THE IOWA ORTHOPAEDIC JOURNAL

2015 • Volume 35

EDITORS
Christopher Martin, M.D.
Robert Westermann, M.D.

STAFF ADVISERS
J. Lawrence Marsh, M.D.
Jose A. Morcuende, M.D.

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INSTRUCTIONS FOR AUTHORS, 2016 EDITION


We will consider any original article relevant to orthopaedic surgery, orthopaedic science or the teaching of orthopaedic surgery 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 June 2016 edition is Monday, January 4, 2016.

Published articles and illustrations become the property of The Iowa Orthopaedic Journal. The journal is peer reviewed and referenced in Index Medicus and MEDLINE. Articles previously published will not be accepted unless their content has been significantly changed. The IOJ receives approximately 57,000 downloads per month.

When submitting an article, send the following:

1. The original manuscript with illustrations and ABSTRACT.
2. The corresponding author must be clearly identified with mailing address, telephone/fax numbers and e-mail address. Manuscripts will not be returned unless requested.
3. The bibliography must list references in the order of their appearance, and be double-spaced. References must be presented in the text by superscript numbers.
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5. Illustrations/Images:
   a. Color illustrations may not be used unless it is the opinion of the journal that they convey information not available in black and white.
   b. Each image should be sent to iorthojournal@gmail.com as an individual .tif or .jpg file. All images must have resolution of 600 pixels per inch (ppi). Web page images are to be avoided. Set digital cameras to their highest quality (ppi) setting for photographs.
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Preparation of manuscripts: Manuscripts must be typewritten and double spaced. Write out numbers under 10 except percentages, degrees or numbers expressed as decimals. Direct quotations should include the exact page number on which they appeared in the book or article. All measurements should be given in SI metric units. In reporting results of surgery, only in rare instances can cases with less than two years of follow-up be accepted.

Additional copies of these instructions may be obtained at http://www.uiortho.com/index.php/education/iowa-orthopaedic-journal.html or by writing to Renae Thompson, University of Iowa Hospitals and Clinics, Department of Orthopaedics and Rehabilitation, 200 Hawkins Drive – 01020 J.P.P., Iowa City, Iowa, 52242-1009 or by emailing renae-thompson@uiowa.edu.

Printed on acid-free paper effective with Volume XV, 1995.
It is with great pleasure that we present the 35th edition of the Iowa Orthopaedic Journal (IOJ). This year has been another great success for the journal, and we have seen a large volume of high quality submissions from across the United States, as well as from contributors in Europe, Asia, and the Central Americas. The articles are indexed on Pub Med, and freely available. Since its initial publication in 1981, the IOJ has seen a steady increase in its recognition, and in the number of citations attributed to our published articles. For example, in 1999 the IOJ’s impact factor was 0.18, and this had risen to 0.7 in 2013. We feel that this year represents an especially strong year for the journal, with an excellent overall quality of the scientific articles and reviews. We are hopeful that the ongoing Pub Med exposure and high quality of our articles will continue to increase the IOJ readership and promote ongoing growth.

We would like to recognize the departing senior residents Drs. Mai Nguyen, Jared Daniel, Andrew Pugely, Emily Wagstrom, Mark McCarthy, and Christopher Graves. Throughout their five years at Iowa they have provided excellent leadership and guidance. They will be sorely missed, and we wish them the best as they head off into fellowship and into their future careers.

The IOJ would not be possible without the help of the faculty and residents in the Department of Orthopaedics. The residents are responsible for reviewing the articles and providing suggestions for revision or recommendations for acceptance/rejection of the manuscript. Dr. Jesse Otero deserves special recognition for securing corporate sponsorships and for assisting in the organization of the journal. We would also like to thank our corporate sponsors for their generous support that makes this publication possible. Furthermore, a special thanks goes out to Dr. Jose Morcuende who is the faculty advisor for the journal, as well as to Renae Thompson, who is the administrative coordinator.

Lastly, we would like to thank our wives Jody Martin and Beth Westermann, who have provided tremendous support and patience throughout this process, as well as throughout the whole of residency. We could not have done it without them.

It has been an honor to serve as the editors for the IOJ for the 2015 publication. The University of Iowa is a special place, and we feel privileged to have trained here and contributed to its legacy. We are excited for the future of the department, and hope that the readership enjoys this year’s publication of our journal.

Sincerely,

Christopher T. Martin, MD
Robert W. Westermann, MD
Co-Editors
Iowa Orthopaedic Journal
Department of Orthopaedics and Rehabilitation
University of Iowa Hospitals and Clinics
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<tr>
<th>Year</th>
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      | Randall F. Dryer                                   |
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| 2006 | Mohana Amirtharajah  
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| 2013 | Cameron W. Schick  
      | Michael C. Willey                                  |
| 2014 | Mai Nguyen  
      | Andrew Pugely                                      |
| 2015 | Christopher Martin  
      | Robert Westermann                                  |
2015 DEDICATION OF THE IOWA ORTHOPAEDIC JOURNAL

DR. JOHN J. CALLAGHAN
Honoring a Career of Excellence and Leadership in Orthopaedics

Christopher T. Martin, MD and Robert W. Westermann, MD

Each year, we dedicate the Iowa Orthopaedic Journal to a distinguished alumnus or faculty member who has made a truly exceptional contribution to the field of orthopaedics. This year, it is with great pleasure that we present this honor to John J. Callaghan.

John Callaghan graduated from his Orthopaedic Residency at the University of Iowa in 1983 and subsequently completed a fellowship in adult joint reconstruction at the Hospital for Special Surgery (HSS) in 1984. From HSS, Dr. Callaghan went on to serve in the U.S. Army at Walter Reed and on the faculty of the Uniformed Services University of the Health Sciences, where he maintains an appointment. He then moved to Duke University before returning to Iowa in 1990, where he currently serves as the Lawrence and Marilyn Dorr Chair in Adult Hip Reconstruction.

