniquet was anesthetized circumferentially using a cream composed of 5% lidocaine and 5% prilocaine (Emla® Astra) (Figures 1 and 2). In group 2, the area under the tourniquet was anesthetized with a ring type infiltration of the skin and



Figure 2. The application of the tourniquet over the nylon covering for the cream.

subcutaneous tissues using 50% diluted Citanest solution using 22 G × 3^{1/2}" size spinal needle (Sujia®) with three injections (Figures 3, 4, 5). All local anesthetics were administered by two orthopaedic surgeons. Emla was applied at the tourniquet site for one minute for group 1 and the local anesthetic solution was injected over two minutes for group 2. Before inflation of the tourniquet, we waited 1 hour for group 1 and 30 minutes for group 2 after the application of anesthetics. In all patients, we applied 1gr / cm² Emla or 15 cc 1/1 diluted Citanest under the tourniquet. We limited loss of the Emla cream into the tourniquet wrap by applying a nylon cover over the cream. This improved the skin absorption. A 10 cm wide single-cuff was placed 8 cm proximal to the distal wrist crease. The patients' arterial blood pressures were measured and noted before inflating the tourniquet. The limb was exsanguinated by an Esmarch bandage and the tourniquet was inflated to 100 mmHg above the systolic blood pressure. Total tourniquet time and total operation time were recorded and tourniquet and operative site related discomforts were assessed by visual analogue scale (VAS). All the patients were instructed about the use of the horizontal linear VAS for tourniquet pain. Tourniquet pain was assessed by means of a 100-mm VAS, one end of which represented no pain and the other end the worst pain imaginable. VAS and vital functions were recorded at 5 minute intervals. Mean values of VAS during the operation were calculated and noted. All the patients were reviewed on the second and fourteenth postoperative days for wound inspection and suture removal respectively. For the control group, the tourniquet was placed at the same position as the study patients. Sedative, local or topical anesthetics were not administered to these volunteers for tourniquet pain. The tourniquet was inflated to 100 mmHg above the

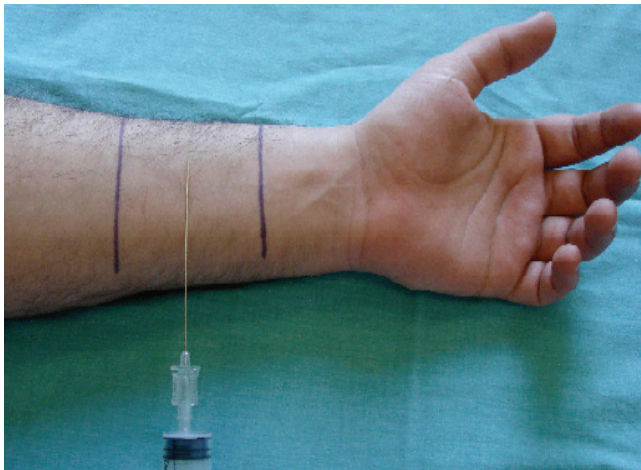


Figure 3. The application of the diluted 2% prilocain solution. We applied the solution under the skin and subcutaneous tissues with three injections. All three injections were applied at the line which passes through the central longitudinal axis of the tourniquet. The first entrance point of the spinal needle was volar at anteromedial corner of the ulna. Second entrance point was the anterolateral corner of the radius and the third entrance point was the dorsal interosseous area of the radius and ulna.

systolic blood pressure, and the tolerability of the tourniquet pain was measured and noted according to VAS in these volunteers. In the control group the tourniquet was inflated for 13.3 minutes (average total mean time of ischemia in patients). These volunteers were seen and assessed for any complication on the second and seventh days after the application of the tourniquet.

RESULTS

The mean patient age was 41.5 (17-60). 62 were female and 30 were male. Surgical procedures performed were: carpal tunnel release 29 cases; tumor excision 16; ganglion excision 15; trigger finger release 15; trigger thumb release 11; metacarpal or phalanx fracture 8; foreign object excision 5; and removal of implant 1. Fifty-eight patients were in group 1 and 42 were in group 2.

The total mean time of ischemia (time when tourniquet was inflated) was 13.3 minutes (5-29 minutes) (number=100) (Standard Deviation=5.229). The average tourniquet time was 13.5 minutes in group 1 (5-24 min.) (n=58) (St. Deviation=5.127) and 13.1 minutes in group 2 (5-29 min.) (n=42) (St.Deviation=5.422). The total mean tourniquet pain according to VAS was 3.0(0-100) (St. Dev.=7.173) (n=100). The average tourniquet pain according to VAS was 3.8(0-100) (St.Dev.=8.80) (n=58) in group 1, and 2.0(0-100) (St.Dev.=3.89) (n=42) in group 2 (Table 2). The average tourniquet pain according to VAS was 41.0(0-100) (St.Dev.=14.65) (n=20) in the control group (Table 3). All the patients except one in group 1 tolerated the procedure well. In this patient, the tourniquet was released and operation was performed without tourniquet. We operated on recurrent carpal

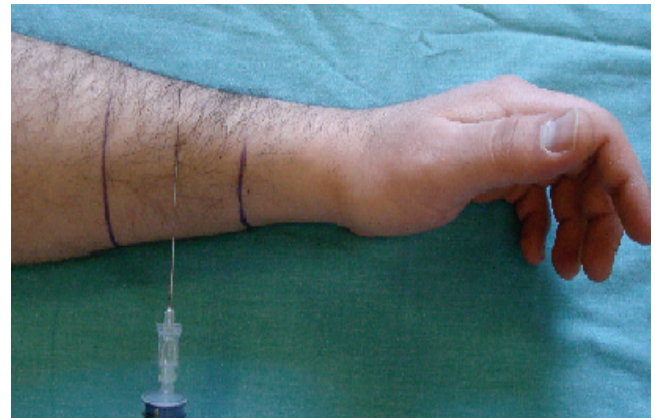


Figure 4. After the entrance of the second point, the needle was progressed up to the lateral side of the radius and then the forearm was pronated. After full pronation, the needle was progressed up to the third entrance point.



Figure 5. During the infiltration of the solution, we attempted to get a 1 cm expansion below the skin.

tunnel syndrome in one patient. Four volunteers could not tolerate the tourniquet for 13.3 minutes, so they were excluded from the control group. To compare the difference between the two groups with respect to average tourniquet pain (tourniquet VAS), both independent samples t-test and Mann-Whitney tests are used. There were no statistically significant differences between the means of the two groups with respect to both tests (p value=0.18 [t-test], p=0.951 [Mann-Whitney test]). There was no correlation between tourniquet time and tourniquet-VAS in both groups (p=0.86 in group 1 and p=0.85 in group 2). To compare the effect of Emla or Citanest on tourniquet pain, the Kruskal Wallis test was used. There were statistically significant differences between the means of two groups (Group 1-control group or group 2-control group) with respect to this test (p<0.01). Tourniquet related anesthesia technique discomfort was more in group 2 (p=0.001). A bloodless field was achieved in all cases except one. There were no serious complications during surgery or at follow-up.

| TABLE 2 | | | | | |
|---------|---------------------------|--|-------|---|-------|
| | n (Number of Patients) | Mean of tourniquet pain-St. Dv. VAS | | Mean of tourniquet time-St. Dv. (MIN.) | |
| Group 1 | 58 | 3.8 | 8.801 | 13.5 | 5.127 |
| Group 2 | 42 | 2.0 | 3.894 | 13,1 | 5.422 |

DISCUSSION

The mechanism of tourniquet pain is still poorly understood but is probably multifactorial. Cole suggested that tourniquet pain had both a superficial and a deep component and may be caused by compression or possibly ischemia of large nerves.¹ Cole believed it was autonomic in origin and of sufficient intensity to penetrate a spinal block. The role of the autonomic system is disputed by Farah and Thomas who demonstrated the occurrence of tourniquet pain during IV regional analgesia (IVRA) of the upper limb despite stellate ganglion block.² Rousso et al. and Lowrie et al. proposed that tourniquet pain has a significant cutaneous component.^{3,4} Yu-Chuan et al. found in their study that Emla and subcutaneous ring anesthesia provided predominantly superficial analgesia, and both provided only limited analgesia, suggesting that skin compression is one component of tourniquet pain.⁵ Subcutaneous ring anesthesia was reported by Rousso et al. to be an excellent analgesic technique for tourniquets. However, Yu-C.Tsai et al. found that subcutaneous ring anesthesia only provided similar analgesia to Emla. It is possible that both lidocaine and prilocaine may affect the pain threshold by a central effect. Ohlsen et al. measured the plasma concentrations of lidocaine and prilocaine in 106 patients after application of Emla for split-skin grafting,⁶ and Lowrie et al. found it unlikely that sufficient lidocaine or prilocaine was absorbed to exert a central analgesic effect, even if absorption was altered by the inflation of the tourniquet.

When we look at the literature, there is no study like ours that compares the effects of two local anesthetic agents (Emla and Citanest) on forearm tourniquet pain.

In this study, our aim was to determine whether there is a superiority between Emla or Citanest on forearm tourniquet pain. We found that one is not superior to the other. Both techniques were found to be equally effective. We did find, however, that using Emla cream is less disturbing than injection. For testing the effectiveness of anesthetic agents against tourniquet pain, we chose a control group of 24 volunteers and compared them with groups 1 and 2. In the control group, VASs were dramatically higher than in the patients in groups 1 and 2 (>10 times).

There are a few studies about forearm tourniquet pain tolerance, and most authors believe that the forearm tourniquet can be tolerated for up to 20-30 minutes without any anesthesia.⁷ But in our study, the mean time of tourniquet duration was 13.3 minutes. Contrary to the literature, we found that short tourniquet time produces enough pain to require anesthesia for forearm tourniquet pain.

Yousif et al. also found that the forearm tourniquet is well tolerated without anesthesia.⁸ Like Douglas et al., they found these results in patients who did not undergo surgical procedures.

The Edwards et al. study was undertaken to compare the use of forearm and upper arm tourniquets for local anesthetic procedures on the hand.⁹ They did not use any anesthesia for tourniquet pain. They found that the use of a forearm tourniquet was well tolerated and was not associated with an increase in complications. The study results were similar to ours. Operation time was always less than 20 minutes. The mean forearm tourniquet duration was 8.5 (3-20) minutes and the pain score was 3.7 (0.5-9) according to VAS (0-10). 3.7/10 VAS score

| TABLE 3 | | | | |
|------------|---|--|--------------------------------------|--------|
| | Cream (EMLA) (Tourniquet Vas-St. Dev.) | 2% Prilocaine solution (CITANEST) (Tourniquet Vas-St. Dev.) | Control (Tourniquet Vas-St. Dev.) | p* |
| Tourniquet | 3.8-8.80 | 2.0-3.83† | 41.0-14.65† | <0.001 |

*Kruskal Wallis test

†Difference between control group was statistically significant (p<0.001).

was similar to the result that we found in our control group (41/100). We feel that this study supports ours. The difference in our study was that we used anesthesia for the tourniquet pain and compared two techniques.

No other studies used preoperative sedation with oral diazepam. Also, we compared two different anesthetic techniques in the patients who are operated on with local anesthesia so that we protected the patients from the complications of high dose anesthetics. Edwards et al.⁷ found that the forearm tourniquet could be used quite safely in patients undergoing surgical procedures with local anesthesia. However, no significant improvement in pain relief was noted when compared to the group with the above-elbow tourniquet. Using the forearm tourniquet with Emla or Citanest for anesthesia, there was no increase in the rate of significant complications associated with the use of the forearm tourniquet, and we had no particular problem with hemostasis. Complications were minimal in the short and long term. Only two mild hypertensive crises and two mild vagal reactions were noted, which resolved without treatment. Regarding long term complications, we found no problems due to the cuff or the punctures. In conclusion, the tourniquet placed at the distal forearm is an effective, safe and useful technique for hand surgery. Anesthesia using Emla cream is equally effective and less disturbing than the injection technique (subcutaneous ring anesthesia).

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PRE-OPERATIVE AND INTRA-OPERATIVE FACTORS RELATED TO SHOULDER ARTHROPLASTY OUTCOMES

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ABSTRACT

The purpose of this study was to analyze pre-operative and intra-operative factors that affect the outcome of shoulder arthroplasty. We undertook a retrospective review of all shoulder arthroplasties performed at our institution between 1986 and 2003. Patients were contacted and outcomes were assessed using the Simple Shoulder Test and the Western Ontario Osteoarthritis of the Shoulder Index questionnaires. One hundred six patients (126 shoulders) participated in the study. The average length of follow-up was 6 years 9 months (range 2 to 20 years). Revision arthroplasty surgery and female gender were associated with worse outcomes. Age, the number of medical comorbidities, obesity, pre-operative range of motion, prior non-arthroplasty surgery, smoking, and alcohol abuse did not correlate with outcome. Patients who had shoulder arthroplasty for osteoarthritis had better outcome scores than those with rheumatoid arthritis. For intra-operative variables, significantly worse outcomes were found both with the use of hemiarthroplasty and in patients with a rotator cuff tear identified at the time of surgery. These findings may help to optimize patient and surgery selection in shoulder arthroplasty and assist in preoperative patient counseling.

INTRODUCTION

The outcome of shoulder arthroplasty can be affected by several factors. These include patient related variables, such as the underlying etiology for glenohumeral

degeneration, comorbid conditions and demographics, as well as intra-operative findings. Pre-operatively, the diagnoses most frequently encountered in advanced glenohumeral degeneration include osteoarthritis (OA), rheumatoid arthritis (RA), severe proximal humerus fractures, post-traumatic degenerative arthritis, avascular necrosis and cuff-tear arthropathy. For the diagnosis of OA, multiple studies have shown that arthroplasty reliably improves pain and ROM.^{2,6,17} Likewise, several studies have demonstrated that RA patients benefit from shoulder arthroplasty.^{8,13,14,29} There is less information on the impact of demographics and comorbid conditions.¹¹

Intra-operative findings and decisions may impact patient outcomes in shoulder arthroplasty as well, including the presence of a rotator cuff tear and whether a HA or TSA is performed. Multiple studies have suggested that a rotator cuff tear is associated with worse outcomes by both subjective and objective scores,^{3,7,10,11} although other studies have not validated this finding in OA^{5,12} or RA.⁸ Controversy still exists regarding the superiority of TSA versus HA for the treatment of glenohumeral arthrosis from OA and RA.

Although prior studies have examined the effect of some preoperative and intra-operative factors,^{4,5,7,11,12} none has simultaneously examined the effect of multiple pre-operative and intra-operative variables on outcomes in shoulder arthroplasty patients. The goal of the present study was to validate previous findings of preoperative and intraoperative factors that have been shown to affect outcome as well as attempt to delineate other characteristics of patients whose outcomes are better (or worse) after shoulder arthroplasty in a group of patients with varying etiologies of shoulder degeneration.

MATERIALS AND METHODS

Institutional Review Board Approval was obtained for the study. We searched hospital records between 1986 and 2003 for current procedural terminology (CPT) codes involving shoulder arthroplasty (23470 and 23472). A chart review was performed and underlying diagnosis, patient demographics, length of follow up, medical comorbidities, pre-operative range of motion, and prior ipsilateral shoulder surgery were recorded. Significant medical comorbidities were recorded as present or absent in a binary fashion and then summed. The impact of the total number of comorbidities on outcome was

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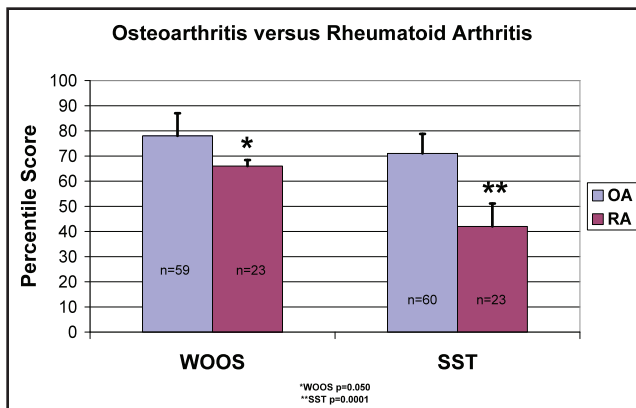


Figure 1. Osteoarthritis patients has significantly higher WOOS and SST scores compared to patients with Rheumatoid arthritis.

analyzed. The following comorbidities were recorded: chronic obstructive pulmonary disease, hypertension, heart disease (CAD, arrhythmia, congestive heart failure), diabetes mellitus, tobacco abuse, alcohol abuse, Axis I psychiatric disease, and other rheumatologic disease. Patient weight, as measured by body mass index, was assessed as well, and patients were divided into normal weight (BMI less than 25), overweight (BMI greater than or equal to 25), and obese (BMI greater than or equal to 30) based on standard BMI cutoffs. For each case a chart review of the operative report was done to identify those patients who had a rotator cuff tear identified at the time of surgery. When no specific mention was made of a cuff tear the patient was recorded in the database as having an intact rotator cuff. The use of a TSA or HA was also documented.

Questionnaires and informed consent documents were sent by mail to each patient. Patients who had had bilateral shoulder arthroplasties returned separate outcomes measures for each shoulder. Each patient received and returned two outcomes questionnaires, the Simple Shoulder Test (SST) and the Western Ontario Osteoarthritis of the Shoulder Questionnaire (WOOS).^{15,16}

The Simple Shoulder Test consists of 12 simple 'yes' or 'no' questions and is easy to administer and understand. It has been tested in populations of patients with multiple shoulder pathologies, including OA, RA, avascular necrosis, and rotator cuff tears.¹⁵ It has been shown to be able to distinguish between normal shoulders and those with the previously listed conditions. In the present study SST scores were expressed as a percent of tasks that the patient could complete. A score of 50 meant that the patient could complete half of the tasks, while a score of 100 meant that the patient could complete all of the tasks with that shoulder. The WOOS is a validated questionnaire designed specifically for use in patients with OA.¹⁶ It has been correlated with multiple other

measures of shoulder function. The WOOS was chosen for these reasons and because the plurality of patients studied had OA as their primary diagnosis. As for the SST, the WOOS score has been expressed as a percent of a total best score (i.e., 100 is best possible score, 0 is lowest score possible).

Data was analyzed using the SAS statistical analysis package (v. 9.0 Cary, NC). For comparisons between two groups, we used t-test for univariate variables and Pearson's correlation for continuous variables. T-tests were used for the analysis of revision surgery, patient sex, and individual comorbidities. T-tests were also used for paired comparison of variables after ANOVA analysis. Pearson's correlation was used for analysis of SST and WOOS scores and patient age, length of follow-up, and range of motion. We used ANOVA for data where multiple comparisons were made, including underlying diagnosis, comorbidities, and BMI.

RESULTS

We identified 169 patients who had undergone either a HA or TSA during the study period who were still living. Six patients were mentally or physically unable to participate, leaving 163 patients. We were unable to contact 21 patients after a thorough search using hospital records and internet search databases. This left a total of 142 patients. Of those we were able to locate and contact, 106 participated in the study. Of the 106 participants, 20 had bilateral shoulder arthroplasty, for a total of 126 shoulders.

There were 43 men and 63 women. Average time to follow-up was 6.8 years (range 2-20 years).

Pre-operative Factors

The underlying diagnoses were as follows: 61 patients had primary OA, 23 had RA, 9 had acute fractures, 10 had revision of a failed HA to a TSA, 8 had cuff tear arthropathy, 5 had post-traumatic OA, 4 had osteonecrosis, 5 had revision of a prosthesis for other reasons, and one had a recurrent giant cell tumor. Outcomes were compared for patients with a diagnosis of primary OA (n=60) to patients with RA (n=23). Both WOOS and SST scores were significantly better for patients with primary OA (WOOS 78 versus 66, p=0.05; SST 70 versus 42, p<0.0001) (Figure 1). Multivariate regression of outcomes based on underlying diagnosis revealed OA patients had the best outcomes overall.

The effect of patient demographics on outcome was examined. The 54 shoulders in male patients had better outcomes than the 72 shoulders in females (WOOS 68 versus 53, p=0.0065, SST 75 versus 52, p=0.0001) (Figure 2). Neither age nor length of follow-up correlated with outcome (p>0.05, WOOS and SST).

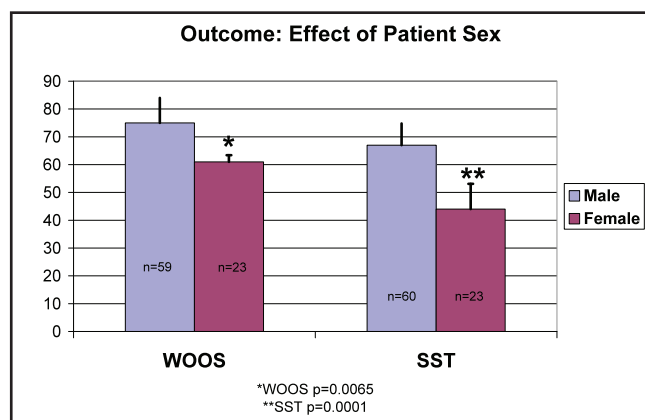


Figure 2. Males had statistically significant higher WOOS and SST scores compared with females.

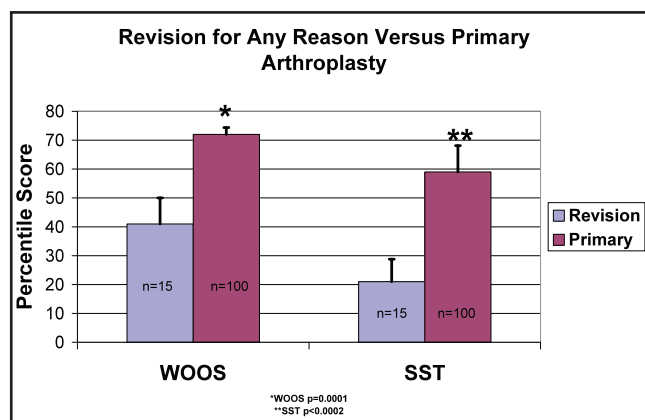


Figure 3. Primary arthroplasty patients had higher WOOS and SST scores compared to revision cases.

The total number of comorbidities ranged from 0 to 6. There was no correlation between the number of comorbidities and outcome ($p=0.63$ for WOOS and $p=0.77$ for SST). There was no correlation between BMI and outcome ($p=0.61$ for WOOS and $p=0.50$ for SST). No range of motion variable correlated with outcome ($p>0.05$ for all measures of ROM, WOOS and SST).

Revision surgery for any reason was analyzed as a pre-operative risk factor. Ten revisions were for glenoid arthrosis after HA and five were for other reasons. When these 15 revisions were compared with primary arthroplasty, revisions were found to do significantly worse on both the WOOS and SST (Figure 3). The mean WOOS score for revisions was 44.2 versus 70.1 for primary arthroplasty ($p<0.001$). Revision shoulders scored only 28 on the SST and primary arthroplasty patients 56 ($p<0.001$).

We compared the ten shoulders which had revisions of HA to TSA to the 64 patients who had primary TSA. These “conversion” patients had worse outcomes (Figure 4). The average WOOS score for revision HA to

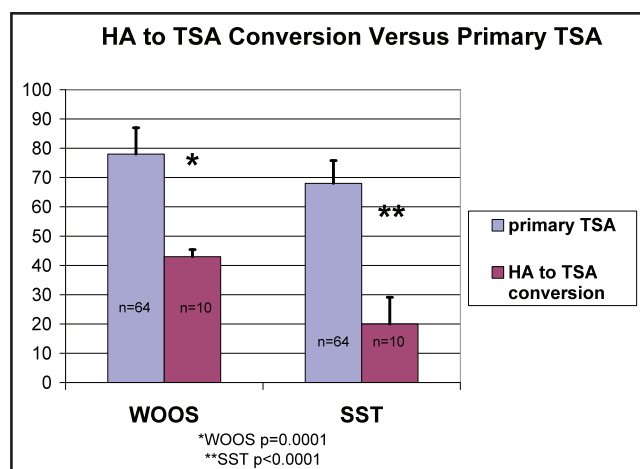


Figure 4. Patients who underwent conversion of hemiarthroplasty to total shoulder arthroplasty had worse average WOOS and SST scores compared to patients undergoing total shoulder arthroplasty as their primary procedure.

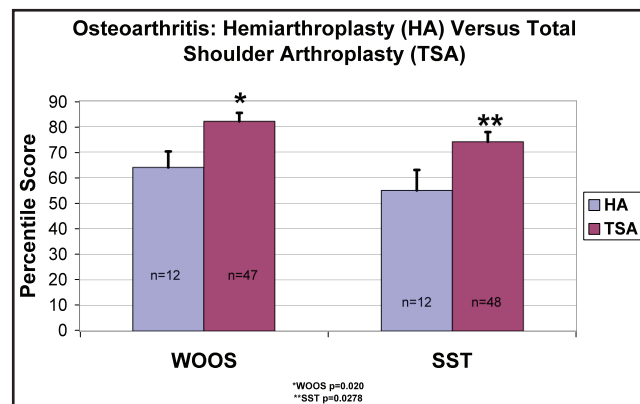


Figure 5. In patients with OA, total shoulder replacement resulted in better outcomes than hemiarthroplasty.

TSA was 43 and for primary TSA it was 78 ($p=0.0001$). On the SST, HA revisions scored 20 while primary TSA scored 68 ($p<0.0001$).

Only 8 patients in our study group had a documented *previous* rotator cuff tear (RTC) repair. There was no significant difference in outcome by either WOOS or SST between this small group of patients with a prior RTC repair and those without ($p=0.58$ for WOOS, $p=0.58$ for SST, student's t-test). Twenty patients had had a prior non-arthroplasty surgery on the shoulder (including prior RTC repair). Compared with the remaining shoulders, these patients tended to do worse, but this was not statistically significant (WOOS [$p=0.052$] SST [$p=0.13$]).

Intra-operative Factors

Of those patients with primary OA forty-seven had TSA and twelve had HA. The TSA shoulders had better outcomes than the HA shoulders on both the WOOS (64.1 versus 81.5, $p=0.050$) and SST (42 versus 71, $p=0.028$) (Figure 5). In the 23 patients with an underly-

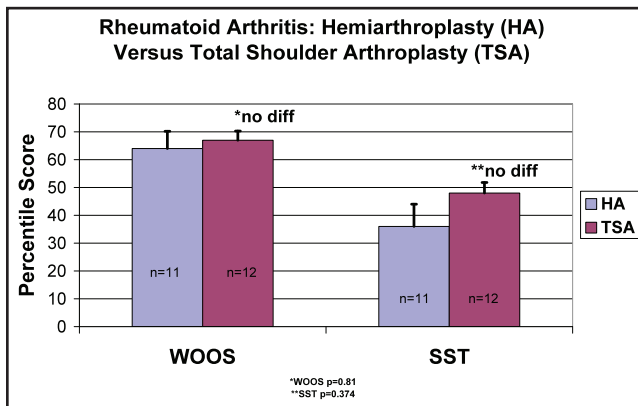


Figure 6. In patients with RA, there was no significant difference between outcomes from total shoulder replacement and hemiarthroplasty.

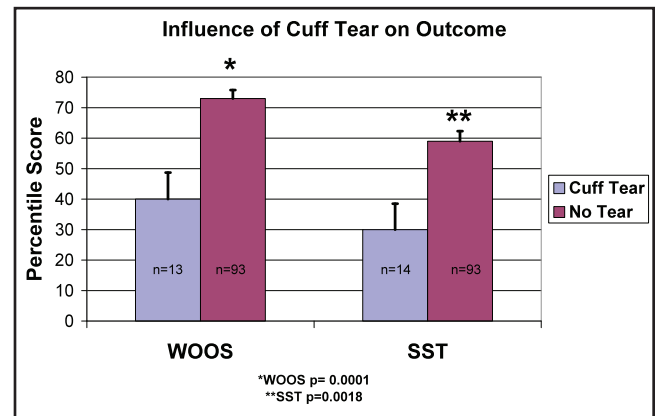


Figure 7. Patient with rotator cuff tears diagnosed at the time of surgery had worse outcomes than those without rotator cuff tears.

ing diagnosis of RA there were 12 who underwent TSA and 11 that underwent HA. There were no detectable differences between TSA and HA ($p=0.81$ and 0.37 for WOOS and SST, respectively) (Figure 6).

Excluding cuff tear arthropathy patients, there were 14 patients with a cuff tear and 93 where the operative note indicated the cuff was intact or no mention was made of a rotator cuff tear. The cuff tear was repaired at the surgeon's discretion. The mean WOOS score of patients with cuff tear was 40.5 versus a score of 72.8 with an intact cuff ($p<0.0001$). The SST score was 30 for those with a cuff tear and 59 for those with an intact cuff ($p<0.001$) (Figure 7).

DISCUSSION

Shoulder arthroplasty is a well-established procedure which is used for pain relief and functional improvement in multiple pathological conditions ranging from osteoarthritis to trauma. As with all surgical interventions there is variability in the subjective success and outcome of the operation. This variability is potentially reflective of variability in the pre-operative factors present in each case. Previous literature has defined some pre-operative factors predictive of outcome, including glenoid erosion, fatty degeneration of the rotator cuff, gender, and humeral head subluxation.^{5,7,11,12} The present study was designed to identify other pre-operative and intra-operative factors that could be associated with outcome after shoulder arthroplasty. In our study, statistically significant worse outcome scores were found for female patients, patients with rheumatoid arthritis, and patients who were undergoing revision arthroplasty on the operative shoulder. For intra-operative variables, significantly worse outcomes were found both with the use of hemiarthroplasty and in patients with a rotator cuff tear identified at the time of surgery.

We were unable to show a significant correlation with several other demographic pre-operative factors, comorbid conditions, and preoperative clinical status measures. These included weight, number of comorbidities, smoking status, EtOH abuse, and pre-operative range of motion. The lack of correlation is in contrast to the findings of some other studies. Matsen et al reported that higher pre-operative measures of physical function, social function, and shoulder function were predictive of improved outcomes after shoulder arthroplasty.¹⁸ Similarly, a study of arthroplasty for fracture showed a correlation between age, EtOH use, tobacco use and outcome.²³ Rozencaiwag et al. found that an increased number of comorbidities correlated with poorer outcomes from total shoulder arthroplasty.²⁴ Our inability to identify similar correlations in our study may be due to a lack of power. Matsen et al. did find, consistent with our study, that male gender predicted improved outcomes,¹⁸ whereas Hettrich et al. found that gender did not significantly affect outcome from hemiarthroplasty.¹¹

Regarding the effect of preoperative diagnosis on outcome, our finding that RA patients had worse outcomes than OA patients is consistent with other reports. Kelly et al reported worse outcomes in their RA group undergoing total shoulder replacement, mostly related to poor elevation, compared to outcomes in their OA patients.¹³ In their report on 71 hemiarthroplasties, Hettrich et al. found that patients with RA had significantly less functional improvement than those with primary degenerative joint disease.¹¹ We did not have preoperative functional values for comparison, but did find that postoperative WOOS and SST scores were significantly lower for RA patients than for OA patients, consistent with the studies by Kelly and Hettrich.^{11,13} It should be noted, however, that in the current study and other studies on shoulder arthroplasty in RA patients,

although functional improvement is modest, the majority of patients do receive significant pain relief.

Revision surgery was also found in this study to be a significant preoperative predictor of outcome in shoulder arthroplasty patients. We found that patients undergoing revision shoulder arthroplasty had significantly poorer outcomes compared to patients undergoing primary arthroplasty procedures. Our finding is consistent with other authors, including Hettrich et al, who reported that shoulders that had not had previous surgery had greater functional improvement after hemiarthroplasty than did those that had previous surgery.¹¹ Bosch et al. had the same result in their analysis of primary and secondary hemiarthroplasty after fracture.¹ In addition, we looked specifically at the subgroup of revision patients who had conversion of a HA to a TSA. We found that the conversion group had statistically worse outcomes than primary TSA. This finding is useful in considering HA as a primary procedure. Many surgeons continue to recommend HA as primary treatment for OA and RA, accepting a known risk of glenoid wear. It is believed that these patients could then be converted to a total shoulder by glenoid resurfacing. Results from the present study suggest that secondary TSA to treat arthrosis from glenoid wear in hemiarthroplasty patient is inferior to a primary TSA. Sperling et al similarly reported a high incidence of unsatisfactory results in this group of patients, with 7 of 18 patients with conversion from HA to TSA found to have limited range of motion or need for a subsequent operation.²⁷ These findings may influence a surgeon to consider TSA as the primary procedure rather than a hemiarthroplasty in certain patients.

The relative merits of HA versus TSA for primary glenohumeral OA are debated. Some studies have shown a trend toward TSA performing better than HA at intermediate follow-up,^{6,9,17,22} while at least one study did not show a difference.²¹ Two randomized controlled trials showed a trend toward superiority of TSA to HA for OA, but the studies included a small number of patients.^{9,17} A meta-analysis of published and unpublished randomized controlled trials showed better outcomes after TSA at minimum 2-year follow-up.² Our results agree with that meta-analysis, showing better outcomes for patients treated with TSA than HA in for glenohumeral OA and intact rotator cuffs. However, the modest outcome advantage of TSA as well as the risk of glenoid arthrosis from HA need to be balanced against the risk of glenoid loosening and failure in TSA at longer follow-up. Currently it is not definitely known what the best treatment is. Other patient factors should be considered, including pre-operative glenoid wear, shoulder subluxation, and activity level when making a decision about HA versus TSA.

In patients with RA, both HA and TSA have been demonstrated to improve pain and function.^{8,13,14,19,25,26,28,29} No significant difference has yet been demonstrated following HA or TSA in this group of patients.²⁹ Consistent with that, we found no significant difference between HA and TSA in RA patients.

Multiple studies have suggested that shoulder arthroplasty in patients with a rotator cuff tear is associated with worse outcomes than in patients with intact cuffs by various measures,^{3,9,10,11} although other studies have not validated this finding in OA^{5,12} and RA.⁸ Edwards et al. could not demonstrate a difference in Constant scores in a large cohort of shoulder arthroplasty patient with a rotator cuff tear at the time of surgery versus those who had intact rotator cuffs; the same study actually showed a superior outcome in regards to pain relief for those patients with a full-thickness tear.⁵ Another recent study of 128 shoulders showed no effect of repaired rotator cuff tears on final outcome.¹² A recent study by Hettrich et al. reviewed seventy-one shoulders undergoing HA for multiple diagnoses and concluded that the presence of a rotator cuff tear predicted worse outcomes.¹¹ The present study also found that the presence of a rotator cuff tear at the time of shoulder arthroplasty predicted worse outcomes in a large group of combined TSA and HA patients. Regression analysis showed that among factors including OA versus RA, TSA versus HA, male versus female, and presence of a cuff tear, only a cuff tear independently correlated with outcome. The other variables affected outcome only insofar as they were related to cuff tear.

Our study is limited inherently due to its retrospective nature. In addition our results reflect subjective outcomes using validated quality of life measures focused on the shoulder. We did not collect physical examination or radiological follow up of these patients which would have provided additional important information relevant to their outcomes. We also did not have preoperative functional measures on this cohort as some of these patients are nearly 20 years from surgery and questionnaires were not standard at that time at our institution.

In summary, our study reflects the outcomes of 106 shoulder arthroplasty patients with varying preoperative factors. Female gender, revision arthroplasty, and a non-osteoarthritis diagnosis were correlated with lower outcome scores. Hemiarthroplasty and the presence of a rotator cuff tear at the time of surgery also correlated with lower outcome scores. This information can be very valuable in counseling patients who are candidates for shoulder arthroplasty and can aid in surgeons' decision making.

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PREVALENCE OF METHICILLIN RESISTANT STAPHYLOCOCCUS AUREUS IN UPPER EXTREMITY SOFT TISSUE INFECTIONS AT JACKSON MEMORIAL HOSPITAL, MIAMI-DADE COUNTY, FLORIDA

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David C. Landy, M.P.H.,**** Patrick Owens, M.D.,*****

ABSTRACT

Purpose

Methicillin resistant *Staphylococcus aureus* (MRSA) has been a hospital based problem since first being reported in the 1960s. Recent increases in outpatient MRSA infections suggest that there may be increased incidence of MRSA in upper extremity soft tissue infections (UESTIs). The aim of this study is to describe the current microbial flora responsible for UESTIs at an urban, tertiary care, teaching hospital.

Methods

A retrospective chart review was performed of all orthopaedic consultations for UESTIs from June 2006 to December 2007. The only exclusion criterion was a diagnosis of osteomyelitis. Logistic regression was used to describe the association between demographic and clinical characteristics

identified on univariate analysis, and a MRSA positive culture. Odds ratios and confidence intervals are reported.

Results

There were 432 orthopaedic consultations for UESTIs. Twelve cases of osteomyelitis were excluded per protocol. Therefore, 420 patients comprised our study population, ranging in age from 4 months to 95 years, (mean: 40 years), with 327 (77.9%) men and 93 (22.1%) women.

Wound cultures were available in 335 of 420 patients (79.8%). Positive cultures were found in 292 patients with a 53.4% MRSA rate (156 of 292). Methicillin sensitive *Staphylococcus aureus* was the second most prevalent microbe, found in 73 of 292 patients (25.0%). All MRSA isolates were susceptible to gentamicin and linezolid, and 98% or more were sensitive to vancomycin, rifampin, and trimethoprim-sulfamethoxazole combination. Univariate analyses and logistic regression identified infection location proximal to the wrist (Odds Ratio = 1.81, 95% Confidence Interval = 1.06-3.09, $p < 0.03$) and diagnosis of abscess or felon (Odds Ratio = 3.22, 95% Confidence Interval = 1.84-5.63, $p < 0.001$) as significantly associated with a MRSA positive culture.

Conclusions

This is the largest study examining the prevalence of microbial flora in UESTIs. We found that MRSA has become the most common microbe in UESTIs comprising 53.4%, consistent with current trends at other urban medical centers.

INTRODUCTION

Methicillin resistant *Staphylococcus aureus* (MRSA) was first reported in the 1960s soon after the introduction of methicillin.¹ It remained a hospital based problem for decades. Since 2000, several reports have documented the presence of MRSA infections in previously unaffected outpatient populations. In 2007, Daum² reported that more than 10% of *Staphylococcus aureus* strains found in the community were MRSA. Recently, affected populations include children,³ sports participants,⁴ incarcerated persons,⁵ and military recruits undergoing training.⁶ Recent studies have also demonstrated an

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increasing prevalence of MRSA in various communities as a whole, with particular focus in the inner cities.^{7,9} A meta-analysis by Salgado et al. in 2003 showed a community acquired MRSA infection rate among hospitalized patients of 30.2% in 27 retrospective studies and 37.3% in 5 prospective studies, and a community wide MRSA infection rate among non-hospitalized patients of 1.3%.¹⁰

This community acquired MRSA is distinct from hospital acquired MRSA in that it is often susceptible to antibiotics such as clindamycin and sulfonamides, whereas hospital acquired MRSA is typically resistant to these antibiotics. There is, however, an ever-blurring line in the behavior of community acquired versus hospital acquired MRSA.¹¹ USA 300 has been identified as the most common form of community acquired MRSA.^{7,8} This strain of MRSA has also been noted to contain various virulence factors including Panton-Valentine leukocidin, which allows for necrosis of soft tissue.^{12,13} The change in susceptibility patterns of the microbial flora in communities served by hospitals across the country has changed the empiric antibiotics initially chosen to treat common soft tissue infections.

The aim of this study is to describe the current microbial flora responsible for community acquired upper extremity soft tissue infections seen at a large, urban teaching hospital, examining the prevalence of MRSA in these infections. Our data will help increase awareness amongst healthcare providers of current microbial trends in upper extremity soft tissue infections. This is especially important for early identification and intervention when MRSA presents as a localized soft tissue infection,⁷ as it can progress to systemic infection, i.e., pneumonia¹⁴ or necrotizing fasciitis.¹⁵

METHODS

A retrospective chart review of all orthopaedic consultations for upper extremity soft tissue infections (UES-TIs) at Jackson Memorial Hospital (JMH) consecutively from June 29, 2006 to December 31, 2007 was performed. JMH is a large, 1550 bed, urban, tertiary care, teaching hospital serving Miami-Dade County, Florida. All consultations for upper extremity soft tissue infections at JMH are handled by the orthopaedics service. Institutional Review Board approval was obtained for this study. Patients with presence of osteomyelitis were excluded from this study. Demographic and history of present illness data was collected on each patient. Demographically, age, gender and hand dominance were recorded. Information on history of present illness included the following parameters: location of infection, injury diagnosis, bacterial culture, anti-microbial sensitivity, white blood cell count (WBC), sedimentation rate (ESR), C-reactive protein levels (CRP), admission to hospital, length of

stay in hospital, number of operating room visits, and number of incisions and debridements.

Logistic regression was performed to identify if any of the variables identified on univariate analysis with a p value less than or equal to 0.05, were significantly associated with a MRSA positive culture. Odds ratios with 95% confidence intervals are reported. Variables examined in univariate analysis included age, gender, infection location, diagnosis, WBC, CRP, and ESR.

RESULTS

In the period from June 29, 2006 to December 31, 2007 (552 days), a total of 432 orthopaedic consultations for upper extremity soft tissue infections were performed. There were twelve cases of osteomyelitis that were excluded per protocol from the study. Therefore, 420 patients comprised the study population.

77.9% (327 patients) of the infected patients were men, and 22.1% (93 patients) were women (see Table 1). The ages of patients ranged from four months to ninety-five years of age, with the average age being forty years old.

TABLE 1
Subject Demographics

| Subject Characteristic | N (%) |
|---------------------------------|--------------|
| Age (years) | |
| 0-18 | 20 (4.8) |
| 19-44 | 246 (58.6) |
| 45-64 | 135 (32.1) |
| 65-79 | 16 (3.8) |
| > 80 | 3 (0.7) |
| Gender | |
| Male | 327 (77.9) |
| Female | 93 (22.1) |
| Dominant Upper Extremity | |
| Right | 268 (89.6) |
| Left | 31 (10.4) |
| WBC Count | |
| < 10 | 171 (42.5) |
| < 15 | 165 (41.0) |
| < 20 | 53 (13.2) |
| 20 + | 13 (3.2) |
| C-Reactive Protein (CRP) | |
| | (Median=3.1) |
| < 1 | 78 (21.7) |
| 1-3 | 96 (26.7) |
| 3-10 | 160 (44.6) |
| > 10 | 25 (7.0) |
| Sedimentation Rate (ESR) | |
| | (Median=25) |
| < 20 | 141 (41.3) |
| 20-35 | 81 (23.8) |
| 35-75 | 88 (25.8) |
| > 75 | 31 (9.1) |

The distribution of ages was 4.7% (20 patients) between 0-18 years old, 58.2% (246 patients) 19-44 years old, 31.9% (135 patients) 45-64 years old, 3.8% (16 patients) 65-79 years old, and 0.7% (3 patients) 80-95 years old. None of our population was 96 years or older (see Table 1).