In over 25 years as a faculty member at Iowa, Dr. Callaghan has achieved the highest levels of academic success, authoring over 331 peer-reviewed publications, as well as numerous textbooks, and countless presentations at national and local meetings. He has served as the president or as a senior chairperson for nearly every major orthopaedic society, including the American Academy of Orthopaedic Surgeons (President 2010-2011), the Orthopaedic Research Society (Board of Directors 1999-2006), the American Association of Hip and Knee Surgeons (President 2000), the American Orthopaedic Association (Secretary 2000-2005), the Hip Society (President 2006), the Mid America Orthopaedic Association (President 2003), the Iowa Orthopaedic Society (President 2004), the Knee Society (Board of Directors 2005-2008, 2012-present), and the American Board of Orthopaedic Surgeons (Vice President 2005-2006). He was an AOA North American Traveling Fellow in 1986, an ABC Traveling Fellow in 1991, and was named an Honorary Fellow in the British Orthopaedic Association in 2014. In addition, in 2014 he became the President of the International Hip Society, an honor which has been bestowed on only 6 Americans in the 40 year history of the organization.

Throughout his time at Iowa, Dr. Callaghan’s research program has been known for incredible quality and for the substantial impact of its contribution. His research has been supported by numerous grants, including from the NIH, the OREF, and the VA Merit Awards, and he has been the recipient of numerous research awards, including six Hip Society, two Knee Society, two Harris ORS Hip, the Nicholas Andre Award, the OREF Career Development Award, and two OREF Clinical Research Awards. He continues to be very active in research, and has lent his expertise to the development of numerous designs for hip and knee arthroplasty implants.

In addition to his many personal accomplishments, Dr. Callaghan has been a tireless supporter of education for residents and medical students. John has mentored over 20 undergraduate students who went on to medical school after completing research projects with him. No less than 59 medical students have completed peer-reviewed publications with John, and 16 of those students went on to graduate with an honors distinction in research for their efforts. Many of those students have received awards from the Iowa Orthopaedic Society, including multiple Bonfiglio Student Awards, as well as from the Mid America Orthopaedic Association. Dr. Callaghan’s mentorship also extends to the post-graduate level. No fewer than 20 residents have completed their senior research project with John, and 14 graduate students have completed their PhD thesis in biomechanics under Dr. Callaghan’s guidance. Many of these students went on to win Hip or Knee Society awards for their contributions. In the entire history of the medical faculty, few can claim such a track record of excellence in mentorship. These contributions were recently recognized by the AOA when he was granted the Distinguished Educator Award for a lifetime of education in orthopaedics at every level.

In addition to contributing substantial amounts of his own time and expertise, Dr. Callaghan has also furthered the educational mission through philanthropy. Of particular note are the gifts he made at the highest level for the OREF, the American Orthopaedic Association, the
Mid America Orthopaedic Association, and the endowed chair in sports medicine that he created at the University of Iowa. Furthermore, during his presidential year with the AAOS, he and the presidential line made a major commitment to education through the development of a new educational fund.

Throughout his academic career, John has remained a dedicated family man. He has been married to his wife Kim for 32 years, and together they have raised two very successful children, Patrick and Katie. John counts the success and happiness of his family as his most important accomplishment!

In reviewing Dr. Callaghan’s CV, it is clear that in virtually every year of his career he has made a major contribution to the field of orthopaedics. Whether it has been through his research productivity, through his activities with the national societies, or through his mentorship of students and residents at the University of Iowa, Dr. Callaghan has continuously exemplified qualities of leadership and excellence. The Iowa Orthopaedic Residency is honored and proud to be able to claim Dr. Callaghan as one of its own.
2015-2016
DEPARTMENT OF ORTHOPAEDICS AND REHABILITATION
SCHEDULE OF LECTURESHIPS AND CONFERENCES

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

Carroll B. Larson Shrine Memorial Lecture
May 8-9, 2015
Peter Waters, MD
Chief - Boston’s Children’s Hospital
Boston Children’s Hospital Orthopaedic Center
300 Longwood Avenue
Fegan, 2nd Floor
Boston, MA 02115
Spring 2016 to be arranged. Contact Nancy Love @ (319) 356-1872

2015 Senior Resident’s Day
June 12-13, 2015
Andrew J. Weiland, MD
Professor of Orthopaedic and Plastic Surgery
Cornell University and Medical College
Orthopaedic, Hand and Microsurgery
Hospital for Special Surgery
535 East 70th Street
New York, NY 10021

And

Rick W. Wright, MD
Dr. Asa C. and Mrs. Dorothy W. Jones
Professor of Orthopaedic Surgery
Vice Chairman for Clinical Affairs
Residency Director
Washington University Department of Orthopaedic Surgery
660 South Euclid Avenue, Campus Box 8233
St. Louis, MO 63110

31st Annual Hawkeye Sports Medicine Symposium
December 10-11, 2015
Marriott Hotel & Conference Center
300 East 9th Street, Coralville
Guest Speaker – to be arranged
Contact Kris Kriener @ (319) 353-7954

Ponseti Races
September 7, 2015
FRYfest
Coralville, IA

2016 Senior Residents Day
June 10-11, 2016
Discussants to be arranged.
DEPARTMENT OF ORTHOPAEDICS AND REHABILITATION STAFF 2014-2015
1. Jesse Otero, MD
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3. Tyler CarlLee, MD
4. Joseph Gholson, MD
5. Matthew Hogue, MD
6. Robert Westermann, MD
7. Heather Kowalski, MD
8. Joshua Holt, MD
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19. Emily Wagstrom, MD
20. Elizabeth Fitzpatrick MD
21. Mai Nguyen, MD
22. Jessica Hanley, MD
23. Nicolas Noiseux, MD
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25. Richard Johnston, MD
26. James Nepola, MD
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36. Reginald Cooper, MD
37. Shane Cook, MD
38. Sean Sitton, MD
39. Blake Dowdle, MD
40. Joseph Tofte, MD
41. Christopher Graves, MD
2015 GRADUATING ORTHOPAEDIC RESIDENTS

Jared Daniel, MD

Jared grew up on small town farm outside of Fonda, IA (est. pop 631). His dad, Bill, was a farmer who raised hogs and grew corn and soybeans, while his mom, Kathy, worked full-time at a local bank. Hard work, dedication, and attention to detail were some of the lifelong lessons that Jared learned growing up on a family farm. He was an extension of his dad’s shadow growing up, learning to drive a tractor at age 5. He attended Newell-Fonda High School where he met his eventual wife, Molly.

After graduating from high school, Molly and Jared got married and went off to the University of South Dakota with their one year old daughter, Madison. Jared continued to stay busy in Biology studies and his multiple jobs in work-study and summer grilling at the Hy-Vee shack. During college, Molly and Jared added another daughter, Claire, to the family. After college, he attended the Sanford School of Medicine at the University of South Dakota and discovered his passion for Orthopaedic surgery through the guidance of Dr. Haft and Dr. Van Demark. Jared was fortunate to match into Orthopaedic residency at the University of Iowa where many of his family members received their care growing up.

Residency has continued to teach Jared many important lessons all while developing his surgical skills. He has enjoyed the past five years and being able to work with many life-long friends. Molly and Jared added another daughter, Abigail, to the family during his second year of residency.

Jared would like to thank all of the Orthopaedic staff for all of the assistance over the last 5 years. Learning from many influential staff has provided many opportunities and Jared truly appreciates their patience and guidance. In addition, he appreciates all of the loving support from his family, especially Molly.

Upon graduation, Jared will complete a Pediatric Orthopaedic fellowship at The Hospital of Sick Children (Sick-Kids) in Toronto, Canada.

Christopher M. Graves, MD, MS

Chris was born in a small suburb of Philadelphia, the son of an Internal Medicine Resident and a Social Worker. He spent his formative years on the east coast until his father completed a fellowship in Nuclear Medicine, then moved with his family to Evansville, Indiana when Chris was in junior high school. After high school, Chris chose to attend Northwestern University, where he completed a degree in Biomedical Engineering and competed on the varsity wrestling team. After graduating and deciding to go to medical school, he completed a Masters degree at Indiana University’s combined health campus (IUPUI) and medical school at The University of Illinois in Chicago.

Chris must have remembered the butt whooping by his competition from Iowa, as he adopted the “if you can’t beat em, join em” philosophy, and was fortunate enough to earn a spot in the Orthopaedics residency here at Iowa. After residency, he will complete an Adult Spine Fellowship at the Leatherman Spine Institute in Louisville, Kentucky.

Chris would like to thank his family, for without their love and support he would not be here today. In particular his wonderful wife Jennifer, his two little girls, Aubrey and Hannah, and his parents, Mark and Sheree. He also would like to thank his mentors here at Iowa for always believing in him and helping him to truly reach his fullest potential as a surgeon.
Mai Nguyen, MD

Mai was born in Hanoi, Vietnam. She was taught the value of hard work and perseverance by her parents at a young age. Mai came to the US by herself at 16 to study science and pursue higher education. She spent her senior year of high school studying English as a foreign exchange student in Fort Wayne, IN. Culture shock is how Mai described her high school experience during her first year in the US. Mai moved on to attend Illinois Wesleyan University where she double majored in Biology and Chemistry. During college, she was introduced to scientific research, a passion that she carries throughout her career. Mai completed medical school training at Vanderbilt University where she met her future husband, Michael Reich. Both Mai and Michael are orthopaedic surgery residents and have been in a long distance relationship for the past 5 years. Michael is a resident at Case Western Reserve, 550 miles away from Iowa City. Thanks to their co-residents who make their long distance relationship possible, they got married last year... twice, in the US and in Vietnam. Influenced by Dr. Nepola, Dr. Marsh and Dr. Karam, Mai decided to specialize in orthopaedic trauma.

After residency, Mai will join her husband, Michael in Cleveland, OH for her trauma fellowship at MetroHealth Hospital. Afterwards, the sky is the limit for Mai and Michael, both will pursue academic positions in orthopaedic surgery. Mai is thankful for the training, the friendships, and the mentorships she has received in Iowa City.

Mark McCarthy, MD

Mark McCarthy grew up in Winthrop, MN, 90 minutes southwest of the Twin Cities. After high school, he attended St. John’s University in Collegeville, MN, where he majored in Biology and played football and baseball. After college, Mark attended the UW-La Crosse / Gundersen-Lutheran / Mayo Physician Assistant program. He then worked as a PA at the University of Minnesota, Department of orthopaedic surgery, for nearly four years, before deciding to apply to medical school. He graduated from the University of Minnesota Medical School in 2010.

While working as a PA, Mark met his wife, Deb. After a two year friendship, they began dating and fell in love. The two have been married for nearly eight years and have been blessed with three wonderful children: Mason, age 6, Ava, 4 and Colin, 2.

Mark is grateful to Deb and his three children for their support throughout residency. He also thanks his parents, Tom and Patty, as well as his older sister, Becky, for their support and encouragement. He is thankful for the incredible training he has received at the University of Iowa. After residency, the McCarthy’s will move to Chicago for Mark’s fellowship in Sports Medicine with Midwest Orthopaedics at Rush University.
Emily Wagstrom grew up in Faribault, MN. In order to keep her out of trouble, her parents encouraged her to participate in several character-building activities such as swimming, basketball, track and orchestra. It was during a spectacular fast break that she tore her ACL. Although at the time it was a devastating injury, the event was the inspiration to go into medicine and, ultimately, orthopaedic surgery. She graduated from Faribault High School as valedictorian.

In the fall of 2001, she moved to Iowa City to attend the University of Iowa. Sports remained an integral part of her life and she was a four-year member of the Women’s Rowing Team, a National Scholar-Athlete and awarded the Robert F. Ray Faculty Representative award, which is given to the most outstanding female student-athlete at Iowa. Academics were also a big part of her undergraduate experience, as she graduated with honors in Exercise Science and inducted into Phi Beta Kappa.

After graduation, she took a year off from school and was the assistant rowing coach for the University of Iowa Women’s Rowing Team. Although it was a great experience, medicine was where her heart was. She then enrolled in the Carver College of Medicine and ultimately fell in love with orthopaedic surgery. She was fortunate enough to have matched at the University of Iowa. After residency, she will be completing a trauma fellowship at Hennepin County Medical Center in Minneapolis, MN.