Injuries occurred in the dominant upper extremity in 58.9% (175 patients) of cases (see Table 2). The finger was the most common site of infection at 50.2% (210 patients). The second most prevalent site of infection was the in hand with 23.2% (97 patients). Other common sites for infection of the upper extremity included the forearm and the elbow (see Table 2). There was one case involving multiple sites including both the hand and the forearm.

The diagnosis of abscess was most common, found in 256 patients (61.0%). Cellulitis was the second most common diagnosis, present in 53 patients (12.6%). A felon, defined as an abscess of the distal finger pulp, was found in 21 patients (6.4%) (see Table 2).

TABLE 2
Injury Characteristics

| Characteristic | N (%) |
|--------------------------|------------|
| Injured Extremity | |
| Dominant | 175 (58.9) |
| Non-Dominant | 122 (41.1) |
| Location | |
| Finger | 210 (50.2) |
| Multiple Fingers | 6 (1.4) |
| Hand | 97 (23.2) |
| Wrist | 14 (3.4) |
| Forearm | 49 (11.7) |
| Elbow | 31 (7.4) |
| Arm | 5 (1.2) |
| Shoulder | 5 (1.2) |
| Hand and Forearm | 1 (.2) |
| Diagnosis | |
| Abscess | 256 (61.0) |
| Cellulitis | 53 (12.6) |
| Felon | 27 (6.4) |
| Fight Bite | 21 (5.0) |
| Paronychia | 16 (3.8) |
| Flexor Tenosynovitis | 14 (3.3) |
| Septic Bursitis | 10 (2.4) |
| Postoperative Infection | 8 (1.9) |
| Septic Arthritis | 7 (1.7) |
| Animal Bite | 6 (1.4) |
| Other | 2 (0.5) |
| Culture | |
| Positive Culture | 292 (69.5) |
| Negative Culture | 43 (10.2) |
| No Culture | 85 (20.2) |

Wound culture results were available in 335 of 420 patients (79.8%). 43 (12.7%) cultures were negative (see Table 2). Of all patients, methicillin resistant *Staphylococcus aureus* was found in 37.1%. Of positive cultures, methicillin resistant *Staphylococcus aureus* was found in 156 of 292 cultures (53.4%). The second largest group, at 25.0% (73 patients), had cultures that were positive for methicillin sensitive *Staphylococcus aureus* (MSSA). A third group (17 patients, 5.8%) was found to have a positive culture for coagulase negative *Staphylococcus aureus*. There were 27 patients (9.2%) with cultures positive for Alpha Hemolytic *Streptococcus* and 33 patients (11.3%) found to have positive cultures for Beta Hemolytic *Streptococcus*. One patient was found to have vancomycin resistant enterococcus. 48 patients had positive cultures for more than one bacterial species (see Table 3).

All of the MRSA isolates were sensitive to gentamicin and linezolid. 99.4% of isolates were susceptible to vancomycin and rifampin, and 98.0% of isolates were sensitive to trimethoprim-sulfamethoxazole combination. Clindamycin and tetracycline also had high MRSA sensitivity (90.8% & 89.8% respectively), but only 7.8% of isolates were sensitive to erythromycin, implying there is potential to develop resistance to clindamycin if exposed to erythromycin. All MRSA isolates were resistant to penicillin, augmentin, imipenem, oxazolidone, and cephalosporins such as cefaclor, cefazolin, and cefuroxime, and 92.2% were resistant to erythromycin (see Table 4).

TABLE 3
Microbial Prevalence in Patients with a Positive Culture*

| Microbe | N (%) |
|------------------------------|------------|
| <i>Staphylococcus aureus</i> | |
| Methicillin Resistant | 156 (53.4) |
| Methicillin Sensitive | 73 (25.0) |
| Coagulase Negative | 17 (5.8) |
| Epidermidis | 1 (0.3) |
| Not Otherwise Specified | 1 (0.3) |
| <i>Streptococcus</i> | |
| Alpha Hemolytic | 27 (9.2) |
| Beta Hemolytic | 33 (11.3) |
| <i>Corynebacterium</i> | |
| <i>Enterobacter</i> | 11 (3.8) |
| <i>Eikenella</i> | 5 (1.7) |
| <i>Eikenella</i> | 4 (1.4) |
| <i>Enterococcus</i> | 4 (1.4) |
| <i>Klebsiella</i> | 4 (1.4) |
| <i>Klebsiella</i> | 3 (1.0) |
| <i>Proteus Mirabilis</i> | 3 (1.0) |
| <i>Other</i> | 15 (5.1) |

*48 Subjects had positive cultures for more than one species of bacteria

198 patients (47.1%) were admitted to the hospital for treatment. Of those admitted, all but 27 patients (13.6%) underwent at least one incision and debridement in the emergency room or the operating room. Of the 222 patients not admitted, 186 (84.9%) underwent incision and debridement in the emergency room (see Table 5). The number of days spent in the hospital was recorded for 197 of the 198 admitted patients. Hospital stays ranged from one to 34 days, with a median of five days and an interquartile range of four to seven days.

Univariate analyses identified both infection location and diagnosis as associated with a MRSA positive culture. Logistic regression was performed using both variables. Infections located proximal to the wrist were significantly associated with a MRSA positive culture (Odds Ratio = 1.81, 95% Confidence Interval = 1.06-3.09, $p = 0.03$). A diagnosis of abscess or felon (abscess of the finger nail pulp) was also significantly associated with a MRSA positive culture (Odds Ratio = 3.22, 95% Confidence Interval = 1.84-5.63, $p < 0.001$).

DISCUSSION

Our study showed that the rate of methicillin resistant *Staphylococcus aureus* infections in upper extremity soft tissue infections was 53.4% (156 patients) in patients who underwent culture. Our study is the largest of its kind, with a patient population over eight times greater than previous studies examining the prevalence of microbial flora in soft tissue infections of the upper extremity. Our study is consistent with the findings of multiple studies across the country examining the prevalence of MRSA

in both rural and urban settings. Of particular comparative importance are studies examining similar inner city populations.

Our study's results most closely compare to those of Bach et al in 2007 who reported data on 52 patients from Chicago's Cook County Hospital with a 73% (38 patients) predominance of MRSA infections in the hand.⁹ King et al. in 2006 reported 389 patients from Atlanta's Grady Memorial Hospital which showed that community acquired MRSA was the predominant *Staphylococcus aureus* (63%) responsible for generalized skin and soft tissue infections.⁷ King et al. had a similar inner city population to our own primarily inner city study population. Moran et al in 2006 reported data from 11 different emergency departments which similarly demonstrated 59% of isolates were MRSA.⁸ Interestingly, a study out of the same institution as Bach et al. by Weinzwieg in 2002 looked at data from 1992-1995 as opposed to 2005, where only 16.2% of *Staphylococcus aureus* infections were methicillin resistant.¹⁶ Thus, a dramatic shift in the microbial flora of soft tissue infections has occurred recently in the United States. Popovich et al. in 2008 reported data from 2000-2006 in Chicago's Stroger Hospital/Rush University Medical Center that showed a stable rate of hospital acquired strains of MRSA infections, but a rapidly increasing rate of community acquired strains of MRSA seen in the hospital from 24% between January 2000 and June 2003 to 49% between July 2003 and December 2006.¹¹ While rates may differ slightly in a city to city basis, our study and other similar studies indicate that there is an increasing trend of the prevalence of community acquired MRSA infections.

The strength of this study is the large sample size at 420 patients seen by the orthopaedic service for upper extremity infection consultation in a 552 day period

TABLE 4
Antimicrobial Agent Susceptibility
of 156 MRSA Positive Cultures

| Antimicrobial Agent | Susceptible/Tested (%) |
|---|------------------------|
| Augmentin | 0/155 (0.0) |
| Cefaclor | 0/152 (0.0) |
| Cefazolin | 0/151 (0.0) |
| Cefuroxime | 0/151 (0.0) |
| Clindamycin | 138/152 (90.8) |
| Erythromycin | 12/155 (7.8) |
| Gentamicin | 155/155 (100.0) |
| Imipenem | 0/152 (0.0) |
| Linezolid | 151/151 (100.0) |
| Oxazolidone | 0/156 (0.0) |
| Penicillin | 0/154 (0.0) |
| Rifampin | 151/152 (99.4) |
| Tetracycline | 140/156 (89.8) |
| Trimethoprim-Sulfamethoxazole Combination | 150/153 (98.0) |
| Vancomycin | 155/156 (99.4) |

TABLE 5
Subject Management

| Management | N (%) |
|---|--------------------|
| Admitted | 198 (47.1) |
| Emergency Room Incision and Debridement | 88 (44.4) |
| Operating Room Incision and Debridement | 64 (32.3) |
| OR and ER Incision and Debridement | 19 (9.6) |
| No Incision and Debridement | 27 (13.6) |
| Not Admitted | 222* (52.9) |
| Emergency Room Incision and Debridement | 186 (84.9) |
| No Incision and Debridement | 33 (15.1) |

*For 3 subjects not admitted, no data was obtained regarding incision and debridement.

from June 29, 2006 to December 31, 2007. Based on being at a large, county teaching hospital in an urban setting, patients were able to be seen in the hospital and emergency department regardless of insurance status, which is an on-going barrier to care in many institutions. The markedly larger study population at 420 patients far exceeds that of the next largest study by Bach et al. whose study population comprised of 52 patients.⁹ The increased study size enabled us to go beyond simply describing the microbial flora present in upper extremity soft tissue infections, and search for correlations between certain patient clinical characteristics and a MRSA positive culture. A diagnosis of abscess or felon (Odds Ratio = 3.22, 95% Confidence Interval = 1.84-5.63, $p < 0.001$), and infection location proximal to the wrist (Odds Ratio = 1.81, 95% Confidence Interval = 1.06-3.09, $p = 0.03$) were both found to be significantly associated with a MRSA positive culture on logistic regression, a form of multivariate analysis. Statistically significant correlation between a MRSA positive culture and diagnosis of abscess is further supported by similar findings by Jacobus et al in a study of 182 patients from three urban medical centers.¹⁷ Therefore, diagnosis of abscess and infection location proximal to the wrist should be used in working to establish a clinical diagnostic algorithm for identification of patients likely to have MRSA based on injury characteristics alone so that effective treatment can be started before cultures are available.

Our study is limited by the demographics of the patient population. Results found in a large, urban, county hospital setting may vary from smaller community hospitals in the region, and may not be as applicable to non-urban hospitals and clinics. While such variance needs to be taken into the account when advising healthcare practitioners in the community, this study still demonstrates that MRSA is an ever increasing problem in the community we serve. As such, rates are also likely to be on the rise at other institutions nearby. Expanded study of nearby community hospital MRSA rates would be beneficial in analyzing the applicability of this study's results to the broader surrounding community. Further prospective investigation with elevated diagnostic and therapeutic modalities would be beneficial.

Our study is further limited by its retrospective nature. Due to lack of completely electronic medical record system for the entire study period, some data was unavailable on certain patients. The use of the computer-based hospital medical records system made obtaining lab results possible for a majority of patients; however, not all data was present for every patient. Comprehensive and consistent past medical and social histories were not able to be established to a significant level due to lack of available data. Therefore, social risk

factors associated with MRSA infection were not able to be determined from this study. Due to the retrospective nature, genotyping to confirm that MRSA strains were community acquired was not able to be performed, but should be examined in future study. Future prospective study utilizing a standardized information gathering modality would be beneficial in remedying the limitations of a retrospective analysis, further analyzing the results of this study, and establishing demographic and social characteristics associated with MRSA infection.

The study is potentially limited in the diagnostic results due to hospital consultation protocols. While upper extremity soft tissue infections are not handled by other surgical services such as plastic surgery or general surgery, an orthopaedics consultation may not be ordered for less advanced infections, as in the case of a cellulitis where oral antibiotics may be given by emergency room physicians, without notifying the orthopaedics service. Additionally, when diagnosed with cellulitis, as per treatment protocol, no culture is performed, which dilutes our ability to determine the microbial etiology of the infection.

The increasing trend in MRSA should indicate new approaches to therapy that are sensitive to community acquired strains of MRSA. With the growing prevalence of increasingly virulent community-acquired MRSA strains, antibiotic usage is indicated along with incision and drainage, particularly with the presence of an abscess with surrounding cellulitis.¹⁸ Ruhe et al. in a 2007 retrospective study reported that incision and drainage occurred in most patients with community-acquired MRSA skin and soft tissue infections, and that active antibiotic therapy was 95% successful.¹⁹ Therefore, therapy modalities that take into account the growing prevalence of community acquired MRSA infections would be beneficial.

Our current treatment algorithm for patients with suspected soft tissue infections of the upper extremity is as follows. All patients are evaluated for a fluid collection. If they have a distinct collection, the fluid collection is incised, debrided, and cultured. If the patient is immunocompetent and there are no systemic symptoms or signs of infection such as an elevated white blood cell count or temperature elevation, then the patient is discharged home on oral antibiotics with soap and water washes to the wound. If they have systemic signs or symptoms of infection or they are immunocompromised, then they are admitted to the hospital where intravenous antibiotics are given until the resolution of symptoms. Infections of the flexor tendon sheath or joints are admitted regardless of the presence of systemic signs or symptoms. Based on the high prevalence of MRSA in our patient population, most of our patients are started empirically on vanco-

mycin in conjunction with piperacillin and tazobactam, and then switched to an appropriate antibiotic based on culture sensitivities. Empiric oral antibiotics for patients being discharged had been levofloxacin in addition to clindamycin, before our study was performed. After this study was performed, based on MRSA prevalence and susceptibilities, oral antibiotic therapy has been switched to trimethoprim-sulfamethoxazole combination.

CONCLUSION

Our study is the largest reported cohort of upper extremity soft tissue infections. As in other studies of inner-city populations, we have shown a marked increase in community acquired methicillin resistant *Staphylococcus aureus* infections. The increasing rate of MRSA necessitates careful monitoring, vigilance and treatment by healthcare professionals. The prevalence of MRSA isolates in relation to both traditional methicillin sensitive *Staphylococcus aureus* strains as well as other non-*Staphylococcal* bacterial infections make MRSA a prime target for both therapy and study, currently and into the future.

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ANEURYSMAL BONE CYSTS OF THE SACRUM: A REPORT OF TEN CASES AND REVIEW OF THE LITERATURE

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ABSTRACT

Ten cases of aneurysmal bone cysts are presented. Patients ranged in age from five years to 64 years. Treatment was resection or curettage; four patients had preoperative embolization. Treatment results were excellent. Six patients had no recurrence while recurrences in the other four patients were successfully treated by recurettage, two with adjunctive CyberKnife therapy. All ten patients are currently disease free for at least two years. Only two patients have residual neurologic deficit in the form of bowel or bladder dysfunction.

INTRODUCTION

Aneurysmal bone cysts are destructive, expansile bone lesions characterized by a reactive proliferation of connective tissue containing multiple blood filled cavities. Presumably due to the local hemodynamic disturbances, the process arises de novo in bone or is engrafted on preexisting bone lesions histologically identifiable in 30 percent of cases.¹ Conventional therapy is curettage and bone grafting, although lesions may recur in anywhere from 12 to 59% of cases.^{2,3,4}

Aneurysmal bone cysts most commonly occur in the distal femur or proximal tibia. The pelvis and posterior elements of the spine are also commonly involved. Rare-

ly, aneurysmal bone cysts occur in the sacrum. In this location, therapy is limited by lesion's close association with sacral nerve roots and the possibility of resultant neurologic deficit. We are reporting ten cases of aneurysmal bone cyst of the sacrum, and we will describe the clinicopathologic features, therapy, and follow-up of these lesions.

MATERIALS AND METHODS

The ten cases were from the personal files of one of us (EFM).

In all cases, images and histologic slides were available for review. All patients had detailed clinical history with long term follow-up (Table 1).

PATIENTS

Patient 1

A 64 year-old woman had low-back pain for eight to ten years. Recently, there had been a history of a right sciatic sciatica, and there had been difficulty walking due to weakness of the right foot. She also had a loss of sensation and some tingling in the right foot. She had no history of bowel or bladder dysfunction. An MRI demonstrated a destructive lesion in the S1 vertebral body with extension into the sacral ala. The lesion contained multiple fluid-fluid levels. She underwent a partial resection of the left side of the sacrum with a curettage. She also underwent a posterior lumbar fusion with fixation. She had a year of post-operative pain. Four years after surgery, the patient is without recurrence or neurological deficit.

Patient 2

A 26 year-old woman had a three month history of low back pain. An MRI showed a lesion in her sacrum with multiple fluid-fluid levels consistent with an aneurysmal bone cyst. She had no evidence of weakness, but there was some intermittent posterior leg numbness. She had no difficulty with bladder or bowel function. After preoperative embolization she underwent a thorough intralesional curettage. One and a half years post curettage she developed a recurrence in the sacrum and adjacent soft tissue. She had a resection of the soft-tissue portion of this mass followed by a curettage of the sacrum underneath. Six years after surgery she had a

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TABLE 1

| Patient | Age/Gender | Treatment | Recurrence | Disease free follow-up | Neurologic Deficit |
|---------|------------|--|--|------------------------|-----------------------------------|
| 1 | 64F | Resection | None | 4 years | None |
| 2 | 26F | Curettage | 1.5 years – | 2 years | None |
| 3 | 39M | Resection | 6 years Curettage 6 months – Embolization & Curettage ? Giant Cell Tumor | 2 years | Bowel & Bladder Dysfunction |
| 4 | 16 F | Embolization & Curettage | None | 12 years | None |
| 5 | 32 M | Curettage | 2 Years – Embolization, Radiation, Resection | 5 years | None |
| 6 | 60 F | Mid-Sacral Amputation | None | 2 years | None |
| 7 | 57 M | Embolization & Mid-Sacral Amputation | 3.5 years – Curettage ? Osteoblastoma | 2 years | Bowel Bladder Dysfunction |
| 8 | 10 F | Embolization & Curettage | None | 2 years | None |
| 9 | 5 F | Curettage | None | 2 years | None |
| 10 | 17 F | Mid-Sacral Amputation | None | 2 years | None |

second recurrence in the S1 sacral ala. She had a third curettage of this lesion followed by packing with bone graft. Three years after this third surgery she is without recurrent disease or neurologic deficit.

Patient 3

A 39 year-old male had a one year history of constipation and bladder dysfunction. His MRI showed a multiloculated sacral tumor at the S2-3 level. The patient underwent a laminectomy at S2, S3 with corpectomy of these segments. The diagnosis was aneurysmal bone cyst with a suggestion of an underlying giant cell tumor. The patient developed a significant recurrence of this lesion six months after surgery. Patient underwent embolization, radiotherapy, and another excision of the mass. The patient continues to have bowel and bladder dysfunction, but there is no evidence of recurrence two years after the last surgery.

Patient 4

A 16 year-old woman had a three month history of low-back pain. There were no neurological symptoms and no bowel or bladder dysfunction. MRI's demon-

strated a destructive lesion of the sacrum consistent with an aneurysmal bone cyst. An open biopsy confirmed this. After preoperative embolization the patient underwent a thorough curettage of this lesion. There was resolution of the symptoms following surgery and no evidence of recurrence after 12 years.

Patient 5

A 32 year-old man had low-back pain and radiation to his right leg. He was found to have a destructive lesion involving his sacrum and a portion of the adjacent pelvis. After a needle biopsy, he underwent a curettage of this lesion. However, two months following curettage he developed a recurrence. The patient had an embolization followed by therapy with the CyberKnife. He has had no recurrence and no neurological defect after five years.

Patient 6

A 60 year-old woman had a seven month history of pain in the lower back with a 30 pound weight loss. There was a mild bowel and bladder dysfunction. Imaging studies revealed a multi-locular cyst which on needle biopsy proved to be a aneurysmal bone cyst.

The patient underwent a mid-sacral amputation with an en bloc resection of the tumor. She recovered from the surgery well and has no abnormal bowel and bladder function. She has no evidence of recurrence two years post-operatively.

Patient 7

A 57 year-old man who presented with severe pain in the low back and difficulty walking for 5 months. Imaging studies demonstrated a destructive sacral lesion. The biopsy showed aneurysmal bone cyst. The patient underwent an embolization followed by sacral resection with sparing of the L5-S1, nerve roots. Histologic study of the entire neoplasm showed aneurysmal bone cyst with a suggestion of an underlying osteoblastoma. Three and one half years later there was a recurrence which was reembolized and curetted. Two years after the last surgery, the patient has residual bowel and bladder dysfunction but no evidence of recurrence.

Patient 8

A ten year-old girl had increasing left leg extremity pain. An MRI showed a multi-locular cyst consistent with aneurysmal bone cyst. She had a preoperatively embolization followed by a laminectomy of S1 and S2 with an extensive curettage and bone grafting of the lesion. Two years after surgery there is no neurologic deficit and no recurrence.

Patient 9

A five year old girl had back pain and difficulty walking for 3 months. An MRI showed a lesion consistent with an aneurysmal bone cyst. After a needle biopsy, she underwent a curettage with bone grafting and has been without evidence of recurrence or neurologic deficit for two years.

Patient 10

A 17 year old woman presented with low back pain and bowel and bladder dysfunction. An MRI showed a lesion consistent with aneurysmal bone cyst. The patient underwent a mid sacral amputation at the S2 level. Two years post op there is no evidence of recurrence and no bowel and bladder dysfunction.

CLINICAL PRESENTATION

Patients ranged in age from five years to 64 years old. There were six women and four men. All patients presented with low back pain from three months to 10 years duration. Two patients had numbness and tingling in a leg, and four patients had bowel or bladder symptoms.

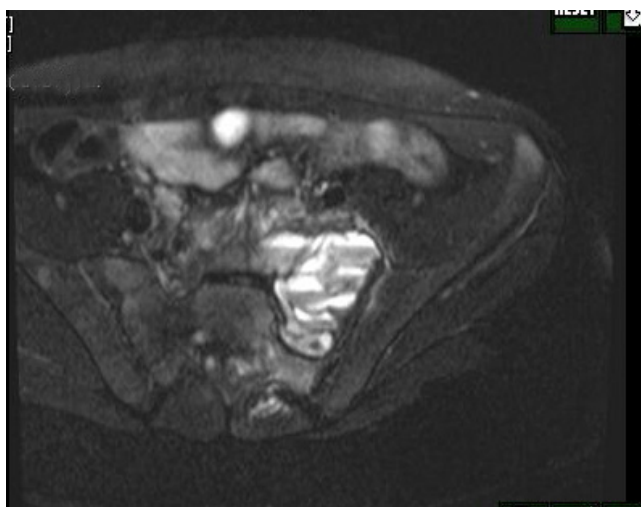


Figure 1. A T₂-weighted MRI showing the aneurysmal bone cyst of patient #8. The characteristic fluid-filled lines are present.

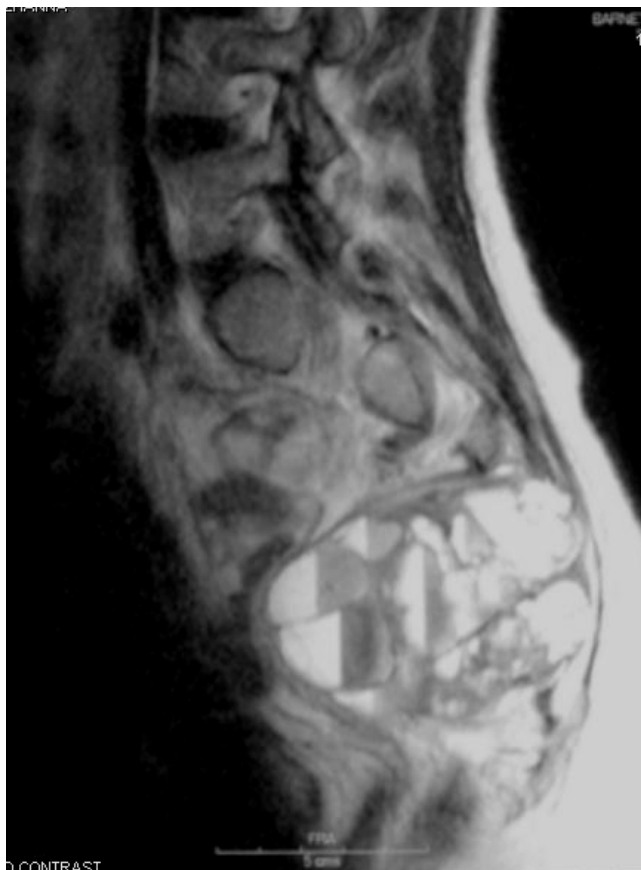


Figure 2. A T₂-weighted MRI showing the aneurysmal bone cyst of patient #6. There is a large soft tissue extension of the mass.



Figure 3. An axial cut with the CT scan of patient #4. The image shows the extent of bone invasion.

RADIOLOGIC FEATURES

In all patients, the diagnosis of aneurysmal bone cyst was suspected on imaging studies. All patients had an MRI which showed a multi-locular cystic lesion with fluid-fluid lines on T2-weighted images (Figure 1). Several patients had an associated soft tissue mass (Figure 2). Seven patients also had a CT scan, a modality best suited for evaluating the degree of bone destruction (Figure 3).

PATHOLOGIC FEATURES

Seven patients had CT guided needle biopsies. Three of these procedures did not provide diagnostic material and the patients required open biopsy. The other four needle biopsy procedures provided enough tissue to be interpreted as aneurysmal bone cyst only because the MRI image was highly characteristic. In the remaining three patients, the diagnosis was made by frozen section at the time of surgery.

All lesions showed multiple blood filled cavities, the characteristic feature of aneurysmal bone cyst best seen on low power. The cavities lacked an endothelial lining, and the stroma showed proliferating fibroblasts and scattered multinucleated giant cells. Reactive bone was often abundant (Figure 4).

In two patients, after meticulous study of many histologic slides, there was evidence of an underlying neoplasm. One patient had areas highly suggestive of a giant cell tumor and the other patient showed a few areas with features of osteoblastoma.

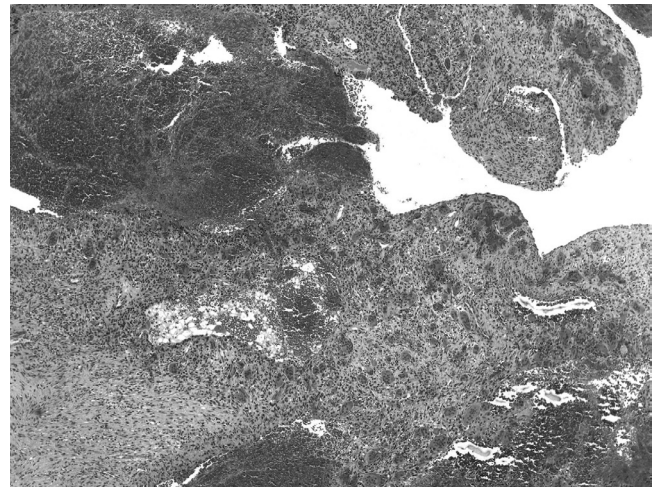


Figure 4. Medium power photomicrograph (H+E x 40) of the aneurysmal bone cyst of patient #3. Characteristic blood lakes are present.

TREATMENT AND RESULTS

Six patients had no recurrence after the initial treatment. Three of these six had curettage. Two of these six patients had pre-operative embolization. The other three patients with no recurrence had resections or mid-sacral amputations; one of these had pre-op embolization.

Four patients suffered a recurrence from 6 months to 3.5 years following surgery. Patient 2 had a second recurrence. Recurrences were treated by curettage. One patient also had pre-op embolization, and two patients had CyberKnife therapy. All ten patients are currently disease free from two years to 12 years post surgery.

Two patients have residual bowel and bladder impairment and must catheterize themselves. These were the two patients who had histologic features suggesting an underlying primary bone tumor. All other patients are neurologically intact.

DISCUSSION

Prior discussions of sacral aneurysmal bone cysts has been limited. A few cases have been included in broad discussions of sacral tumors or as anecdotal case reports.^{5,6,7,8}

Pagoda et al. described a single case of sacral aneurysmal bone cyst and reviewed the literature.⁹ This reported case was successfully treated by resection. Papagelapoulos et al. described 44 cases of pelvic aneurysmal bone cyst, twelve of which were in the sacrum.¹⁰ Those twelve cases were discussed with only limited detail, although the authors noted that there were no recurrences.

Despite the difficulties of achieving total extirpation of an aneurysmal bone cyst of the sacrum, these 10 cases confirm previous suggestions that surgical results

are excellent. Six patients had no recurrence. These patients had distal sacral amputation if the lesions were caudal. Those lesions that involved the upper sacrum were curetted after careful dissection and preservation of the nerve roots. Of the patients who had recurrence, the recurrent lesions were successfully treated with recurettage. All patients are currently disease free for at least two years.

Five patients had adjunctive preoperative embolization, either for the primary lesion or for a recurrence. This modality is frequently used in the treatment of aneurysmal bone cysts because lesions are highly vascular, and embolization prevents heavy bleeding at surgery.^{5,11,12} This modality may have contributed to the excellent results of these cases.

In two cases, recurrent treatment of recurrent lesions included CyberKnife therapy. Conventional radiotherapy has been performed for sacral neoplasms. However, because aneurysmal bone cysts are benign, the possibility of malignant transformation after convention radiotherapy cannot be excluded. The CyberKnife system, used in our two patients, may be a safer modality.¹³

Neurologic manifestations are common in sacral neoplasms.¹⁴ However, in this series of sacral aneurysmal bone cysts, neurologic symptoms were mild. These included mild leg weakness and numbness in two patients. Four patients had bowel or bladder symptoms. These neurologic symptoms resolved in all but two patients who continue to have bowel or bladder dysfunction (patients 3 and 7). These two were patients who were found to have underlying benign neoplasms, a factor which possibly made the process more aggressive.

In summary, these ten cases suggest some management principles. First, the diagnosis is most strongly suggested by the MRI study. If the MRI findings are characteristic, a needle biopsy may be confirmatory. Occasionally, an open biopsy must be performed. Second, preoperative embolization is desirable. This significantly reduces intra-osseous bleeding and allows more meticulous surgery. Third, L5-S1 nerve roots must be preserved where possible. Caudal lesions can be treated by mid sacral amputation. More proximal lesions can be treated with a careful curettage which preserves nerve roots. Recurrences can be recuretted. Finally, the entire specimen must be examined histologically to rule out an underlying more aggressive neoplasm. Using these principles, therapeutic results for sacral aneurysmal bone cysts are excellent.

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GIANT CELL TUMOR OF BONE IN ELDERLY PATIENTS: A STUDY OF TEN PATIENTS

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INTRODUCTION

Giant cell tumor of bone, sometimes referred to as conventional giant cell tumor, is a benign locally aggressive neoplasm which accounts for five percent of primary osseous neoplasms. Giant cell tumors most commonly occur in the distal femur, proximal tibia and distal radius. This neoplasm usually affects young adults; about two thirds of patients are between ages 20 and 40. Giant cell tumor is very unusual in patients older than age 55.¹ This study reports ten patients with giant cell tumor who range in age from age 62 to 78. We discuss whether giant cell tumors in elderly patients behave differently than those that occur in the usual age group. In addition, we outline how problems of differential diagnosis in this age group differ from those in conventional patients.

MATERIALS AND METHODS

These ten patients were collected from the personal consultation files of one of us (EFM). The images, histologic material, and clinical information with follow-up were available on all ten patients (see Table 1).

RESULTS

The ten patients ranged from age 62 to age 78. There were three males and seven females. Seven lesions were in long bones, and two were in the vertebrae. Vertebral lesions were T-11 and C-4. In the long bones there were two lesions each in the distal radius, proximal tibia and distal femur. Two patients had involvement of the humerus. All patients presented with pain. One patient (patient 3) presented with a pathologic fracture.

RADIOGRAPHIC FEATURES

Lesions in the long bone were well defined lytic lesions which involved both the epiphyseal and metaphyseal portions of the bone (Figure 1). Patient 3 presented with a pathologic fracture (Figure 2). Lesions in the spine (patient 7 and patient 10) involved the vertebral body.

HISTOLOGIC FEATURES

All lesions showed characteristic features of conventional giant cell tumor of bone (Figure 3). Two patients had extensive secondary histologic features. Patient 4 had a pronounced fibrohistiocytic reaction (Figure 4) and patient 8 showed extensive necrosis throughout the lesion.

With the exception of the two spinal lesions and the fractured distal radius lesion which were treated with resection, all other lesions were treated with curettage followed by bone graft or methyl methacrylate cement. Two patients died from causes unrelated to the giant cell tumor. Patient 1 died after a 14 year disease free follow up and patient 6 died after 4 years with no evidence of recurrence. All other patients are disease free from two years to ten years.

DISCUSSION

Rare isolated reports of giant cell tumors in patients over age 60 illustrate either chromosomal imbalances or treatment options.^{2,3} Numerous large series of giant cell tumors include a few elderly patients. However, these series do not focus on any distinctive features in these older patients.^{4,5,6,7} The ten cases in the present series illustrate that the behavior of giant cell tumor in elderly patients is no different from lesions occurring in more commonly involved younger patients. First, the location distribution is identical. In this series, the most common locations were the distal femur, proximal tibia and distal radius. These are the most common locations for giant cell tumor in all age groups. Second, the radiographic features of these lesions are identical to the giant cell tumors in younger patients. Lesions are well defined and involve both the epiphyseal and metaphyseal portions of the long bone. Third, the behavior of these lesions is identical to giant cell tumors in general. In fact, lesions in this age group may be less aggressive than those in younger patients because there were no recurrences. In general the recurrence rate after curettage for giant

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TABLE 1

| Case # | Patient Age/Gender | Location | Years of disease free follow up | Treatment | Comments |
|--------|--------------------|------------------|---------------------------------|-------------------------|-------------------------------------|
| 1 | 78 / F | Distal femur | 10 | Curettage w/ bone graft | Patient also had osteoarthritis |
| 2 | 70 / F | Distal radius | 14 | Curettage w/ bone graft | Patient died of unrelated causes |
| 3 | 73 / M | Distal radius | 2 | Resection w/ allograft | |
| 4 | 72 / F | Proximal humerus | 6 | Curettage w/ MMA | Extensive fibrohistiocytic reaction |
| 5 | 72 / F | Distal femur | 3 | Curettage w/ MMA | |
| 6 | 68 / F | Proximal tibia | 3 | Curettage w/ MMA | Patient died of unrelated causes |
| 7 | 64 / F | Spine T-11 | 4 | Resection | |
| 8 | 63 / F | Proximal tibia | 5 | Curettage w/ MMA | Extensive necrosis |
| 9 | 63 / F | Distal humerus | 2 | Curettage | |
| 10 | 62 / F | Spine C-4 | 3 | Resection | |



Figure 1. Plain radiograph of the giant cell tumor in the proximal tibia of patient 6. The lesion is a well defined zone of radiolysis involving the epiphyseal and metaphyseal end of the bone. This is a characteristic pattern for giant cell tumor.



Figure 2. Radiograph of the giant cell tumor of the distal radius from patient 3. There is a pathologic fracture through an otherwise typical giant cell tumor.

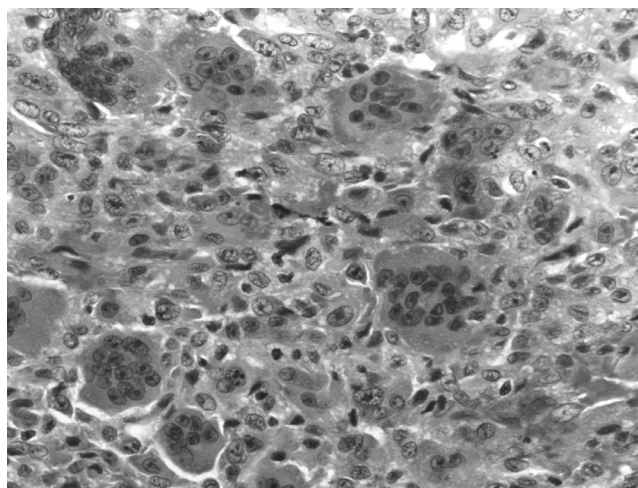


Figure 3. (right) Photomicrograph (H&E x 40) of the giant cell tumor from patient 5. The histologic features are characteristic of giant cell tumor.

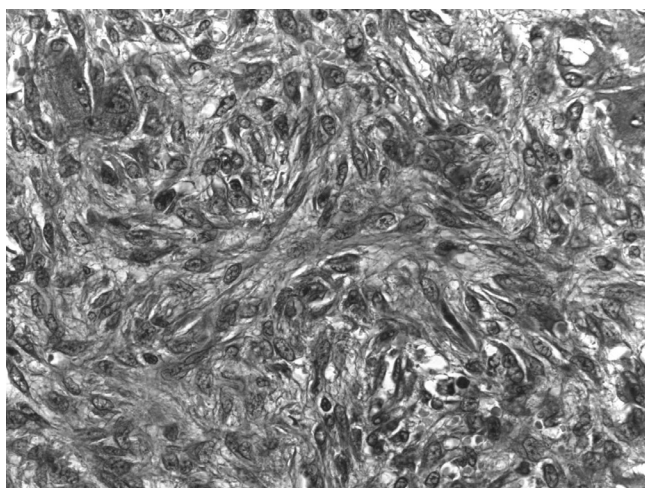


Figure 4. Photomicrograph (H&E x 40) of the lesion from patient 4 showing extensive fibrohistiocytic reparative reaction.



Figure 5. Radiograph of a 54 year old man with pigmented villonodular synovitis of the knee. There is extensive bone erosion in the proximal tibia which is causing radiolysis of the epiphysis and metaphysis. This is producing an identical radiographic picture as a conventional giant cell tumor.



Figure 6. Radiograph of a 70 year old man with a large osteoarthritic cyst of the proximal tibia. The radiolysis involves both the epiphysis and the metaphysis in the pattern of a giant cell tumor. However, there is marked medial compartment osteoarthritis which is the clue that this is an osteoarthritic cyst.

cell tumor is between 25 and 35 percent. Although recurrence may be delayed as long as fourteen years,⁴ almost all recurrences occur before two years.⁸ In our study, two years was the minimum follow up. Two patients showed histologic features of senescence (necrosis and fibrohistiocytic repair). These features may be signs of indolent lesions present for many years.

Giant cell tumor of bone in elderly patients presents diagnostic problems that are not seen in the more commonly involved younger patients. First, in this age group, the most common bone neoplasm is metastatic carcinoma. Although metastatic carcinoma favors the axial skeleton, some carcinomas will metastasize to the ends of long bones. Moreover, some carcinomas, including carcinomas of the breast, kidney, lung and pancreas, contain heavy populations of osteoclast-like giant cells.⁹ This histologic pattern may be mistaken for giant cell tumor of bone. Therefore, metastatic carcinoma must be ruled out in giant cell tumor patients in this age group. Lesions in these elderly patients should be stained with cytokeratin despite the number of giant cells present.

A second differential diagnostic problem in this age group is pigmented villonodular synovitis. From 15 to 50 percent of cases of pigmented villonodular synovitis involve bone.¹⁰ Because the process arises in joints, the bone involvement is almost always epiphyseal and

metaphyseal, identical to the bone destruction pattern seen in giant cell tumor.¹¹ Also, pigmented villonodular synovitis has a large population of giant cells which can be mistaken for giant cell tumor. Indeed, pigmented villonodular synovitis in bone can be mistaken for a primary bone neoplasm (Figure 5). A pre-operative MRI will help eliminate this diagnostic confusion because pigmented villonodular synovitis will show extensive synovial membrane involvement and secondary bone invasion.

A third differential diagnostic problem in this age group is the possibility that patients may have, instead of a giant cell tumor, a large osteoarthritic cyst. Large osteoarthritic cysts, sometimes known as geodes, involve the subchondral bone and may spread into the metaphysis causing identical radiographic features of giant cell tumor.^{12,13} Sometimes the evidence of osteoarthritis is minimal. Any older patient with an epiphyseal metaphyseal lesion should be carefully evaluated for the presence of osteoarthritis (Figure 6). The presence of an osteoarthritic cyst can be confirmed with an MRI that shows a bright signal on a T-2 weighted image. This will help eliminate the possibility of a giant cell tumor.

Finally, giant cell tumor is a well-documented but rare complication of Paget's disease, a disease of older patients.^{14,15} Therefore, any elderly patient with a giant cell tumor should be studied for the possibility of Paget's disease.

In summary, giant cell tumor of bone in elderly patients has a similar biologic behavior to lesions in the more commonly involved younger patients. In fact, lesions in this age group may be less aggressive. Problems in differential diagnosis can be eliminated if biopsies are studied with cytokeratin immunostains and pre-operative MRIs are done to rule out pigmented villonodular synovitis or osteoarthritic cysts.

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HEALTH PROMOTION PROGRAM: A RESIDENT WELL-BEING STUDY

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ABSTRACT

Background

Surgical training places unique stresses on residents that can lead to decreased levels of presenteeism. We hypothesized that presenteeism levels could be positively influenced by improving workplace hygiene.

Methods

A cohort of surgical residents was asked to complete the Stanford Presenteeism Scale: Health Status and Employee Productivity (SPS-6) questionnaire before, and one year after the implementation of a workplace health promotion program.

Results

Twenty-six of thirty-three residents responded to the initial survey and reported a mean SPS-6 score of 17.3 +/- 4.5, well below population normative value of 24 +/- 3 ($p < 0.0001$). At one-year post intervention 25 of 32 residents responded, reporting a mean SPS-6 score of 18.3 +/- 4.6. The mean SPS-6 score improved by 1.2 +/- 3.8 ($p = 0.35$). Subgroup analysis showed a trend toward improved SPS-6 in those who participated in the health promotion program ($p = 0.15$) and a significant

difference when junior residents were compared to seniors ($p = 0.034$). Overall, results were limited by our small sample size.

Conclusions

Presenteeism scores for surgical residents at our institution are well below population values. Use of validated tools such as the SPS-6 may allow for more objective analysis and decision making when planning for resident education and workload.