She would like to thank her parents and brother for their never-ending support and for frequently calling to make sure that she is still alive. Thank you to all of the staff in the Department who have shaped her as a surgeon and instilled the love and passion for Orthopaedics. A special thank you to Dr. Found, for not only fixing her spine four times, but for the mentorship over the last 10 years. And finally, thank you to my friends and co-residents who have been in the trenches through this journey. There is not a better group of people.

Andrew Pugely grew up in Milwaukee, Wisconsin. He attended Marquette University High School where he learned discipline and the importance of hard work. Andrew moved to Madison, WI where he attended both College and Medical School at the University of Wisconsin. While living across from the Wisconsin Badger Football Stadium he met his wife, Hallie. Andrew “sealed the deal” after impressing Hallie with his manly passion for trucks and dirt bikes. They stayed together throughout medical school and residency, before getting married in Andrew’s 4th year of residency. After finishing his degree in Neurobiology, he moved down the street for medical school. There, experiences within the Orthopaedics Department inspired Andrew to seek residency at the University of Iowa. He was ecstatic to match and get the opportunity to be an orthopaedic resident at one of the best departments in the world. After residency he will complete an Adult Spine Fellowship at Washington University in St. Louis. He will seek an academic job afterwards.

Andrew has many friends and family that he needs to thank for support. His wife, Hallie, has always provided endless love and support throughout their time together. Over the years, Hallie has tirelessly supported Andrew throughout all of his clinical and academic endeavors. Tolerance of long nights at the hospital, hours at home in front of the computer, and many meetings out of town has been deeply appreciated. Andrew and Hallie were blessed to bring their handsome son, Harrison into the world. He has brought them much joy and happiness this past year. Also, his parents, Julie and Michael, have always been dedicated to making sure that their children achieved their goals and understand the importance of hard work, common sense, persistence, and honesty. His younger siblings Patrick and Jacob were always entertaining growing up and kept him grounded throughout his training.

Lastly, Andrew would like to thank the faculty and Department of Orthopaedics for the continual support. Through intense mentorship, Andrew has learned the importance of prioritizing clinical and surgical excellence. From each mentor, Andrew has developed research, advocacy, and leadership styles that will serve him well in the future. Finally, his friends and resident colleagues at the University of Iowa have provided invaluable teaching, support, and unforgettable experiences; he could not think of a more enjoyable or talented group of individuals to spend five years with in training.
2015 GRADUATING FELLOWS

Youssef El Bitar, MD

Youssef El Bitar, MD is the University of Iowa Orthopaedic Sports Medicine fellow for 2014-2015. He was raised in Beirut, Lebanon. He earned his medical degree in 2005 and completed his orthopaedic residency training in 2011 at the American University of Beirut and its Medical Center, Beirut, Lebanon. He has completed fellowship training in Adult Reconstruction for 2011-2012 at the Southern Illinois University School of Medicine in Springfield-IL, then fellowship training in Hip Preservation for 2012-2013 at Hinsdale Orthopaedics in Westmont-IL, then fellowship training in Spine for 2013-2014 at the Southern Illinois University School of Medicine in Springfield-IL. After fellowship at the University of Iowa, Youssef is planning on pursuing an academic career in sports medicine and hip preservation in the US.

Youssef deeply thanks his loving wife Mireille and son Luca for their constant support and love. Youssef also wishes to send his thanks to the entire University of Iowa Orthopaedic Department and deepest appreciation to Drs. Amendola, Wolf, Bollier, Hettrich and Nepola for their commitment to education and excellence. He would like to send his thanks to the entire Iowa Hawkeyes Football organization for the chance to be part of the team for the 2014 season, an experience he will always cherish.

Jason Patterson, MD

Jason Patterson grew up in Mesa, Arizona. He received a bachelor’s degree in Spanish and Biochemistry from Arizona State University before attending medical school at University of Iowa Carver College of Medicine. He returned home to Arizona for residency at Banner Good Samaritan in Phoenix, but couldn’t stay away from Iowa for long as he is back completing his fellowship in Foot and Ankle. After fellowship, Jason will return home to Arizona to join OrthoArizona in the Phoenix area.

Jason has been supported through all the years and cross country moves by his wife Chelise of 11 years, and has been blessed with three children Drew (7), Nash (3), and Kendy (1). Jason would like to give a special thanks to Drs. Femino, Phisitkul, and Amendola for their constant example, guidance, mentorship, and friendship. He looks forward to remaining colleagues for years to come as part of the Iowa family.
Art Phruetthiphat, MD

Art is the University of Iowa Adult Reconstruction Fellow for 2013-2014 and Orthopaedic Trauma Fellow for 2014-2015. He was born in Bangkok, Thailand. He received his undergraduate schooling at Trimit Wittayalai School and medical training at Phramongkutklao Hospital and College of Medicine. During studying in medical school, he got a Scholarship of Distinction from General Pichit Kullavanichaya, Privy Councilor 1996-2002, and he graduated with the 2nd Class Honor Medical Doctor from Mahidol University in 2002. His orthopaedic training was completed at Phramongkutklao Hospital and College of Medicine. He will then return to Bangkok, Thailand to continue on as a Faculty Member of Adult Reconstruction and Orthopaedic Trauma at Phramongkutklao Hospital and College of Medicine.

Art would specifically like to thank Drs. Callaghan, Marsh, Phisitkul, and Karam for all they have taught him. They have made it a great education and enjoyable experience.

Chamnanni Rungprai, MD

Chamnanni (Nickname is Eye) is the University of Iowa Foot and Ankle fellow for 2012-2015 and Sports Medicine Fellow of the lower extremity with Dr. Amendola 2014-2015. He was born and raised in Chiang Rai, Thailand. He attended medical school at Phramongkutklao Hospital and College of Medicine, Bangkok, Thailand and graduated with honors. He then attended the orthopaedic residency training at the same College. After the fellowship at University of Iowa, Chamnanni will return to Bangkok this summer and join Foot and Ankle and Sport Medicine unit in Phramongkutklao Hospital and College of Medicine and continue his serve in the Army.

Chamnanni has been supported by his loving bride Natharat Rungprai for the past 6 years and has been blessed with one daughter, Nichaphat.