PRESENTEEISM*: the ability while on the job to produce quality work at maximum productivity

DECREASED PRESENTEEISM*: a state of decreased productivity and below-normal work quality related to health/workplace distracters

BACKGROUND

The decision to enter a surgical training program is one that fewer senior medical students are choosing to make.¹ The single most significant factor being cited is controllable lifestyle—a concept implying rigid control of time spent on professional pursuits, thus allowing personal time free of practice commitments.^{1,2}

The surgical discipline hardest hit has been General Surgery though decreasing numbers of applicants are anticipated in other specialties. In the U.S. the number of unfilled general surgery programs increased from 5 in 1997 to 41 in 2001, with a corresponding decrease in the number of medical students ranking surgery as first choice from 12.1% in 1981 to 6.1% in the 2001 match.³ Over this same period the percentage of senior medical students who perceived that surgeons have inadequate control over their time increased from 67% to 92%.¹ As senior medical student perceptions are likely influenced by exposure to the hectic schedule of a surgical resident, these attitudes may be difficult to reverse without addressing workplace and lifestyle issues in residency.

Concurrent with declining interest by medical students is the recognition for need of change in the surgical training paradigm, driven mainly by patient safety concerns. Concern regarding sleep deprivation and

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* as defined by the Stanford Presenteeism Scale: Health Status And Employee Productivity Questionnaire

resultant mental acuity has culminated in the mandated regulation of work hours by the Accreditation Council for Graduate Medical Education as of July 2003.⁴ Residency programs in New York have been under work hour restriction since 1989 and review of this experience has yielded mixed results; although generally accepted by residents, there is concern that work hour limitation may adversely affect both patient care and resident education.⁵ Surveys of faculty in major teaching centers have also raised concern over the implications of work hour limitation. Specifically 87% of faculty predicted that limiting work hours would be detrimental to resident education and 70.4% felt it would increase attending staff work hours.⁶ The unproven efficacy and significant concerns have led some to suggest that we must look beyond the counting of hours to truly improve surgical education, ensure patient safety and attract first rate students to surgical fields.^{7,8}

Many studies from the industrial sector have explored methods to improve workplace productivity and job satisfaction. The intervention that has repeatedly led to decreased absenteeism and increased productivity is the initiation of a "Work Place Health Promotion Program."⁹ However in studies of "professional workers" absenteeism has not been found to be a problem. Rather professional workers tend to appear for work but are inefficient and unproductive necessitating a different outcome measure. One such measure, Presenteeism, can be defined as: "a worker's ability to concentrate and produce quality work at maximal productivity while on the job." Decreased presenteeism occurs when a worker, though still present, produces poorer quality work at a reduced rate of productivity. Presenteeism levels can be measured using the Stanford Presenteeism Scale: Health Status and Employee Productivity Questionnaire (SPS-6).¹⁰ The SPS-6 (Figure 1) is a questionnaire composed of six questions, producing a maximal score of 30 (ideal presenteeism), designed to measure a worker's perception of his or her ability to overcome the distraction of current physical and or psychological problems in order to handle job stress, complete tasks, achieve goals and maintain sufficient focus and energy levels. This scale has been validated and is currently being used in the assessment of health promotion and disease management interventions at many levels including the automotive industry, Procter & Gamble and IBM.^{10,11}

By nature of surgical training and call commitments, residents have an obligate amount of time spent in hospital with a bi-product being significant periods of "down time"; spent waiting for test results, operating room availability and other unavoidable delays. This down time is frustrating, often wasted and we believe, a contributor to negative workplace hygiene. We hypothesized that resi-

dents are at high risk for decreased presenteeism and that an intervention aimed at improving work hygiene could help alleviate this problem.

MATERIALS AND METHODS

In January of 2003 the Stanford Presenteeism Scale: Health Status and Employee Productivity questionnaire was distributed to all orthopedic and general surgery residents at a University affiliated Tertiary Care Level 1 trauma center to obtain a baseline measure of Presenteeism. In accordance with the design of the SPS-6, we substituted "insufficient time for exercise" as the physical/ psychological distracter. Additional questions regarding exercise and absenteeism over the past year were collected. A health promotion facility was installed which comprised a 24 hour, in hospital access to a room equipped with a high quality Treadmill, Spin Bike, Power Cage total weight training system, floor mats and a 27" flat screen TV with full cable programming. Surgical residents were provided with free access to this facility provided they documented their usage (name, date, and time) in a specific study logbook.

After one year residents were reevaluated using the Stanford Presenteeism Scale-6.

RESULTS

In 2003, thirty-three eligible residents were identified and asked to complete the SPS-6 questionnaire. Twenty-six (79%) responded and reported a mean SPS-6 score of 17.3 +/-4.5. In 2004, thirty-two eligible residents were identified and 25 (78%) responded reporting a mean SPS-6 score of 18.3+/- 4.6. The 2003 and 2004 resident responders do not represent a continuous cohort. Two graduating residents who completed the initial survey were lost to follow-up in 2004. Four PGY 1 residents not surveyed in 2003 responded in 2004. One resident left the surgical training program after completing the initial survey, three 2003 responders did not complete the 2004 survey and two non-responders in 2003 responded in 2004.

When compared to a population normative sample (SPS-6 24+/-3),¹³ surgical residents (SPS-6 17.3 +/- 4.5) have a statistically significant level of decreased presenteeism ($p < 0.0001$).

Twenty-six of thirty-three residents responded to the initial questionnaire and reported a mean SPS-6 score of 17.3 +/- 4.5. At one year, twenty-five of thirty-two responded with a reported mean SPS-6 score of 18.3 +/- 4.6. Mean improvement in SPS-6 over the study period was 1.2 +/- 3.8 ($p = 0.35$). A power analysis revealed that 200 participants would be required to show this degree of change to be significant.

During the study period there were 320-recorded usages, which is probably an underestimate as compliance with the logbook was not uniform. Two subgroups could be identified; those who were frequent users (>20 recorded usages) and those who did not take advantage of the facility. Eighteen different residents, who had completed the initial and one year SPS-6 were recorded in the logbook, nine of which had >20 visits. Using a paired *t* test the mean change in users SPS-6 (2.7 +/- 4.8) compared to non- users (0.4 +/-3.3) showed a strong trend toward improvement (*p* = 0.15).

There are no significant differences between specific years in training, however when average SPS-6 score (16.6) for junior residents (PGY 1-3) is compared to the average of SPS-6 score (20.5) of senior residents (PGY 4-5), the later have a statistically significant improvement in presenteeism level (*p* = 0.034).

In 2003, 25 of 26 respondents reported that work commitments precluded desired exercise time with

an average of 2.4 exercise episodes per week. In 2004, only 19 of 25 respondents reported work commitments interfering with exercise, averaging 2.9 episodes per week for an increase of 0.5 times.

DISCUSSION

The surgical training paradigm is shifting, driven in part by “progressive” legislation and also the changing values of trainees. The challenge faced by training programs is to accommodate for this shift without eroding patient care, resident education or research productivity intrinsic to the academic setting.

Given the new reality of restrictive work hours, real efforts must be made to maximize the efficiency of time spent on the job. Industry has a long history of exploiting this concept: the recent economic upturn in North America has been described as a “jobless recovery.” Industrial output has increased without an associated creation of new jobs. This is attributed to maximizing

Stanford Presenteeism Scale: Health Status and Employee Productivity

Describe your work experiences in the last month. Please use the following scale.

1. strongly disagree
2. somewhat disagree
3. uncertain about your agreement
4. somewhat agree
5. strongly agree

Statement:

1. Because of my long hours and inability to get exercise the stresses of my job were much harder to handle
[1 2 3 4 5]
2. Despite long hours and difficulty to get exercise I was able to finish hard tasks in my work
[1 2 3 4 5]
3. My long hours and inability to get sufficient exercise distracted me from taking pleasure in my work
[1 2 3 4 5]
4. I felt hopeless finishing certain work tasks due to my inability to get sufficient exercise
[1 2 3 4 5]
5. At work I was able to focus on achieving my goals despite limitations on my ability to get sufficient exercise
[1 2 3 4 5]
6. Despite having limited time to get sufficient exercise I felt energetic enough to complete all my work
[1 2 3 4 5]

I would rank my job satisfaction as _____ out of ten.

Last year I was absent from work _____ days for health related reasons.

Do the time commitments of your job prevent you from exercising? Yes / No

At present I exercise _____ times per week on average.

Figure 1. The Stanford Presenteeism Survey as presented to residents

the output of a company's existing workforce with an emphasis on a healthy human capital.¹²

The eventual impact of work hour restriction is uncertain. A number of studies have found that a majority of residents support the concept of duty hour limitation.^{4,13} In New York where this policy has been in place since 1989, a survey of residents reported that these regulations have resulted in residents being better rested (64%) and having improved quality of life outside the hospital (66%) while only 42% reported an improvement of life in hospital. Of note, only fifteen percent of respondents "somewhat agreed" or "strongly agreed" that they would be willing to add an extra year of training to accommodate shorter working hours and yet in the same survey 35% of residents felt duty restriction had a negative impact on patient care and resident education.⁵ A recent American Academy of Orthopedic Surgeons survey of 148 training programs regarding duty hour restriction found that 48% of programs report a negative impact on patient care and 84% report a negative impact on resident education since implementation of work hour restrictions.¹⁴ A study conducted prior to work hour limitations, found that residents reporting the least number of weekly work hours were more likely to moonlight and that a 6.8 weekly work-hour difference between PGY1 and PGY 2 residents correlated with only 1.6 hrs of increased sleep per week (13.8 minutes nightly).⁸ These studies suggest that duty hour restriction may not have the anticipated benefit while potentially compromising patient care and resident education. Given these concerns alternatives to duty hour restriction must be evaluated to provide avenues for effective and balanced reform.

The concept of presenteeism arose from industry's attempt to qualify employee productivity. Presenteeism can be defined as a worker's ability to concentrate and produce quality work at maximal productivity while on the job. Decreased presenteeism occurs when a worker, though still present, produces poorer quality work at a reduced rate of productivity and is somewhat analogous to the lay term "burnout." Improving presenteeism levels then, may really be at the core of effective surgical training reform. Presenteeism levels may be quantified as previously described by The Stanford Presenteeism Scale: Health Status and Employee Productivity Questionnaire.

The significantly low values of presenteeism that we demonstrated among surgical residents highlights common perception about the demands of a surgical resident's lifestyle and the need to devise and assess the potential benefit of various interventions. Though significant research has been aimed at residency training, much of it is based on non-validated questionnaires

and logbooks tracking duty hours which are then used to make subjective inferences regarding work satisfaction and safety of performance. To our knowledge, this is the first study to apply a validated tool to this area.

Initiation of a work place health promotion program (a simple method to improve workplace hygiene) has been shown to decrease absenteeism rates and improve productivity¹⁵ thus providing the rationale for our intervention. The results of our study are intuitive; the improvement in workplace hygiene improves presenteeism rates only for those affected by the change. The institution of a free hospital based fitness center affected the workplace hygiene of only those residents interested in pursuing physical fitness and who found the time commitment of work and in hospital call limiting their life. Although fewer residents reported work interfering with desired exercise the mean number of exercise episodes increased by only 0.5 per week suggesting that the exercise completed in hospital may free up out of hospital time for other pursuits such as family or study. Though statistically we were only able to show a trend in this area, as results were limited by the small sample size. The importance of our study is not to advocate specifically for a hospital based exercise facility, but in the finding that improved workplace hygiene can increase presenteeism levels possibly independent of work hours. Duty limitation is not mandated in Canadian training programs and after the time frame of this study residents retrospectively reported working in excess of 90 hours per week (informal survey).

Our subgroup analysis showed that senior residents reported significantly higher levels of presenteeism than junior residents though reported number of hours worked was not different. This probably reflects the increasing knowledge and associated independence/responsibility as well as less time spent on non-educational, non-specialty specific tasks, which have been reported to occupy up to 35 % of resident's time.⁷ This apparent benefit to senior residents may be placed at risk by duty hour limitation. There has been a reported uploading of these tasks to senior residents with the decreased availability of junior trainees.⁵ This trend has affected faculty members as well with a recent AAOS survey finding 48% of programs report increased staff surgeon hours despite 51% of programs using more physician extenders.¹⁴

There are a number of weaknesses in our study. Our sample size was small and limited by the number of surgical residents at our center. A power analysis was not performed prior to beginning the study as we were unaware what level of change in presenteeism scores to expect. A retrospective power analysis showed that for a 2 point difference to be significant 40 residents would be required in each group (i.e., user vs. non-user) thus the

p-values achieved can be viewed as strong trends though not statistically significant. Though matched pairs were used for subgroup analysis this was not possible for the initial SPS-6 and final SPS-6 comparison due to resident turnover and inconsistent compliance with completing questionnaires. This may be a perceived weakness but as our aim was to study resident presenteeism levels as a group, before and after the intervention we do not feel that this introduces a significant bias.

Though restricted work hours may prove to be a positive step in the evolution of surgical education, it truly is an intervention thrust upon us without real validation. We believe that further work toward improving the conditions of resident training is needed if we are to optimize presenteeism in current residents as well as encourage the next generation of trainees to view surgery as a viable career option.

CONCLUSIONS

Surgical residents exhibit significantly decreased levels of presenteeism compared to the published population norms. Although our study was limited by size, we have shown the benefit of implementing a no fee hospital based fitness center on surgical resident presenteeism levels and submit this as a model for change aimed at improving workplace hygiene and lifestyle of surgical residency. After reviewing the literature related to early experience with work hour limitation we strongly suggest that further reform be focused on improving the way residents work rather than simply analyzing how much they work.

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ARE HONORS RECEIVED DURING SURGERY CLERKSHIPS USEFUL IN THE SELECTION OF INCOMING ORTHOPAEDIC RESIDENTS?

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ABSTRACT

The purpose of this study was to review institutional statistics provided in dean's letters and determine the percentage of honors awarded by institution and clerkship specialty.

Institutional and clerkship aggregate data were compiled from a review of dean's letters from 80 United States medical schools. The percentage of honors awarded during 3rd year clerkships during 2005 were collected for analysis. Across clerkship specialties, there were no statistically significant differences between the mean percentage of honors given by the medical schools examined with Internal Medicine (27.6%) the low and Psychiatry (33.5%) the high. However, inter-institutional variability observed within each clerkship was high, with surgery clerkship percentage of honors ranging from 2% to 75% of the students. This suggests some schools may be more lenient and other more stringent in awarding honors to their students. This inter-institutional variability makes it difficult to compare honors received by students from different medical schools and weakens the receipt of honors as a primary tool for evaluating potential incoming residents.

INTRODUCTION

Previous studies have shown a positive correlation between honors in medical school clerkships and residency performance especially among an applicant's chosen specialty.^{1,2,3} However, few studies have specifically focused on the distribution of honors among clerkship specialties. A common belief is that there are medical schools and certain clerkship specialties more prone to awarding

Clerkship Honors

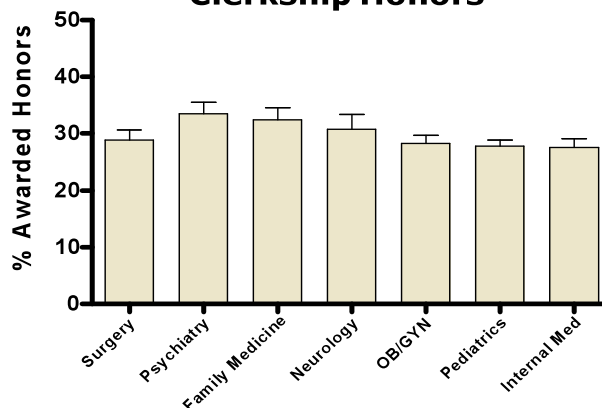


Figure 1. Mean \pm Standard Error of the Mean (SEM) for the percentage of honors awarded in 3rd year clerkships.

honors. The purpose of this study was to review institutional statistics provided in Dean's letters and compare across and between medical schools the percentage of honors given out in each clerkship specialty.

MATERIALS AND METHODS

Institutional and clerkship aggregate data were compiled from a review of Deans' letters from United States Medical Schools. The percentage of honors awarded by each institution during 3rd year clerkships from 2005 was collected for analysis. Honors were identified and included based upon the institution's designation of "honors" or "outstanding." Data were entered into an Excel worksheet and analyzed by GraphPad Prism using a one-way analysis of variance (ANOVA). Statistical significance required a p value <0.05 .

RESULTS

A survey of dean's letters was obtained for 80 medical schools. Three of the 80 schools did not report or provide in the dean's letter any combined clerkship student rankings or proportion of honors received. Seventy-seven schools were identified to have provided clerkship rankings and were included in our final analysis (Table 1).

Across clerkship specialties, there were no statistically significant differences between the mean percentage of honors given by the medical schools examined ($p=0.0723$) (Figure 1). The lowest and highest mean percentages of honors were observed in Internal

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TABLE 1

Medical Schools identified for potential inclusion in the study.

| | |
|---|---|
| Albany Medical College | University of Alabama School of Medicine |
| Albert Einstein College of Medicine of Yeshiva University | University of Arizona College of Medicine |
| Baylor College of Medicine | University of Arkansas for Medical Sciences College of Medicine |
| Brody School of Medicine | University of California, Davis, School of Medicine |
| Brown University School of Medicine | University of California, Irvine, School of Medicine |
| Case Western Reserve School of Medicine | *University of California, Los Angeles |
| Chicago Medical School | University of California, San Francisco, School of Medicine |
| Columbia University | University of Colorado School of Medicine |
| Creighton University School of Medicine | University of Connecticut |
| Drexel | University of Hawaii John A. Burns School of Medicine |
| Eastern Virginia Medical School | University of Illinois Champaign |
| Florida State University | University of Illinois Chicago |
| Georgetown University School of Medicine | University of Illinois Peoria |
| George Washington University | University of Iowa |
| Keck School of Medicine, University of Southern Cal. | University of Kansas Wichita |
| Loma Linda University School of Medicine | University of Louisville |
| Louisiana State University | University of Maryland School of Medicine |
| Loyola University of Chicago Strich School of Medicine | University of Medicine and Dentistry of New Jersey |
| *Mayo Medical School | University of Michigan Medical School |
| Marshall University School of Medicine | University of Minnesota Medical School |
| Medical College of Georgia | University of Missouri-Columbia School of Medicine |
| Medical College of Wisconsin | University of Missouri-Kansas City School of Medicine |
| Medical College of Ohio | University of Nebraska College of Medicine |
| Meharry Medical College | University of Nevada School of Medicine |
| New York Medical College | University of New Mexico |
| Northeastern Ohio University College of Medicine | University of North Carolina School of Medicine |
| Ohio State University College of Medicine | University of North Dakota |
| Oregon Health and Science University | University of Oklahoma College of Medicine |
| Robert Wood Johnson Medical School | University of Rochester School of Medicine and Dentistry |
| Rush Medical College | University of Tennessee Health Science Center |
| School of Medicine and Biomedical Sciences | University of Texas Medical Branch at Galveston |
| Southern Illinois University School of Medicine | University of Texas Medical School at Houston |
| St. Louis University School of Medicine | University of Texas Medical School, San Antonio |
| SUNY Upstate Medical University | University of Texas Southwestern Medical School |
| Temple University School of Medicine | University of Utah |
| Texas A&M, Health Science Center | University of Washington School of Medicine |
| Thomas Jefferson University | University of Wisconsin Medical School |
| *Tufts University School of Medicine | Vanderbilt University School of Medicine |
| Tulane University School of Medicine | Washington University |
| | Wayne State University School of Medicine |
| | West Virginia University School of Medicine |

**No rankings provided in letter*

Medicine (27.6%) and Psychiatry (33.5%). However, there was a high level of inter-institutional variability observed within each clerkship and this contributed to high standard deviations (range 10.4-18.4) (Figures 2 and 3). For Surgery Clerkships, the percentage of honors given between individual medical schools ranged from 2% to 75%, with most institutions falling between 15 and 40% (Figure 4).

DISCUSSION

Although a common thought is that certain clerkships are more prone to awarding honors than others, this data cross section does not statistically support this idea. However, data within each clerkship does show a high degree of variability between the schools. This finding suggests that certain schools may be more lenient and others more stringent in awarding honors to their students. This variability contributed to a lack of statistical significance in our sampling.

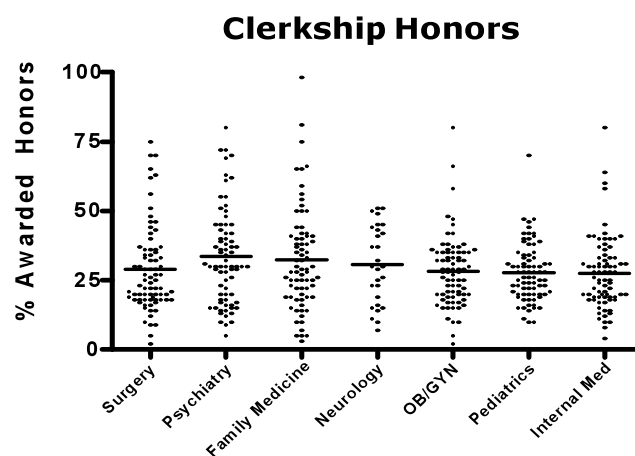


Figure 2. Scatter plot showing the variability among institutions in their awarding of honors across 3 year clerkships.

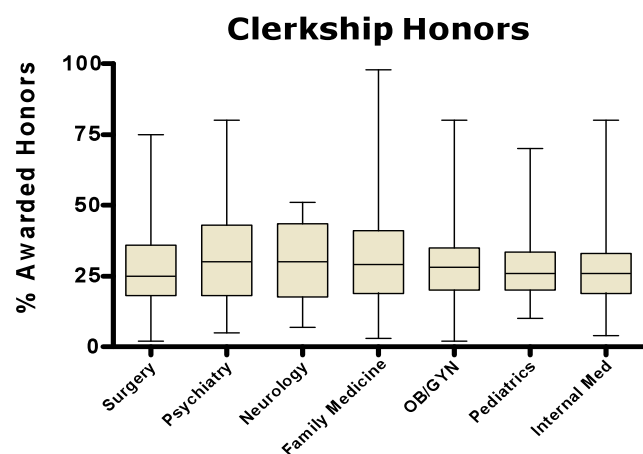


Figure 3. Box plots representing the median (solid line), 25th (bottom of box) and 75th (top of box) percentiles, and the high and low values (error bars).

In summary, inter-institution variability makes it difficult to compare honors received by students from different medical schools and weakens receipt of honors as one of the primary tools for student assessment. This finding may necessitate the need to stratify institutions in a way that allows residency programs and residency program directors a method of comparing prospective applicant's honors from one institution to the next.

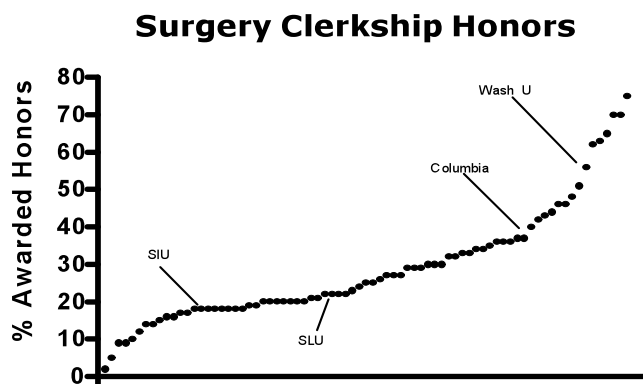


Figure 4. Awarding of honors in Surgery Clerkships. Plot of each school's percentage lowest (2%, Albany Medical College) to highest (75%, University of Arizona College of Medicine).

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COMPARABLE EFFECTIVENESS OF CAUDAL VS. TRANS-FORAMINAL EPIDURAL STEROID INJECTIONS

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ABSTRACT

Study Design: Retrospective case-control study.

Objective: To compare the effectiveness between caudal and trans-foraminal epidural steroid injections for the treatment of primary lumbar radiculopathy.

Summary of Background Data: Spinal injections with steroids play an important role in non-operative care of lumbar radiculopathy. The trans-foraminal epidural steroid injection (TESI) theoretically has a higher success rate based on targeted delivery to the symptomatic nerve root. To our knowledge, these results have not been compared with other techniques of epidural steroid injection.

Methods: 93 patients diagnosed with primary lumbar radiculopathy of L4, L5, or S1 were recruited for this study: 39 received caudal epidural steroid injections (ESI) and 54 received trans-foraminal epidural steroid injections (TESI). Outcomes scores included the SF-36, Oswestry disability index (ODI) and pain visual analogue scale (VAS), and were recorded at baseline, post-treatment (<6 months), long-term (>1 year). The average follow-up was 2 years, and 16 patients were lost to follow-up. The endpoint "surgical intervention" was a patient-driven decision, and considered failure of treatment. Intent-to-treat analysis, and comparisons included t-test, Chi-square, and Wilcoxon rank-sum test.

Results: Baseline demographics and outcomes scores were comparable for both treatment groups (ESI vs. TESI): (SF-36 PCS (32.3 \pm 7.5 vs. 29.5

\pm 8.9 respectively; $p = 0.173$), MCS (41.2 \pm 12.7 vs. 41.1 \pm 10.9, respectively; $p = 0.971$), and VAS (7.4 \pm 2.1 vs. 7.9 \pm 1.2, respectively; $p = 0.228$). Surgery was indicated for failure of treatment at a similar rate for both groups (41.0% vs. 44.4%, $p=0.743$). Symptom improvement was comparable between both treatment groups (ESI vs. TESI): SF-36 PCS improved to 42.0 \pm 11.8 and 37.7 \pm 12.3, respectively; $p=0.49$; ODI improved from 50.0 \pm 21.2 to 15.6 \pm 17.9 and from 62.1 \pm 17.9 to 26.1 \pm 20.3, respectively ($p=0.407$).

Conclusions: The effectiveness of TESI is comparable to that of ESI (approximately 60%) for the treatment of primary lumbar radiculopathy. The increased complexity of TESI is not justified for primary cases, and may have a more specific role in recurrent disease or for diagnostic purposes.

INTRODUCTION

To understand the effects of therapeutic measures for the treatment of lumbar radiculopathy, it is important to recognize the natural history of this disease. To our knowledge, there are no recent descriptions of the natural history. However, this can be inferred from the placebo controls of 3 prospective randomized controlled trials. These control groups show us that between 23% and 48% of the patients present significant relief of their symptoms at 1 to 2 years^{11,13,14} without any specific treatment measure. Multiple conservative care options have been studied, with the goal of modifying the natural history of this disease.

Radicular pain has been attributed to both mechanical deformation as well as to the action of inflammatory cytokines on the dorsal root ganglion.^{23,24} For this reason, the local delivery of steroids seems to be a rational option. This can be delivered in multiple forms. Clinical results of epidural steroid injections (ESI) have been extensively studied, and have demonstrated to provide significant relief of symptoms at 1 year follow-up in 36%–43% in two prospective cohort studies.^{4,5,6,7,8,10,17} This does not seem to be very different from the natural history of this disease. In an attempt to improve these results, trans-foraminal epidural steroid injections (TESI) have been devised to provide a more specific and targeted delivery of the steroids to the dorsal root ganglion. Previous results have been described, and vary between 65%–84%

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Human subjects research approved by the University of Iowa
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at 1-year follow-up, and compare favorably to control groups in 3 prospective randomized controlled trials.^{9,11,14}

When choosing a therapeutic technique, we must not only consider efficacy, but also safety and reproducibility. The delivery of steroids by inter-laminar or caudal techniques fails to reach the epidural space in 25%–40% of cases.¹⁷ This could be one of the reasons to account for the low efficacy of previous studies. Alternatively, trans-foraminal epidural steroid injections (TESI) present with intra-vascular injection of the steroid crystals in 13.1% of the cases.²⁵ This may not only compromise its efficacy, but may also induce serious neurologic complications.²² Furthermore, this procedure requires increased radiation exposure from longer fluoroscopy usage.

It then becomes necessary to compare the clinical efficacy of both procedures, to support further cost-benefit analysis. For this reason, the aim of this study is to directly compare the effectiveness of trans-foraminal and caudal epidural steroid injections in the treatment of primary lumbar radiculopathy.

MATERIALS AND METHODS

This study was designed as a retrospective case control (Class III-A evidence). During the period between June 2002 and July 2004, 132 patients were diagnosed for primary lumbar radiculopathy of L4, L5, or S1. Patients with previous surgeries at the same motion segment, those with unclear topographical diagnosis, those with major neurological dysfunction, and those under 18 years of age were excluded, as well as those patients without a thorough understanding of the English language.

The treatment plans were analogous for all patients: Surgical and non-surgical care was discussed, including all risks and potential benefits. The dialogue was aimed to be as unbiased as possible. The concept of failure of medical care was emphasized, and particularly, the fact that the patient is the protagonist of the decision-making process, based on complete and unbiased medical information. All patients in the study group elected to undergo conservative care options as their initial treatment method. In subsequent follow-up visits, this was again reviewed with the patients. At every point in time, patients were free to elect between continuing conservative care and surgery.

Conservative care consisted of activity modifications, physical therapy and epidural steroid injections. Physical therapy included extension-based exercise program and light, isometric core strengthening. Medications were also used, and included non-steroidal anti-inflammatory agents, muscle relaxants, and in some cases, narcotics. These patients were subject to two different types of epidural steroid injections as part of their treatment plan. Treatment groups were allocated according with

randomly assigned appointments to the clinics of either of the two senior authors. In each of these clinics, a different preference of epidural injection technique was maintained.

All procedures were performed by the same group of interventional musculo-skeletal radiologists, with a standardized technique. The caudal epidural steroid injections (ESI) were performed under fluoroscopic guidance with a 22g needle, and either 2cc of Depo-Medrol (40mg/ml), or 3cc Celestone (6mg/ml) were injected. The trans-foraminal epidural steroid injections (TESI) were also performed under fluoroscopic guidance for the L4 and L5 nerve roots, and under CT-guidance for the S1 nerve roots. A 20/25 coaxial system was utilized, and 1.5–2cc 1:1 solution of Marcaine 0.25% with Depo-Medrol (40mg/ml) or Celestone (6mg/ml) were injected.

Patients who consented to participate in the study included 39 of 58 patients (67.2%) treated with caudal Epidural Steroid Injections (ESI) and 54 of 74 (72.9%) treated with Trans-Foraminal Epidural Steroid Injections (TESI). Of the 93 patients, 16 were lost to follow up. Thus, we were able to account for 87.9% of the patients. This human subject research was approved by The University of Iowa Institutional Review Board (#200505762).

Baseline data collection included demographics, comorbidities, BMI, and imaging studies confirming the etiology of the lumbar radiculopathy. Information was collected at baseline, during the early post-treatment period (<6 months), and at a long-term post-treatment (24 months).

Primary outcomes include: Visual Analog Scale (VAS), the disease specific Oswestry Disability Index (ODI) and generic SF-36. Data was obtained from the University of Iowa Hospitals and Clinics electronic medical records. Long-term follow-up information required contact with patients by telephone or by mail-in questionnaires. The average follow-up was 24 months (12–36 months).

STATISTICAL ANALYSIS

The data was interpreted on an intent-to-treat basis. The SF-36 Physical (PCS) and Mental (MCS) Summary Scales were used as our primary outcome measures for generic health-related quality of life. To account for the effects of age and gender, the SF-36 summary scale scores were adjusted to corresponding age and sex normative data. Since the SF-36 summary scale scores are not only affected by back pain and sciatica, but also by other co-morbid conditions, these were also considered for the purpose of our analysis.

Co-morbid conditions were identified and annotated at baseline. These were stratified according to Charlson's criteria, and divided into the categories of 0, 1 or ≥ 2 co-morbid conditions. Other confounding variables that

were controlled for included BMI, and the etiology of the radiculopathy.

Once collected, the data was exported to Statistical Analyzing System (SAS Institute Inc., Cary, N.C.) for statistical analysis. Repeated ANOVA was used to study the effectiveness of treatment, and independent sample mean comparisons to compare treatments. The LOCF (Last Observation Carried Forward) method was used to replace missing values on individual patients. Kaplan-Meier disease-free survival curves were constructed, and for this study, represents the number of patients that had not requested surgery for the management of their symptoms at a specific time point.

Results are expressed as mean \pm standard deviation. An alpha (p-value) < 0.05 was accepted for statistical significance.

RESULTS

Baseline Demographics and Treatment Group Allocation

The two treatment groups included 39 patients subject to caudal epidural steroid injections and 54 patients subject to trans-foraminal epidural steroid injections. Both treatment groups (ESI vs. TESI) were comparable, at baseline, in age (38.9 ± 12.8 vs. 39.0 ± 13.3 , respectively; $p = 0.9596$), Body Mass Index (BMI) (29.1 ± 5.6 vs. 28.8 ± 7.3 , respectively; $p = 0.814$), duration of symptoms (25.9 ± 27.4 vs. 35.5 ± 40.5 , respectively; $p = 0.181$), and co-morbidities (0 co-morbid conditions: 27 (69.2%) vs. 43 (79.6%), respectively and ≥ 1 co-morbid condition 5 (12.8%) vs. 4 (7.5%) respectively; Wilcoxon rank-sum test $p=0.2435$). Finally, the etiology of the radiculopathy was attributed to disc herniation in 38 (97.4%) vs. 49 (97.4%) respectively, spondylolsthesis in 0 vs. 2 (3.7%) respectively, and stenosis in 1 (2.6%) vs. 3 (5.5%) respectively; $p=0.203$.

The baseline health-related quality of life measures were also comparable between treatment groups (ESI vs. TESI): The SF-36 physical compound scores (PCS) was 32.3 ± 7.5 vs. 29.5 ± 8.9 respectively; $p = 0.173$. The SF-36 mental compound score (MCS) was 41.2 ± 12.7 vs. 41.1 ± 10.9 , respectively; $p = 0.971$. The visual analogue pain scale was 7.4 ± 2.1 vs. 7.9 ± 1.2 , respectively; $p = 0.228$. Finally, the Oswestry disability index was 54.8 ± 15.5 vs. 62.1 ± 17.9 , respectively; $p = 0.128$.

Additional Therapeutic Interventions

Subsequently to the index procedure, a number of patients required additional interventions for the management of their symptoms (Table 1). This included a similar number of repeat injections for both treatment groups (ESI 25.6% vs. TESI 18.5%; $p=0.5183$), as well as surgical interventions, which were also requested by

TABLE 1

| Variable | ESI (n=39) | TESI (n=54) | p-value |
|-------------------------|---------------|----------------|--|
| Surgery (% operated) | 16 (41.03%) | 24 (44.4%) | Chi-square test $p = 0.7425$ |
| Repeat Injections | | | Wilcoxon rank-sum test $p = 0.5183$ |
| 0 | 29 | 44 | |
| 1 | 10 | 7 | |
| 2 | 0 | 3 | |

Comparison of additional therapeutic interventions following the index procedure between the caudal epidural steroid (ESI) and trans-foraminal epidural steroid (TESI) groups, throughout the study period.

patients in similar proportion for both groups (ESI 41.0% vs. TESI 44.4%; $p = 0.743$). A Kaplan-Meier surgery-free survival curve illustrates that the rate of surgical endpoint was similar between groups over time (Figure 1), and surgery was requested and executed mostly within 3-6 months following the initial visit to our institution. This did not vary between treatment groups ($p = 0.91$).

Health-related Quality of Life

Both patient groups displayed comparable improvement with treatment, by all measures of outcome. The visual analogue scale for pain (VAS) improved from 7.4 ± 2.1 at baseline to 4.4 ± 3.2 at 24-month follow-up ($p < 0.0001$) in the group treated with caudal ESI. This was comparable to the improvement seen in the patients treated with foraminal epidural steroid injections (TESI), where the baseline VAS of 7.9 ± 1.8 improved to 5.7 ± 3.0 , $p < 0.0001$. This improvement was statistically equivalent for both groups ($p=0.933$). Similar results were found for Oswestry disability index: The caudal ESI group improved from a baseline of 50.0 ± 21.2 to 15.6 ± 17.9 at 24-month follow-up, $p < 0.0001$. Similarly, the TESI treated group improved from a baseline of 62.1 ± 17.9 to 26.1 ± 20.3 at follow-up. This improvement was also comparable between both groups ($p=0.407$).

Finally, both groups displayed comparable improvement with treatment as measured by their SF-36 scores. The physical compound score was 32.3 ± 7.5 at baseline and improved to 42.0 ± 11.8 at follow-up for the ESI group ($p=0.0004$), which compared to the TESI group (29.5 ± 8.9 at baseline and 37.7 ± 12.3 at 24-month follow-up, $p=0.0003$). This improvement was comparable between both treatment groups ($p=0.49$). The mental compound score was 41.2 ± 12.7 at baseline and improved to 48.8 ± 13.1 at follow-up for the ESI group ($p=0.0032$), which compared to the TESI group (41.1 ± 10.9 at baseline and 51.1 ± 9.9 at 24-month follow-up, $p < 0.0001$). This improvement was comparable between both treatment groups ($p=0.83$).

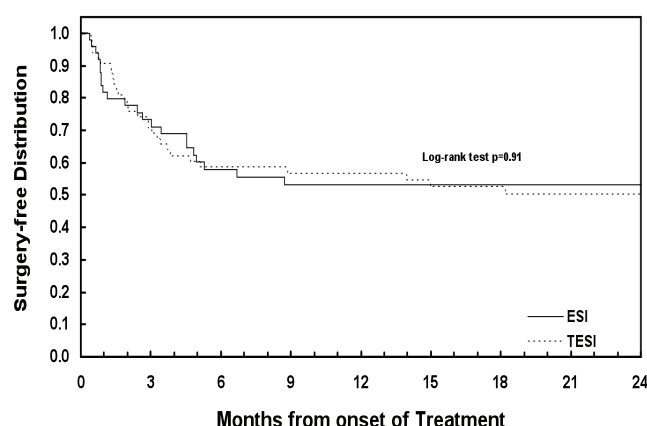


Figure 1. Kaplan-Meier curve demonstrating the surgery-free distribution as a function of time following initial treatment. This was comparable for the caudal epidural steroid (ESI) group as well as the trans-foraminal epidural steroid group (TESI); Log-rank test $p=0.91$.

DISCUSSION

In order to assess the effectiveness of epidural steroid injections for the treatment of lumbar radiculopathy, we must first recognize the natural history of the disorder. Hakelius¹² described a favorable prognosis for patients with sciatica, and after treating a group of patients with bed rest and brace, 70% were clinically improved in 3 months time. This study lacks the rigorous evaluation criteria used in modern clinical trials, but gives us a broad idea that not all patients require surgery to obtain relief of their symptoms within a reasonable timeframe. From 4 prospective randomized studies, we may use the control groups as a source of information for natural history. The study by Vad¹⁴ compares trans-foraminal epidural injections with steroids versus saline trigger-point injections, and after a 1.4 year follow-up, the trans-foraminal steroid group had a significantly higher success rate of 84% as compared with 48% for the control group ($p<0.005$). Fraser¹³ reports on the results of intradiscal injections with chymopapain versus normal saline solution, and at final follow-up, 57% of the chymopapain group was free of pain, compared to only 23% of the saline group. Of these, 20% of the chymopapain group, and 47% of the saline group requested surgery during the observation period of 2 years. Karppinen¹¹ found that periradicular infiltrations of Methylprednisolone + Bupivacaine had only short-term clinically meaningful benefits over periradicular infiltrations with normal saline solution. At 1 year, 22.5% of the steroid group, and 18.8% of the saline group had requested surgery. These results have been attributed to a possible “wash-out” effect of the saline injection, altering the concentrations of inflammatory cytokines. Finally, Riew⁹ found that selective nerve-root injections of corticosteroids were significantly more effective in obviating the need for surgical intervention,

than a control group with similar injections of Bupivacaine alone (28.6% vs. 66.7% requested surgery during the follow-up period of 13–28 months). In general, the control groups of the previously described trials show that within 1–2 year follow-up periods, a range between 33.3%–81.5% of the patients had not requested surgery for the management of their sciatic pain. If we exclude the “wash-out” results from saline- or Bupivacaine-only nerve root injections, the placebo control groups may have a success rate of only 23%–48%. Treatments that provide benefit to a larger percentage of patients can be called clinically effective.

Three of the previously described trials^{9,11,14} describe the efficacy of trans-foraminal injections with steroids to lie within the range between 65%–84%, expressed as improved quality of life outcomes scores and decreased surgical rates. On the other hand, there are adverse events related to intra-vascular uptake,^{18,25} which occurs in up to 11.2 % of the cases, not observed with either caudal or inter-laminar application of epidural steroids. Both caudal and inter-laminar epidural injections may fail to reach the epidural space in 25%–40% of the cases.¹⁷ In a recent review of the literature^{16,20} based on 12 controlled clinical trials, only 4/5 caudal ESI studies, and 2/7 inter-laminar ESI studies demonstrated increased effectiveness over controls. In 2 prospective cohort studies^{1,2,3,19} comparing conservative care with surgical treatment for lumbar radiculopathy, patients reported significant symptomatic improvement with conservative care in 36%–43% at 1-year follow-up, and 51%–56% at 5 years. Conservative care included physical therapy, bed rest, spinal manipulation, narcotic analgesics and epidural steroids. Finally, McDonald²¹ presents a 31% failure rate in patients treated for lumbar radiculopathy with interlaminar epidural steroids and local anesthetic, which is not different from the 41% failure rate of a control group treated with an intramuscular injection of local anesthetic and steroid.

The current study was designed to assess the relative effectiveness of caudal and foraminal epidural steroid injections, performed with a standardized technique by a constant group of interventional musculo-skeletal radiologists. Both techniques successfully provided relief from the major complaint of radiculopathy to similar proportions of patients. A comparable number of patients elected to have surgery after the index procedure was considered to have failed (37.93% of the TESI and in 39.19% of the caudal ESI treated patients ($p=0.883$)). Most of the patients that elected to have surgery did so within 3 to 6 months of treatment. Treatment was considered successful by all other patients, and this was quantified by significant changes in VAS, ODI and SF-36 scores. As described in other clinical trials, a decline in VAS to 50%

of baseline, as well as a decrease in ODI of at least 15 points is considered as a standard of clinically relevant difference. These goals were obtained for both the TESI as well as the caudal ESI treated groups. However, the end result was that there was no statistical difference in outcomes between treatment groups, demonstrating that there is no outcomes benefit to performing one injection technique instead of the other.

LIMITATIONS OF THE STUDY

This is a retrospective study, and patients were not randomized to be included into this study. Two carefully selected cohorts were chosen from the clinics of the two senior authors, following rigorous entry criteria. They were not randomized, but they were comparable in their baseline characteristics. The choice of the steroid injection technique was determined by the individual preferences of the senior authors. Although there is no randomization, the two matched cohorts give us the opportunity to compare effectiveness of two variations of epidural steroid injections.

The technical aspects of the epidural injection techniques include standardized technique by the same group of interventional radiologists, with minimal differences in dosage and drugs, which similarly affects both cohorts.

CONCLUSION

The effectiveness of caudal and trans-foraminal epidural steroid injections for the treatment of primary lumbar radiculopathy were compared in a retrospective case control study. They were found to be equivalent, and allowed patients to decline surgery in approximately 60% of the cases.

Regardless of the technique, 24%–28% of the patients required 1 or 2 repeat injections for the management of their primary complaint—radiculopathy.

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PILOT DATA: ASSOCIATION BETWEEN GLUTEUS MEDIUS WEAKNESS AND LOW BACK PAIN DURING PREGNANCY

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ABSTRACT

This cross-sectional study examines whether there is an association between gluteus medius weakness in the presence of low back pain in pregnant women at any stage of gestation. Prevalence of low back pain during pregnancy is high, and identifying potential etiologies and targeted interventions is lacking. Thus, identification of an association between specific muscle weakness and pain would have clinical relevance. Initial pilot data suggests that weakness of the gluteus medius is strongly associated with the presence of low back pain during pregnancy.

INTRODUCTION

Low back pain during pregnancy is considered a significant public health issue due to its high prevalence and associated health care costs. Prevalence ranges between 49-68.5%^{2,13,14} with up to one third of these women having pain that limits their ability to perform basic activities of daily living.¹³ Ten percent of women with chronic low back pain link the onset of their pain to pregnancy.²⁷ Physical therapy literature and physical therapy clinical practice relating to low back pain in pregnancy has historically involved discussion of postural dysfunction, sacroiliac joint dysfunction, and “sciatica.” The authors of this proposal would like to offer another possible correlation explaining back pain during pregnancy relating to gluteus medius performance.

It is the experience of the authors of this proposal that pregnant women routinely present to our physical therapy clinic with “radiculopathy” or “sciatica.” In fact, the incidence of herniated disc in pregnancy is actually quite rare (1%).¹⁶ Often, the physical exam does not reveal any neurologic findings indicative of radiculopathy, but instead reveals weakness and/or strain of the gluteus medius. Gluteus medius strain can present as low back pain either due to facet joint irritation relating to Trendelenburg gait, or can be referred pain from the gluteus medius itself. If a true neurologic weakness were

present, one would expect to find both tensor fascia lata (TFL) and posterior gluteus medius (PGM) weak as they are commonly innervated (L5). Rather, in our experience weakness is specific to the gluteus medius. Foti et al. performed 3-dimensional gait analysis on 15 pregnant women during the second half of their pregnancy and again one year post-partum. Gait analysis includes both kinetic and kinematic parameters. The authors found significant changes in kinetic gait parameters during pregnancy, and offer this as an explanation for how gait motion overall remains relatively unchanged. They found increased demand on the ankle plantar flexors, hip abductors, and hip extensors.¹¹ Atrophied tissues, or weak muscles, are less tolerant of physical stresses applied.¹⁹ Pregnant women with weakness of the gluteus medius are therefore vulnerable for tissue injury—both because of the increased magnitude of stress applied (weight gain), and a decrease in stress tolerated before injury/strain.

Thus, the primary aim of this pilot study was to determine the association between weakness of the gluteus medius and the presence of low back pain during pregnancy.

METHODS

All women (pilot data with N = 65) underwent a basic physical examination by one of three blinded examiners (KB, DB, or DM). Standardization of muscle grading was done prior to the initiation of the study with several review sessions throughout the study. Physical exam involved supine passive straight leg raise (SLR) testing for neural tension, and manual muscle testing of the bilateral gluteus medius and tensor fascia lata. Tension signs were graded as absent/present. Muscle grading was based on the method described by Florence Kendall. Strength was graded as 0, 1, 2, 3, 4, or 5/5 then grouped as either ‘weak’ (3/5 or less) or ‘strong’ (4 or 5/5). Participants were recruited from private clinics and resident clinics at a tertiary care center. All participants were 18 years or older, and at any gestational stage. Exclusion criteria included non-English speaking women, incarcerated women, and women with any known history of neuromuscular disease (such as multiple sclerosis). All participants completed questionnaires (see Table 1) in addition to the aforementioned testing. Data was analyzed using Chi-squared to test significance of the

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TABLE 1

| | GM Left | | GM Right | |
|--------------|------------|------------|------------|------------|
| | Strong (%) | Weak (%) | Strong (%) | Weak (%) |
| No Back Pain | 19 (73.08) | 9 (24.32) | 19 (67.86) | 9 (24.71) |
| Back Pain | 7 (26.92) | 28 (75.68) | 9 (32.14) | 26 (74.29) |

association between weakness and pain, and Fisher's exact test was applied when expected count of frequency table was small. Wilcoxon rank-sum test used to compare body mass index (BMI) and activity levels between those with low back pain (LBP) and without LBP (>0.05 is significant).

RESULTS

We identified a significant correlation between gluteus medius weakness and presence of low back pain. Gravid women were 8.44 times more likely to have low back pain if there was left gluteus medius weakness ($p=0.0002$, 95% CI is (2.68, 26.58)), and 6.10 times more likely to have low back pain if there was right gluteus medius weakness ($p=0.0010$, 95% CI is (2.04, 18.27)).

One individual was found to have a positive SLR. However, there were no neurologic findings on further exam (negative bowstring, normal/symmetric deep tendon reflexes, symmetric myotomal strength). While BMI was marginally positively correlated with severity of low back pain, women with LBP had gained more weight during pregnancy than those without LBP. This fits with weeks of gestation (those with low back pain have more weeks gestation, $p=0.009$).

DISCUSSION

As mentioned, prevalence of low back pain in pregnant women is high. Yet our knowledge is limited to descriptions of natural history. Unfortunately, most clinicians are limited in both work-up and treatment options due to the pregnancy. Often, women are advised to wait until after delivery for appropriate tests and treatment.

The rationale for postural change as a contributor to back pain during pregnancy involves increased lumbar lordosis with subsequent extension-related facet pain. Treatment is then guided toward improving posture, abdominal strengthening, and improved lumbopelvic stability. Lengthening of the abdominal muscles is a known consequence of a growing uterus, causing possible weakness of this musculature. It is thought that this lengthening and weakness contributes to poor lumbar stabilization and pain. Few studies exist showing a correlation between abdominal weakness and back pain in pregnant women. Fast et al. looked at rectus abdominus

function in terms of ability to perform a sit-up. They found no significant difference between performance of a sit-up and incidence of back pain.¹⁰ Moore et al. performed a longitudinal study of 30 pregnant women and found the line of gravity, measured using special markers along the spinous processes, to be unaffected for the majority of women. Those who did experience a change, tended toward flattening of the lumbar spine.¹⁸ Other studies have found no correlation between postural patterns and the presence of low back pain.^{7,11}

Sacroiliac joint dysfunction is a much debated issue in the physical therapy literature. There is disagreement relating to whether the sacroiliac joints are mobile, and if so, to what extent. An excellent review by Walker documents review of multiple articles citing greater tendency toward fracture than joint displacement with high impact injury.²⁹ This review also notes motion of the SI joint averaging about four degrees or three millimeters.²⁹ This brings into question whether this small amount of movement can be detected through physical exam alone. The discussion changes somewhat in the context of pregnancy, as there is known joint laxity around the pelvis. As the SI joint is not crossed by any muscle, we assume that stability is achieved through bony morphology and ligaments. During pregnancy, it is thought that the hormone relaxin contributes to the decreased strength of collagen. There appears to be conflicting evidence relating to whether a correlation exists between relaxin levels, pain, and SI joint movement/sympheseal distension.^{1,5,7,14,23} Specific provocative maneuvers to detect SI joint pain, as well as tests to determine symmetry/joint motion exist. However, at this time, reliability and validity of these tests does not appear sound, particularly in the case of detecting symmetry/abnormal joint motion.^{24,29}

CONCLUSION

Pregnant women with gluteus medius weakness were roughly 6 to 8 times more likely to have low back pain than those without weakness. There were no neurologic findings indicative of radiculopathy. This pilot data encourages us to continue this study with larger numbers. We also will consider a treatment trial looking to see if strengthening exercises prescribed at the first OB visit can reduce incidence of LBP.

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BILATERAL PATELLAR TENDON RUPTURE AT DIFFERENT SITES WITHOUT PREDISPOSING SYSTEMIC DISEASE OR STEROID USE

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ABSTRACT

Simultaneous bilateral patellar tendon ruptures are extremely rare, and even more rare in patients without systemic disease. We describe bilateral simultaneous patellar tendon disruptions in the absence of systemic disease or steroid usage, with one tendon disruption at the inferior pole and the other an intrasubstance tear. The different locations of the ruptures are also exceedingly rare, as only two cases of non-identical ruptures have ever been reported. We also review all bilateral patellar tendon rupture case reports from English and German literature.

INTRODUCTION

Bilateral patellar tendon rupture is an extremely rare occurrence, with approximately 50 reported cases in the English and German literature. It is thought to be associated with systemic disease such as rheumatoid arthritis, lupus erythematosus, and hyperparathyroidism. In addition, long-term microtrauma and corticosteroid use may also contribute to bilateral rupture.^{1,2} Bilateral rupture in the absence of systemic disease or corticosteroid use is exceedingly rare, accounting for only a small percentage of the reports in the literature.

MATERIALS AND METHODS

In August 2006, a 36-year-old man playing soccer jumped, brought both feet off of the ground and, upon landing, had immediate pain and a subjective popping sensation in both knees simultaneously. He was unable to ambulate at the scene. He denied any prior trauma, any pre-existing symptoms of either knee or extensor mechanism, any past medical history, and any history of corticosteroid or anabolic steroid usage. At presentation to the emergency department, plain radiographs of his bilateral knees revealed effusions and slight patella alta; however, the films were taken with the knees in near-full extension (Fig. 1).



Figure 1. Injury radiographs showing bilateral patella alta.

Physical examination showed a healthy appearing man who was approximately 190 cm tall and 104 kg in weight. Both knees had large effusions without skin lacerations, abrasions, or other skin defects. A noticeable step-off of the normal patellar tendon was palpated on his right knee, but a step-off in his contralateral knee was only palpated after some difficulty. Quadriceps contractions did cause translation of his patella in a cranial direction, but he was unable to extend either knee or hold either knee in extension when passively positioned.

Operative repair of his bilateral patellar tendon ruptures was performed the following day. Intraoperatively the right patellar tendon had an intrasubstance rupture with mop-like ends and complete disruption of the retinaculum. The left patellar tendon was avulsed from its origin at the inferior patellar pole with similar complete disruption of the retinaculum. There were no other intra-articular injuries. The ruptures were each repaired with FiberWire suture (Arthrex, Inc., Naples, FL) in Krackow

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Figure 2. Postoperative radiographs showing restoration of the patella level.

fashion and supplemented with 18-gauge wire cerclage; the retinaculum was also repaired using absorbable suture. Excellent range of motion was achieved without any gapping of the tendon repair. Knee immobilizers were applied at the end of the case. Postoperative x-rays are shown in Figure 2.

Postoperatively, he began ambulation on the day of surgery with both legs locked in extension braces. He was allowed to bear weight as tolerated with crutches. His recovery course was complicated by a pulmonary embolism diagnosed on postoperative day 19, which was treated successfully with heparin and warfarin. His bilateral patellar tendon ruptures healed uneventfully. At four months postoperatively, the patient had 120° flexion of both knees; at one year postoperatively, he had returned to light athletic activities and had full range of motion of both knees.

DISCUSSION

Bilateral patellar tendon rupture is an extremely rare occurrence, with approximately 50 reported cases in the English and German literature. It is thought to be associated with systemic disease such as rheumatoid arthritis, lupus erythematosus, and hyperparathyroidism, as well as long-term microtrauma and corticosteroid use.^{1,2} Bilateral patellar tendon rupture in patients without

TABLE 1
Cause of Rupture

| Cause of Rupture | Systemic Disease ²⁻²⁰ | No Systemic Disease ^{1,21-50} |
|------------------|----------------------------------|--|
| Traumatic | 9 | 28 |
| Atraumatic | 10 | 5 |

Note: Systemic disease includes: rheumatoid arthritis, systemic lupus erythematosus, ulcerative colitis, osteogenesis imperfecta, renal failure, and primary hyperparathyroidism.

TABLE 2
Site of Tear

| Cause of Rupture | Systemic Disease ²⁻²⁰ | No Systemic Disease ^{1,21-50} |
|------------------------------|----------------------------------|--|
| Inferior pole | 25 | 41 |
| Midsubstance | 6 | 17 |
| Insertion at tibial Tubercle | 5 | 4 |
| Not noted in study | 4 | 2 |

Note: Table contains number of tendons total that were disrupted at each site. Since each patient had bilateral rupture, the number of tendons is equal to double the number of patients.

systemic disease or corticosteroid use is exceedingly rare and comprises only a small percentage of the case reports in the literature. Tables 1 and 2 summarize the reported bilateral patellar tendon ruptures with respect to the presence/absence of systemic disease, traumatic versus atraumatic injury, and site of tear.¹⁻⁵⁰

In order to discuss bilateral patellar tendon rupture, one must first address the extensor mechanism of the knee. The extensor mechanism consists of the quadriceps tendon, the patella, the patellar tendon, and the insertion of the patella on the tibial tubercle. Patellar tendon rupture is the third most common cause of extensor dysfunction, after patellar fracture and quadriceps tendon rupture.³ The muscle moment arm of the extensor mechanism is increased by the patella. Patellar rupture is thought to result from contraction of the quadriceps in a flexed knee. The juxtaposition of these opposite contractile forces creates a superior moment arm across the quadriceps and an inferior moment arm pointing towards the tibial tubercle. If the opposing forces are strong enough, the patellar tendon will rupture. Zernicke, et al.⁵¹ reported that a force of 17.5 times the body weight is required to rupture this tendon. To put this into perspective, climbing stairs is reported to create a force of 3.3 times body weight.⁵² Athletic movements such as acceleration, deceleration, and jumping are reported to create forces of seven-to-eight times the body weight.

Men have an increased propensity for bilateral patellar tendon rupture as compared to women: the calculated ratio based on the case reports in the literature is 5:1 (12/62 cases). Although bilateral rupture is often dis-

cussed in the realm of systemic disease, it has been reported that approximately 60% have no evidence of systemic or autoimmune disease.⁴⁹

Bilateral patellar tendon rupture has been shown to be difficult to diagnose and has often been overlooked in clinical assessments. Siwek and Rao⁵³ found that 28% of the reported bilateral tendon ruptures were misdiagnosed on initial examination. These patients often present with a sudden onset of bilateral knee pain, bilateral knee effusions, and extensor dysfunction. On inspection, there are bilateral effusions and high-riding patellae. It is often difficult to appreciate the high-riding patella on inspection because of a lack of a contralateral normal knee for comparison. A palpable infrapatellar defect may be present, but again this may be difficult to discern due to a substantial effusion or lack of a normal knee for comparison. Patients also have difficulty with extension of the knee. This usually manifests as a complete inability to extend the knee, but some patients may still have some extension function if extensile forces are able to be conducted through intact medial and lateral retinacula.

Bilateral rupture may be diagnosed radiographically via the presence of bilateral patella alta. The best way to make this diagnosis is through a lateral view of the knee in slight flexion to tension the patellar tendon. On this view, an Insall-Salvati ratio can be calculated.⁵⁴ This ratio is the longest diagonal length of the patella over the length of the patellar tendon, measured from the inferior pole to the tibial tubercle. A patellar length:tendon length < 0.8 is indicative of patella alta and this finding bilaterally may be indicative of bilateral patellar tendon rupture. Another radiographic test for patella alta involves the use of Blumensaat's Line. In a lateral x-ray view, with the knee in 30° of flexion, a line is drawn through the roof of the intercondylar notch in the distal femur. A patella that is > 2 cm above Blumensaat's line is considered to exhibit patella alta.⁵⁴ A final radiographic evaluation can be performed using the Blackburne and Peel method, which also uses the lateral x-ray view of the knee in approximately 30° of flexion. The ratio between the perpendicular distance from the lower articular margin of the patella to the tibial plateau articular surface and the length of the articular surface of the patella should be 0.80. Ninety-five percent of the population will be in the range of 0.54 and 1.06. Any increase in this ratio indicates patella alta.⁴

The underlying pathophysiology of bilateral patellar tendon rupture has been reported in the literature as falling under three categories. The first group consists of patients with underlying systemic or autoimmune disease who are thought to have a higher risk for bilateral patellar tendon rupture. This includes patients with lupus

erythematosus, rheumatoid disease, diabetes mellitus, chronic renal disease, and hyperparathyroidism. These conditions are thought to cause inflammatory changes that alter the structure of the tendon. Histologic examination of these patients' tendons has shown chronic inflammation and amyloid deposition.⁵⁵ The second group involves oral or injectable corticosteroids, which are thought to have an association with bilateral patellar tendon rupture. It is believed that the steroids affect collagen synthesis and compromise blood supply, thereby weakening the tendon.^{1,3,21} Patients in group three exhibit inflammatory and degenerative changes on histologic studies attributed to chronic microtrauma.²² This theory of repetitive microtrauma leading to rupture has been referred to as the Davidson Theory in the literature.²³

These tendon tears are classified according to a three-part system:^{24,25} Type 1—at the origin of the tendon at the inferior pole of the patella, Type 2—a midsubstance tear through the tendon, or Type 3—at the insertion of the patellar tendon to the tibial tubercle. Types 1 and 3 are referred to as tears of the osteotendinous junction. It was once thought that patients with tears related to steroid use had a greater propensity for the midsubstance of the tendon, but a Fisher exact test showed no relationship between midsubstance or osteotendinous tears and steroid use.³ Of note, the patient in this report had a midsubstance tear on the left side and a rupture at the inferior pole on the right; this variance in tear pattern from one knee to another has only been reported in two other cases in the literature.^{5,26}

Treatment for bilateral patellar tendon rupture is early primary operative repair. The necessity for early repair cannot be overemphasized, as retraction of the tendon and scarring occur fairly shortly after injury and can greatly complicate repair.⁵³ If repair is delayed, it may be necessary to release scar tissue, use patellar traction, and adjunct allograft or gracilis/semiotendinosus autograft to facilitate repair. Delayed fixation also leads to increased rehabilitation time due to atrophy of the tendon. In fact, delay in repair (more than 2 weeks post-injury) has been reported as the strongest determinant of final outcome.⁵³ Rehabilitation protocols are not well described, as only one brief report makes recommendations regarding guidelines for postoperative physiotherapy.²⁷

CONCLUSION

In summary, a 36-year-old athletic man experienced bilateral patellar tendon ruptures while playing soccer. Bilateral rupture was accurately diagnosed in the emergency department and early primary repair was performed. Of note, the patient had a midsubstance tear on the left and a rupture at the inferior pole on the right. To our knowledge, there have only been two other

published reports in which the rupture occurred at a different portion of the tendon in either knee. Despite the rarity of similar cases, surgeons must be able to recognize and appropriately treat these patients in an early manner for optimal outcomes.

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CASE REPORT AND LITERATURE REVIEW

ANTERIOR SHOULDER DISLOCATION WITH THREE-PART PROXIMAL HUMERUS FRACTURE AND HUMERAL SHAFT FRACTURE

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ABSTRACT

Dislocation of the shoulder and proximal humerus fracture with coexistent humeral shaft fracture is a rare injury reported in literature. There have been a total of 20 cases reported in the literature since 1940¹⁻¹³ (see Table 1). These injuries often occur as a result of high velocity trauma and most have been treated, at least partially, with invasive or operative management. We present the case of a woman with an anterior dislocation, three-part proximal humerus fracture and concomitant humerus shaft fracture and discuss her non-invasive treatment.

CASE REPORT

A 69-year-old right-hand dominant woman slipped on the ice and fell onto her left side. She was diagnosed with a left-sided humerus fracture at an outside emergency room and was transferred to our hospital for further management. Upon arrival, she had a visible deformity of her left humeral mid-shaft with no neurovascular deficits. Her exam further revealed an anteriorly displaced humeral head and a positive sulcus sign lateral to the acromion.

Radiographs showed a spiral humeral shaft fracture with apex lateral angulation, a three-part proximal humerus fracture and an anterior dislocation of the humeral head (see Figures 1-5). After a closed reduction of the humeral shaft fracture, a coaptation splint was placed to prevent radial nerve injury during shoulder reduction. Her shoulder was then reduced with the splinted brachium supported by an assistant and lateral force on the humeral head in the axilla under monitored conscious sedation in the emergency department. Upon awakening, the patient remained neurologically and vascularly intact. A sling was provided and the patient instructed to keep her arm immobile. At four weeks, the patient was fitted in a Sarmiento brace and began pendulum exercises as well as isometric training. Radiographs at five months showed complete healing of the fractures, at which time she had 110 degrees flexion and 90 degrees abduction (see Figures 6 and 7). At eight-month follow up, she was able to perform all of her activities of daily living with no difficulties and has full grip strength in her left hand. Clinically, she had 120 degrees forward

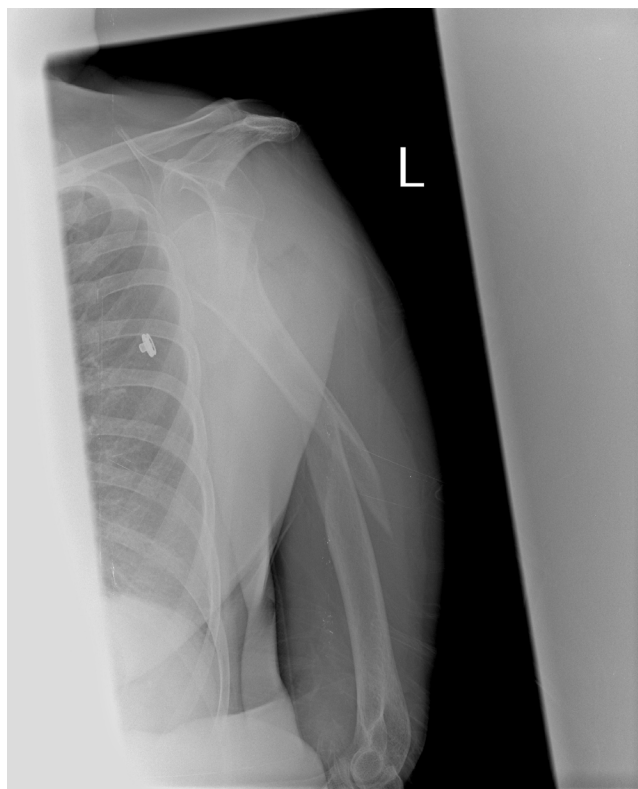


Figure 1. AP of patient's left shoulder immediately after injury. Note the fracture-dislocation of the shoulder as well as the midshaft humerus fracture.

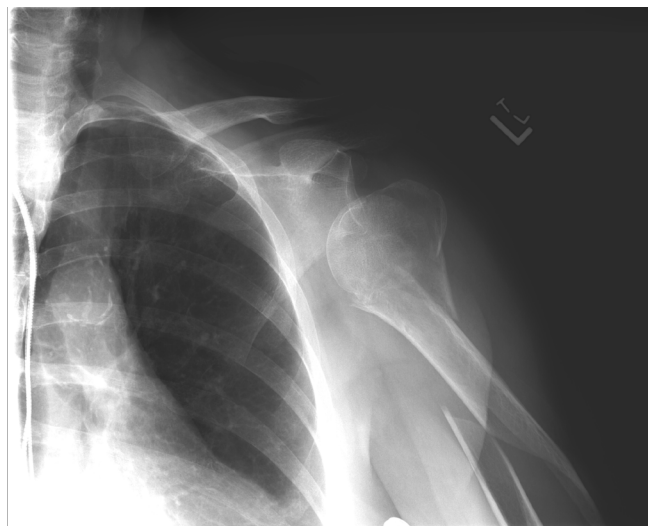


Figure 2. AP of the left shoulder. Note the shoulder dislocation as well as the surgical neck fracture and displacement of the greater tuberosity.

TABLE 1

This table reviews the reported proximal humerus fracture-dislocations with associated humerus fractures, their treatment and outcome.

| Author/Date | Age/Sex | Mechanism | Dislocation | Shaft Fracture | Dislocation Tx | Fracture Tx | Results |
|-------------------------------|---------|----------------------------------|------------------|---------------------|--|--|------------------------------------|
| Flint/2008 | 69 F | Fall | Anterior, 3 part | Mid/3 | Closed | Coaptation Splint | Good |
| Inan/2008 | 27 M | conveyer belt | Anterior, GTF | Mid/3 | Closed | ORIF Dynamic Compression Plate | Good |
| Sasashige/2006 | 18 M | MCC | Anterior | Mid/3 | Closed | Retrograde Intramedullary Nailing | Good |
| Chen/1998 | 35 M | MCC | Anterior | Mid-Low/3 | Closed | Dynamic Compression Plate and Screws | Good |
| | 28 M | MCC | Anterior | Low/3 Butterfly | Closed | ORIF Dynamic Compression Plate | Radial n Palsy |
| Maffulli/1996 | 19 M | MVC | Anterior, GTF | Mid-Low/3 Butterfly | Closed | Dynamic Compression Plate | Dec Abd ER 15 deg, Dec flex/IR 10 |
| Calderone/1995 | 27 M | MVC | Anterior | Mid/3 | Closed | Dynamic Compression Plate | Radial n Palsy, resolved |
| Davick/1995 | 29 M | MCC | Anterior | High/3 | Closed | Splint/Brace | C5-7 plexopathy, resolved |
| | 67 M | MVC | Anterior | M/3 | Closed | Intramed. Rod | Limited abd, flex and ER |
| Kontakis/1995 | 41 M | MVC | Anterior | Mid/3 | Open | Plate and Screws | Dec flex, abd, and ER 10 deg |
| | 45 M | Fall from 2m | Anterior | Mid/3 | Closed | U-Slab (Splint) | Dec ER 10 deg |
| Canosa/1994 | 16 M | MCC | Anterior | Mid/3 | Closed | 2 Pin stabilization w/ Hackethal technizue | Good |
| Sankaran-Kutty/1989 | 28 M | MVC | Anterior, GTF | Mid/3 | Closed w/ Limb Lengthening Apparatus to Assist | Closed Reduction, External LLA Fixation | Dec Abd 20 deg |
| Barquet/1985 | 23 M | Operating Machinery (? Traction) | Anterior, GTF | Mid-Low/3 Butterfly | Closed | Splint | Good |
| | 42 F | MVC | Anterior | Prox/3 | Closed w/ Steinman pin | Splint | Good |
| Baker/1971 | 25 M | Operating Machinery (?Fall) | Anterior, GTF | Mid/3 | Open | Intramedullary Rush pin | NI fcn, Abd weakness |
| Gui/1957* | n/a | n/a | Anterior | Prox/3 | n/a | n/a | n/a |
| Boher/1941 | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| Winderman/1940 | 68 F | fall | Sub-coracoid | Mid/3 | Closed with pin to assist | Splint | Good motion, Displaced GT fracture |
| Milch/1949 | 27 M | Fall down stairs | Sub-coracoid | Prox/3 | Closed | Splint | Full ROM, Ulnar nerve neuropraxia |
| *obtained from Barquet (1985) | | | | | | | |

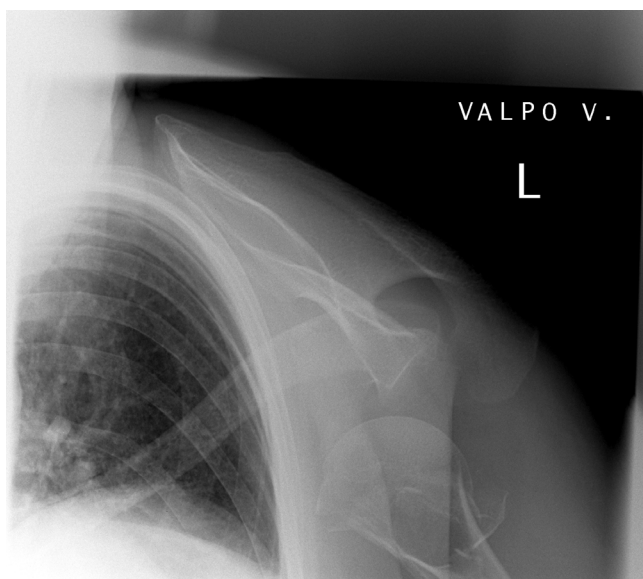


Figure 3. Velpeau view of the left shoulder showing the anterior dislocation of the shoulder.

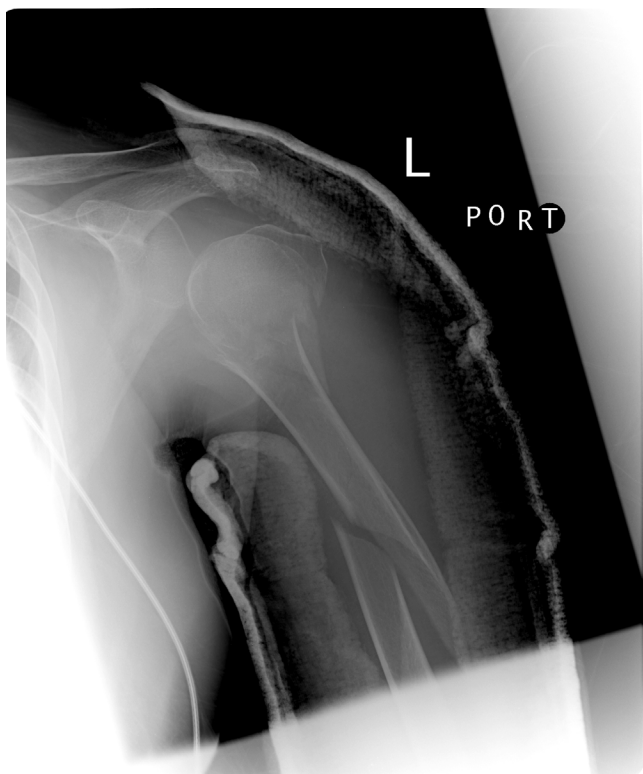


Figure 4. AP of the proximal humerus after reduction and placement into a coaptation splint. Note the 3 part proximal humerus fracture and the midshaft humerus fracture. A short medial metaphyseal calcar region can be appreciated on this film.

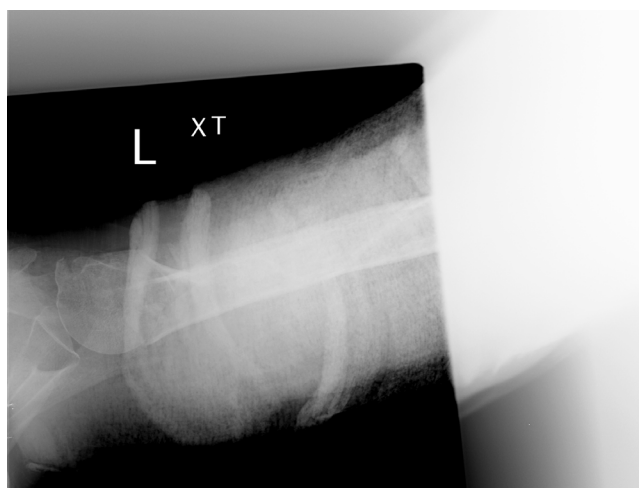


Figure 5. Axillary view of the reduced shoulder.



Figure 6. AP of the humerus at 5 month follow up. Note the healed proximal and mid-shaft humerus fractures. There is obvious deformity but the patient had a well functioning shoulder and arm.



Figure 7. Lateral image of the humerus at 5 months showing the healed fractures.



Figure 8. AP of the humerus at 2.5 year follow-up. Note the healed fractures with mild deformity.

flexion, abduction to 110 degrees, internal rotation to the buttock and external rotation to 45 degrees with the elbow adducted. At 2.5 year follow up showed she had active elevation to 150 degrees, passive elevation to 150 degrees. Active external rotation was 45 degrees and internal rotation to the belt line. Abduction was measured at 120 degrees, cross body adduction at 45 degrees. Rotator cuff muscle testing revealed 5/5 strength. She had a negative Hawkins and Neers signs (see Figures 8-13). The contralateral uninjured shoulder showed forward flexion to 170 degrees, abduction to 160 degrees, external rotation to 65 degrees, internal rotation to T12. Shoulder scores were calculated. The patient's DASH score was as follows: Function 99.1; Sport/Music/Work 100. The shoulder pain and disability index, SPADI score, was as follows: Pain 95.0 and Disability 96.8, 100 being the maximum score representing full normal function of the shoulder. The American Shoulder and Elbow Score was calculated to be 30.0 for ADL's with the right uninjured arm and 27.0 with the left injured arm.

DISCUSSION

A limited number of cases of fracture dislocations and humeral shaft fractures have been reported in the literature. Since 1940 only twenty cases have been documented (see Table 1). Five of these were reported to have greater tuberosity fractures. None of the articles describe a three-part humerus fracture. Most of the reported cases involved high velocity or high force injuries. In previously reported cases, the injuries were caused by high velocity collisions with motorcycles or automobiles, falls from an elevation of greater than two meters or



Figure 9. Lateral of the humerus at 2.5 year follow-up. Note the healed fractures with mild deformity.

machinery accidents. Several authors propose a specific posture in which these incidents occur, namely a flexed elbow with slight abduction of the shoulder. Whether the dislocation and fracture occur simultaneously or subsequently is debated. Some authors have proposed that with injuries involving high velocity trauma, the axial loading force leads to the transfer of energy to the shaft of the humerus and into the shoulder, resulting in the simultaneous injuries.^{2,12} Others postulate that the initial dislocation is due to indirect forces and the fracture of the humeral shaft is due to subsequent direct forces.^{5,9} In our case, this elderly patient suffered a ground level fall which resulted in this complex injury. Presumably, the involvement of ice and its low coefficient of friction led to a more violent fall, more rapid angular velocity to the outstretched hand and arm slipping rapidly on the ice as the patient tried to break the fall, leading to a less controlled fall and more unusual arm position with torsional or bending forces than otherwise would be expected with a ground level fall.

Court-Brown in a prospective study of proximal humerus fractures demonstrated that 49% of the proximal humeral fractures were classified as Neer's type I fractures, representing minimally displaced fractures regardless of the number of fragments.¹⁴ They found that 28% of the fractures were classified as two-part surgical neck fractures and 9% were classified as three-part fractures with surgical neck and greater tuberosity fractures. They pointed out that nearly 90% of proximal humeral fractures can be classified in these three categories. Our patient was classified as having a three-part fracture.



Figure 10. Active forward elevation at 2.5 years.



Figure 12. Active external rotation at 2.5 years.



Figure 11. Active forward elevation at 2.5 years. The left shoulder closest to the camera was the injured extremity.



Figure 13. Active internal rotation at 2.5 years.

Fractures of the greater tuberosity have been noted in 10-30% of shoulder dislocations.¹⁵ Bahrs et al., in a review of over 100 patients with greater tuberosity fractures, found that over 50% of them were associated with traumatic anterior glenohumeral dislocation.¹⁶ Our patient as part of the three-part fracture had a greater tuberosity fracture that was displaced approximately 7 mm.

The humeral head receives its blood supply from the anterior circumflex artery and its ascending branch the acruate artery.^{17,18} Additionally, it also is supplied by vessels entering the posteromedial region of the proximal humerus, the metaphyseal vessels and the vessels of the greater and lesser tuberosities. These arteries anastomose in the head providing redundant blood supply to the head. Brooks noted that even four-part fractures had blood flow if a portion of the medial calcar was attached to the head fragment.¹⁸ Hertel et al. confirmed this with laser Doppler flowmetry and found that if the

head fragment included at least 8 mm of medial calcar the risk of AVN was significantly decreased due to the preserved blood supply.¹⁹ Hertel also showed that AVN could be anticipated 97% of the time if the patient had a fracture at the anatomical neck, short medial calcar, and a disruption of the medial periosteal hinge. Resch showed that a disruption of the medial periosteal hinge occurred with lateral displacement of the head of greater than 6 mm.²⁰ Our patient suffered a humeral surgical neck fracture with essentially no medial calcar attached to the head and lateral displacement of the head laterally of 9 mm, thus putting her at significant risk of AVN. She also suffered a dislocation but surprisingly, the addition of the gleno-humeral dislocation to the proximal humerus fracture has not been found to correlate with vascular status of the proximal humerus.^{19,21} Additionally, it has been observed that ischemic heads can be undergo complete or partial revascularization and that

humeral head AVN does not obligate a unsatisfactory functional outcome.^{19,22}

Recent data on open reduction and fixation of proximal humerus fractures with locking plate technology in older patients has shown less reliable outcomes and high rates of hardware complications when compared to younger patients.^{23,24} Owsley et al. showed that 43% of the patients over 60 years in his series of 53 patients undergoing locked plate fixation of proximal humerus fractures had radiographic evidence of screw cutout. Additionally 57% of the patients over 60 had radiographic evidence of complications including cutout, varus displacement, and AVN. Additionally, those with radiographic complications had worse functional outcomes as measured with the Short Musculoskeletal Function Assessment and the Quick Disabilities of the Arm, Shoulder and Hand questionnaires. Moreover, Robinson et al. in their series of 58 fracture-dislocations of the proximal humerus recommended that patients over 60 years with displaced proximal humerus fractures with soft tissue stripping of the proximal fragments be treated with arthroplasty.²⁴ Given our patient's age of 69 years, the current literature suggests that locked plating to achieve anatomical alignment had a significant chance of resulting in a radiographic complication and therefore decreased functional status and that arthroplasty would be a reasonable and predictable option. Our patient expressed no desire to undergo surgery unless absolutely necessary.

Appropriate treatment of common proximal humerus fractures in the elderly patient is still being debated in the literature. Given the rare nature of this patient's combination of injuries and the few reported cases in the literature, there is no clear consensus regarding the most appropriate treatment. Undoubtedly however, the treatment objective is to guide the patient down a treatment path to a functional and painless extremity. To achieve this, a few simple goals must be achieved. First, the shoulder must be reduced and second, the humeral shaft fracture treated in a manner to promote healing while avoiding complications. Ideally the shoulder would be reduced by closed means, but some have argued that humeral shaft fixation may be needed or even preferred prior to performing a humeral head reduction.^{2,5,9,12,23} Additionally, it is also believed that the use of open reduction of the proximal humerus fracture avoids the vascular and brachial plexus injuries that can result from closed manipulation and encourages earlier return to function after stabilization.¹ Alternatively, open reduction of the proximal humerus fracture may lead to further vascular embarrassment to the proximal humerus due to the soft tissue stripping typically required.^{19,23} Simple humeral shaft fractures however, have been successfully treated

with functional bracing with very high union rates and few malunions.²⁵ Operative indications for humeral shaft fractures are therefore very limited.

The third issue of treatment, although less critical and more controversial, depends on the displacement of the greater tuberosity fracture and its potential for causing shoulder pain and impingement. Several authors have looked at the issue of acceptable displacement of the greater tuberosity. Flatow and Neer both accepted up to 1 cm of displacement.^{26,27} Hertel et al. suggested that greater tuberosity displacement greater than one centimeter and associated shoulder dislocation were poor/moderate predictors of outcome following proximal humerus fractures.¹⁹ However, Park and Platzer recommended only allowing 5 mm of displacement.^{28,29} Platzer in his series of 135 patients, found that 97% of patients had good to excellent results when the tuberosity fracture was displaced 5 mm or less. Alternatively, Koval et al. in a series of 104 patients found no difference regarding outcome with tuberosity displacement at a mean of 41 months post-injury. He found 77% patients had good to excellent results and over 90% of patients had little or no pain and excellent functional recovery.³⁰ Our patient had 6 mm of displacement of the greater tuberosity fracture.

We elected to treat this patient non-operatively with a coaptation splint for reduction of the humeral shaft fracture and closed reduction of her three-part proximal humerus fracture, with early range of motion and conversion to a functional splint for her humeral shaft fracture due to her comorbidities, aversion to operative treatment, ability to function well with the contralateral dominant arm and uninjured lower extremities, mildly displaced nature of the tuberosity fracture, and well reduced humerus fracture in the splint and Sarmiento brace. Additionally, the potential complications of operative treatment of the three-part proximal humerus fracture and humeral shaft fracture, including infection, malunion, AVN, adhesive capsulitis, iatrogenic neurovascular injury, and hardware complication, outweighed what we felt were the good results that could be obtained with non-operative treatment and the patients low functional demands. Additionally, given the fact that the patient had likely disrupted her humeral head blood supply due to having a medial calcar of less than 8 mm, lateral displacement of greater than 6 mm, and likely disruption of the periosteal hinge as well as an anterior glenohumeral dislocation, we felt that further surgical insult to the proximal humerus would increase her chance of humeral head AVN.^{18,19,27} Additionally, in the light of Owsley's data and the patients age, treating the patient with locking plate technology had a 57% chance of leading to a radiographic complication and if present associated with a worse functional outcome.²³

Moreover, given that the patient did not have a perfect reduction of the neck fracture or the greater tuberosity fracture after closed manipulation, we felt that if the patient developed a symptomatic malunion of the tuberosity, it could be treated with a tuberosity osteotomy or acromioplasty. Beredjiklian et al. reported satisfactory results in 9 of 10 patients he treated with tuberosity osteotomy or acromioplasty for malunited tuberosities with congruent joint surfaces.³¹ Additionally, as shown by Antuna and Cofield et al. as well as Boileau et al., if the malunion was significant enough to warrant more aggressive treatment, a delayed arthroplasty could have been performed with good results, with the caveat that the malunited tuberosities are left in their healed position.^{32,33} Other authors have noted that patient functional scores are improved with arthroplasty over the functional state achieved after failed ORIF or failed non-operative treatment of displaced proximal humerus fractures. However, the outcomes are inferior with delayed arthroplasty vs acute arthroplasty.³⁴ Additionally, it has been shown that patients have poorer motion and more pain if they undergo arthroplasty after failed open reduction and internal fixation of proximal humerus fractures, especially if the arthroplasty is performed within two years of the index procedure.³²

In regard to the reduction technique, Inan et al. utilized the same maneuvers as we did, splinting the humeral shaft fracture first, and then reducing the shoulder dislocation.³⁵ There is some risk in manipulating the splinted but obviously marginally stabilized humeral shaft fracture to affect a shoulder reduction. This certainly places the radial nerve at greater risk of traction injury or entrapment. Both our patient and Inan's patient had normal radial nerve exam before and after the reduction. It is imperative that a detailed neurological exam be performed prior to and after the splinting and reduction. We also advocate that the splinted arm not be used for traction to affect the glenohumeral reduction, but that direct pressure be applied to the humeral head in the area subcoracoid area of the anterior chest wall and axilla, while stabilizing the fractured humerus in the splint and in the hands of an assistant during shoulder reduction. Inan reported that this was easily performed under conscious sedation and we also easily achieved reduction in a similar manner in this case.