Chamnanni would like to send his thanks to the entire University of Iowa Orthopaedic department and his deepest appreciation to Drs. Phisitkul, Amendola, Femino, and Callaghan for their commitment to education and excellence as well as residents, numerous of nurses and staff with whom he worked in the past three years in Foot and Ankle, Sport Medicine, and Adult Hip and Knee Reconstruction.
Ross A. Schumer, MD

Major, United States Air Force

Ross was “on loan” for the 2014-2015 academic year from the United States Air Force as an associate fellow specializing in both sports medicine and foot and ankle surgery.

Ross is originally from Blue Bell, Pennsylvania. After earning an undergraduate degree in biology from the United States Air Force Academy, he was selected for the Air Force Health Professions Scholarship Program. He obtained his medical degree from Jefferson Medical College in Philadelphia and completed his orthopaedic residency at Wright State University in Dayton, OH. Following his residency, he returned to the Air Force as an orthopaedic surgeon and team physician at the United States Air Force Academy. He has deployed to the Middle East for six months in support of Operation Enduring Freedom (Afghanistan) and Operation Iraqi Freedom.

Ross is honored to have worked with all of the sports medicine and foot and ankle staff and humbled to work alongside such outstanding residents. He looks forward to taking his new skill-set back to caring for members of our armed services and their families.

Ross would like to thank the other Dr. Schumer (Maj Evelyn Schumer, PhD) and his children (Elora and Ty) for allowing him this tremendous opportunity. They all greatly enjoyed their year in Iowa and leave with lots of good memories.

Tarek Sibai, MD

Tarek completed the earlier part of his medical training in Beirut, Lebanon at the American University of Beirut. He spent most of his spare time pursuing soccer as a potential long term career. Met by family resistance, and in the absence of professional sports in a small country, he was later inspired by family members in the US to pursue a career in basic science. He began a post-doctorate position at Baylor College of Medicine (BCM) in Houston, Texas where he was fortunate to work on bone and cartilage research with a Howard Hughes Medical Institute (HHMI) investigator. His earlier interest in sports and a foundation in bone and cartilage biology manifested into a passion for orthopedics. During residency at Boston University, he acquired a solid foundation in complex traumatic conditions and acquired an interest in the diverse field of upper extremity surgery. He is currently honored to be completing a hand and upper extremity fellowship at the University of Iowa Hospitals and Clinics with an outstanding group of mentors and educators. He is grateful for the guidance and friendships of Drs. Lawler and Shah and the rest of the wonderful Iowa orthopedic family throughout his training. Outside of work, his wife Jennifer and two young daughters are a constant source of love, support and inspiration.
NEW ORTHOPAEDIC FACULTY

Cassim Igram, MD

Dr. Cassim M. Igram is a spine surgeon who joined the Department of Orthopedics at the University of Iowa Hospitals and Clinics in February of 2015. Dr. Igram is a native of Cedar Rapids, Iowa. He earned a BS and MD degree at the University of Iowa, graduating from the Carver College of Medicine in 1988. He completed residency in Orthopedics at The University of Illinois in 1993 and a spine fellowship at LSU in New Orleans in 1994. From 1994 to January of 2015 he was in private practice at the Iowa Orthopedic Center in Des Moines, Iowa. He is a past president of the Iowa Orthopedic Society. He is currently on the board of directors of the IOS as well as the IOS Research Foundation. He is board certified by the American Board of Orthopedic Surgery and is a fellow of the American College of Surgeons and the American Academy of Orthopedic Surgeons. Currently he serves on the Board of Councilors and the Advocacy Resource Committee for the AAOS. Dr. Igram is interested in advocating for Orthopedics at the state and national level. In addition, his interests include clinical research in spine and of course taking part in education of the residents and medical students in Orthopedics.

Heather Kowalski, MD

Heather Kowalski is a Pediatric Orthopaedic surgeon who joined the University of Iowa Hospitals and Clinics staff in September 2014. Dr. Kowalski earned a degree in Exercise and Health Science from Alma College in 2004 and a medical doctorate from Wayne State University School of Medicine in 2008. She completed residency at Henry Ford Health System in Detroit where she was administrative Chief Resident during her 5th year. She completed her Pediatric fellowship at Cincinnati Children’s Hospital. Her interests are in pediatric hip and spine problems as well as pediatric trauma.
The 2015 Michael Bonfiglio Award for Student Research in Orthopaedic Surgery

The 2015 Iowa Orthopaedic Society Medical Student Research Award for Musculoskeletal Research

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

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

This year the selection committee consisted of Dr. Abdul Foad, President of the Iowa Orthopaedic Society, and Drs. Charles R. Clark, Joseph A. Buckwalter, and John Femino, all members of the Department of Orthopaedics and Rehabilitation. They recommended that Adam Norton, M4, receive the 2015 Michael Bonfiglio Student Research Award. Adam’s award was based on his project, “Lower Extremity Alignment”. His advisors were Dr. John Callaghan and Dr. Ned Amendola.

The selection committee recommended that The Iowa Orthopaedic Society Medical Student Research Award be given to Justin Greiner, M3, for his research titled “Fixation and Wear in Contemporary Acetabular Components and Cross-linked Polyethylene at 10 years in Patients 50 and under”. His advisor was Dr. John Callaghan.

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.
The Michael Bonfiglio Professor of Orthopaedic Surgery
From left to right: Ned Amendola, M.D., John Callaghan, M.D., Adam Norton, M4, winner of the 2015 Michael Bonfiglio Student Research Award; Justin Greiner, M3, winner of The Iowa Orthopaedic Society Medical Student Research Award, Phinit Phisitkul, M.D. and Charles R. Clark, M.D., Michael Bonfiglio Professor of Orthopaedic Surgery.
ABSTRACT

Background: Shoulder arthroplasty is increasing in the United States. Reverse shoulder arthroplasty (RSA) has emerged as an alternative treatment for end-stage glenohumeral pathology. Until recently, administrative coding practices have not differentiated RSA from traditional total shoulder arthroplasty (TSA), and thus national procedural volume has been unknown. The purpose of this study was to define the utilization, patient characteristics, indications and complications for RSA, and contrast these to TSA and hemiarthroplasty (HA).

Methods: The 2011 Nationwide Inpatient Sample (HCUP-NIS) dataset was queried using ICD-9-CM codes to identify patients undergoing RSA, TSA, or HA. We used weighted estimates of national procedure volume, per-capita utilization, patient comorbidities, and inpatient complications defined by the Agency for Healthcare Research and Quality (AHRQ) and identified them using standard methods described by Elixhauser. ANOVA statistical analysis was used and significance was defined as p value <0.05.

Results: In 2011, 66,485 patients underwent shoulder arthroplasty; there were 21,692 cases of RSA, 29,359 of TSA, and 15,434 of HA. Utilization of RSA and TSA increased between 2002-2011, and decreased for HA. RSA patients were older (72.7 years vs 67.4 TSA vs 66.8 HA) and more commonly female. Comorbidity burden was highest in patients undergoing HA. Inpatient complications were highest after RSA (p < 0.001). When compared to TSA, RSA was more commonly used in the setting of rotator cuff disease, and post-traumatic sequelae (p<0.001).

Conclusions: Our findings represent the first national estimates of RSA within the United States. RSA is a significant contributor to increasing shoulder arthroplasty utilization nationally representing one-third of arthroplasty cases. Conditions traditionally managed with HA in older populations appear to now be more commonly managed with RSA. RSA is performed on older patients with expanded indications.

INTRODUCTION

For decades, total shoulder arthroplasty (TSA) has been the gold-standard treatment for end stage arthritis of the glenohumeral joint. In appropriate patients, the efficacy of TSA provides long-term survival and satisfaction rates exceeding 86-95%1,2. However, TSA in patients with concomitant rotator cuff pathology has been associated with early failure due to high rates of glenoid loosening. Thus, these patients were traditionally offered hemiarthroplasty or humeral head resurfacing3. Recently, however, reverse shoulder arthroplasty (RSA) has emerged as an alternative surgical option.

RSA provides a mechanical advantage for shoulder elevation in patients with rotator cuff disease4. Early RSA designs suffered catastrophic failures from glenoid loosening3. Modern designs, however, have shown improved results4, and RSA survival rates have exceeded 85% at 10 years5,6. In November of 2003, the Food and Drug Administration (FDA) approved RSA arthroplasty in the United States. Since that time, RSA has been popularized for addressing a wide variety of shoulder conditions; these include glenohumeral arthritis, rotator cuff arthropathy, failed conventional total shoulder arthroplasty, fracture sequelae, rheumatoid arthritis with irreparable rotator cuff tears, proximal humerus tumors and proximal humerus fractures8,9.
The volume of shoulder arthroplasty has been increasing since the early 1990’s. Previous studies describe steadily increasing rates of TSA, outpaced only by the sharply increasing rates of hip and knee arthroplasty. However, since FDA approval, the overall volume of shoulder arthroplasty has accelerated. An aging population, improved implant designs, and broader indications have all been implicated for increasing volume and utilization. Some postulate that RSA has also been the driver of these volume increases. Until 2011, TSA and RSA were coded identically in administrative claims databases; both shared the International Classification of Disease, Ninth Revision (ICD-9) code, 81.80. Delineating United States (US) national volume of each has not been previously possible, and only small, single-institution, case series exist. Given the paucity of epidemiological data, the purpose of this study was to define the national utilization, patient characteristics and indications, and inpatient complications of patients undergoing RSA in the US using the well-established Nationwide Inpatient Sample (NIS) database. A secondary goal was to compare these findings to patients undergoing TSA and hemiarthroplasty.

PATIENTS AND METHODS
This is a multicenter observational epidemiologic study of prospectively collected data of primary total shoulder arthroplasties conducted in the United States in 2011. This study was exempt from IRB approval.

Data Source
The Nationwide Inpatient Sample (NIS) NIS is the largest national all payer database for inpatient hospital stays. First published in 1988, it has subsequently been updated annually, up to 2011. As of 2011, the NIS captured data from 46 states, covering 97% of the U.S. population. All non-Federal, short-term, general, and specialty hospitals in the U.S. are eligible for inclusion, including long-term care facilities. Participating hospitals are stratified according to size and geographic location. Within each strata, the NIS approximates a randomly generated 20% sample of all discharges. A multiplier unique to each strata is then applied in order to provide national estimates for a given data point. In 2011, the NIS captured over 8 million discharges, and the multipliers were used to provide weighted averages for an estimated 38.5 million inpatient stays. The estimated data points include over 100 variables, encompassing patient demographic, medical comorbidities, and morbidity outcomes, as well as hospital characteristics and financial information. Notably, the database includes only in-hospital events. Events that occur after a patient’s discharge or during subsequent admissions are not linked.

Participants, Sample Size & Interventions
We included all patients from the 2011 NIS database with an ICD-9-CM procedure code (International Classification of Diseases, Ninth Revision, Clinical Modification) for primary shoulder arthroplasty (either HA: 81.81; TSA: 81.80; or RSA: 81.88). Patients younger than 40 years or older than 95 years were excluded. Revision shoulder arthroplasty cases were excluded (ICD-9 codes 996.4x, 996.66, and 996.77). Prior to 2011, RSA and TSA shared a common code (81.80), but for the first time in 2011 RSA was given a unique identifier (81.88). Thus, 2011 is the first year in which these procedures could be distinguished. Ultimately, 66,485 procedures were identified. The FDA did not approve RSA for use in the United States until 2013. Thus, in order to provide a comparison with procedure volume and patient characteristics prior to the introduction of RSA, we included a mirrored cohort from the 2002 NIS database, consisting of 24,677 patients, using the same selection criteria. US census data of population estimates by age was used to estimate the number of persons in the US age 40-95 in 2002 and 2011.