CONCLUSION

Fracture-dislocations of the shoulder with a three-part proximal humerus fracture and humeral shaft fracture are very rare injuries. Closed reduction of each of the injuries, if possible, is ideal in that it can be done efficiently in the emergency department setting, preserves the remaining blood supply to the fracture fragments and allows for well thought out individualized treatment regiment. Although open reduction and internal fixation of proximal humerus fractures is technically challenging and increasingly popular, we do not recommend this treatment plan for older patients with these injuries due to poor functional outcomes. Moreover, arthroplasty can be a viable option for complex fractures of the proximal humerus with more reliable results than open reduction and fixation. However, our patient achieved an excellent functional outcome with a functional and pain free extremity with non-operative treatment of her shoulder fracture dislocation with a three-part proximal humerus fracture and humeral shaft fracture. Treating the patient with non-operative modalities avoided the potential complications of infection, hardware cut-out, neurovascular injury, AVN, anaesthetic complications, and chronic surgical pain. This treatment certainly is not appropriate for all patients with this injury, especially younger patients with higher functional demands, but is a reasonable and very viable alternative for older patients with low functional demands. It has the advantage of avoiding serious complications, allows the healing process to proceed unimpeded by operative soft tissue stripping, and leaves open the option for arthroplasty or osteotomies if needed. Advanced operative techniques and implants, such as proximal humeral locking plate technology, should be reserved for younger patients with higher physical demands that are willing to undergo the attendant operative risks for more predictable potential functional gains of restoring anatomy. We advocate treating fracture patterns of the shoulder and humerus in elderly patients, as exemplified by this case report, in the context of the elderly patient's biology and functional demands.

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CHLOROMA OF THE FOREARM: A CASE REPORT OF LEUKEMIA RECURRENCE PRESENTING WITH COMPRESSION NEUROPATHY AND TENOSYNOVITIS

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ABSTRACT

Acute Myelogenous Leukemia (AML) typically involves intramedullary proliferation of myeloid precursor cells. Extramedullary manifestations of AML are exceedingly rare, but do occur. Granulocytic sarcoma, or chloroma, is one example of extramedullary leukemia cells forming a tumorous mass. We report a case of Chloroma in the volar forearm compartment presenting with both median nerve compressive neuropathy and apparent tenosynovitis. Abscess was at the top of the early differential, and the patient was scheduled for operative debridement. However, further evaluation indicated that chloroma was present, thus obviating the need for emergent surgical intervention and necessitating the induction of chemotherapy. To our knowledge this is the first report of chloroma in this location and with these presenting symptoms.

CASE REPORT

A nine-year-old female presented to the emergency room (ER) three years status post bone marrow transplant for AML, which had been in remission. She presented with two distinct complaints, both of the right forearm and hand. The first complaint was a progressive two-month history of paraesthesias in a median nerve distribution. The second complaint was a two-day history of increasing erythema and pain in the flexor tendons of the volar forearm compartment, most marked in the flexor pollicis longus and flexor carpi radialis. The pain was worsening at rest and increased with either passive or active extension of the wrist or fingers, especially the thumb. Overall, her clinical picture was concerning for both median neuropathy and for an evolving tenosynovitis. The patient had recently seen her local pediatrician and radiographs taken at that time did not show any acute skeletal abnormalities; the pediatrician scheduled a Magnetic Resonance Image (MRI) of the hand and forearm on an outpatient basis for further evaluation. The patient presented to the ER three days prior to her scheduled MRI due to the progressive nature of her

symptoms and the onset of erythema and pain in the flexor tendons that was new since being evaluated by the pediatrician.

In addition to the patient's AML, her past medical history was remarkable for a previous multi-organism bacteremia during AML treatment that included *Pseudomonas*, *Enterobacter*, and *Acinetobacter*. Family history was only remarkable for diabetes. There was no history of bone or hematologic cancers in the family. Her social history was noncontributory. Review of systems was negative for chest pain, shortness of breath, or fevers. The patient's mother stated that she did have flu like symptoms a few weeks prior to presentation, which included some nausea and diarrhea, but had not been febrile.

Examination of the patient's right forearm demonstrated erythema on the volar aspect of the forearm spanning from the wrist crease to approximately 2/3 proximally up the forearm. The maximum width of the erythema was approximately three cm. She noted subjective paresthesias on the volar aspects of the thumb, index, long fingers and the radial aspect of the ring finger. The dorsum of her hand was completely neurovascularly intact. Tinel's exam was negative at both the cubital and carpal tunnels. She held her hand in a fixed, flexed position and when asked to extend her thumb, she could do so only 15 degrees secondary to pain. With passive stretch of the fingers and wrist, she also noted pain in the forearm in the area of her erythema.

Laboratory data from the Emergency Room revealed relative neutropenia that was comparable to previous tests (2.6 k/mm³ on day of presentation vs. 3.9 k/mm³ six months prior). Hemoglobin and hematocrit were also relatively stable (hemoglobin of 10.8 g/dl and hematocrit of 31% on day of presentation vs. 12.2g/dl and 35%, respectively, six months prior).

The patient was admitted for diagnostic workup, including an MRI of the forearm and hand. She was also tentatively placed on the operative schedule in the event that workup revealed an inflammatory process or abscess that would require emergent debridement. MRI demonstrated a 9mm x8mm rounded lesion along the course of the median nerve in the forearm lying between the flexor pollicis longus and flexor carpi radialis muscles and tendons (Figure 1). The lesion demonstrated hyperintense signal on T2 FS images. Contrast images

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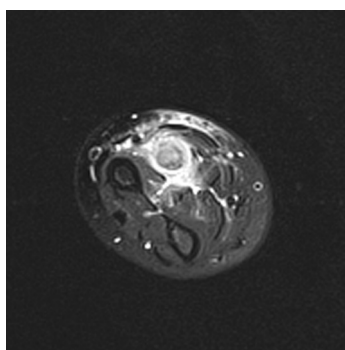


Figure 1. Axial T2 MRI images through demonstrating hyperintense signal of a rounded lesion surrounding the median nerve and lying adjacent to the flexor pollicis longus and flexor carpi radialis muscles.

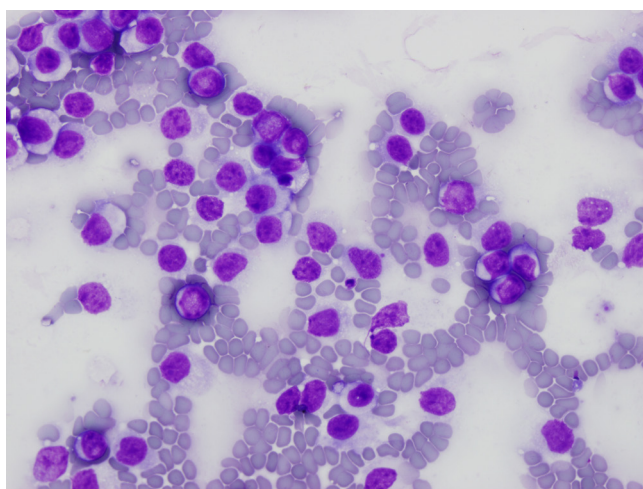


Figure 2. 60X Diff-quick stain on aspirated material from the right wrist, showing numerous immature hematopoietic cells.

showed peripheral enhancement of the lesion. The staff musculoskeletal radiologist felt that the MRI findings most strongly supported a diagnosis of abscess, but also felt chloroma or hematoma were possible. The patient was then made NPO in anticipation of emergent surgical debridement. However, given the patient's history of AML and the possibility that chloroma could account for the MRI findings, the Pediatric Oncology service was consulted prior to taking the patient to surgery. They felt chloroma could indeed account for both the patient's symptoms and MRI findings, and biopsy of the lesion prior to surgical intervention was recommended. Aspiration of the soft tissue of the right wrist, performed by ultrasound guidance, revealed numerous enlarged discohesive cells with a high nuclear to cytoplasmic ratio (Figure 2). The cytoplasm showed occasional vacuoles, and the nuclear chromatin pattern was fine and delicate with visible nucleoli demonstrating morphologically immature hematopoietic cells. Subsequent bone marrow aspiration and core biopsy showed hypercellular bone marrow comprised predominantly (83% of hematopoietic cells) of leukemic blasts (Figures 3, 4, and 5). Flow cytometric analysis from bone marrow aspiration material showed that the blasts were myeloid with monocytic

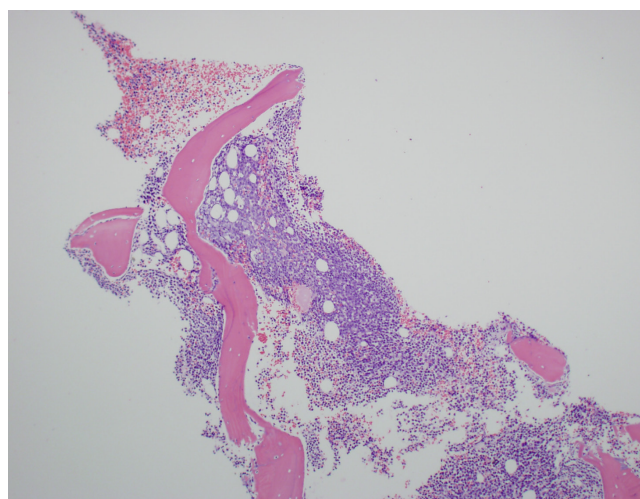


Figure 3. 100X Hematoxylin and Eosin stain of bone marrow core biopsy, showing a hypercellular marrow space.

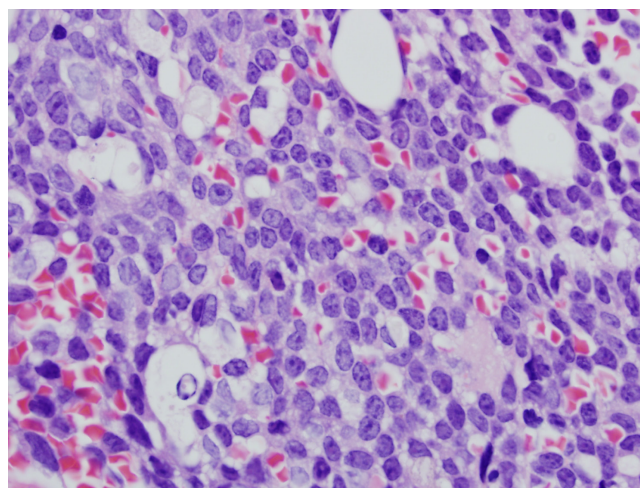


Figure 4. 100X Hematoxylin and Eosin stain of bone marrow core biopsy, showing numerous blasts.

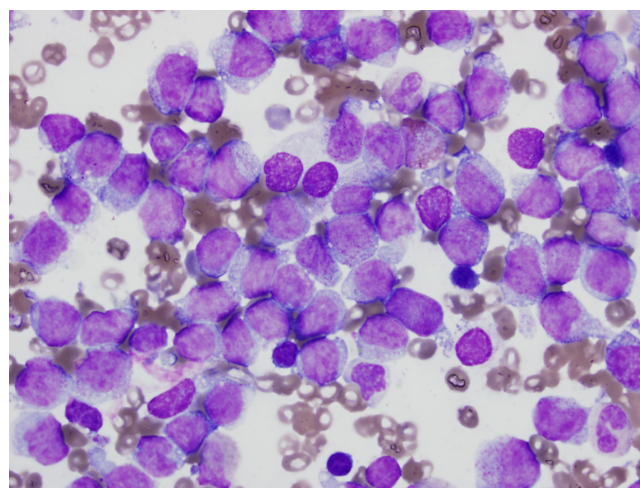


Figure 5. 100X Wright stain of bone marrow aspirate, showing numerous myeloid blasts.

differentiation, indicative of relapsed acute monoblastic leukemia.

The patient was started on chemotherapy including fludarabine, cytarabine, and G-CSF. She had a subsequent bone marrow biopsy read as negative. The patient has reported that both the numbness and pain in her hand improved significantly since starting chemotherapy. The erythema and limited range of motion have resolved. Her strength is full in all motor groups and her sensation is completely intact except for some subjective paresthesias and decreased sensation at the distal tip of her right thumb. Currently, the patient is awaiting a marrow infusion of cells from her father through the Bone Marrow Transplant Clinic.

DISCUSSION

Aggregates of extramedullary myeloid precursor cells associated with leukemia have traditionally been referred to as granulocytic sarcoma (GS) or leukemia cutis (LC). While GS generally refers to a mass of blast cells outside the bone marrow, LC lesions specifically refer to dermal infiltrations by blast cells.¹ GS masses have also been referred to as chloroma secondary to their characteristic green color created by the presence of myeloperoxidase.^{2,3} Collectively, all forms of extramedullary leukemia are rare, and most lesions are associated with medullary leukemia. An isolated chloroma discovered in a patient with a remote history of AML obligates a diagnosis of bone marrow relapse until proven otherwise because primary lesions without underlying systemic leukemia are so rare; indeed, only 154 cases have been reported since 1965.^{4,5} Conversely, Pui et al (1994) found that of children with AML, only 4.7% had an identifiable chloroma.⁶ Risk factors for the development of extramedullary manifestations of leukemia have been associated with low socioeconomic class, decreased cellular immunity, and poor nutrition.⁷

Large clinical reviews suggest that the most common location for chloroma is in the skin, bone, soft tissues, and lymph nodes. Most frequently patients present with a history of AML. On rare occasions the patient will be diagnosed with the chloroma without a primary diagnosis of AML, but in almost all of these cases the patients went on to develop AML within 2 years.⁸ The symptoms most frequently are associated with either the mass itself or disturbance of the organ with which it is associated. Cases of chloroma have been reported in the CNS and spinal canal with associated symptoms of compression such as radiculopathy or cauda equina syndrome. Peripheral nervous system involvement seems to be much less common and a precursory review of the literature shows only two cases which include a facial nerve palsy and involvement of the sciatic nerve.

Treatment for chloromas consists of systemic chemotherapy for the underlying leukemia, and the lesions frequently respond well. When urgent decompression is needed, or if the lesion is refractory to systemic chemotherapy, then surgical debridement or radiation therapy may be considered. The response to systemic therapy is much greater in patients presenting with new onset AML compared to those that are presenting with relapse. Unfortunately, chloromas can be resistant to traditional induction chemotherapy,⁹ and they are a poor prognostic factor for the response to chemotherapy in patients with AML.

In conclusion, the chloroma discussed in this report was unique with respect to both its location and symptomatology. Missing this diagnosis would have led to unnecessary surgery and increased morbidity to the patient. Albeit extremely rare, orthopedists should be aware of chloromas when evaluating a local mass of unknown etiology, especially in patients with a known history of AML. Knowledge of this diagnostic possibility can expedite treatment for the patient and eliminate unnecessary procedures.

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DISTAL TIBIA/FIBULA FRACTURES FOLLOWING CLUBFOOT CASTING REPORT OF FOUR CASES

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INTRODUCTION

The treatment of congenital talipes equinovarus (clubfoot) has evolved over the years, but most orthopedists have agreed that the initial treatment should be non-operative, and the preferred methods are manipulation and application of a plaster cast or physiotherapy started soon after birth. These are very gentle techniques, but there are potential complications. The most common are recurrence/persistence of the deformity and skin lesions/pressures sores. Additional less common complications include rockerbottom deformity secondary to spurious correction, and flattening of the talus. However, there is a paucity of literature describing the true incidence of these less observed complications.

The complication of lower extremity fracture associated with clubfoot treatment has recently been observed at our institution. Several different types of fractures can occur including torus fractures of the distal tibial metaphysis, anterior cortical compression fractures of the distal tibia, distal tibial metaphyseal spurs caused by injury and translation of the epiphyseal plate, and lastly distal fibula fractures. The majority of these fractures have been reported to occur during manipulation with application of forced dorsiflexion/eversion of the ankle usually using Kite's technique.^{8,9} We present four cases of distal tibia/fibula metaphyseal fractures that occurred during the bracing phase of clubfoot Ponseti treatment.

CASE #1

A 6 year 3 month-old female presented to our orthopaedic clinic for evaluation of severe bilateral lower extremity deformities. The parents adopted the patient from China two months prior to presentation. Upon initial evaluation, patient was found to have sacral agenesis, bilateral dislocated hips, left congenital knee dislocation, and bilateral clubfeet. No treatment had been provided

for any of the deformities. She was able to ambulate with assistance, however she was not an independent ambulator. Manipulation and casting for her bilateral clubfeet were recommended and performed on a weekly basis. A total of 13 casts were placed for the right foot deformity and 10 casts were placed on the left. Excellent correction was obtained. Due to persistent equinus contractures of the feet, the patient was indicated for bilateral heel cord tenotomies. Simultaneous left quadriceps tendon lengthening and retinacular releases were performed for treatment of the left knee dislocation. Bilateral long leg casts were placed following surgery. Four weeks following surgery, the casts were removed and bracing was initiated. Mitchell bracing was prescribed for 18 hours per day to prevent relapse of the clubfoot deformities. Bracing was tolerated very well. Five months following removal of the last set of casts, the patient sustained a buckle fracture of the distal left tibial metaphysis during an incident where a fellow student fell onto her left lower extremity while at school. She was placed into a short leg cast to the left lower extremity by a local orthopaedic surgeon. Upon return to our clinic, a short leg cast was applied on the right lower extremity to prevent any relapse of the corrected deformity. Short leg casts were removed at approximately 6 weeks following the injury. Radiographs revealed uneventful healing of the left distal tibia fracture. At latest follow-up, the patient was doing very well. She has maintained excellent correction of her clubfoot deformities, and is able to ambulate using the assistance of crutches or a walker. Her left lower extremity has been maintained in a KAFO for assistance with knee stability in flexion.

CASE #2

A 19 month-old female presented to our orthopaedic clinic for evaluation of bilateral clubfoot deformity. The child was adopted from China and presented to clinic several weeks following arrival in the United States. Upon initial examination, the patient had bilateral clubfoot deformities without any other musculoskeletal or neurologic abnormality. Manipulation and cast treatment of the clubfoot deformity were initiated. She underwent 5 manipulation and casting treatments followed by bilateral percutaneous Achilles tenotomies. Excellent deformity correction was obtained. Bracing using a

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Mitchell orthosis was initiated for 20 hours/day. Patient then sustained a nondisplaced tibia fracture (toddler's fracture) 2 months later following a fall off a chair. The parents were instructed to maintain her in the Mitchell brace at all times until the fracture healed. The fracture healed without event, and patient was allowed to weight bear beginning 4 weeks following the injury. The bracing scheduled was decreased to 20 hours/day followed by 14 hours/day over the next several months. Deformity correction has been maintained, and the patient recovered from her fracture without incident.

CASE #3

A 3 month-old male presented to our orthopaedic clinic for evaluation of recurrent bilateral clubfoot deformity. He was initially treated with manipulation and casting at an outside hospital beginning at the age of 8 days. Casts were changed weekly and bilateral Achilles tenotomies were performed at 3 months of age. Recurrence of the deformity was noted following cast removal several weeks after the procedure. The patient was referred to our Center for treatment of his recurrent clubfoot deformity. Upon initial evaluation, the patient was indicated for repeat manipulation and casting of his bilateral clubfoot deformity. He underwent 5 manipulation and casting treatments resulting in excellent deformity correction. Repeat tenotomies were not performed. Mitchell bracing was initiated at full-time and weaned slowly. The patient sustained a fracture of the distal left tibial metaphysis 2 months later following a fall from 4-5 feet (Figure 1). This was treated in a short leg cast to the left lower extremity and healed without incident. Radiographs of the contralateral leg were also obtained following the injury revealing no abnormalities. During his cast treatment, bracing was continued without interruption. He has maintained his deformity correction and healed his fracture completely.

CASE #4

A 22 month-old male presented to our clinic at the age for the treatment of bilateral clubfoot deformity. His medical history included arthrogryposis. He was adopted from China and received no treatment for his clubfeet as an infant. Prior to presentation at our Center, the patient underwent serial manipulation and casting at an outside hospital resulting in suboptimal deformity correction. Upon presentation, he was indicated for continued manipulation and cast treatment. At total of 5 sets of casts were applied followed by percutaneous Achilles tenotomies. Following adequate correction and transition to AFO bracing, the patient was found to have a slight recurrence of deformity. He was treated with another series of long leg casts followed by Mitchell

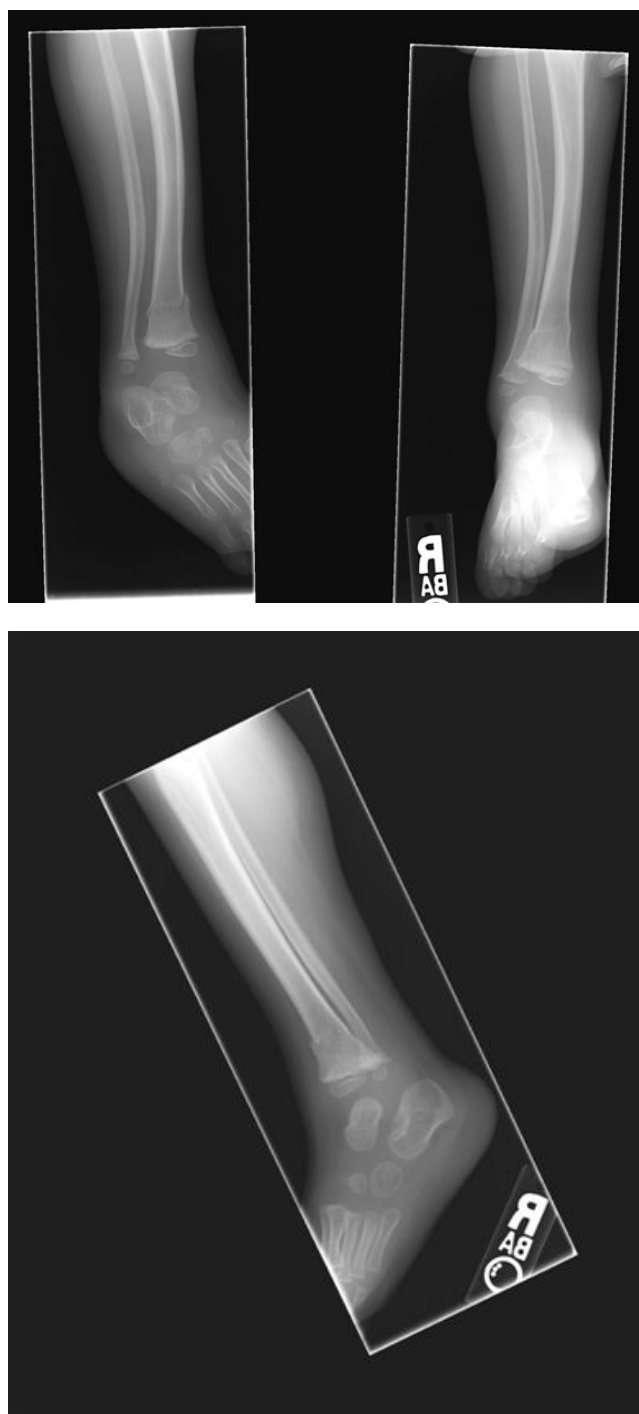


Figure 1. Case #3 AP/Oblique/Lateral views of right ankle taken at the time of injury.

bracing. The deformities recurred one additional time requiring remanipulation, casting, and repeat bilateral percutaneous Achilles tenotomies. Mitchell bracing was prescribed once again after his full course of treatment for the recurrent deformity. He was brought to the ER approximately 2 months following removal of his last

set of casts, for evaluation of left lower extremity pain after a fall from standing height. Radiographs revealed a nondisplaced left tibia/fibula fracture. The patient was treated in bilateral long casts to provide immobilization and prevent a relapse. Casts were kept in place for three weeks to allow adequate fracture healing. Brace treatment was then reinitiated. Patient was last seen 2 months following his injury. His deformity correction has been maintained and his fracture has healed without further event.

DISCUSSION

Only a few studies have reported on distal tibial/fibula metaphyseal fractures associated with nonoperative management of clubfoot deformities. Grayev reported on 8 patients with a total of 14 distal tibia fractures treated with manipulation and casting. They noted that these metaphyseal fractures closely mimic injuries seen in instances of child abuse, however they found definite association between the injuries and forced dorsiflexion and eversion of the ankle during manipulation. Of note, 3 of the 8 patients presented with underlying neuromuscular disorders including spina bifida and arthrogryposis.¹⁰ Clubfeet in association with these disorders are typically more rigid and may require more aggressive manipulation predisposing to possible metaphyseal fracture. Weseley reported on the complications of 300 congenital clubfeet treated both nonsurgically and surgically. In his review, he notes that tibia/fibula fracture can occur during manipulation and casting of clubfeet, however he did not report the incidence and details regarding these iatrogenic injuries.⁸

These cases describe three instances of metaphyseal distal tibia fractures and one toddler's fracture following completion of nonoperative treatment for clubfoot deformity. Three of these fractures occurred within 6 months of final cast removal. All occurred during the period of abduction bracing used for maintenance of deformity correction. It is not felt that these fractures occurred at the time of manipulation of the ankle into dorsiflexion/abduction. None of these patients described or demonstrated pain during the treatments. The parents of each patient in this case report described mechanisms of injury that could easily justify the fracture type and location. Child abuse was not suspected in any case. Each case was treated with immobilization and protection of the injured extremity as well as repeat casting or bracing of the contralateral extremity to prevent recurrence of the deformity. All fractures healed uneventfully.

Further thought regarding the cause of fracture in these causes leads us to consider disuse osteopenia and nutritional status as contributing factors. There have been no reports of suspected osteopenia following cast-

ing for clubfoot deformity. Houde et al described change in bone mineral density in the forearm after immobilization. They found a significant loss in bone density of the distal forearm and ulna after only 4.9 weeks of immobilization. Increases in bone density were noted about 4.7 weeks after remobilization.¹² Numerous other studies have reported the effects of disuse and inactivity on bone density in both animal and human models.^{13,14,15,16} Three of our four cases involve adopted children from China, which has prevented us from obtaining adequate information regarding maternal use of prenatal vitamins and provision of adequate nutrition prior to arrival in the United States.

In summary, metaphyseal fractures can result during nonoperative management of clubfoot deformity. The treating physician must take care to avoid excessive dorsiflexion and eversion at the ankle to prevent iatrogenic fracture. The four cases in our study describe mechanisms of injury not secondary to our manipulation and casting. These children may be predisposed the extremity injury due to altered gait mechanics or other neuromuscular conditions. One may also consider the association of these fractures with prolonged periods of casting that may result in disuse osteopenia of the lower extremity long bones. Nutritional status resulting in metabolic bone disease in children adopted from other countries must also be considered.

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PILOMATRIXOMA OF THE FOREARM: A CASE REPORT

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ABSTRACT

Pilomatrixoma is a benign neoplasm derived from hair follicle matrix cells. Involvement of the upper extremities is relatively uncommon and can be mistaken for malignancy. We present the case of a 52-year-old woman with a pilomatrixoma of the forearm, and we review the literature regarding pilomatrixomas in the upper extremity.

INTRODUCTION

Pilomatrixoma, also known as pilomatricoma or calcifying epithelioma of Malherbe, is a benign neoplasm that derives from hair follicle matrix cells. These lesions are typically found in the head and neck region, but also occur in the upper extremities and are rarely reported in other sites.¹⁻⁷ The largest case series in the literature includes 346 pilomatrixomas of which 15.3 percent were observed in the upper extremities.⁸ Despite the frequency of presentation of this lesion in the upper extremities, discussion of this lesion is essentially limited to the literature of otolaryngology, pathology, and dermatology.

We present a case of a forearm pilomatrixoma. Additionally, we discuss the clinical features and review the literature regarding pilomatrixomas in the upper extremity.

Case Report

A 52-year-old woman presented with a 5 month history of insidious onset of an isolated right forearm mass, located dorsally at the junction of middle and distal third

of the forearm. The mass was painless, slowly enlarging, and not associated with drainage. She denied any history of trauma, fever, chills, weight loss, fatigue, numbness, or tingling.

Physical examination revealed a 1.0 by 1.0 cm, non-tender, firm mass over the radial aspect of the distal one-third of the right forearm. It was superficial and easily mobile. There was no tenderness noted in the region of the first or second dorsal extensor tendon compartments. The neurovascular status of the right hand was noted to be intact, and Tinel's sign over the mass was negative. There were no other palpable masses in the extremities, and no epitrochlear or axillary adenopathy was present. Plain radiographs were unremarkable.

Excisional biopsy was performed under regional anesthesia. Grossly, the mass was white in appearance and well circumscribed. Histopathology revealed a pilomatrixoma, and the histology is presented in figures 1 and 2.

DISCUSSION

Pilomatrixoma, or calcifying epithelioma of Malherbe, is a benign skin neoplasm that arises from hair follicle matrix cells. In 1880, Malherbe and Chenantais first described this lesion, referred to as the calcifying epithelioma, though it was thought to derive from sebaceous glands.⁹ The term pilomatrixoma was introduced in a publication by Forbis and Helwig in 1961 to better convey the histological source.¹⁰ These lesions are typically found in the head and neck region, but they have also been described in various upper extremity locations. These lesions present most commonly in children and young adults, and they are noted more commonly in females.

A rare malignant counterpart, pilomatrix carcinoma, has been described, and approximately 90 cases have been reported in the literature. It is locally aggressive and can recur. In several cases, it has demonstrated metastases. Many key features are similar between these benign and malignant counterparts; the primary differentiating characteristics include a high mitotic rate with atypical mitoses, central necrosis, infiltration of the skin and soft tissue, and invasion of blood and lymphatic vessels.^{11,12}

In this patient's case, the definitive diagnosis was made only after histologic examination following excision

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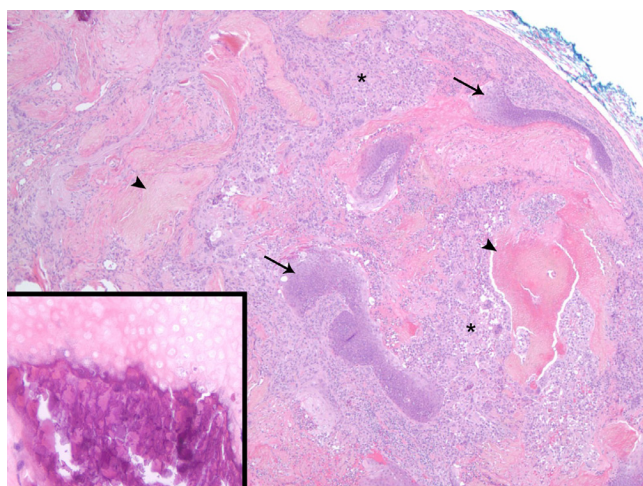


Figure 1. Forearm pilomatrixoma involving deep dermis and subcutis (original magnification 40X). The tumor is well-circumscribed with islands of basaloid cells (arrows) located both peripherally and centrally. Most of the tumor, however, is composed of eosinophilic keratin debris (arrowheads) and a mixed inflammatory infiltrate (asterisks). Focal areas of calcification (inset, 200X) were scattered throughout the tumor.

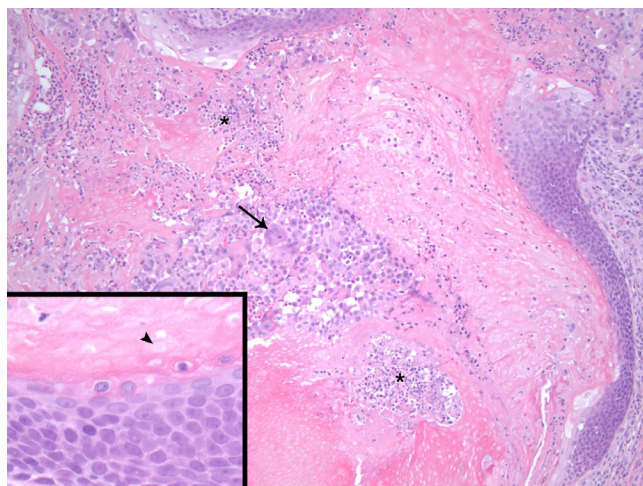


Figure 2. Basaloid matrical germinative cells (far right and top center) blend into keratinized ghost cells (original magnification 200X). Keratin debris elicits an inflammatory response including a mixture of acute inflammatory cells (asterisks) and a foreign body giant cell reaction (arrow). High power view (inset, 400X) showing transition from basaloid cells to ghost cells resulting from matrical keratinization of the basaloid germinative cells. Ghost cells characteristically retain their cell and nuclear borders, however, the nuclei lose their basophilic staining (arrowhead) leaving a "ghost-like" remnant.

of the mass. Pilomatrixomas are often misdiagnosed on preoperative evaluation. In a series of 51 histologically proven pilomatrixomas, Wells et al found that the referring diagnosis was incorrect in 94% of cases, and the preoperative diagnosis was incorrect in 57 percent.¹³ In a recent series of 346 pilomatrixomas, the preoperative diagnosis was accurate and consistent with the pathological diagnosis of pilomatrixoma in only 28.9 percent of cases.⁸ Finally, Kumaran et al. reported a correct preoperative clinical diagnosis in 46 percent following

retrospective review of 78 excised pilomatrixomas.¹ Incorrect preoperative diagnoses most commonly included unidentified masses, as well as epidermoid cysts, sebaceous cysts, dermoid cysts, nonspecified cysts, and foreign bodies.^{1,8}

On presentation, as in this case, palpation of a superficial firm nodule that is not painful or tender is characteristic; however, 32 percent in a series of 346 cases presented with pain and tenderness.⁸ Most commonly, the overlying skin is of normal color and texture; however, the examiner may observe the tent sign, consisting of flattening of some portion or the entire surface of the tumor with angulation resembling the side of a tent, often seen only by stretching the skin.¹⁴ This has been attributed to attachment of the tumor to the overlying epidermis, and the associated bluish or reddish discoloration is due to the growth of blood vessels into the overlying skin.⁶ Although pilomatrixomas are usually solitary, multiple lesions have been reported in association with genetic disorders, such as myotonic dystrophy, Gardner syndrome, xeroderma pigmentosum, and basal cell nevus syndrome.^{6,8,15}

The histopathologic features of a pilomatrixoma include a well demarcated tumor which is often surrounded by a connective tissue capsule. Generally, it is located in the dermal or subcutaneous layer. The tumor is composed of islands of epithelial cells made up of varying amounts of uniform basaloid matrical cells and often shows cystic change. Centrally, there is degeneration of these basaloid cells as the tumor matures. This is characterized by formation of anucleated ghost (or shadow) cells due to the central unstained areas of these cells.¹⁶ It is important to note, however, that these ghost cells, though quite specific, are not unique to pilomatrixomas. There may be a variably prominent inflammatory reaction.⁹ Foreign body giant cells, keratin debris, and central calcifications are also characteristic. Calcification has been noted in 70 to 85 percent of cases.⁷

Diagnostic imaging is generally not obtained in the evaluation of pilomatrixomas as they are usually superficial, small, and well-circumscribed. Plain radiographs in this case were unremarkable, but pilomatrixomas may demonstrate foci of calcification. Computed tomography (CT) demonstrates a sharply demarcated, subcutaneous lesion of soft tissue density, with or without calcification. MRI may reveal a rim-enhancing lesion with small areas of signal dropout which may be consistent with calcifications.¹⁵ Ultrasound demonstrates a well-defined mass with inner echogenic foci and a peripheral hypoechoic rim or a completely echogenic mass with strong posterior or acoustic shadowing in the subcutaneous layer.¹⁷

Wang et al. noted that 45 percent of cases of pilomatrixoma were incorrectly diagnosed by fine needle aspiration cytology based on their review of multiple case

reports and series.¹⁶ Nevertheless, in their study as well as other more recent studies, fine needle aspiration has been found to be quite accurate when two key components, basaloid cells and ghost cells, are visualized, as this has been found to be specific for pilomatrixoma.¹

As performed in this case, management of pilomatrixomas typically involves marginal excision. Lesions on the extremities may be left untreated unless they become large or symptomatic, however in many cases these are excised for definitive diagnosis. If the tumor adheres to the dermis, the overlying skin may be excised. The recurrence rate is low, ranging from 0 to 3 percent.¹⁵ If a lesion recurs after excision or rapidly enlarges, it should be excised due to malignant potential or possible misdiagnosis.

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SEPTIC ARTHRITIS OF THE HIP ASSOCIATED WITH SUPRA-ACETABULAR EXTERNAL FIXATION OF UNSTABLE PELVIC RING: A CASE REPORT

Kyle T. Judd, M.D. and Todd O. McKinley, M.D.

External fixation of unstable pelvic ring injuries is a common method of stabilization often used for definitive management.^{1,3} Pin site infections frequently occur, but typically respond to local treatment.^{2,4} Pin site infections progressing to septic arthritis are rare but disabling occurrences. Septic arthritis secondary to pin tract infection has been reported to occur in 2-10% of cases involving the extremities. In contrast, there are no reported occurrences for pelvic ring fixation.^{5,6} We present a case of septic hip arthritis which presumably developed as a result of communication between an anterior supra-acetabular half-pin and the joint.

CASE REPORT

A 53 year old woman was an un-helmeted passenger in a motorcycle crash in which she sustained a pelvic ring disruption (Figure 1), distal radius fracture and complex lacerations to her face and right thigh. During transport, the patient was tachycardic but hemodynamically stable. Initial physical exam revealed tenderness globally over the pelvis but no gross instability. Neurological examination of the lower extremities was normal. Initial laboratory data revealed a hematocrit of 35, hemoglobin of 11.3, and a lactate of 5.2.

After appropriate resuscitation she was taken to the operating room for closed reduction and percutaneous fixation of her posterior and anterior pelvic ring. Her posterior ring was stabilized with iliosacral screws and the anterior ring stabilized with a low anterior (Hanover) frame and percutaneous screws in her superior rami (Figures 2-4). The patient tolerated surgery well and transferred to a skilled nursing facility one week after surgery. She was allowed to weight bear for transfers on her left leg and was non weight bearing on the right leg.

Ten weeks after surgery the Hanover frame was removed in the clinic. There was no drainage or erythema at the pin sites. The patient continued to do well and she



Figure 1. AP pelvis obtained in Trauma Bay after Placement of Pelvic Binder shows symphysis widening, bilateral superior/inferior pubic rami fractures and posterior sacro-iliac widening.

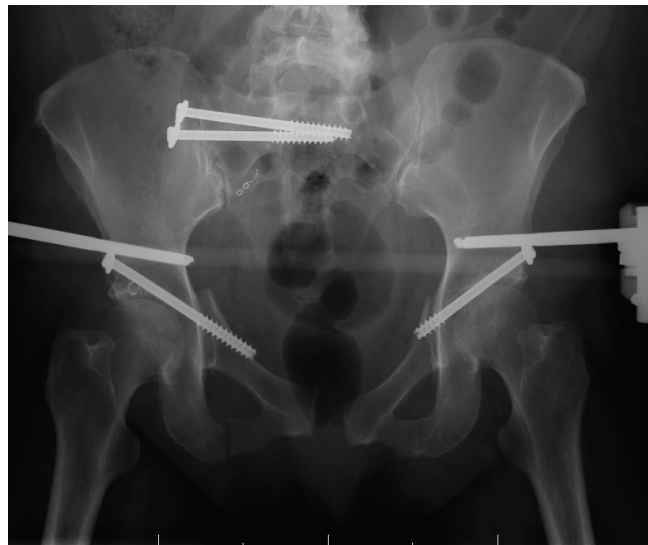


Figure 2. Initial post operative fixation consisted of anterior supra-acetabular external fixation, percutaneous sacro-iliac/anterior column screws.

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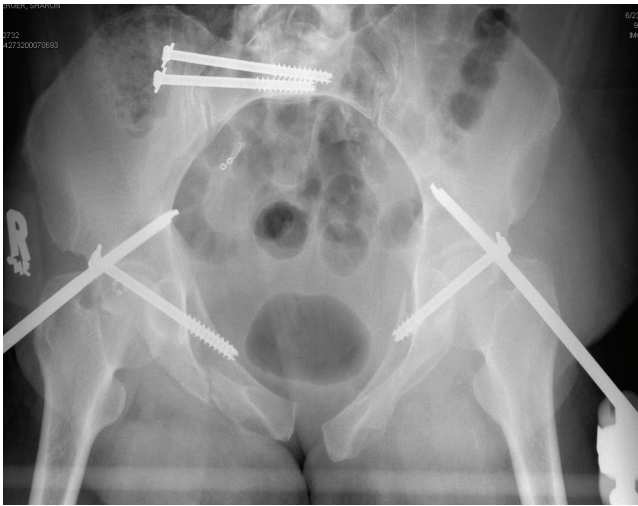


Figure 3. Post operative Inlet view demonstrating anterior supra-acetabular external fixation, percutaneous sacro-iliac/ anterior column screws.

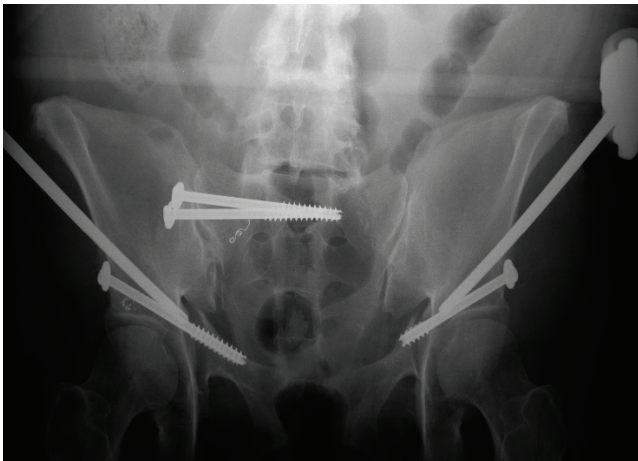


Figure 4. Post operative Outlet view anterior supra-acetabular external fixation, percutaneous sacro-iliac/ anterior column screws.

progressed to full weight bearing. Four months after injury, she began to complain of groin pain and pain with external rotation of the leg. These findings were attributed to a recent soft tissue injury. Six months after external fixation, she presented with purulent drainage from one of the previous pin sites and progressive hip pain. At the time of this evaluation she was febrile and had developed a 3 cm open area over the right anterior pelvis with purulent drainage. Manipulation of the lower extremity was increasingly painful. Laboratory values were obtained and she had a white blood cell count of 20, C-reactive protein of 24.9 and an erythrocyte sedimentation rate >140. X-Rays showed lysis of the right femoral head and acetabulum concerning for septic arthritis and osteomyelitis (Figure 5).

She was taken to the operating room for debridement and proximal femur resection with placement of antibi-

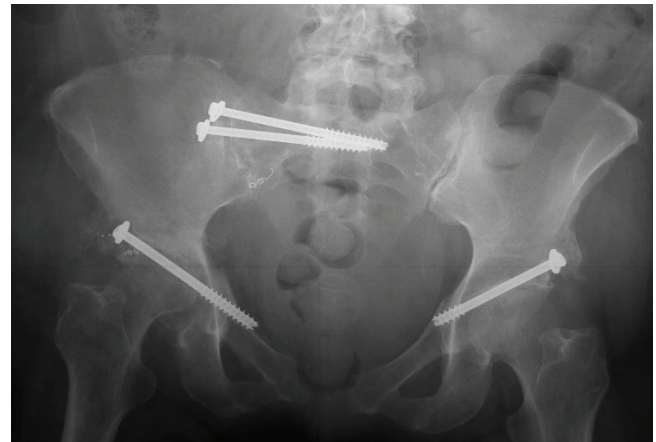


Figure 5. AP pelvis showing signs of bony lysis of right femoral head and acetabulum with apparent interval change in right anterior column screw location.

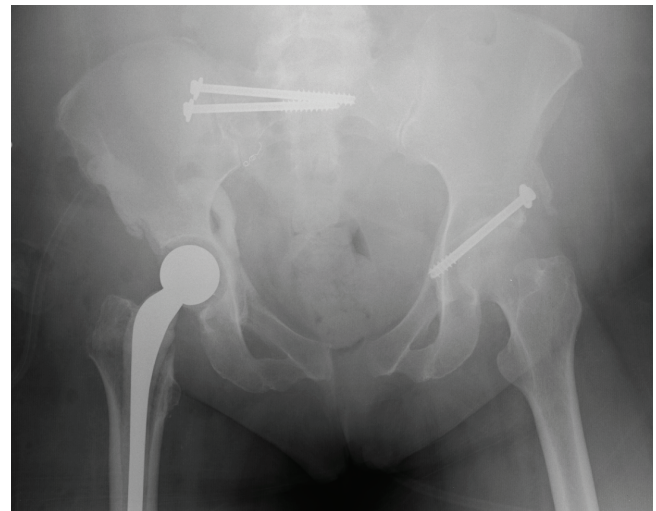


Figure 6. AP pelvis s/p irrigation and debridement demonstrating right Prostalac® spacer, interval removal of right anterior column screw.

otic beads. Two days after the initial procedure she was taken back to the operating room for repeat debridement and placement of a Prostalac® antibiotic spacer (Figure 6). She did well post operatively and was discharged six days later. At her most recent clinical evaluation the patient was weight bearing on the operative extremity without signs or symptoms of infection.

DISCUSSION

This case illustrates a previously unreported complication associated with low anterior external fixation of the pelvic ring, namely septic arthritis. Possible causes include involvement of the joint capsule or breach of the acetabulum itself. Post operative radiographs showed metal debris proximal to the acetabulum where the anterior half-pin came into contact with the superior ramus screw (Figure 7). Aberrant pin trajectory and intra-

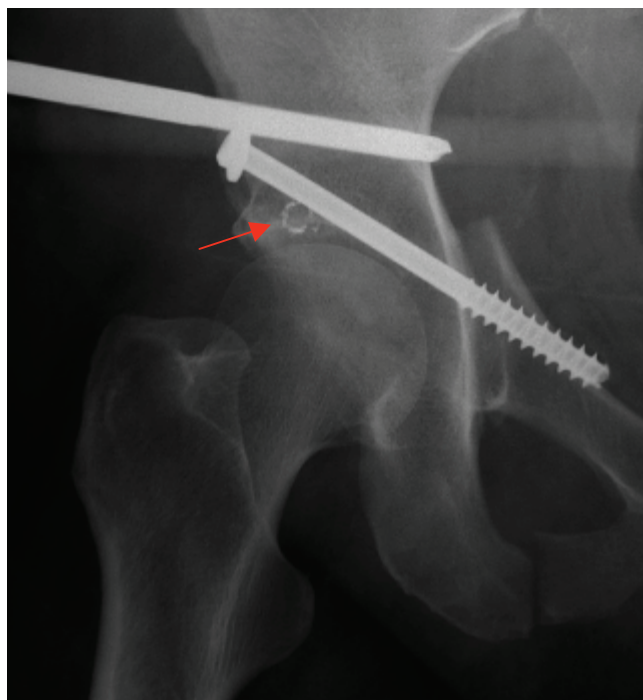


Figure 7. AP view shows metal debris in area of fixation. This denotes contact of the anterior half-pin and superior pubic ramus screw.

articular penetration during attempts to place the half-pin past the ramus screw may have caused communication between the half-pin and joint. Another possible cause would be direct screw penetration of the joint capsule, as the capsule has been shown to extend up to the anterior inferior iliac spine.⁷ Mason et al.² described a series of 100 patients treated with external fixation of pelvic ring injuries for variable durations. Ninety-eight patients had “high” pins placed within the anterior-superior iliac spine; two had “low” pins placed proximal to the acetabulum. Of those patients treated with definitive external fixation (average 60 days), one-half had local infection most of which resolved with antibiotic treatment only. No cases of septic arthritis were reported; however of the two patients treated with “low” pins one pin was found to be intra-articular by CT evaluation. In regards to penetration of the hip capsule, Haidukewych et al.⁷ described the proximity of anterior half-pins to surrounding structures. They found the mean distance from the pins to the insertion of the superior hip capsule to be 10 mm (5-21 mm). The hip capsule was found to be an average of 16 mm above the joint (11-22 mm). This information lends support to the fact that subtly misplaced pins may, in-fact, penetrate the joint via different portals and increase the likelihood of septic arthritis and infection.

CONCLUSION

Anterior external fixation is a safe method of stabilizing pelvic ring injuries. However, the procedure is not without morbidity, local infection being common; deep infection and septic arthritis being very rare. Due to the proximity of the hip capsule and other surrounding structures or associated hardware, care must be taken during application of the device in order to avoid intra-articular placement of half-pins.

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HISTORY OF SELF-EXPERIMENTATION IN ORTHOPAEDICS

Christina Ward, M.D.

During his medical training at the University of Berlin in the 1920's, Werner Forssman encountered a sketch in a physiology textbook of physicians passing a tube through the jugular vein of a horse and into the horse's heart in order to record changes in pressure in the heart. He became convinced that the procedure would work on a human. He cajoled a nurse into being his subject, but once he strapped her to the operating table, he opted to perform the procedure on himself while the nurse acted as his captive witness. He explained his choice by saying, "I was convinced that when the problems in an experiment are not very clear, you should do it on yourself and not on another person."¹ He published his results in 1927, and the procedure revolutionized our understanding of cardiac anatomy and physiology, ultimately earning a Nobel Prize in Medicine in 1956.

Although Forssman's experiment was perhaps one of the most dramatic and well known, he was neither first nor the last physician to engage in self-experimentation. Physicians may choose to be their own subjects for a variety of reasons. There may not be other subjects available, or, as in Forssman's case, the risks of the experiment may be unknown. In some cases, the use of surrogates such as animals is not desirable because the researcher wishes to document the human experience. As discussed below, in cases such as Dr. Scott F. Dye's interest in knee pain, the physician may desire firsthand experience of the treatment or procedure. For these and other reasons, physicians have subjected themselves to sudden changes in atmospheric pressure and extreme temperatures, exposure to infectious agents, and even surgical procedures. Orthopaedic surgeons are no exception, and some orthopaedic self-experiments have resulted in important advances in medical knowledge.

Some of the earliest self-experimentation in orthopaedics occurred in the investigation of osteomyelitis. In the late 1800's, understanding of disease transmission remained very rudimentary. Osteomyelitis was a com-

mon and sometimes deadly problem. A Scottish surgeon named Alexander Ogston had isolated staphylococcus and used the bacteria to infect animal subjects, but the role of staphylococcus in human disease remained unclear. Dr. Carl Garre, a surgeon and bacteriologist in Basel, Switzerland became interested in bacterial transmission of disease after he cultured staphylococcus from both bone and skin infections. Though cultures from both sources appeared to be staphylococcus under the microscope, he was uncertain whether the same staph species could cause relatively harmless skin infection as well as severe osteomyelitis. To determine if the same species could cause this spectrum of infections, he used a wire inoculated with bacteria from a patient's bone infection to scratch his nailbed. That produced a very mild superficial infection, but he wanted to be more certain. In 1883, he scratched his forearm with wire and smeared staphylococcus cultures over the wound. He used his other arm as a control, placing sterile culture medium on that wound. By the end of the first day, he noted that the staph-inoculated wound had already become red and painful. On day 2 of his experiment, he noted that, "the whole thing began to be unpleasant,"² and he ultimately developed an abscess, lymphadenopathy, and fevers. Garre concluded that staphylococcus were responsible for both bone and skin infections. Other scientists confirmed Garre's results, prompting further investigations into the role of staphylococcus in human disease.

Although inadvertent, osteomyelitis also played a role in the self-experiments of another famous orthopaedic surgeon. During his training, Sir John Charnley became interested in the role of periosteum in bone grafts. Against the advice of his superiors, he convinced a colleague to remove a piece of bone from his tibia and reimplant one portion beneath the periosteum and one portion superficial to the periosteum. The exact results he sought are unclear, as the wound became infected within a few days, and Charnley required surgery to eradicate the infection.³

Undaunted, several years later, Charnley performed a second self-experiment that revolutionized hip arthroplasty. In the 1950's, Charnley devoted himself to the creation of a low friction hip arthroplasty. He began performing hip replacements that used polytetrafluoroethylene (PTFE, aka Teflon) as a bearing surface, and published his early results in *Lancet* in 1961. In his article

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entitled "Arthroplasty of the hip: A new operation," he described how, "most patients can execute "a straight-leg raise" and have no pain or spasm on passive movement."⁴ Unfortunately, such promising results were not long lasting. After only a few years, patients returned with failed prostheses and extensive bone loss. Although PTFE had performed well as a bearing surface in the lab and was chemically inert, Charnley suspected that PTFE wear particles were to blame for the osteolysis. To prove this, Charnley placed small particles of PTFE under the skin in one thigh, and particles of his new proposed bearing surface, high molecular weight polyethylene (HMWP)* under the skin in his other thigh. As he suspected, the PTFE elicited an inflammatory response. Fortunately, the HMWP did not.

Meanwhile, the remainder of the orthopaedic community quickly embraced arthroplasty with PTFE. Charnley, devastated by the rapid failure of the PTFE implants, attended the British Orthopaedic meeting intending to warn others of the dramatic failures due to osteolysis. Unfortunately, the chair of the meeting concluded discussion before Charnley could speak.⁵ In an effort to stop the use of PTFE and its unintended consequences, Charnley wrote a letter to *Lancet*, published in 1963 that began, "Sir- Surgeons, and especially orthopaedic surgeons, should be warned that tissue reactions are likely to follow the implantation of polytetrafluorethylene . . . if this material is subjected to abrasion, and that these reactions may not be manifest for two years"⁶ (Figure 1). In this letter, he goes on to describe his self-experiment, stating

I have had introduced subcutaneously into my thigh, . . . two specimens of P.T.F.E. and one specimen of "high-density" polyethylene, prepared in finely divided form. After nine months in situ the two P.T.F.E. specimens are clearly palpable as nodules . . . almost twice the volume of the original implant. The "high-density" polyethylene can not with certainty be detected by palpation, which I take to indicate that no tissue reaction has been produced by this material in finely divided form.⁷

*How Charnley happened upon HMWP as a bearing surface is an interesting story in itself. After the failure of PTFE became evident, Charnley and his engineering lab supervisor Harry Craven began searching for an alternative bearing surface. They tried a number of different materials in the lab, but none were superior to PTFE. With patients piling up in his clinics, and no good treatments available, Charnley and Craven were struggling to find a solution. A young man approached the hospital supplies officer in an effort to sell him plastic gears made for weaving machines. He supplied Craven with a piece of the plastic used in manufacturing the gears. At the time, few people were aware of this material, known as high molecular weight polyethylene, but this serendipitous stop by the plastic gear salesman resulted in handing Craven and Charnley the key to hip arthroplasty. (Waugh, W. *John Charnley: The man and the hip*. London: Springer-Verlag, 1988. p.123-124.)

DECEMBER 28, 1963

LETTERS TO

TISSUE REACTIONS TO POLYTETRAFLUORETHYLENE

SIR,—Surgeons, and especially orthopaedic surgeons, should be warned that tissue reactions are likely to follow the implantation of polytetrafluorethylene (P.T.F.E., 'Teflon', 'Fluon') if this material is subjected to abrasion, and that these reactions may not be manifest for two years.

In biological tests insufficient attention seems to have been paid to P.T.F.E. in finely divided form. After pioneering its use in arthroplasty I abandoned it over two and a half years ago, and I write this because I have been told that a firm which distributes this material is still having frequent requests to supply P.T.F.E. to orthopaedic surgeons in sheet form for insertion between the femur and the tibia as an arthroplasty of the knee. This simple, and therefore attractive, operation was announced at the

Figure 1. Charnley's 1963 Letter to the Editor of *Lancet* reporting the failures of hip arthroplasty and PTFE and his self-experiment comparing tissue reaction to PTFE and HMWP.

Reassured that the HMWP wear particles were less inflammatory than those of PTFE, Charnley moved forward with low friction hip arthroplasty, and his designs remain the basis for total hip arthroplasty performed today.

Although self-experimentation may seem a thing of the past, using oneself as a subject remains the only way to truly understand the human experience firsthand. As JBS Haldane explained, "For rough experiments one uses an animal, and it is really only when accurate observations are needed that a human being is preferable . . . it is difficult to be sure how a rabbit feels at any time. Indeed, many rabbits make no serious attempt to cooperate with one."⁸ Some questions simply require personal involvement to solve.

Dr. Scott F. Dye encountered one such question. After seeing numerous patients with persistent anterior knee pain, he became interested in the source of patellofemoral pain. He noted that many patients who had arthroscopic surgery for other reasons had fibrillated cartilage in their patellofemoral joint, but did not have patellofemoral pain. Meanwhile, patients with presumed patellofemoral pain might have pristine cartilage in their knee at the time of arthroscopy. This led him to ask the question, "What anatomic structures in the knee can really feel pain?" Previous studies examining sensory output from the knee had focused on histologic evidence of neural structures, or nerve transmission from the knee in anesthetized patients. As Dr. Dye stated, "Documentation of sensory evoked potentials with electrical stimulation of intraarticular structures of anesthetized patients at surgery does not address the question of

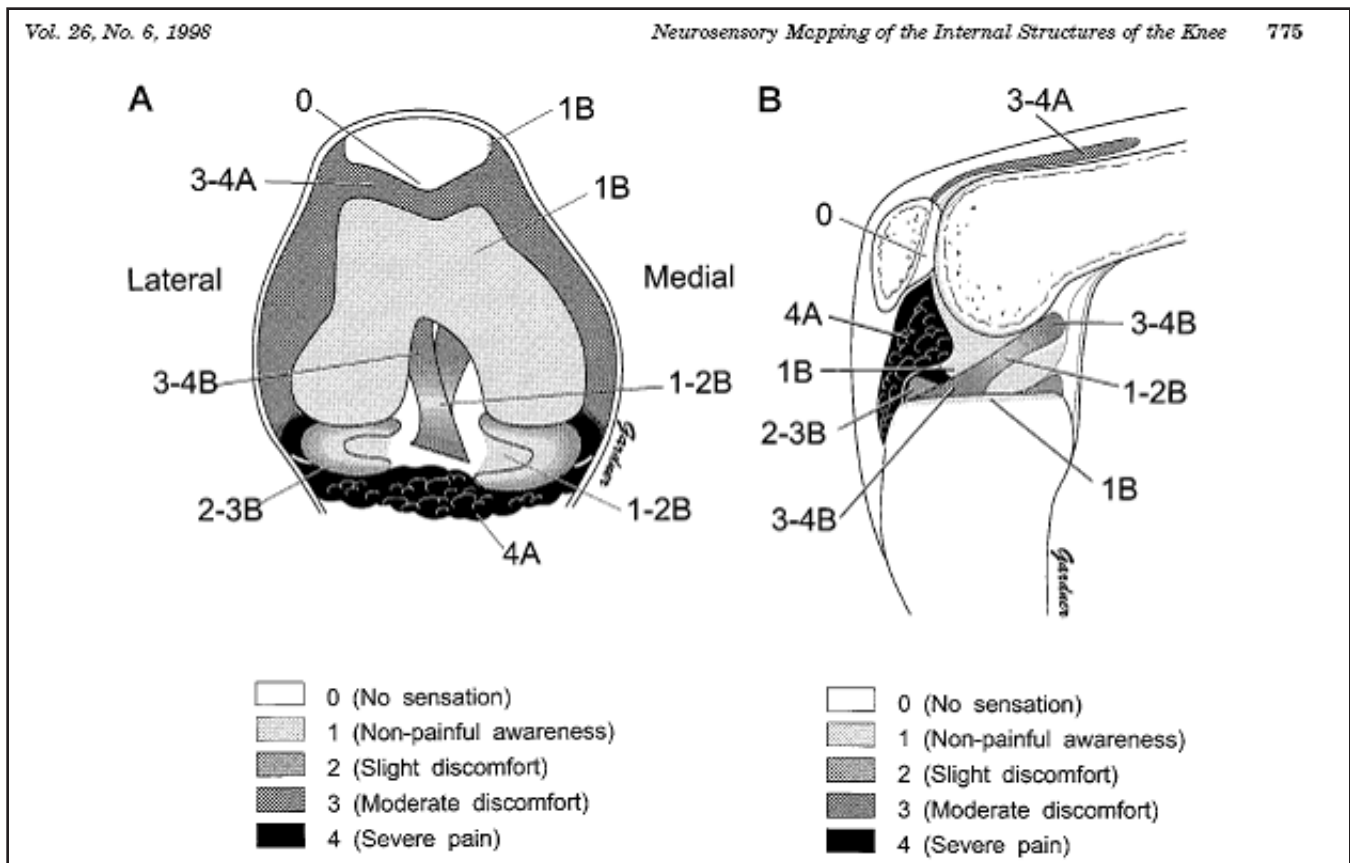


Figure 2. Dye's neurosensory map of the knee. A, accurate spatial localization. B, poorly localized sensation. (Reprinted with permission, SAGE Publication, through Rightslink)

whether and to what extent a person would consciously experience palpation of those structures.”⁹

To answer the question, Dye asked a colleague to perform knee arthroscopy on his knee without anesthetic. During the arthroscopy, the surgeon would probe different anatomic structures, and Dye would report what he felt. He described both the intensity of the sensation and whether he could localize the sensation (Figure 2). As a result, he discovered that he had almost no pain with palpation of the patellofemoral joint, while probing of the anterior fat pad and anterior joint capsule was exquisitely painful. Correctly identifying the anatomic structures that lead to knee pain should help provide direction for treatments in the future.

Although self-experimentation may seem an odd or arcane research method, results of such experiments remain relevant today. Without physicians using themselves as subjects, we might not have effective treatment for cardiac disease, infection, and myriad other diseases. In orthopaedics alone, self-experimentation has yielded important advances in the treatment of osteomyelitis and hip arthroplasty, and may offer more knowledge in the future.

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HIGH ANKLE SPRAINS (SYNDESMOTIC) IN ATHLETES: DIAGNOSTIC CHALLENGES AND REVIEW OF THE LITERATURE

A. Molinari, M. Stolley, BSN, A. Amendola, MD

INTRODUCTION

Although ankle injuries are among the most common injuries that occur in athletes, the severity and degree of these injuries vary greatly owing to the complexity of the ankle and surrounding structures. Compared with lateral ankle sprains, syndesmotic or high ankle sprains occur less often in the general and sport populations and usually experience a longer recovery period further compounding the difficulty of evaluating and treating this type of injury. Syndesmotic injuries that have radiographic widening as evidence of disruption are relatively straightforward in terms of making the diagnosis, and therefore directing treatment. However, as seen much more commonly in sports, those sprains with normal radiographic joint and bony relationships are much more difficult to assess in terms of severity. The reason for the difficulty is that diagnosis is dependent on subjective clinical findings. As a result, these present a significant diagnostic and treatment dilemma for the sports medicine physician. It would be advantageous to be able to delineate the severity of injury in syndesmotic sprains without obvious widening or mechanical abnormalities. The purpose of this paper is to review the literature as a means of elucidating any diagnostic radiographic findings, including MR imaging, with the anticipation this review may lead to further research directions on this topic.

BACKGROUND

Reports of syndesmotic sprain incidence vary from 1% to 11% of all ankle injuries.^{1,2} Jones et al. conducted an in-depth analysis of several studies and found that time lost from sport due to syndesmosis sprains ranged from 0 to 137 days, with averages ranging from 10 to 14 days up to 52 days.³ The ranges stated illustrate the variability in degree and severity of syndesmotic ankle injury. Furthermore, research conducted on the evaluation and treatment of syndesmotic ankle sprains has been relatively nominal, although interest has grown in recent years.^{3,9} In a study done by Wright et al. on National Hockey League players, out of 14 syndesmosis ankles sprains

examined, only one player showed mortise diastasis on stress x-rays although 74% of ankle injuries studied were syndesmosis injuries.¹⁰ Nussbaum et al. also found a low number of radiographs with mortise widening; only 1 out of 17 athletes tested demonstrated widening on his radiograph.¹¹ Therefore, there lies a great importance in augmenting our evaluation and imaging techniques as well as our understanding of the mechanisms and anatomy of tibiofibular syndesmotic injuries in order to improve assessment and management of high ankle sprains with a normal mortise relationship.

ANATOMY

An appreciation of the anatomy related to the syndesmotic relationship is essential in understanding the injury and related pathoanatomy and radiographic findings. In the inferior tibiofibular syndesmosis, the distal fibula (with a convex surface) unites with the distal tibia (with a concave surface).^{6,12,13} The three ligaments that help stabilize this articulation are the anterior tibiofibular ligament (AITFL), the superficial and deep components of the posterior tibiofibular ligament (PITFL), and the interosseous ligament or membrane. The AITFL originates from the anterolateral tubercle of the tibia and its fibers run in an oblique direction, distally and laterally inserting on the longitudinal tubercle on the anterior border of the lateral malleolus.^{9,14,15} This ligament may consist of two to three bands or be multi fascicular.¹⁶ The AITFL is wider at the tibial insertion than at the fibular insertion, and has been described as having a triangular¹³ or trapezoidal shape.^{9,14,15} The PITFL consists of superficial and deep components,^{6,12,14} although some categorize the deep component as a separate ligament.^{13,15} The superficial component fulfills the same purpose as the AITFL holding the fibula and tibia together. Originating from the posterolateral distal fibula, the PITFL runs more horizontally and inserts on the posteromedial distal tibia. The deep component, also known as the inferior transverse ligament, is a strong collection of fibers located below the posterior tibial margin and runs from the posterior ridge of the tibia to the lateral malleolar fossa even more horizontally than the superficial component.^{6,14}

The interosseous membrane (IOM) facilitates the prevention of posterolateral bowing of the fibula during activities that place stress on the fibula.¹⁷ The IOM connects the tibia and fibula along nearly the entire length

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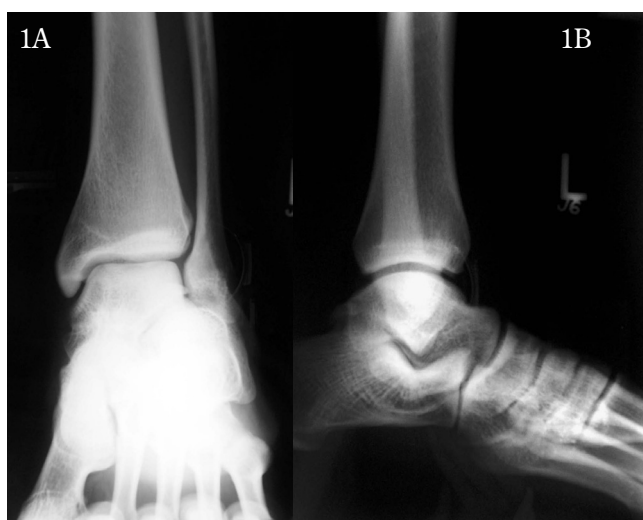


Figure 1A, B. AP and Lat x-ray of 18 year old football player with high ankle sprain. AP shows lack of tibio fibular overlap.

of the medial aspect of the two bones and separates the anterior and posterior muscles in the leg.¹² Located just above the talocrural joint, the interosseous ligament is a collection of fibers at the distal end of the IOM that mostly run from the tibia to the fibula.¹⁴⁻¹⁶ Its function has been described as spring-like, allowing the medial and lateral malleolus to slightly separate during dorsiflexion at the ankle joint.^{6,16}

PATHOANATOMY

Considering the anatomy, the usual injury pattern of syndesmosis sprains will be easier to understand. In an incomplete syndesmotric sprain, the anterior portion of the AITFL (need to be consistent with abbreviation—choose ATFL or AITFL) may be partially or completely torn as a result of the fibula separating from the tibia in an external rotation mechanism, for example. Although this ligament may be completely torn, normal x-rays taken will still appear to be normal (no mortise widening) as the PITFL (need to be consistent with abbreviation) and interosseous membrane provide enough stability to hold the ankle joint in place (see Figures 1A-B, 2A-D, 3A-B, 4A-B). However, a comprehensive physical examination of the ankle joint should indicate a significant ankle injury, usually because the patient has difficulty pushing off and weight bearing, arousing suspicion of a syndesmosis sprain.

On the other hand, in cases where complete disruption has occurred and mortise widening is present, the diagnosis is generally very clear (see Figure 5). In addition to trauma to the anterior tibiofibular ligament, the deltoid ligament, the posterior tibiofibular ligament and interosseous membrane may be affected as well. As a result, the ankle becomes much less stable and the

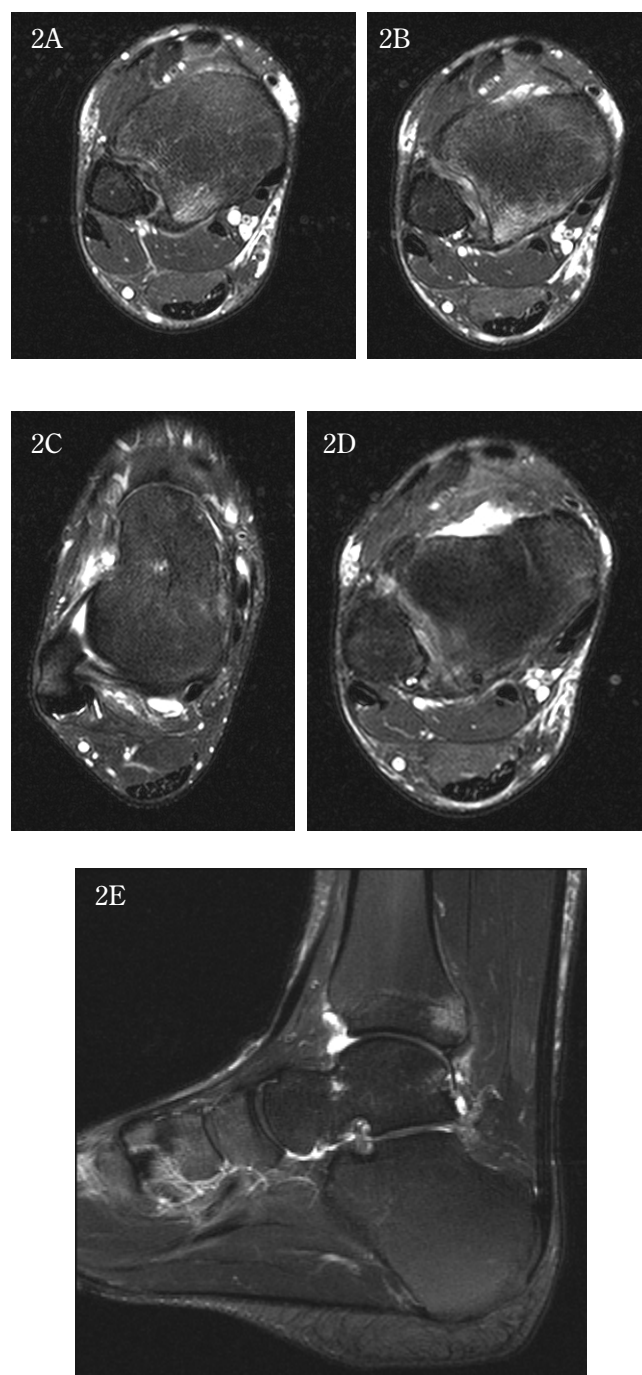


Figure 2. MRI visualization of syndesmosis sprain through injury to the AITFL and PITFL A, B, C: Edema in the area of the PITFL attachment on the tibia, but the ligament is intact; D: AITFL intact therefore likely ER mechanism, not inversion; E: AITFL is disrupted.

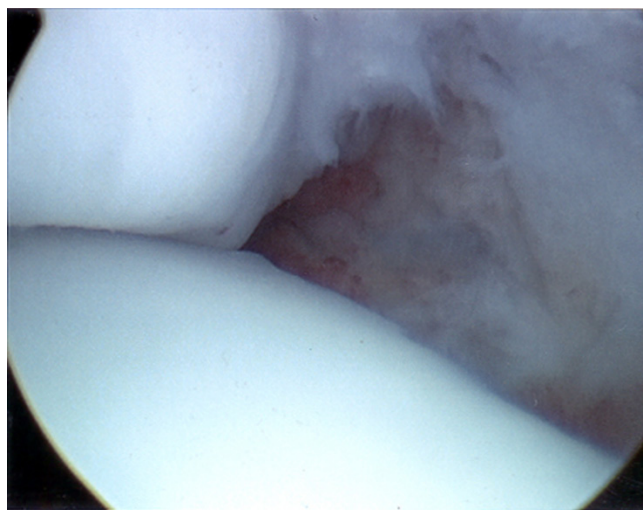


Figure 3. Arthroscopic view with missing anterior inferior tibio fibular ligament (evidence for disruption).

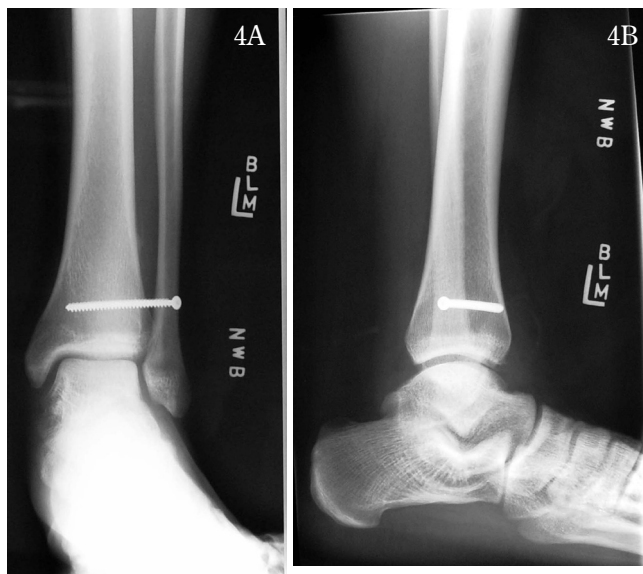


Figure 4 A, B. AP and Lat post arthroscopic debridement and fixation with syndesmosis screw.

mortise relationship is not able to be maintained, thus easily seen on radiographs. As mentioned above, mortise widening only occurs in a small percentage of syndesmotomic injuries^{10,11} and usually the radiographic diagnosis is difficult with those partial injuries.

MECHANISM

Although less frequent in the general population, Boytim et al. noted that there was a greater incidence in the professional football population included in a study on syndesmosis injuries.¹⁸ High ankle sprains are more common in collision sports including football, ice hockey, and soccer¹⁸ (see Figures 6A, 6B). This suggests that athletes participating in such sports are more susceptible

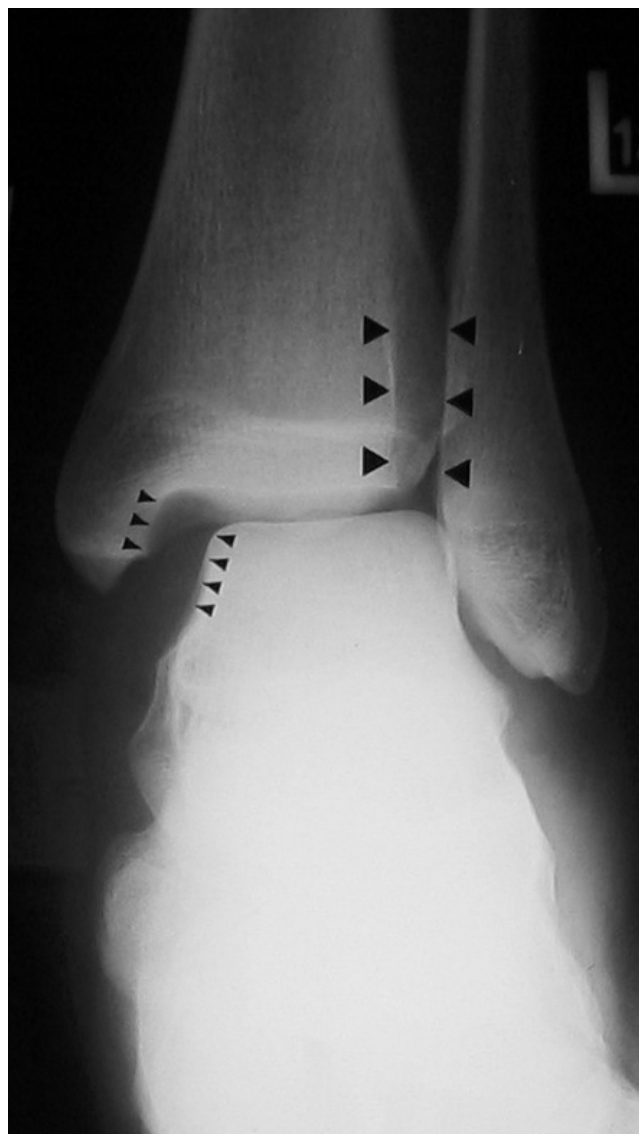


Figure 5. Radiographic AP view of mortise wid

to syndesmosis injuries. Fritschy et al. also did a study on Olympic skiers that experienced external rotation and syndesmotomic injury due to the twisting nature of the sport and the rigidity of ski boots.¹⁹ External rotation has been described as the most common mechanism for this type of injury,^{1,11,18-20} but there have also been reports of hyperdorsiflexion associated with external rotation,^{1,6,18} axial loading of the ankle,¹¹ and inversion.¹ Although these are the major mechanisms which have been discussed, any mechanism which results in a force on the separation of the tibia and fibula or a rotation of the talus within the mortise is significant.



Figure 6A. External rotation mechanism as often observed in football but can occur in other sports. Drawing courtesy of the late Dr. J. C. Kennedy.



Figure 6B. Axial loading and hyperdorsiflexion mechanism observed in baseball players sliding into a base; can occur in other sports. Drawing courtesy of the late Dr. J. C. Kennedy.

DIAGNOSIS

In regards to evaluation of syndesmosis sprains, there remains a controversy over the most effective approach.^{7,8,21,22} In the physical examination, evaluation of the syndesmosis is commonly conducted using localization of pain, anatomic palpation, and a variety of stress tests including the squeeze test, the external rotation test, the fibula-translation (drawer) test, the Cotton test, and the crossed-leg test.^{3,5,9,18,20,23}



Figure 7A. A stabilization taping technique to assess the injury.



Figure 7B. Functional activity improves with the taping technique, confirming syndesmotic instability.

EXAMINATION OF THE SYNDESMOSIS SPRAIN (NORMAL MORTISE RELATIONSHIP)

In a syndesmosis without any mortise widening, physical examination may become an important part of diagnosing the patient. Upon reviewing the mechanism involved in a patient's injury, suspicion of a syndesmosis sprain may be raised. If palpating the areas usually affected in a high ankle sprain (AITFL, PITFL, medial malleolus) causes pain, the examiner may surmise further that the syndesmosis is involved in the injury.^{5,9,18,20} The stability of the ankle joint may be examined by asking the patient to perform a number of maneuvers including performing a toe raise, walking, and jumping. In a gait analysis performed by Spaulding,²⁴ findings



Figure 8. External rotation stress test reproduces pain in the syndesmotic area.

showed that syndesmosis injury decreased the ability to push off of the toes while walking, and therefore the above-mentioned actions should be painful or hindered if there is a syndesmosis injury. Described by Williams et al., Amendola has incorporated the “stabilization test,” which is performed by tightly taping patient’s leg just above the ankle joint in an attempt to stabilize the syndesmosis⁹ (see Figure 7A). If toe raises, walking, and/or jumping are less painful upon taping, this would indicate a positive test result⁹ (see Figure 7B). The Cotton test, performed by translating the talus medial to lateral within the mortise, may also indicate deltoid ligament injury associated with the syndesmosis sprain if increased translation or pain is noted.^{9,20,23} Finally, as external rotation is one of the more common mechanisms, the external rotation test proves to be useful in confirming suspicions of syndesmosis involvement in the injury (see Figure 8).^{5,9,11,20,23}

IMAGING

Although helpful in identifying problematic areas, these physical tests are mostly used in conjunction with radiographic findings. With imaging, the ankle may be examined in the anteroposterior (AP), lateral, and mortise views. The mortise view is another form of the AP view internally rotating the tibia by 15° to 20° which allows a better visualization of any diastasis in the syndesmosis.⁵ Again, with sprains these views will be normal.

SYNDESMOSIS INJURIES WITH MORTISE WIDENING

Among the AP and mortise views, there are a number of measurements taken in an attempt to quantify the severity of the injury. On the AP view, the tibiofibular clear space (TFCS) is measured horizontally between the lateral border of the posterior tibial malleolus at its widest point and the medial border of the fibula.^{25,26} Also measured horizontally on the AP view, tibiofibular overlap (TFO) is the distance between the medial border of the fibula and the lateral border of the anterior tibial tubercle.^{25,26} Finally, the medial clear space (MCS) measured on the mortise radiograph is described as the distance between the lateral aspect of the medial malleolus and medial border of the talus.^{25,26} There remains a controversy over the reliability of these three parameters,^{5,7,25,26} although a study conducted by Nielson et al. indicates a correlation between MCS widening and deltoid ligament tears.²⁶ Beumer et al. also proposes that syndesmotic injury may be indicated by a unilateral absence of TFO.²⁵

Even though the combination of physical examination and radiology is the more common diagnostic tool in the field of orthopaedics, a number of studies have found that radiographic measurements fail to be entirely reliable due to the difficulty in accurately positioning the ankle even in ideal laboratory conditions.²⁵⁻²⁷ Therefore, other forms of radiology, including CT (Computed Tomography) and MRI (Magnetic Resonance Imaging) have been utilized in order to improve accurate diagnosis.^{7,8,21,22,26} It has been noted that CT is more effective at picking out 2-mm and 3-mm diastases than plain radiography.²⁷ Although CT is more sensitive than radiography in visualizing the syndesmosis, more subtle 1-mm diastases remain difficult to pick out in a CT scan.⁸ Taser et al. introduced a novel solution to this problem. Taser used CT in order to render a three-dimensional reconstruction of the tibiofibular joint space thereby allowing calculations of the volume.⁸ In this manner, using CT to render three-dimensional images may enable the physician to more effectively grade the severity of a syndesmotic ankle sprain when compared to the normal joint volume.

SYNDESMOSIS SPRAINS: NORMAL MORTISE RELATIONSHIP

Initial investigation should include routine x-rays. Occasionally there may be some suggestion of injury, but not commonly. On a delayed basis, calcification may occur at the posterior tibia and the interosseous membrane following the initial injury (see Figure 9).

Under normal mortise relationship, it remains difficult diagnosing a syndesmosis sprain with plain radiography.



Figure 9. AP view calcification in the interosseous space 2 mos after a high ankle sprain.

If there is suspicion of a syndesmotic injury but no evidence on a plain x-ray, one may choose to perform stress views. These may be performed manually or with a Telos stress device. Beumer et al. utilized the Telos device (Austin and Associates) on cadaver specimens and concluded that external rotation stress radiostereometric analysis (RSA) is useful in detection of some forms of syndesmotic instability.²⁸ However, we have found that due to the stability of the mortise these stress views will usually be stable unless it is a complete disruption. (see Figure 10)

Owing to this uncertainty, close follow-up should be conducted on the patient. Moreover, follow-up is also important in regards to delayed heterotopic ossification occurring on the posterior aspect of the tibia and the distal portion of the interosseous membrane.^{9,11,18, 23} If trauma occurred in the PITFL or the IOM, bleeding may have occurred and subsequently healed as an abnormal formation of bone on these surfaces. It has been noted in the literature that this may not be visible until 6 months after the injury. This reinforces the importance of following up on syndesmosis sprains even after symptoms have subsided.

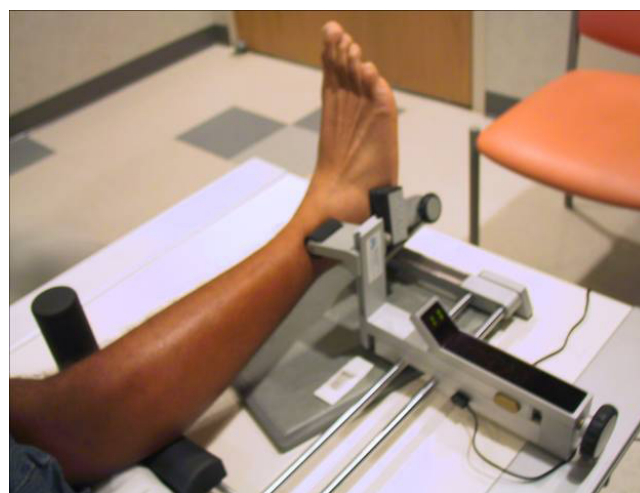


Figure 10A. External rotation stress test using the Telos device to apply force to the syndesmosis.



Figure 10B. Radiographic view of the ankle while utilizing the Telos external rotation stress test.