Indications and Comorbidities
Indications were identified by querying the primary ICD-9-CM code for incidences of osteoarthritis (715.xx), proximal humerus fracture (812.0x), proximal humerus nonunion/malunion (733.8x), aseptic necrosis (733.41), rotator cuff tear arthropathy (716.91), disorders of shoulder bursae and tendons (726.10), rheumatoid arthritis (714.0x), partial (726.1x) or massive (727.6x) rotator cuff tears. Patient comorbidities were identified from a query of the secondary ICD-9-CM codes, and included chronic respiratory insufficiency (518.83), anemia (280.x, 281.x, 282.x, 283.x, 284.x), asthma (493.x), diabetes mellitus (250.x, 249.x), obstructive sleep apnea (327.23), obesity (278.01), overweight (278.02), coagulopathy (286.x), atrial fibrillation (427.31) or tobacco use disorder (305.1).

In-Hospital Complications
We identified in-hospital procedure related complications by searching for any ICD-9 code specifying a complication of surgical care (ICD-9-CM: 996.x to 999.x). In addition, we evaluated several specific adverse diagnoses, including in hospital mortality from surgical causes (995.4, 968.4, 348.8, 798.2, 798.1, 798.9), spinal cord or nerve injury (952-965), venous thrombosis (453.4), respiratory distress following surgery (518.5), and acute post hemorrhagic anemia (285.1). All indications, comorbidities and complications within the dataset are reliant on medical documentation and in-hospital coding practices.
Table I: Demographics and Comorbidities of patients undergoing RSA (Reverse Shoulder Arthroplasty), TSA (Total Shoulder Arthroplasty), and HA (Hemiarthroplasty) within the US in 2011.

<table>
<thead>
<tr>
<th></th>
<th>RSA</th>
<th>TSA</th>
<th>HA</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Patient Age (years)</td>
<td>72.71</td>
<td>67.44</td>
<td>66.84</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Female Sex (%)</td>
<td>63.86</td>
<td>50.65</td>
<td>62.48</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Race (%)</td>
<td></td>
<td></td>
<td></td>
<td>0.001</td>
</tr>
<tr>
<td>Black</td>
<td>4.75</td>
<td>4.73</td>
<td>4.77</td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>89.36</td>
<td>89.66</td>
<td>87.28</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>5.9</td>
<td>5.6</td>
<td>7.95</td>
<td></td>
</tr>
<tr>
<td>Type of Insurance (%)</td>
<td></td>
<td></td>
<td></td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Private</td>
<td>14.96</td>
<td>31.28</td>
<td>28.42</td>
<td></td>
</tr>
<tr>
<td>Medicaid</td>
<td>1.45</td>
<td>1.79</td>
<td>4.25</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>83.59</td>
<td>66.94</td>
<td>67.33</td>
<td></td>
</tr>
<tr>
<td>Comorbidities</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chronic Respiratory Insufficiency (%)</td>
<td>0.13</td>
<td>0.07</td>
<td>0.4</td>
<td>0.0005</td>
</tr>
<tr>
<td>Chronic Anemia (%)</td>
<td>2.77</td>
<td>2.35</td>
<td>4.36</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Asthma (%)</td>
<td>8.95</td>
<td>9.11</td>
<td>8.72</td>
<td>0.8215</td>
</tr>
<tr>
<td>Diabetes Mellitus (%)</td>
<td>21.32</td>
<td>19.39</td>
<td>22.16</td>
<td>0.0033</td>
</tr>
<tr>
<td>Obstructive Sleep Apnea (%)</td>
<td>7.27</td>
<td>9.32</td>
<td>6.66</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Obesity (%)</td>
<td>11.69</td>
<td>14.97</td>
<td>13.09</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Overweight (%)</td>
<td>0.22</td>
<td>0.26</td>
<td>0.47</td>
<td>0.1253</td>
</tr>
<tr>
<td>Coagulopathy (%)</td>
<td>0.27</td>
<td>0.25</td>
<td>0.36</td>
<td>0.6668</td>
</tr>
<tr>
<td>Atrial fibrillation (%)</td>
<td>8.81</td>
<td>5.15</td>
<td>7.07</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Tobacco use disorder (%)</td>
<td>6.32</td>
<td>7.24</td>
<td>10.33</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Any Comorbidity (%)</td>
<td>47.52</td>
<td>47.13</td>
<td>51.20</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

RESULTS

Volume & Utilization

In 2002, 24,677 patients underwent primary shoulder arthroplasty, of which 10,125 (41%) were TSA and 14,552 (59%) were HA. In 2011, 66,485 patients underwent shoulder arthroplasty procedures, of which 21,692 (32.6%) were RSA, 29,359 (44%) were TSA, and 15,434 (23%) were HA [Figures 1 & 2]. Between 2002 and 2011, the US population between the ages of 40-95 increased by 21.37% (100,637,078 in 2002 versus 122,142,979 in 2011). The per-capita utilization of shoulder arthroplasty increased from 24.5 arthroplasties per 100,000 population in 2002 to 54.4 arthroplasties per 100,000 population in 2011. The utilization of HA during this same period decreased from 14.5 arthroplasties per 100,000 population in 2002 to 12.6 arthroplasties per 100,000 population in 2011. The utilization of TSA increased from 14.5 per 100,000 population in 2002 to 24.0 arthroplasties per 100,000 population in 2011. The utilization of RSA for patients between the ages of 40-95 in 2011 was 17.8 arthroplasties per 100,000 population.

Demographics

The mean age of patients undergoing RSA in 2011 was 72.71 years. This is significantly higher than that of patients undergoing TSA (67.44 years) or HA (66.84 years).
The presence of certain patient comorbidities varied between the three procedures. Patients undergoing RSA were more likely to carry a diagnosis of atrial fibrillation (p<0.001) and chronic respiratory insufficiency (p<0.001). Chronic anemia, diabetes mellitus, and tobacco use disorder were more common in HA cases (p<0.001). Patients undergoing TSA were more commonly diagnosed with obstructive sleep apnea or obesity (p<0.001) [Table I]. When co-morbid conditions were pooled, patients undergoing HA were significantly more comorbid (p<0.001).