In a CT scan of an ankle with normal mortise relationship, visualization of any diastasis will not be applicable. Therefore, CT has another useful application in order to detect an additional injury associated with some syndesmosis sprains: avulsion fractures. Avulsion fractures occur when a fragment of bone tears away from the main mass of bone where a ligament attaches. In syndesmosis sprains, avulsion fractures may occur on either the anterior or posterior aspect of the tibia and have been noted to occur in up to 50% of syndesmosis injuries.²⁹

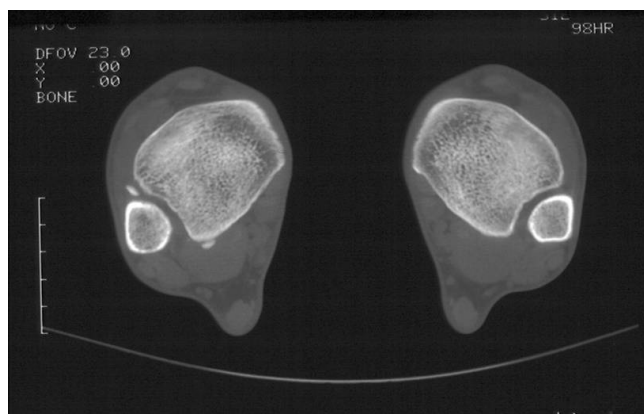


Figure 11. CT view of anterior and posterior avulsion fractures of the tibia as a result of syndesmosis sprain.

In this case, CT becomes an important radiographic tool owing to the fact that avulsion fractures can occur without diastasis (see Figure 11). Therefore, if CT is not utilized this type of fracture may be missed.

MRI provides yet another important method of diagnosing syndesmosis injuries with a normal mortise relationship. Looking at MRI films, it becomes much easier to visualize ligament tears, ankle joint fluid leaking into the tibiofibular space, and edema.^{4,30} Therefore, syndesmosis sprains may again be identified despite an ankle appearing normal on plain x-ray. Oae et al. found that obtaining transverse sections offered the view most useful for evaluation of the tibiofibular syndesmosis. Furthermore, in their MR imaging study, the two criteria that they employed in assessing ligament disruption were ligament discontinuity and either a wavy or curved ligament contour or nonvisualization of the ligament.⁷

Utilizing MR imaging, soft tissue injuries are visualized more extensively than plain radiography, allowing the observer to improve assessment of syndesmotic diastasis and ligament damage.^{4,7,30} Numerous studies have indicated a much higher accuracy, sensitivity, and specificity associated with MR imaging when confirmed by ankle arthroscopy.^{7,8,21,22} Furthermore, a study done by Brown et al. noted that syndesmotic disruption may be associated with a number of secondary findings in MR imaging including anterior talofibular ligament injury, osteochondral lesions, bone bruise, and tibiofibular joint incongruity⁴ (see Figures 2A-E).

DISCUSSION

Even after a thorough review of the literature, it is difficult to identify an adequate method of evaluating syndesmosis sprains with a normal mortise relationship. The literature on these types of injuries is lacking, and the severity of the injuries has been poorly appreciated. As a result, predictions on time lost from sport continue

to be elusive to the physician. A complete diagnosis is best made through appropriate imaging modalities in conjunction with and correlated with the history and physical examination. Using all of these tools along with repeat examinations and complete follow-up, it may be easier to determine the extent of the injury.

Currently, more prospective research is needed to accurately assess the extent and severity of these injuries. This information is essential in order to improve predictability of down time associated with syndesmosis sprains as well as conservative versus operative treatment options. Currently, non-operative treatment seems to be the conventional approach, with Nussbaum et al. and Williams et al. both preferring a 3-phase approach.^{9,11} The first phase (acute phase) aims to protect the injured joint and reduce pain and swelling through complete immobilization (splint, cast, or boot) and pain control. The second phase (subacute phase) includes an increase in exercise intensity with goals of restoring strength and function in basic motions such as ambulation. The third phase (advanced training phase) continues with the goal of discharging the patient back to sports participation. The patient engages in continued strengthening, neuromuscular training, and sport-specific exercises in order to evaluate stability of the syndesmosis. Determining when the patient may return to sports is a difficult decision and is based upon a combination of physical examination and ability to perform sport-specific skills and movements.^{9,11}

If diastasis on plain or stress radiography or arthroscopic evidence of instability in the syndesmosis exists, surgical treatment is recommended. Indications for operative treatment in the case of sprains without any evidence of diastasis still remain controversial. Surgical treatment consists of reduction and fixation of the syndesmosis across the distal fibula and tibia using either 1 or 2 screws or a recently described suture technique known as the TightRope Syndesmosis Repair (Arthrex) which is gaining increased recognition as an alternative to trans-syndesmotic fixation.³¹ This suture and button technique eliminates complications associated with screws such as hardware pain and screw breakage.

Future investigation and research will likely prove to be very useful in improving knowledge and treatment of syndesmosis injuries. Controversy surrounds almost every aspect of syndesmosis injuries from diagnosis to treatment and more research will help in defining all these aspects of this injury. One important topic of research can include assessing the value of current physical examination techniques and investigating the correlation of new diagnostic techniques. Further investigation on imaging modalities and their value in aiding the evaluation of severity should be helpful. Research

on treatment should include investigating conservative versus surgical treatment in patients with very similar severity of syndesmosis sprains, in particular those injuries without syndesmotic widening. Overall syndesmotic sprains still remain a controversial subject, diagnostic imaging remains cloudy at best, and therefore this subject will benefit greatly from further study.

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THE FUTURE OF UIHC REHABILITATION SERVICES: DEFINING AND MEASURING QUALITY REHABILITATION SERVICES

Joseph J. Chen, M.D., Robert K. Yang, M.D., MHA

INTRODUCTION TO UIHC REHABILITATION PHYSICIAN SERVICES

The Carver College of Medicine and the UIHC have integrated many operations. The integration of rehabilitation physician and hospital services should follow naturally. The Department of Rehabilitation Therapies employs many talented entry-level therapy providers, but has lacked a physician champion advocating for quality outcomes in rehabilitation services. UIHC has never established an inpatient rehabilitation unit but because of the efforts of our four physical medicine and rehabilitation faculty, UIHC has developed excellent working relationships with local rehabilitation physicians and units across Iowa. Dr. Chen was appointed Medical Director of Rehabilitation Services in 2004 and has led the UI Spine Center to become a regionally recognized disease management program providing interdisciplinary spine care for Iowans with chronic spine pain. This program follows national evidence-based guidelines for the treatment of chronic back pain. The development of additional interdisciplinary disease management programs for Iowans with chronic musculoskeletal or neurological conditions can accomplish health care cost savings and improve patient access to quality care and satisfaction.

It is commonly accepted that when quality is improved, costs are also reduced. An integrated team of rehabilitation specialists led by the rehabilitation physicians will develop and direct the structure, process, and outcomes of rehabilitation care at UIHC using evidence-based medicine, process improvement, and outcomes management.

Clinical practice guidelines for chronic musculoskeletal and neurological disease management conditions can be developed to measure and improve under-utilization, reduce over-utilization and inappropriate utilization of rehabilitation services.

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DEFINING REHABILITATION SERVICES

Rehabilitation services can be provided by a therapist alone, a physician alone, or together as a part of a comprehensive team. Most physicians are not specifically board-certified in rehabilitation, but may work with rehabilitation therapists for their orthopaedic, or neurologically-impaired patients. When more complicated services and interventions are required as a part of a comprehensive rehabilitation team, these services are typically coordinated by a board-certified physical medicine and rehabilitation physician or physiatrist. Rehabilitation treatment interventions should be an integration of medical, psychosocial, and functional interventions.

Physical medicine and rehabilitation providers are direct service providers as well as a supportive and consultative service that provides management of neuromuscular and musculoskeletal disorders that alter functional status. This treating specialty places emphasis on the restoration and optimization of function through physical modalities, therapeutic exercise and interventions, adaptive equipment, modification of the environment, education, and assistive devices. Rehabilitation services are provided along a continuum from wellness preventative or occupational settings, acute care hospital settings, comprehensive inpatient rehabilitation units, outpatient rehabilitation centers, and long-term self-care management.

Leadership of physical medicine and rehabilitation services vary among across the country depending on hospital size, scope, and affiliation. Larger programs in most academic medical centers especially those with rehabilitation bed units, are typically housed in a Department of Physical Medicine & Rehabilitation with a complement of 10-40 faculty of various ranks.* These Departments have individual rehabilitation therapy staff numbering over 100 physical therapy, occupational therapy, psychology, rehabilitation nursing, and social work staff and assistants.

*Examples include: Northwestern University (58 physiatrists), Mayo College of Medicine (37), Indiana University (14), University of Minnesota (8), University of Kansas (12), University of Nebraska (15), Cleveland Clinic (17); University of Rochester (16); University of New Jersey (75), University of Washington (38), New York Presbyterian (12)

“Recent trends in health care have emphasized the importance of comprehensive rehabilitation for individuals with disabilities. The Department of Veterans Affairs has reorganized Physical Medicine and Rehabilitation Service leadership structures in order to assist facility leadership in establishing, maintaining, and improving programs in PM&RS by establishing principles in planning, administering, and improving care provided to patients with disabilities.”

VA 2007 PM&R HANDBOOK

The population served by physical medicine and rehabilitation services ranges from child, to adult, to geriatric, with a wide spectrum of neurological, surgical, medical, psychiatric and surgical conditions including the special populations of stroke, brain dysfunction/traumatic brain injury, and amputation.

BENEFITS OF COMBINED PHYSICIAN AND HOSPITAL REHABILITATION SERVICES

This rehabilitation physician consultation service is already being performed for selected spinal cord injury, polytrauma, and burn patients who require coordination of care, durable medical equipment needs, exercise therapy, and management of permanent impairment or disability determination managed by a physiatrist. Early-supported discharge¹ will shorten length of stay and follow-up with outpatient physiatry visits and rehabilitation therapies at UIHC will increase revenues. Patient populations including amputee, stroke, polytrauma patients have complicated medical and physical function require coordination of prosthetic/equipment prescription, gait training exercise with therapy, and coordination of medical complications by the physiatrist.

In some cases, rehabilitation physician involvement may not directly shorten length of stay, but early consultation may prevent or decrease complications of immobility (JCAHO “never” events), educate patient and family about the rehabilitation process, and improve patient-centered care and satisfaction following devastating injuries requiring hospitalization.

Decrease costs and improved efficiency through defining and measuring quality rehabilitation outcomes through disease management programs like that currently in the UI Spine Center.

Hospitalized patients with stroke, brain injury, or medical complex patients now being seen only by rehabilitation therapists through only PT/OT/ST referral and in the absence of PM&R consultation, would return to UIHC for the completion of their rehabilitation continuum through outpatient physiatry and rehabilitation clinics, rather than being left to follow-up with non-UIHC providers as they are currently leading to missed opportunities for outpatient revenue.

Physical therapists are working diligently to achieve the degree of professional autonomy that physicians have held. Physicians now understand that more important than autonomy is that the public health care systems wish to hold all professionals accountable for high quality outcomes. A health care team of rehabilitation specialists led by rehabilitation physicians will mutually increase the autonomy for which physical therapists strive and enhance the accountability of quality rehabilitation outcomes that the public demands.

Advantages in marketing and community advocacy of both physician and therapy services as a package, dramatically increasing utilization of UIHC Rehabilitation services, with new development of Institute of Orthopaedics, Sports Medicine & Rehabilitation as well as River Landing project.

Potential for collaboration in translational research as new medications and devices are developed to aid patients with neuromuscular, orthopaedic, rheumatologic, or other impairments, functional limitations, or disabilities.

Education of medical students and entry-level physical therapists, and ongoing professional development would benefit from integrated clinical and educational rounds that span the continuum of rehabilitation services.

Development of Clinical Practice Guidelines to decrease variability of care among patients, a current significant opportunity for improvement. Guidelines and algorithms would be used to determine the best interventions and steps of care for patients to optimize healthcare utilization and achieve optimal outcomes. Although guidelines would facilitate, not replace, clinical judgment, they would notably enhance coordination of care, benefiting patients and the institution. Practice parameters/guidelines can eliminate much of the costly variation in rehabilitation care, but will not eliminate innovation in care delivery. Eventually care maps or case management can be performed after such parameters have been vetted by all those professionals involved in the patients’ care.

DEFINING QUALITY REHABILITATION SERVICES

Quality in medicine has been difficult to define and even harder to measure. The Institute of Medicine defined “quality” in 1991 as “The degree to which health services for individuals and populations increase the likelihood of desired health outcomes and are consistent with current professional knowledge.”

In rehabilitation, efforts to measure the quality of rehabilitation services have lagged behind objective measures for medical or surgical outcomes. Newer randomized controlled trials of rehabilitation interventions

for spinal cord injury, brain injury, stroke, and musculoskeletal impairments are beginning to be performed.

The traditional Donabedian tripod of quality involves structure, process, and outcomes. Structure involves something that one can touch, see, or feel. In a rehabilitation setting, this includes the number of nurses, physical therapists, occupational therapists, presence of state of art equipment, physical plant and beds. The process of rehabilitation involves whether an organization follows agreed upon methods of care such as standing orders for patients with stroke, spinal cord injury, or brain injury. In traditional medical units such as for cardiology patients, such a process measures include the number of patients with an acute myocardial infarction who get who get TPA in less than 4 hrs, or door to balloon time. Medical and surgical outcomes are generally easier to measure and include morbidity/mortality rate, unexpected return to OR, post-operative infections, average LVEF of patients who present within 4 hrs of chest pain. In rehabilitation patients, outcomes could involve the number of stage 3-4 pressure sores that develop in inpatients or any other desired health outcome such as an improvement in functional status (improved ability to return to work or perform recreational activities measured by valid and reliable instruments such as SF-36 or other tools), reduced impairment, and decrease or elimination of pain.

As evidence based-medicine has come to become more meaningful, the traditional quality tripod has been revised to focus on evidence-based medicine methods of measuring structure, process improvement, and outcomes management. This has been refined to include the evidence for best practices for staffing ratios, number of operating rooms, clinical expertise, and patient values towards a host of process improvement actions including shared decision making, electronic decision support for physicians, to finally involving outcomes management. Good outcomes without good processes may represent luck or result from random interactions. However, good processes without good outcomes do not improve the quality of patient care. Only good outcomes linked to good processes are likely to be real and sustainable.

The Institute of Medicine's "Crossing the Quality Chasm," focus is placed on 6 domains of patient care goals in order of importance: These include safe, effective, efficient, personalized, timely, and equitable health care. Even within standard medical/surgical patients, there have been few identifiable "roadmaps" to show healthcare organizations how to address the changes in the structure or process that lead to improvements in outcomes. Based upon these patient care domains, healthcare organizations are focusing on 10 principles that traditionally rehabilitation providers have been using in practice for decades.

Care is based on continuous healing relationships. When spinal cord injury patients are treated with a rehabilitation team, their medical treatment, physical therapy and equipment needs, and psychosocial support needs are constantly being addressed by the entire team throughout the rest of their lives.

Care is customized according to patient needs and values. Concepts of shared decision making and shared goal setting are already tenets in rehabilitation practices. Issues related to mobility and functional goals, neurogenic bowel management and need for colostomy, management of bladder incontinence and sexuality have been tailored to individual patients needs and values.

The patient is the source of control. Neurologically devastated spinal cord injured patients have lost control of significant bodily functions. Rehabilitation teams attempt to educate and equip such patients to maintain as much control that is physiologically or psychologically possible.

Knowledge is shared freely. Rehabilitation involves all different types of medical and allied health professionals sharing their expertise with the patients and their families.

Decision making is evidence-based. Evidence-based medicine recommendations are typically arranged into Standards or practice that must be done, professional guidelines, clinical protocols, suggested clinical management given certain parameters, or other practice options given best expert consensus. Rehabilitation researchers have developed clinical practice guidelines for stroke, spinal cord injury, venous thrombosis management to reduce the wide variation in care.

Safety is a system property. Rehabilitation does not frequently involve procedural intervention but systemic safety processes for blood transfusion, patient identifiers for medications, or patient elopement while under rehabilitative care are systemic safety issues.

Transparency is necessary. Utilizing physician champions is becoming ever more important to ensure compliance with and compliance with processes. All professionals including therapists, physicians, and nurses should be involved in the development of new process initiatives.

Patient needs are anticipated. Disease management programs in rehabilitation can be utilized for patients with chronic neuromuscular and musculoskeletal conditions. This system of coordinated health care intervention and communication for populations of patients with conditions in which patient self-care efforts for a healthy lifestyle are significant. According to the Disease Management Association of America (DMAA), clinical risk factors are being developed now, but the future will involve identifying and modifying behavioral risk factors.

Data from Healthy People 2020 indicate that more than 50% of global health care costs are related to modifiable behavioral risk factors. Disease management programs support the physician or support practitioner/patient relationship and plan of care, emphasizing prevention of exacerbation and complications, patient empowerment strategies, and evaluate clinical, humanistic and economic outcomes on an ongoing basis with the goal of improving overall health (DMAA.org). A core requirement for a successful disease management program to be effective is an involved, active patient having productive interactions with a prepared, proactive practice team (Wagner et al., 1999 Planned Care Model for Chronic Illness Care). Rehabilitation teams function best with such involved, motivated patients.

Waste is continuously decreased. At a time when Congress is spending nearly \$1 billion dollars per day on Medicare A & B, health care costs and quality must be addressed simultaneously. High health care costs can negatively impact quality. Patients who are losing their insurance coverage have less money to spend on care. Disease management programs can also be helpful in reducing overall health care costs. The Pareto principle indicates that 20% of patients are responsible for 80% of overall costs. Therefore, even 1:1 case management of the highest risk, most severe or highest complexity of patients should decrease costs significantly.

Cooperation among clinicians is a priority. Professional Autonomy and public accountability are viewed by some as a zero sum game. For accountability to increase, autonomy needs to decrease. Few physicians with such autonomy are ready to give up their autonomy but in order to decrease variability and improve public accountability for results, such decrease in autonomy may be necessary. Physical therapists frequently complain about their lack of autonomy. For physicians and physical therapists to work together, therapists can increase their autonomy if the rehabilitation physicians are willing to be held accountable for his/her team's results.

MEASURING QUALITY REHABILITATION SERVICES

National guidelines frequently references for quality databases include www.guidlines.gov, the Institute for Clinical System Improvement www.icsi.org, the Cochrane Library www.informedhealthonline.org, and the Vanderbilt Center for Evidence Based Medicine www.ebm.vanderbilt.edu.

With a change in our electronic documentation to the EPIC system, new documentation and additional clinical decision support may be available for us to establish

a database of all rehabilitation services provided and reference their conformity to national guidelines for therapeutic exercise.

There are many possible outcome measures that can be utilized for acute inpatient hospitalizations. A less than comprehensive list includes:

- development of stage 3-4 pressure sores (JCAHO never events), complications related to patient falls (JCAHO never events), length of stay for acute hospitalization, time to transfer to inpatient rehabilitation, SF-36 measures
- Functional Independence Measure, Hospital anxiety and depression scale
- mini-mental state examination, number of minutes of rehabilitation, number of therapy sessions, and discharge disposition (home, rehabilitation unit, nursing home).

Outpatient quality outcomes can also utilized including: pain visual-analog scale, instruments looking at overall bodily function like the SF-36, Oswestry Disability Index, or selected scales like the Beck Depression Inventory, return to work rates, number of minutes or units of rehabilitation sessions, or patient satisfaction.

SUMMARY

UIHC can be known as a leader in quality of rehabilitation care with the further development of integrated physician and hospital rehabilitation services based upon these principles. We can develop guidelines to be used at UIHC for both inpatient and outpatient care and show that we deliver high quality musculoskeletal rehabilitative care with superior outcomes to the most satisfied patients at the lowest cost.

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THE DIRECT LATERAL APPROACH TO THE DISTAL TIBIA AND FIBULA: A SINGLE INCISION TECHNIQUE FOR DISTAL TIBIAL AND PILON FRACTURES

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ABSTRACT

Distal tibia fractures remain difficult injuries to treat when fracture displacement precludes non-operative treatment. Different methods of treatment including limited internal fixation with external fixation, as well as open reduction and internal fixation have been recommended. Open reduction and internal fixation is often favored for the improved ability to anatomically reduce displaced fractures, particularly articular fractures. However, wound complications due to the associated trauma to the fragile soft tissue envelope in this region continue to be a significant concern.

The authors present a surgical approach for open reduction and fixation of distal tibia and fibula fractures through a single lateral incision, which respects the angiosomes of the distal leg and ankle. This can, in some cases, resolve the need to delay ORIF of the tibia since the incision is essentially the same as that used for the immediate ORIF of fibula fractures, which is commonly used in the staged treatment of distal tibial and plafond fractures. This approach can be extended proximally and distally to allow treatment of other injuries about the ankle and hindfoot. Illustrative cases are provided.

INTRODUCTION

Current treatment of displaced pilon fractures is frequently performed with immediate ORIF of the distal fibular fracture and delayed ORIF of the tibial plafond by various approaches,¹⁻⁴ which require temporary spanning external fixation of the medial side of the ankle. Delay of ORIF of the tibia is based on the concern of the risk of

significant wound healing problems with early incisions over the tibia whether anteromedial or anterolateral.^{3,4} The anteromedial approach provides good exposure of the articular surface centrally and medially and allows for placement of a medial buttress plate to support the comminuted metaphyseal portion of the fracture. It is however less advantageous for exposure of the lateral column of the distal tibia and the syndesmosis. This is especially important in cases where the lateral tibial plafond is dissociated from the fibula and indirect reduction of this lateral fragment cannot be obtained by reducing the fibula fracture. The anteromedial approach has been associated with concerning wound complications. When wound complications do occur with the anteromedial approach they can leave the distal tibia and hardware exposed. Even when healing is uneventful, the subcutaneous location of an anteromedial plate can lead to patient discomfort.^{3,6,8} The minimally invasive percutaneous plating through a medial approach has been recommended by some^{9,10} but often the skin over the medial malleolus, which is the location of the incision for inserting the plate, is particularly thin and commonly traumatized with displaced fractures. For these reasons, delayed treatment has been recommended to minimize the risk of wound complications.⁵

An anterolateral approach to distal tibial pilon fractures has been described.^{11,12} This approach uses a skin incision placed between the distal tibia and fibula, overlying the anterior border of the fibula. This approach avoids the fragile medial soft tissues and allows for a single incision for plating of both the tibia and fibula fractures. This approach also has the advantages of utilizing a single incision for open reduction and internal fixation of both the distal tibia and fibula, and provides excellent exposure of the articular surface and lateral plafond, and lateral column of the distal tibia.¹¹ However, the superficial peroneal sensory nerve is at risk as it traverses this incision and must be directly identified and retracted. Also, the anterior perforating peroneal artery originates from the deep posterior compartment and passes anteriorly through the hiatus that lies between the proximal aspect of the syndesmosis and the interosseous membrane. While this is often traumatized by the injury, and is frequently not of significant size, it can be the sole dorsal artery of the foot in 3% of cases.

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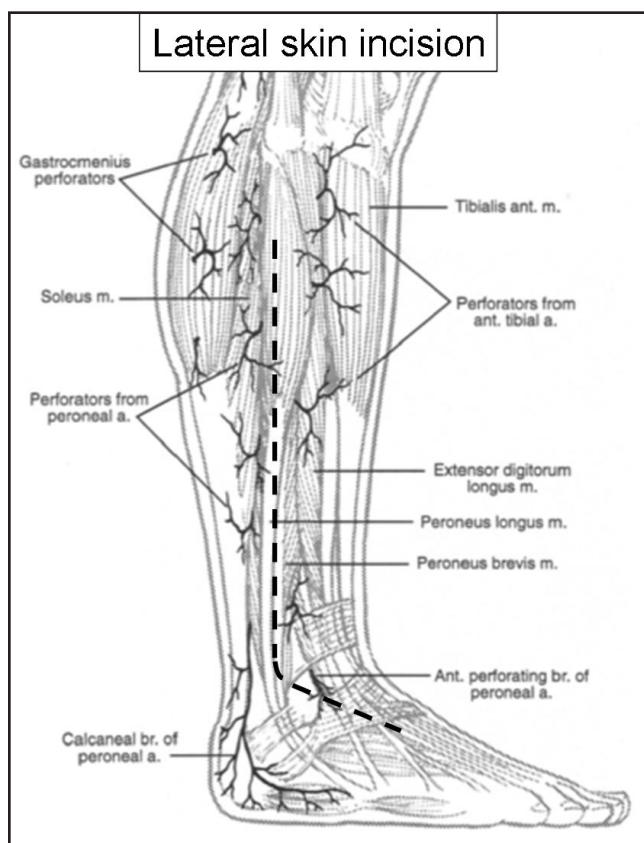


Figure 1. The lateral skin incision was made between the course of the terminal calcaneal branch and anterior perforating branch of the peroneal artery. Reprinted with permission from Attinger, C. Vascular anatomy of the foot and ankle.

A wound dehiscence however will occur directly over the hardware for both the tibia and fibula.

The direct lateral approach to the distal tibia and fibula is performed through a skin incision that is made along the posterior border of the fibula, which is the same incision used for immediate fixation of distal fibula fractures. This incision is generally considered safe for performing immediate open reduction and internal fixation of the distal fibula in cases of displaced and intra-articular distal tibia fractures. The deep portion of the dissection used to approach the tibia from the lateral side does not involve any devitalization of the bone or of the soft tissue flap overlying the distal tibia. The incision preserves the angiosomes of the anterior skin over the distal tibia and ankle by keeping the anterior soft tissues envelope completely intact and thus preserving the blood supply from the anterior tibial artery¹³ (Figure 1). This approach provides excellent exposure of all aspects of both the tibia and fibula fractures, and when closure is performed the intact anterior compartment soft tissues lie over the bone and hardware, which are well away from the skin incision (Figure 2). The superficial peroneal nerve is also maintained within the anterior soft

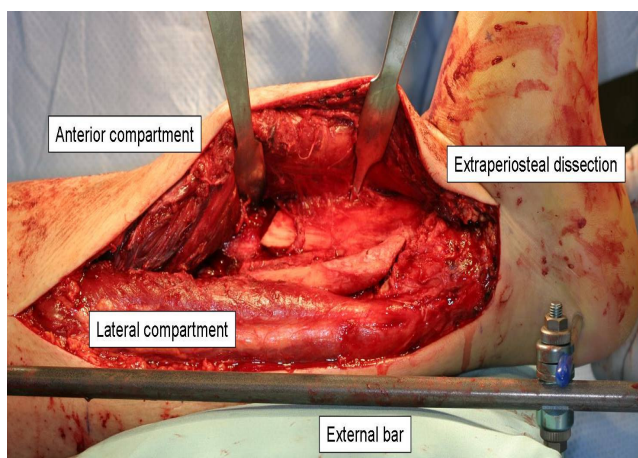


Figure 2. Exposure to the distal tibia from the single extensile lateral approach in an extraperiosteal plane. The anterior compartment has been mobilized with only release of the superior extensor retinaculum and anterior compartment fascia from the intermuscular septum.

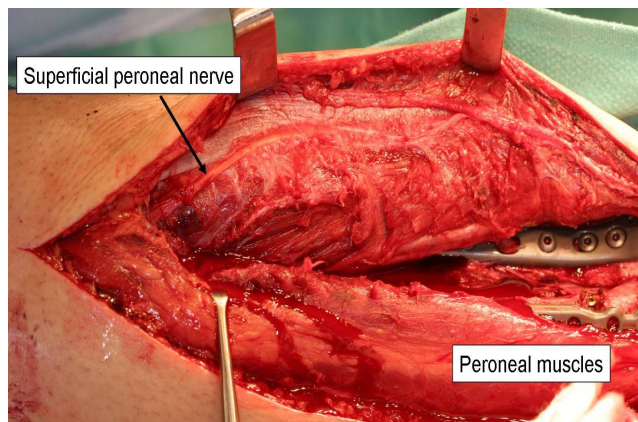


Figure 3. The superficial peroneal nerve crosses anteriorly. In this case the nerve was mobilized with the anterior compartment after the intermuscular septum was released. No dissection at the fascial exit or in the subcutaneous plane was needed.

tissue flap without the need for subcutaneous dissection (Figure 3). The anterior perforating peroneal artery can be identified and if intact can be preserved when warranted, although it rarely supplies the anterior skin to any significant extent, since the anterior tibial artery usually provides most of the anterior angiosome (Figure 4). Extension of the incision distally utilizes the standard lateral hindfoot approach, and the proximal extent of the incision can reach the proximal third junction of the tibia, and would only be limited by the proximal branching of the common peroneal nerve and anterior tibial artery through the interosseous membrane.

OPERATIVE TECHNIQUE

A lateral skin incision is made along the posterolateral border of the fibula. At the tip of the fibula this is then directed toward the base of the fourth metatarsal. The skin incision is extended to the level of the anterior cal-

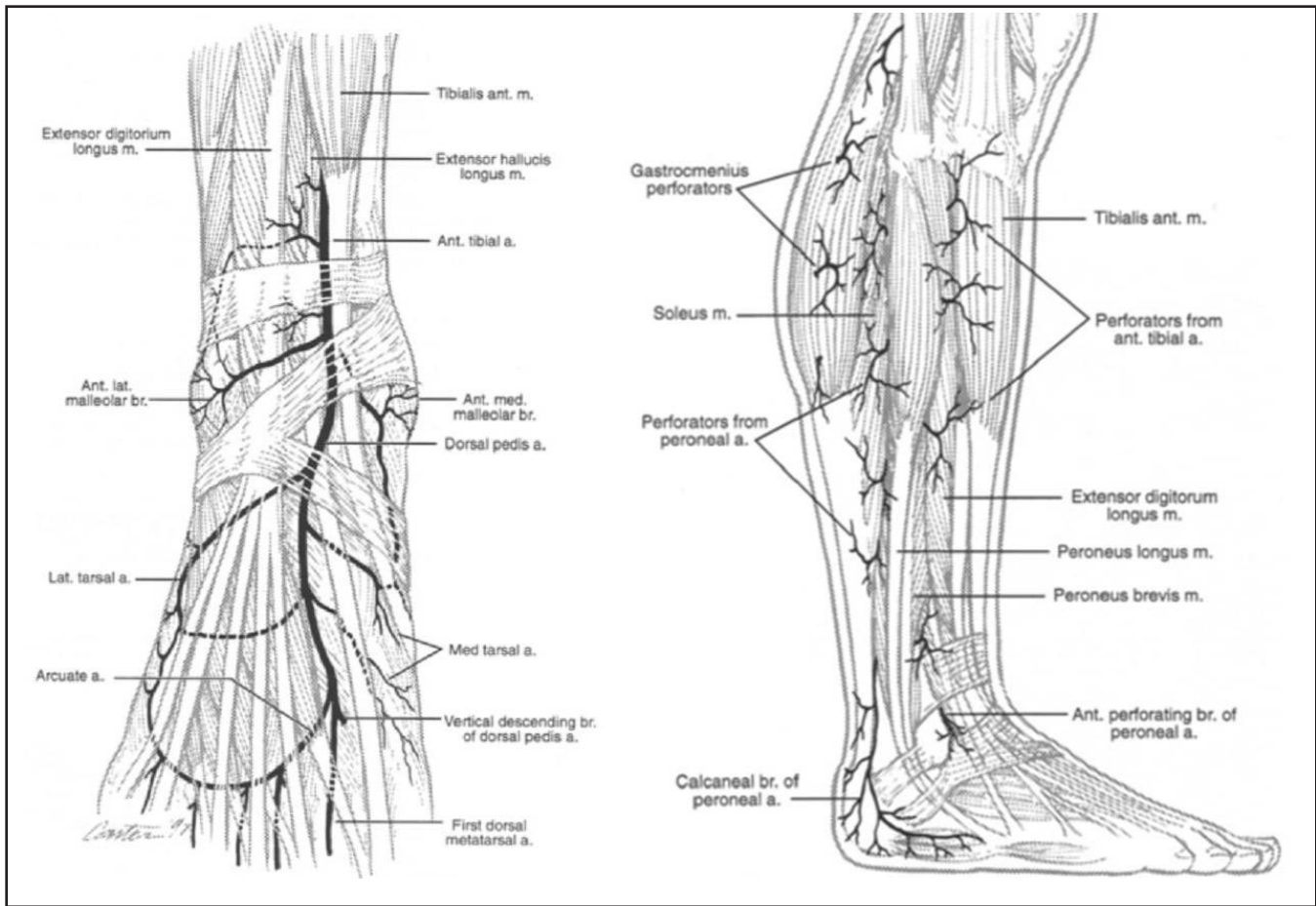


Figure 4. The typical anastomosis of the anterior perforating branch of the peroneal artery and the lateral malleolar artery supplies the skin over anterolateral part. Reprinted with permission from Attinger, C. Vascular anatomy of the foot and ankle. *Operative Techniques in Plastic and Reconstructive Surgery* 1997;4:183 – 198.

canal process, although deep dissection distally is not necessary unless there is an associated talus, calcaneal or cuboid fracture. The dissection is deepened to the fibula and extraperiosteal dissection is carried anteriorly to the anterior syndesmotic fibers and the attachment of the superior extensor retinaculum (SER) onto the fibula. The SER is released sharply off of the anterior border of the fibula with care not to inadvertently cut the underlying anterior perforating branch of the peroneal artery. If the vessel is intact it is usually easiest to directly cauterize it, as it can retract posteriorly if cut at the interosseous membrane exit (Figure 5). The only other soft tissue attachment that must be released is the anterior ankle joint capsule. A blunt elevator such as a freer is passed in the extraperiosteal plane deep to the anterior compartment just above the ankle joint. This plane is advantageous because there are no soft tissue attachments to the distal tibia anteriorly, as the anterior compartment structures must glide over the bone in this area to allow for necessary soft tissue excursion with ankle and hindfoot motion. The anterolateral capsule

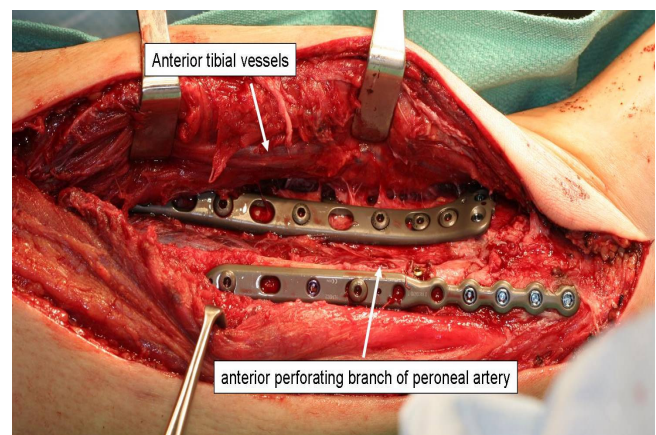


Figure 5. The anterior perforating branch of the peroneal artery which was sacrificed in this case does not lend any meaningful blood supply to the anterior ankle skin flap.

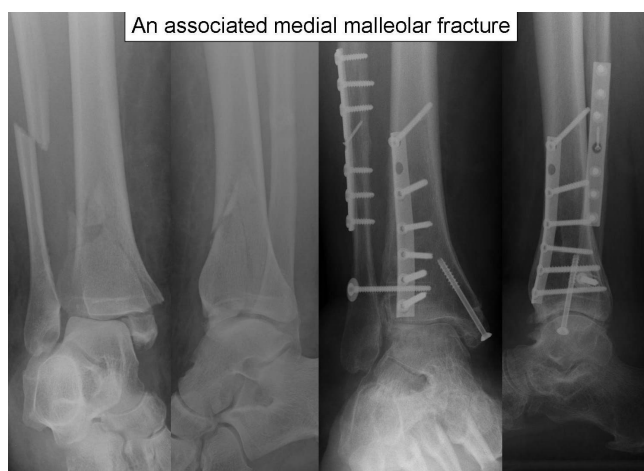


Figure 6. Anatomic reduction and fixation of a Pilon fracture, syndesmotom disruption and fibula fracture. A medial malleolar fracture reduction can be visualized through the lateral incision and fixation applied percutaneously through an incision placed distally.

of the ankle joint is thin and can be found between the inferior aspect of the anterior syndesmotom fibers and the superior border of the anterior talofibular ligament (ATFL). A freer elevator is used to retract the anterior soft tissues, while another freer elevator is placed across the anterior ankle joint to retract the anterior joint capsule anteriorly as well. This places the anterior ankle joint capsule attachment onto the tibia under tension. It can then be sharply elevated off of the anterior edge of the tibial plafond. In some cases the ATFL can be sharply incised to allow for greater visualization of the tibial articular surface. This can later be directly repaired. Proximally the plane between the anterior and lateral compartments is followed until the superficial peroneal nerve (SPN) is identified. It can run along either side of the intermuscular septum, but most commonly within the lateral compartment. The nerve is mobilized without the need for superficial dissection in most cases (Figure 3). In some cases a fibula fracture may occur at the fascial exit of the SPN, in which case a local release of the nerve at the fascial exit may be prudent. At this point the anterior flap can be retracted medially, and broad exposure of the tibia can be appreciated (Figure 2). If the anterior perforating peroneal artery is still intact after the fracture and preserving it is preferred, such as in the case of a large vessel that represents the main blood supply to the dorsal foot, then it is best to use angled retractors rather than a straight retractor to avoid stretching the vessel. The distal 6-7cm of the tibia can be easily approached without sacrificing the vessel, but a plate can be slid beneath it and accessed above and below. Fortunately this anatomic variant is rare occurring only 3% of the time. Posteriorly, the fibula can

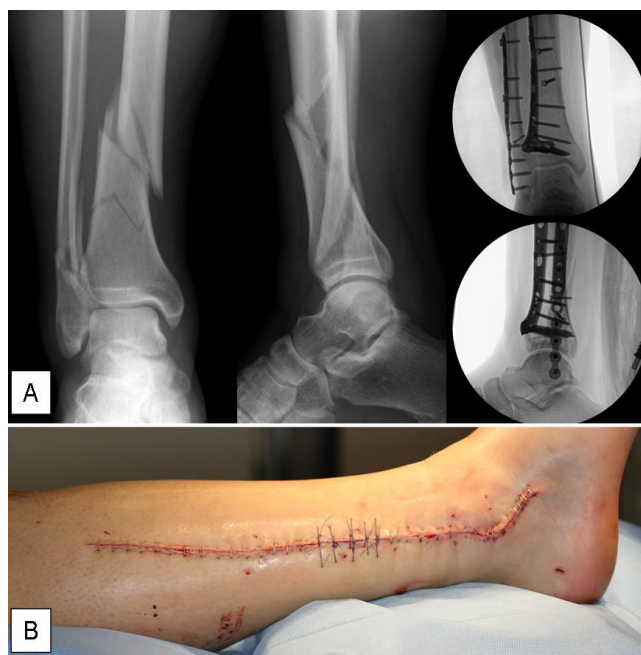


Figure 7. (A) An anatomical reduction and internal fixation with lateral plating of distal tibia and fibula, which was not amenable to intramedullary rodding due to traumatic abrasion over the knee. Operative treatment was performed within 24 hours of injury. (B) The closed surgical skin incision of the direct lateral approach.

be exposed by release of the lateral compartment from the posterolateral border of the fibula with preservation of the superior peroneal retinaculum (SPR). The authors prefer to reduce and fix the tibia first to gain anatomic length and alignment and allow the fibular fracture to provide easier access to the tibial fracture. The syndesmotom incisura is reconstructed and the fibula is reduced and fixed. Medial malleolar fractures can be visualized and reduced from the lateral side and percutaneous fixation can be placed through an incision placed distal to the medial malleolus or at a later time if the medial skin is too fragile even for this (Figure 6).

Finally, the syndesmosis can be reduced and fixed and any remaining soft tissue reconstruction such as the ATFL or SPR can be repaired.

Proximal Extension

The incision can be extended proximally by furthering the mobilization of the anterior compartment off the interosseous membrane and releasing the anterior compartment fascia from the intermuscular septum. There is at least one perforating vessel from the deep posterior compartment that will require cauterization. The proximal extension is limited only by the branching of the common peroneal nerve and the tibial artery exiting through the proximal interosseous membrane.

Distal Extension

Distal extension of the incision can allow access to the lateral talus, calcaneus via the sinus tarsi and the calcaneocuboid joint. The inferior extensor retinaculum can be mobilized from the lateral talar neck for exposure of a talar neck fracture. The inferior extensor retinacular attachment to the calcaneus can be released and the extensor digitorum brevis muscle reflected distally and dorsally to expose the calcaneocuboid joint. The sinus tarsi and posterior facet of the calcaneus are directly observed at this level, inferior to the Anterior talofibular ligament.

DISCUSSION

The classic principles of the treatment of pilon fractures were described by Ruedi and Allgower in 1979. They included restoration of fibular length, anatomical reconstruction of the articular surface of the tibia, bone-grafting to the metaphyseal defect and use of a medial buttress plate.¹⁴ Operative treatment of distal tibial fractures requires flexibility in choosing a treatment based on the fracture pattern and soft tissue injuries. One limitation of the classic approach of Ruedi and Allgower is that the lateral column of the tibia does not always reduce with reduction of the fibula. Lateral approaches are thus more favorable for approaching this fragment and the syndesmosis injury. Newer plates allow for buttressing of the metaphyseal fracture from the lateral side as opposed to the medial side, thus large medial plates can be avoided in some cases.^{6,15} Some fracture patterns may not be amenable to a lateral-only approach, and smaller medial incisions for placement of augmentation may be required.⁵ The combined medial and lateral incisions may be at risk of skin slough, particularly if the injury involves more extensive soft tissue damage or as has been reported, the two incisions are not separated by 7 centimeters or more.¹⁶ Knowledge of the angiosomes and vascular anatomy of skin over the ankle would make the length of parallel incisions and the skin bridge between the edges of the bipedicle flap created by parallel incisions more important than the absolute distance between two incisions.

The posterolateral approach which makes incision through the abundant soft-tissue coverage of the posterior distal tibia does not eliminate the complications common to others approaches.¹⁷ The postero-medio-anterior approach has been described for pilon fracture which prevents further soft tissue injury but there are limited in their ability of visualization for entire articular surface exposure.¹⁸ Minimally invasive percutaneous techniques have been reported and have the advantage of preserving soft tissues, but limited exposure may limit

the extent of reduction.^{10,19} Articular reduction under fluoroscopic imaging without direct visualization may limit full appreciation of incongruity when it exists.²⁰

CONCLUSION

The direct lateral approach to the distal tibia and fibula is a useful surgical approach that utilizes a single skin incision commonly used for immediate open reduction and internal fixation of distal fibula fractures. This approach respects the angiosomes of the skin overlying the anterior ankle region, and preserves the entire soft tissue envelope overlying the distal tibia, which allows for complete coverage of the internal fixation upon wound closure. The skin incision is advantageously remote from the hardware. The lateral column of the tibia and syndesmosis can be directly visualized and reduced. The superficial peroneal nerve can be minimally dissected and preserved within the subcutaneous plane. The incision can be extensile both proximally and distally, and may provide for earlier open treatment of some pilon fractures.

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VARIABILITY IN ANTAGONIST MUSCLE ACTIVITY AND PEAK TORQUE DURING ISOMETRIC KNEE STRENGTH TESTING

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ABSTRACT

BACKGROUND & OBJECTIVE: Strength testing is common in the treatment of people with knee pathology and in research related to knee health. Variability in the magnitude of antagonist muscle activity and peak torque measurements during isometric knee strength testing is not well defined and has potential implications of strength test validity and reliability. The aim of this study was to determine the magnitude and variability (side-to-side, session-to-session) of antagonist muscle activity and peak torque during isometric knee strength testing and to compare and contrast the results of males and females.

METHODS: Electromyograms and torque data were collected from 30 active young people (15 males, 15 females) during isometric strength testing of the knee extensors and flexors at two sessions that took place approximately one week apart. The magnitude of antagonist muscle activity and peak torque during isometric knee strength testing was calculated and the variability in these parameters assessed.

RESULTS: Significant side-to-side differences were observed in the magnitude of antagonist muscle activity when the leg with higher antagonist activity was contrasted with the leg with lower antagonist activity ($P < 0.001$). Significant side-to-side differences were also observed when peak torque measurements were contrasted in a similar manner ($P < 0.001$). No significant differences were observed in peak torque and antagonist activity measurements between sessions. Significantly higher vastus medialis antagonist activity was observed in females ($P < 0.001$).

CONCLUSIONS: Our findings suggest that significant variability in antagonist muscle activity and peak torque is present during maximal isometric knee strength testing. This variability may reduce the accuracy of knee strength tests, especially when side-to-side comparisons are made as is typical in clinical settings. The results of this study may be helpful when interpreting strength test results and setting criteria for patient progression.

INTRODUCTION

Knee strength tests are commonly used by clinicians who treat patients with knee pathology and scientists who study the etiology and effects of knee disorders, treatment methods for these conditions, and treatment outcomes in this population. Isometric knee strength tests allow the knee to be fixed in a safe position during testing and inherently provide control that assists with test reproducibility. Isometric tests are also preferable when performing knee strength tests involving superimposition of electric stimuli (i.e., interpolated twitch or burst superimposition tests), which allow quantification of quadriceps muscle activation levels in addition to voluntary torque generation capacity.¹

It is widely accepted that the peak torque generated at a joint is the sum of the moments generated by the agonist and antagonist muscles acting at the joint.² Antagonist muscle activity, commonly referred as coactivation or co-contraction, is defined as simultaneous activation of both agonist and antagonist muscle groups during static or dynamic contractions.³ Antagonist muscle activity during maximal contractions theoretically produces a moment that may counter the moment of interest, thereby reducing test accuracy. For example, hamstring muscle activity during knee extensor strength testing produces a flexion moment that may result in an underestimation of true knee extensor strength. It is generally assumed that antagonist muscles are essentially silent during strength tests; however, evidence from studies evaluating isokinetic strength tests suggests otherwise.^{4,6} It is unclear whether findings from dynamic isokinetic tests are translatable to isometric strength tests. Moreover, data on the side-to-side and session-to-session variability in antagonist muscle activity during knee strength testing is lacking. An understanding of the variability in antagonist activity is meaningful as this information could have

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important implications for strength testing validity and reliability. Finally, it is unknown if there are sex differences in the magnitude of antagonist activity present in maximal isometric contractions about the knee. Recent evidence of sex differences in muscle activation during sub-maximal contractions about the knee suggests that this is a possibility.⁷ Knowledge of such differences would be meaningful as it would further understanding of sex differences in human physiology and may have implications for strength tests and rehabilitation.

The aim of this study was to determine the magnitude and variability (side-to-side, session-to-session) in antagonist muscle activity and torque measurements during maximal isometric strength testing of the knee extensors and flexors. Based on pilot work, we hypothesized that significant (approximately 10% maximum) antagonist activity would be observed in the lateral hamstrings and the quadriceps muscles during maximal voluntary isometric contractions (MVICs). In addition, we hypothesized that significant side-to-side and session-to-session variability in antagonist muscle activity and peak torque measurements would be observed. A secondary aim of the study was to contrast the results of males and females of similar age and activity-level to determine if antagonist activity during maximal isometric contractions differs by sex. We hypothesized that no significant differences in antagonist muscle activity would be observed between males and females.

METHODS

Subjects

Thirty active young people (age 22.6 ± 1.7 years, BMI 22.7 ± 2.7 , Tegner Activity Score⁸ 6.3 ± 1.1) with no history of significant lower extremity injuries volunteered to participate in this study. The sample included 15 males and 15 females who were similar in age (male 22.9 ± 1.4 years, female 22.3 ± 2.0 years) and activity level (Tegner Activity Scores: male 6.4 ± 1.4 , female 6.1 ± 0.7). Exclusion criteria included a history of significant lower extremity muscle or tendon injury, knee ligament injury, abnormal KT-2000TM evaluation (≥ 3 mm side-to-side difference in laxity), history of lower extremity surgery, an ankle sprain or fracture within the prior six months, lower extremity nerve injuries, abnormal gait pattern, and the inability to complete two testing session within a 2 week period. A brief physical examination of the lower extremity was performed bilaterally to confirm that subjects could be considered to be injury-free with good lower extremity function. No potential subjects were excluded from the study based on their physical exam or medical history. All subjects were right leg dominant as determined by asking the subjects which leg they would use to kick a ball as far as possible. This

study was approved by the University of Iowa Human Subjects Research Institutional Review Board and each subject provided written informed consent to participation using a form approved by this review board.

Testing Procedures

Subjects performed a five minute "warm-up" on a cycle ergometer just prior to participation. Double differential surface electromyography (EMG) preamplifiers (model MA-311, Motion Lab Systems, Inc., Baton Rouge, LA, USA; 20x gain, > 100 dB minimum common mode rejection, input impedance > 100,000 M Ω , noise < 1.2 μ V RMS) were then applied over the muscle bellies of the semitendinosus (MH), biceps femoris longus (LH), vastus lateralis (VL), rectus femoris (RF), and vastus medialis (VM) muscles after cleaning the skin with alcohol swabs. Electrode placement sites were selected according to the recommendations of Perotto.⁹ Manual muscle testing was performed to confirm appropriate electrode placement and to check for signs of crosstalk from adjacent muscles. Subjects were then positioned on and secured to a HUMAC NORM Testing and Rehabilitation System (Computer Sports Medicine, Inc., Stoughton, MA, USA) according to the manufacturer's testing guidelines. Subjects sat on a small platform placed on the testing system's chair to unload the thigh and thereby minimize the likelihood of noise associated with pressure on the EMG preamplifiers fixed over the hamstrings muscles. Knee and hip position were standardized at 60° and 90° of flexion, respectively. The test system's torque arm pad was fixed to the shank approximately 7 cm proximal to the medial malleolus. The length of the torque arm and all test system position settings were recorded for use in repeat testing. The order in which subjects' legs were tested was randomized *a priori* using a computer-based random number generator.

Three baseline EMG traces were collected just prior to strength testing while subjects sat quietly on the test system. Five sub-maximal isometric knee extension and flexion trials were then performed to familiarize the subjects with isometric contractions and prepare the subjects' muscles for testing. Strength testing was initiated following a one minute rest period. Subjects performed five maximal isometric knee extension contractions (Figure 1) and five maximal isometric knee flexion contractions in alternate order (i.e., extension, flexion, extension, flexion, etc). All trials were five seconds in duration. Fatigue was minimized by standardizing 90 seconds of rest between extension and flexion trials so that 180 seconds transpired between like trials. Maximal effort was facilitated through the use of loud verbal encouragement and by allowing subjects to view their real time torque curves on the test system's display

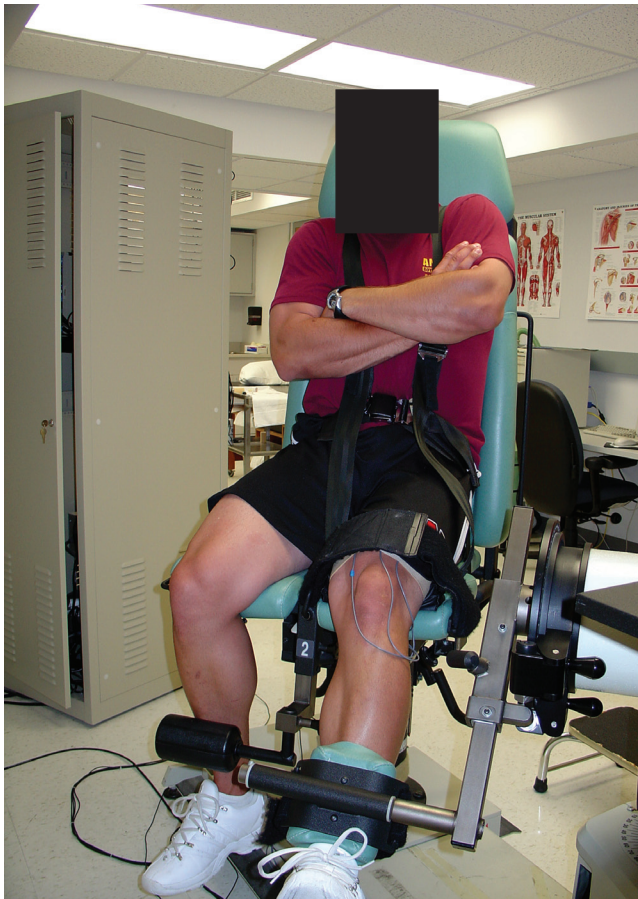


Figure 1. A subject performing an isometric knee strength test on the test system.

during testing. When testing was completed on the first side, subjects were positioned for testing of the opposite side. The testing procedures for the opposite leg were identical to those used when testing the first leg. When subjects had completed testing with both legs they were scheduled to return to the laboratory one week later when repeat testing was performed using identical methods.

Signal Sampling, Conditioning, and Processing

Electromyograms and torque signals were sampled at 1000 Hz using software written in LabVIEW 7.0 (National Instruments Corporation, Austin, TX, USA). The signals from the HUMAC NORM Testing and Rehabilitation System were passed through an eighth order analog Butterworth low pass filter with a cut-off frequency of 10 Hz and then converted to torque values (N·m) using calibrated conversion factors that were validated onsite prior to testing. Electromyographic signals were conditioned by passing them through an eighth order analog Butterworth low pass filter with a cut-off frequency of 500 Hz. A second LabVIEW program was used to

determine the peak torque value in each trial and to post-process the EMG data. All EMG data were full-wave rectified. The baseline EMG trials were averaged and then subtracted from the EMG data recorded during each trial. The integrated EMG (IEMG) magnitude during the 100 ms window preceding peak torque was used for the analysis of antagonist muscle activity. This window provides EMG data that are particularly meaningful because these are the data that are most closely related to the peak torque measurement. The five 100 ms IEMG samples recorded for each muscle in each direction were averaged for use in analysis (i.e., the five 100 ms IEMG samples for the VL muscle recorded during the extension trials were averaged and the five 100 ms IEMG activity for the VL muscle in the flexion trials were averaged). The magnitude of antagonist muscle activity present during testing (hamstrings muscle activity in extension trials and quadriceps muscle activity in flexion trials) was determined by representing the values recorded when the muscles were antagonists as a percentage of the respective values recorded when the muscles were agonists. For example, the magnitude of lateral hamstrings activity present during knee extensor strength testing was determined by: $(\text{mean LH IEMG activity in extension} / \text{mean LH IEMG activity in flexion}) \times 100$. Each subject's mean peak torque for knee extension and flexion was determined by averaging the peak torque values from the five maximal trials in the respective movement directions. The torque produced by each subject was corrected for gravity to account for the weight of the subject's limb. A limb symmetry index was calculated for each subject using the following equation: $(\text{mean peak torque produced by the weaker leg} / \text{mean peak torque produced by the stronger leg}) \times 100$.

Data Management and Analysis

All statistical analyses were performed using SPSS for Windows (SPSS Inc., Chicago, IL, USA). Descriptive statistics were calculated for each variable. Repeated measures ANOVA with 2 within-subjects factors (side, session) and sex as a between-subjects factor was used to evaluate differences by side, session, and sex for each dependent variable (MH activity in peak extension, LH activity in peak extension, VL activity in peak flexion, RF activity in peak flexion, VM activity in peak flexion, peak torque in extension, and peak torque in flexion). Our pilot-testing suggested that the limb that had higher magnitude of antagonist activity and peak torque varied considerably between subjects and was not related to subjects' limb dominance. Consequently, the variability between legs mathematically canceled out making it appear that there was no difference by side. Therefore, the magnitude of antagonist muscle activity was contrasted

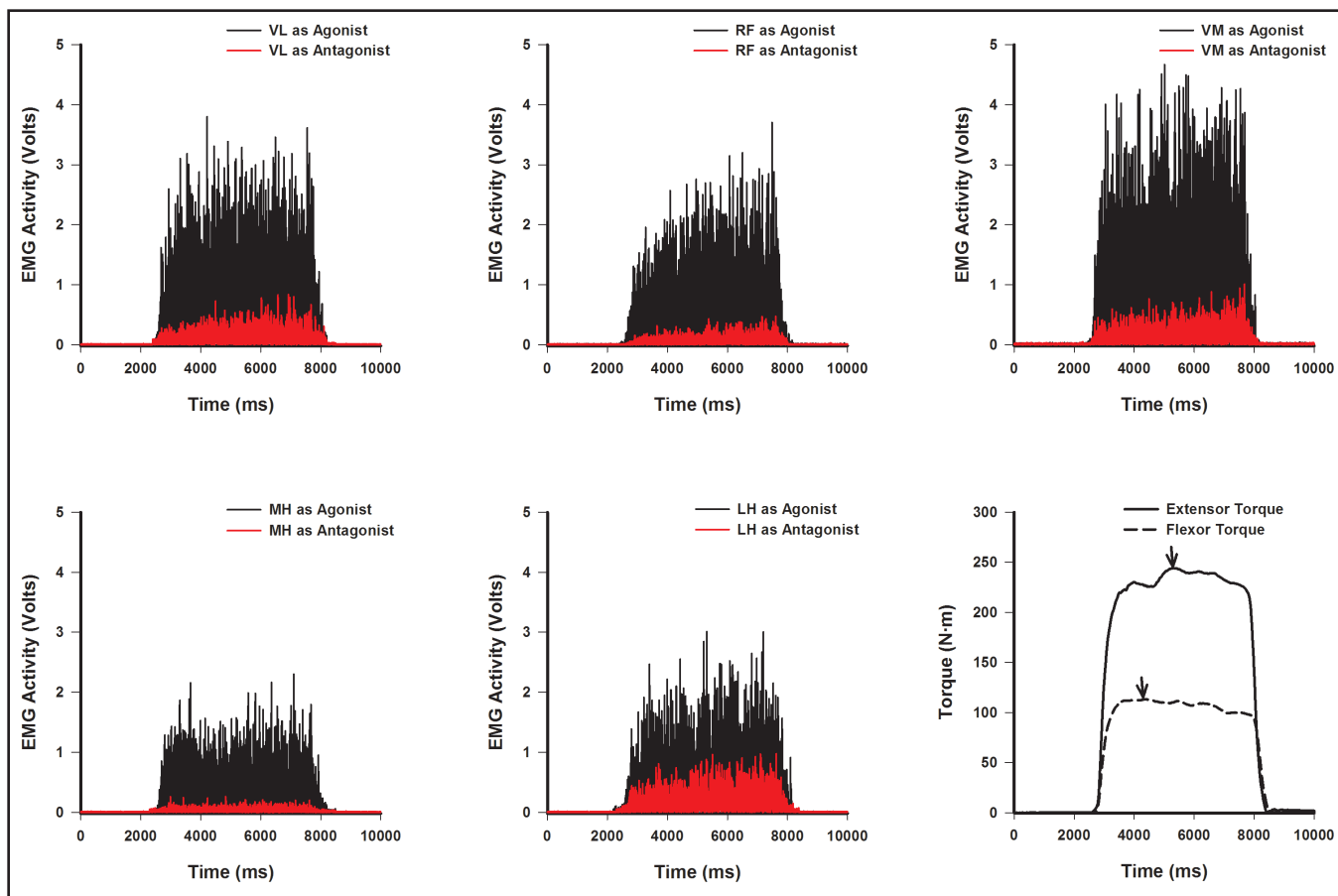


Figure 2. A sample raw electromyographic recording of muscle activity with associated torque traces from a subject's isometric knee extensor and flexor strength tests. The agonist (black) and antagonist (red) activity of the five knee muscles tested demonstrate the noteworthy antagonist activity during isometric knee strength testing. Arrows indicate the epoch at which the subject produced peak torque values. VL: Vastus Lateralis; RF: Rectus Femoris; VM: Vastus Medialis; MH: Semitendinosus; LH: Biceps Femoris Longus.

by side (right vs. left) and also by contrasting the results of the leg that produced higher antagonist muscle activity with the leg that produced lower antagonist muscle activity. Similar contrasts (right vs. left and higher vs. lower) were performed for peak torque measurements.

RESULTS

Antagonist Muscle Activity

Antagonistic muscle activity (Figure 2) was observed in each muscle during maximal isometric knee strength testing (mean quadriceps activity: 7 to 16% maximum, mean hamstrings activity: 7 to 19% maximum) (Table 1). Each of the five muscles had significant differences ($P < .001$) in mean antagonist IEMG activity between sides when the leg producing higher IEMG activity was contrasted with the leg producing lower IEMG activity (Figure 3); however, when the activity of each muscle was contrasted by side (i.e., right vs. left), no significant differences were observed ($P = 0.192$ to 0.670 , Figure 4A). No muscle displayed significant differences in activity between sessions ($P = 0.078$ to 0.848 , Figure

4B); however, the leg that produced higher antagonist activity changed across test sessions in about 50% of the sample. Females had significantly higher ($P = .001$) mean antagonistic vastus medialis IEMG activity than males; all other muscles displayed no significant difference by sex ($P = 0.130$ to 0.518 , Figure 3).

Peak Torque

Males produced greater mean peak torque ($P < .001$) than females (Table 1). As was the case with antagonist muscle activity, there was no significant difference by side when the peak torque generated by the subjects' right thigh muscles was contrasted with the results from their left side ($P = 0.150$ for extensor peak torque, $P = 0.536$ for flexor peak torque, Figure 5A); however, a significant difference ($P < .001$) was observed for both torque directions when results of the leg that produced higher peak torque were contrasted with those from the leg that produced lower peak torque (Figure 5B). The mean knee extensor side-to-side symmetry index

TABLE 1
Antagonist muscle activity (% maximum) and peak torque (N•m) during isometric knee strength testing

| Sex | Limb | | Session 1 | 95% CI | Session 2 | 95% CI |
|--------|-------|--------------------|----------------|-----------------|----------------|-----------------|
| Female | Right | VL _{Flex} | 11.63 ± 1.44 | 8.81 - 14.45 | 9.17 ± 1.08 | 7.05 - 11.29 |
| | | RF _{Flex} | 12.05 ± 1.85 | 8.42 - 15.68 | 10.75 ± 1.95 | 6.93 - 14.57 |
| | | VM _{Flex} | 16.32 ± 1.08 | 14.20 - 18.44 | 13.57 ± 0.87 | 11.86 - 15.28 |
| | | MH _{Ext} | 9.12 ± 1.57 | 6.04 - 12.20 | 10.06 ± 1.70 | 6.73 - 13.39 |
| | | LH _{Ext} | 14.17 ± 3.53 | 7.25 - 21.09 | 12.24 ± 1.60 | 9.10 - 15.38 |
| | | PT _{Ext} | 177.87 ± 8.24 | 161.72 - 194.02 | 180.95 ± 9.83 | 161.68 - 200.22 |
| | | PT _{Flex} | 93.47 ± 4.55 | 84.55 - 102.39 | 91.98 ± 4.84 | 82.49 - 101.47 |
| Female | Left | VL _{Flex} | 8.85 ± 0.83 | 7.22 - 10.48 | 9.13 ± 0.74 | 7.68 - 10.58 |
| | | RF _{Flex} | 10.83 ± 2.17 | 6.58 - 15.08 | 10.76 ± 1.62 | 7.58 - 13.94 |
| | | VM _{Flex} | 15.77 ± 1.16 | 13.50 - 18.04 | 16.49 ± 1.49 | 13.57 - 19.41 |
| | | MH _{Ext} | 10.57 ± 1.75 | 7.14 - 14.00 | 8.13 ± 1.23 | 5.72 - 10.54 |
| | | LH _{Ext} | 15.46 ± 2.65 | 10.27 - 20.65 | 15.75 ± 2.72 | 10.42 - 21.08 |
| | | PT _{Ext} | 193.79 ± 9.47 | 175.23 - 212.35 | 181.98 ± 10.94 | 160.54 - 203.42 |
| | | PT _{Flex} | 98.32 ± 4.39 | 89.72 - 106.92 | 95.91 ± 5.03 | 86.05 - 105.77 |
| Male | Right | VL _{Flex} | 7.11 ± 0.72 | 5.70 - 8.52 | 8.96 ± 0.97 | 7.06 - 10.86 |
| | | RF _{Flex} | 7.84 ± 1.09 | 5.70 - 9.98 | 7.43 ± 1.48 | 4.53 - 10.33 |
| | | VM _{Flex} | 12.28 ± 0.83 | 10.65 - 13.91 | 11.37 ± 1.04 | 9.33 - 13.41 |
| | | MH _{Ext} | 6.64 ± 0.71 | 5.25 - 8.03 | 7.24 ± 1.42 | 4.46 - 10.02 |
| | | LH _{Ext} | 14.83 ± 3.05 | 8.85 - 20.81 | 15.99 ± 3.76 | 8.62 - 23.36 |
| | | PT _{Ext} | 246.59 ± 11.45 | 224.15 - 269.03 | 254.10 ± 12.40 | 229.80 - 278.40 |
| | | PT _{Flex} | 141.45 ± 7.94 | 125.89 - 157.01 | 136.12 ± 8.05 | 120.34 - 151.90 |
| Male | Left | VL _{Flex} | 7.39 ± 0.83 | 5.76 - 9.02 | 8.19 ± 2.09 | 4.09 - 12.29 |
| | | RF _{Flex} | 9.87 ± 2.67 | 4.64 - 15.10 | 9.35 ± 2.60 | 4.25 - 14.45 |
| | | VM _{Flex} | 12.15 ± 1.42 | 9.37 - 14.93 | 10.44 ± 0.87 | 8.73 - 12.15 |
| | | MH _{Ext} | 8.22 ± 1.01 | 6.24 - 10.20 | 7.82 ± 1.04 | 5.78 - 9.86 |
| | | LH _{Ext} | 19.13 ± 2.70 | 13.84 - 24.42 | 16.06 ± 2.50 | 11.16 - 20.96 |
| | | PT _{Ext} | 251.81 ± 12.10 | 228.09 - 275.53 | 258.70 ± 10.0 | 239.10 - 278.30 |
| | | PT _{Flex} | 138.86 ± 7.49 | 124.18 - 153.54 | 137.66 ± 8.26 | 121.47 - 153.85 |

Data are presented as mean ± standard error of the mean with 95% confidence intervals. VL, Vastus Lateralis; RF, Rectus Femoris; VM, Vastus Medialis; MH, Semitendinosus; LH, Biceps Femoris Longus; Flex, Flexion; Ext, Extension; PT, Peak Torque.

was 89.9% for females and 91.5% for males. The mean knee flexor symmetry index was 92.5% for females and 87.1% for males. Peak torque values were similar across sessions for both muscle groups (Figure 4B). The leg that produced higher peak torque remained the same in majority of the subjects across test sessions (knee extensors: 70% consistent, knee flexors: 80% consistent).

DISCUSSION

The mean antagonist muscle activity observed in the hamstrings and quadriceps muscles of the subject in this study during maximal isometric knee extensor

and flexor strength testing ranged from 7.1% to 19.1% of maximum values (Table 1), which supports our first hypothesis. These data are consistent with the findings from studies evaluating antagonistic muscle activity in isokinetic tests.^{5,6} The magnitude of antagonistic activity observed in the lateral hamstrings and vastus medialis muscles was similar and substantially higher than the magnitude of activity observed in the vastus lateralis, rectus femoris, and medial hamstrings muscles. This finding is also consistent with of results in the isokinetic testing literature.⁴ The magnitude of lateral hamstrings activity during knee extension trials was generally about

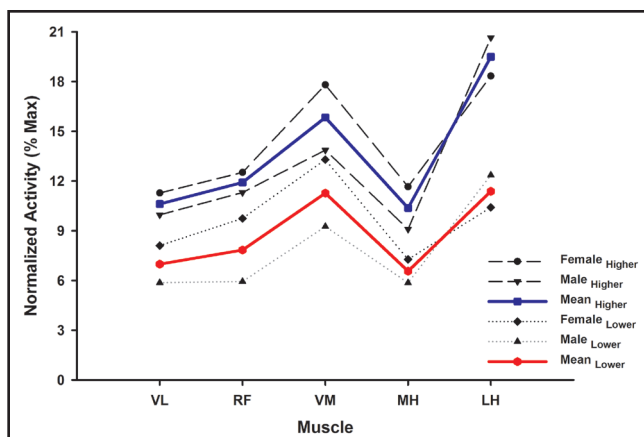


Figure 3. Plots demonstrating the difference between the mean normalized antagonist activity by side for the 5 muscles of the male and female subjects when the values of the leg that produced higher antagonist activity was contrasted with those from the leg that produced lower antagonist activity. Bold colored lines represent the mean for all subjects irrespective of the sex of the subject. All muscles exhibited significant differences between sides ($P < 0.001$). Females had significantly higher VM antagonist activity when compared to males ($P = 0.001$). Note the limb that produced lower VM antagonist activity in females is similar in magnitude to the limb that produced higher VM in males. VL: Vastus Lateralis; RF: Rectus Femoris, VM: Vastus Medialis; MH: Semitendinosus; LH: Biceps Femoris Longus.

twice that recorded from the medial hamstrings irrespective of the side tested or test session. This agrees with the results of Aagaard et al.⁶ who reported values of approximately 30% maximum for the lateral hamstrings and 10% maximum for the medial hamstrings during maximal isokinetic knee extension. Aagaard et al.⁶ attributed the

observed hamstrings activity during knee extensor testing to a protective mechanism associated with loading of the ACL during intense quadriceps muscle contraction in terminal knee extension. In the current study, however, subjects were tested in an isometric fashion at 60° of knee flexion, which is a point in the knee range of motion at which the ACL experiences little strain.¹⁰ Despite this fact, we observed significant hamstrings activity during maximal knee extension trials. This finding argues against ACL strain being a primary source of the observed antagonistic hamstrings activity.

There are several possible explanations for the observed antagonist activity. At least some of the antagonist activity could be directed at stabilizing the femur so that the agonist musculature has a stable platform from which to transfer force to the tibia. This simple and reasonable explanation is, however, rather difficult to test. Another plausible explanation relates to a broad increase in excitability in the nervous system during maximal effort. Although standard testing procedures includes the use of seatbelts and positioning aimed at minimizing compensation strategies and loss of energy (e.g., crossing the arms over the chest), it is obvious that muscle contraction is occurring broadly when one observes the facial expressions and muscle tone of the arms, shoulders, and opposite legs of the person being tested. This broad activity suggests that the excitability in the nervous system is increased in a relatively global manner as it is unlikely that there is a direct benefit from most of this extraneous muscle contraction. Mini-

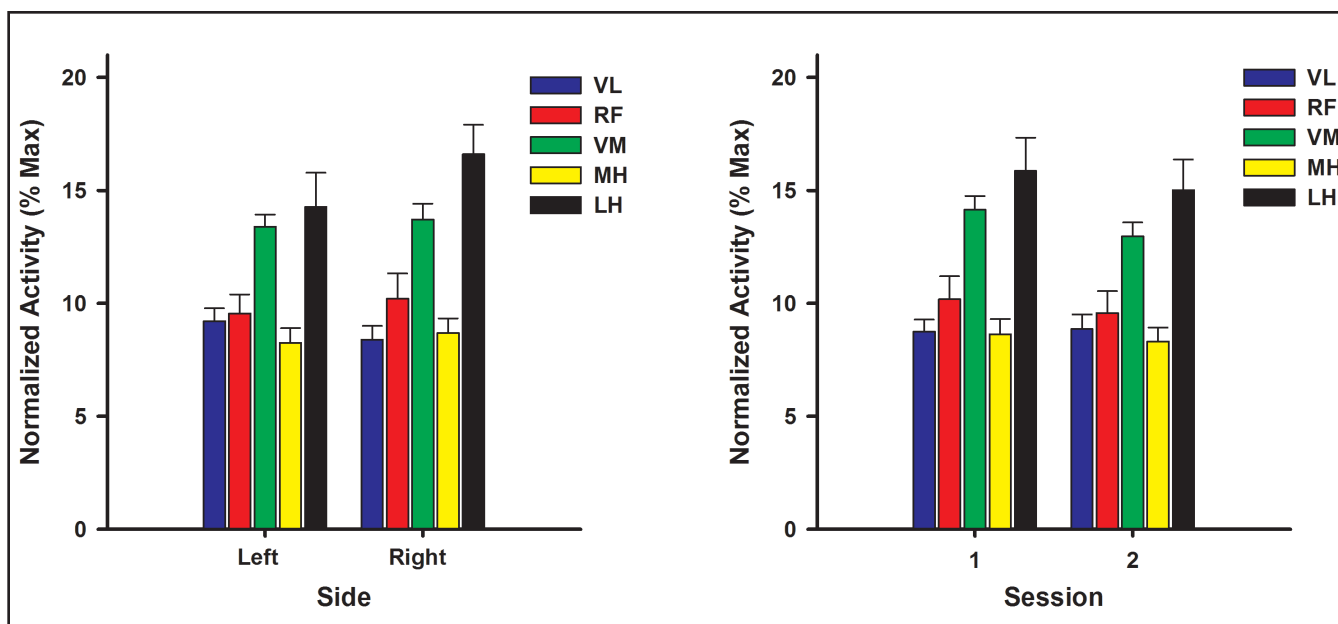


Figure 4. The mean normalized antagonist activity for the 5 knee muscles contrasted between left and right side (A) and across test sessions (B). Note that there are no differences in the magnitude of antagonist activity between left and right side and across test sessions. Error bars represent standard error of the mean. VL: Vastus Lateralis; RF: Rectus Femoris, VM: Vastus Medialis; MH: Semitendinosus; LH: Biceps Femoris Longus.

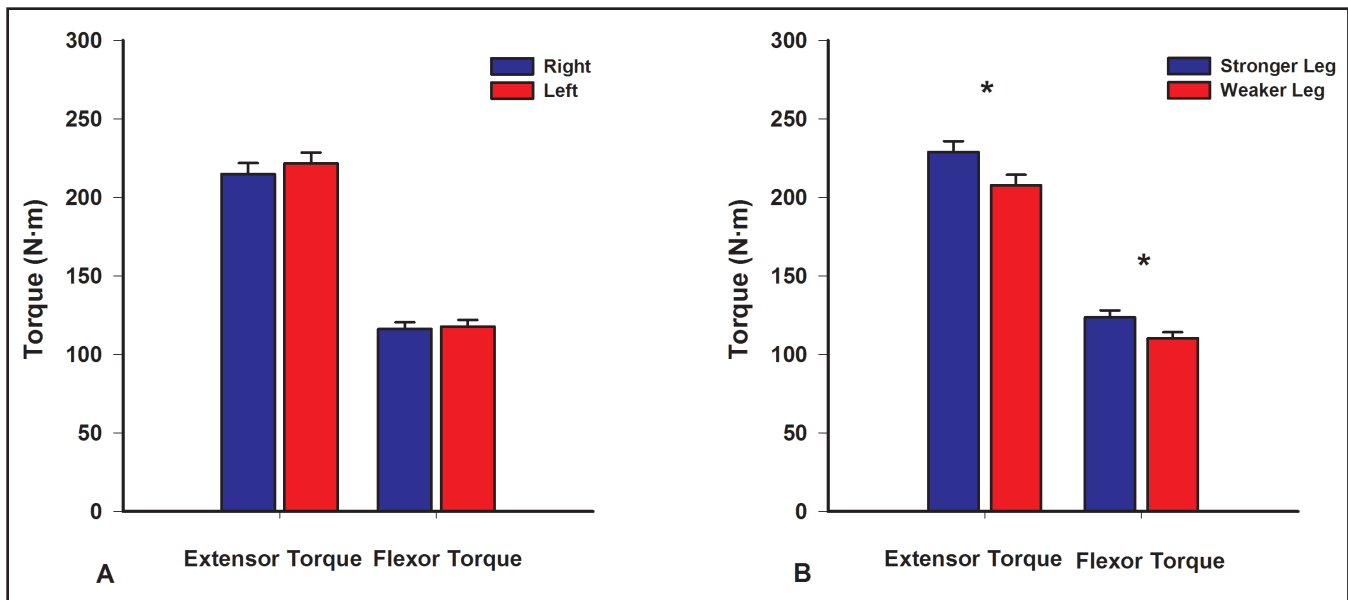


Figure 5. The mean peak torque for the knee extensors and flexors when contrasted as left versus right side was not significantly different. Conversely, significant differences ($P < 0.001$) were observed when the leg that produced higher peak torque was contrasted with the leg that produced lower peak torque (B). This was consistent across test sessions. Error bars represent standard error of the mean and asterisks identify significant differences ($P < 0.05$).

mizing (inhibiting) this widespread increase in neural drive without reducing torque generation is difficult without considerable practice with real-time feedback on performance. Hence, it is reasonable that at least some of the observed antagonist activity is a result of a spillover of neural drive that is difficult to control. A related issue that may also be a factor in the observed antagonist activity is the fact that MVICs are a novel task for many people. Evidence indicating that training can reduce the magnitude of antagonist activity of observed in isometric contractions supports the idea that some of the antagonist activity may be associated with task novelty.^{11,12} Although practice trials are routinely performed before strength testing, the number of practice trials that can be given is limited as fatigue can set in and compromise the test results. Providing a series of training sessions before administering strength tests is generally impractical. Consequently, task novelty is a difficult issue to address.

It is generally assumed that antagonist activity is negligible during knee strength testing based on the widely held concept of reciprocal inhibition (i.e., antagonist muscles are inhibited during tasks in which agonist muscles are highly active).¹³ This assumption is the result of an oversimplification of the phenomenon of reciprocal innervation. Sir Charles Sherrington,¹⁴ who is credited with introducing the concept of reciprocal innervation, in fact suggested that under certain circumstances the nervous system may concurrently activate both the extensor and flexor “half center,” a process that he referred

to as double reciprocal innervation. Antagonist muscle activation is most frequently observed in tasks that require high precision, those that involve high magnitudes of force production, or those that include high velocities of limb movement.¹³ Our findings suggest that although antagonist muscles are largely inhibited, this inhibition is incomplete and/or double reciprocal inhibition is present.

Scientists postulate that antagonist muscle activity is primarily controlled by central mechanisms.^{3,15,16} De Luca and Mambrito¹⁵ suggested that in flexion-extension tasks, agonist-antagonist pairs operate under “common drive” as if they belong to the same motoneuron pool. Researchers have since suggested that while antagonist activity does appear to be controlled primarily through supraspinal mechanisms, the excitation of antagonist motoneuron pools may occur via a pre-synaptic mechanism in which the nervous system actively inhibits the disynaptic Ia inhibitory pathway through descending commands rather than through a common drive mechanism.^{3,16} Understanding the source of this antagonist activity is meaningful with respect to the neurophysiology and sensorimotor control of knee function. Although the exact source of this activity is currently unknown, our results and the literature cited suggest that such activity should be expected and is strongly supported.

We hypothesized that there would be significant variability in the magnitude of antagonist activity observed by side and across days. A significant difference in the magnitude of antagonist activity was observed in like muscles across legs, but there was no difference across

sessions. Close inspection of the data revealed that the leg displaying higher antagonist muscle activity changed across test sessions in about half of the sample. Hence, some variability is in fact present across test sessions.

The observed side-to-side difference in antagonist activity is an important finding because it indicates that this activity (and the moment associated with it) does not mathematically cancel across sides. Although the mean differences in antagonist activity observed in each muscle across sides were relatively small (4 to 6% maximum values), some people had large differences between legs. This suggests that side-to-side differences in antagonist activity are likely to have a larger effect on side-to-side strength comparisons on a patient-by-patient basis than they are when the results of a sample of people are being considered. Moreover, it is the combined effect of the antagonist activity in the muscles of each functional group that must be considered rather than the values of the individual muscles alone. It is not possible to determine whether the observed antagonist activity leads to clinically meaningful measurement error based on the results of the current study alone because the quantification of the moment associated with the antagonist activity would require knowledge of muscle morphology and the EMG-force relationships of each muscle. Determining the moments and measurement error associated with antagonist muscle activity in knee strength testing is the focus of a follow-on research project.

Females consistently demonstrated higher vastus medialis antagonist activity than males, which agrees with data from other studies.^{7,17} Hence, there is a growing body of evidence suggesting that females and males differ in the way they use their vastus medialis muscle. This is interesting considering the evidence related to female predisposition to certain types of knee injury.¹⁸⁻²⁰ We note, however, that it remains unclear whether the observed sex difference in vastus medialis activity is clinically relevant.

A significant difference in peak torque was observed between sides when comparing the leg that produced higher peak torque to the leg that produced lower peak torque, but no significant difference was observed in peak torque measurements across sessions. The significant difference in peak torque between sides was a consistent finding in our sample. About 40% of the subjects displayed a difference of at least 10% between sides at both test sessions. The approach of contrasting the subjects' stronger legs with their weaker legs instead of simply performing a right-to-left comparison has been used by others who have reported similar variance in side-to-side peak torque in isokinetic testing designs.²¹

²² The opposite leg is commonly used as a comparison for strength tests with the assumption that knee exten-

sor or flexor strength is similar across sides. Although a side-to-side comparison is often the only practical method because pre-injury data are unavailable, our results suggest that the opposite side is in fact a less than ideal comparison for knee strength measurements. The observed side-to-side differences in peak torque may be related to inter-limb variations in muscle morphology, voluntary activation, and/or antagonist activity. Tate et al.²³ have demonstrated that young athletic people usually have side-to-side differences in thigh muscle morphology. Although we are unaware of any published studies in which side-to-side differences in voluntary muscle activation have been assessed by contrasting side-to-side results in the manner used in the current study, preliminary data from our laboratory indicate that side-to-side differences in voluntary activation are common.

The prevalent misconception that knee extensor and flexor strength is similar between sides is understandable because most researchers have evaluated strength by contrasting a sample's right and left legs or their "dominant" and "non-dominant" legs. The variability between legs mathematically cancels out with this approach because about half a sample is usually stronger on the right each side and the other half on the left. Our data provide an example of this cancellation. The side-to-side differences in peak torque observed in this study and by others in isokinetic designs have important implications for clinicians who use strength test results as criteria for patient progression and return-to-sport and for research who use side-to-side strength comparisons in defining the effects of pathology or outcomes of treatment. The fact that it is typical for healthy people to have about 10% differences in knee strength across sides suggests that in the absence of pre-injury data, it is equally likely that a 90% limb symmetry index indicates that there is a 20% strength deficit or no strength deficit at all as it is to indicate that there is a 10% strength deficit. Hence, clinical decision making criteria based on strength should be moderate (e.g., 80% contralateral strength) rather than stringent.

Although our results indicate that knee strength tests are imperfect, it would be inappropriate to conclude that these data argue against using strength tests in clinical practice or research. There is strong evidence that quadriceps strength is critical to knee function and health (references²⁴⁻²⁷ are a small sample from the large body of evidence supporting this statement), which argues for the use of some form of strength testing. In our opinion, isometric strength testing or a derivative of this method²⁸ (i.e., a technique involving superimposition of electrical stimuli during isometric testing to quantify quadriceps activation levels) is the gold-standard for measuring knee strength. Judgment on the amount of error associated

with antagonist activity in strength testing should be withheld until it is quantified. It is likely that the effect of the antagonist activity on knee extensor strength results will be much smaller than the effect on knee flexor test results because the quadriceps are much stronger than the hamstrings and similar amounts of antagonist activity are observed.

This study has some potential limitations that warrant discussion. Our goal was to describe the magnitude of variability of antagonist activity during isometric knee strength testing in “healthy” people so that normative data are present. Consequently, we excluded people with a history of serious lower extremity injuries. This introduced some selection bias into the study. The findings from previous research²⁹ suggest that patients with knee pathology may exhibit greater absolute magnitudes and side-to-side differences in antagonist activity than were observed in this study. Assumptions are made whenever surface electromyography is used. One assumption is that the recording from an electrode is representative of the entire muscle of interest; however, the validity of this assumption is unknown. It is also assumed that the recordings from each muscle are untainted by volume conduction (crosstalk). In order to minimize the likelihood of recording crosstalk, we carefully placed our electrodes using established guidelines, minimized pressure over the electrodes by seating subjects on an elevated platform, performed due diligence in verifying electrode placement and signal quality, and used high quality EMG preamplifiers with a double differential design that is known to minimize the recording of volume conducted signals.³⁰ The fact that antagonist muscle activity was observed in each of the quadriceps and hamstrings muscles tested strongly argues against the observed antagonist activity being a product of crosstalk. Moreover, we have observed similar magnitudes of antagonist activity when recording with intramuscular “fine wire” electrodes during knee strength testing, which has also been reported by other researchers.³¹ For these reasons, we believe that volume conduction was negligible, but acknowledge that it is impossible to rule out the presence of crosstalk.

CONCLUSIONS

The results of this study suggest that antagonist muscle activity is a relatively global finding in the knee extensors and flexors during maximal voluntary isometric contractions. Antagonist muscle activity varied significantly across sides in each of the muscles studied. Peak torque results also varied significantly by side, but not across sessions. Our results highlight the importance of assessing absolute differences between sides rather than simply contrasting the means of right and left or domi-

nant and non-dominant sides. The side-to-side variability in antagonist muscle activity and peak torque indicates that the opposite side is a less than ideal comparison for knee strength. The results of this study may help clinicians and scientists in interpreting the results of strength tests and in setting appropriate strength related criteria for patient progression and return-to-sport.

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