Indications
Osteoarthritis (OA) was the primary indication for 88.63% of TSA cases in 2011. This was significantly higher than the percentage of patients who underwent RSA (43.67%) or HA (40.51%) (p<0.001) [Table III]. 35.19% of HA cases were performed for proximal humerus fractures compared to 9.36% of RSA and 0.99% of TSA cases (p<0.001). Similarly, posttraumatic sequelae including nonunion or malunion were more commonly indicated in RSA and HA (p<0.001). RSA was performed more often for rotator cuff arthropathy, or shoulder bursa and tendon disorders (p<0.001) [Table III]. The mean age of patients who underwent RSA was significantly higher than TSA or HA for the indications of osteoarthritis, proximal humerus fractures, aseptic necrosis and rotator cuff tear arthropathy (p<0.001).

In-Hospital Complications
The incidence of any in-hospital morbidity or mortality was higher in RSA (27.38%) compared to TSA (16.64%) or HA (23.96%) (p<0.001) [Table II]. The incidence of in-hospital mortality was higher in RSA (0.2%) and HA (0.26%) when compared to TSA (0.04%) (p=0.014). Acute respiratory distress (p<0.001), post-hemorrhagic anemia (p<0.001), general complications of surgical care (p<0.001), post-operative hypotension (p<0.001) and pulmonary embolism (p=0.019) were more common in RSA [Table II].

Table II: In-hospital morbidity and mortality in patients undergoing shoulder arthroplasty in 2011 for RSA (Reverse Shoulder Arthroplasty), TSA (Total Shoulder Arthroplasty), and HA (Hemiarthroplasty).

<table>
<thead>
<tr>
<th></th>
<th>RSA</th>
<th>TSA</th>
<th>HA</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incidence of Any Morbidity or Mortality (%)</td>
<td>27.38</td>
<td>16.64</td>
<td>23.96</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Mortality (%)</td>
<td>0.2</td>
<td>0.04</td>
<td>0.26</td>
<td>0.0137</td>
</tr>
<tr>
<td>Neurologic Injury (%)</td>
<td>0.17</td>
<td>0.11</td>
<td>0.4</td>
<td>0.012</td>
</tr>
<tr>
<td>Venous Thrombosis (%)</td>
<td>0.19</td>
<td>0.05</td>
<td>0.15</td>
<td>0.0797</td>
</tr>
<tr>
<td>Acute Respiratory Distress (%)</td>
<td>1.19</td>
<td>0.43</td>
<td>1.07</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Post-hemorrhagic Anemia (%)</td>
<td>16.73</td>
<td>9.75</td>
<td>15.77</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>General Complications of Surgical Care (%)</td>
<td>7.54</td>
<td>3.56</td>
<td>6.11</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Paralytic Ileus (%)</td>
<td>0.24</td>
<td>0.23</td>
<td>0.31</td>
<td>0.7586</td>
</tr>
<tr>
<td>Post-Operative Hypotension (%)</td>
<td>2.17</td>
<td>1.18</td>
<td>0.96</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Hypovolemia (%)</td>
<td>0.37</td>
<td>0.21</td>
<td>0.26</td>
<td>0.3358</td>
</tr>
</tbody>
</table>

Table III: Indications for patients undergoing shoulder arthroplasty in 2011; RSA (Reverse Shoulder Arthroplasty), TSA (Total Shoulder Arthroplasty), and HA (Hemiarthroplasty).

<table>
<thead>
<tr>
<th>(ICD-9-CM) Primary Diagnosis</th>
<th>RSA</th>
<th>TSA</th>
<th>HA</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>(715.xx) Osteoarthrosis and allied disorders</td>
<td>43.67</td>
<td>88.63</td>
<td>40.51</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>(812.0x) Fracture of proximal end of humerus, closed</td>
<td>9.36</td>
<td>0.99</td>
<td>35.19</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>(73341) Aseptic necrosis of head of humerus</td>
<td>0.98</td>
<td>1.9</td>
<td>6.46</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>(716.91) Unspecified arthropathy shoulder (cuff tear arthropathy)</td>
<td>11.83</td>
<td>3.58</td>
<td>2.37</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>(726.10) Disorders of bursae and tendons in shoulder</td>
<td>14.03</td>
<td>0.54</td>
<td>1.86</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>(733.8x) Nonunion or Malunion</td>
<td>3.27</td>
<td>0.39</td>
<td>3.17</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>(714.0) Rheumatoid arthritis</td>
<td>1</td>
<td>0.95</td>
<td>0.48</td>
<td>0.0311</td>
</tr>
<tr>
<td>(726.1x) Partial RTC Tear</td>
<td>0.12</td>
<td>0.06</td>
<td>0</td>
<td>na</td>
</tr>
<tr>
<td>(727.6x) Massive RTC Tear</td>
<td>2.55</td>
<td>0.16</td>
<td>0.23</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>
DISCUSSION

Reverse total shoulder arthroplasty has emerged as an alternative to TSA and HA with rapid acceptance in the United States over the past decade. Previously, the national volume of RSA in the United States has been largely unknown. Changes in administrative coding practices in 2011 have allowed for separation of RSA and TSA procedures. In this study, we have analyzed patient data from 66,485 total shoulder arthroplasties queried from a national discharge database. Relative to the growth of TSA over the last decade, RSA volume represents a significant portion. The patient demographics, inpatient complications, and indications of patients undergoing RSA and TSA also differ significantly. Several of these findings merit further discussion.

This study has several limitations. First, indications and comorbidities within the dataset are reliant on medical documentation and in-hospital coding practices. Secondly, short term and long-term patient outcomes after discharge are not available in the NIS-HCUP database as all data is collected prior to discharge; we are therefore unable to address differences in certain complications including infections and dislocations that more commonly occur after discharge. Third, the data presented represents hospital discharged from a single year; only one year of complete data (2011) presently exists that distinguishes RSA and conventional TSA. Also, due to the size of data collection the NIS-HCUP database, availability of comprehensive data is generally delayed two years. Last, this study is limited to the population in the United States.

Since the FDA approval of RSA in 2003, overall shoulder arthroplasty volume has been sharply increasing. Between 2002 and 2011, the utilization of shoulder arthroplasty more than doubled. The utilization of conventional TSA increased by 66% between 2002 and 2011. While use of RSA was limited prior to 2003, RSA comprised one-third of all shoulder arthroplasty cases in 2011. RSA, therefore, may be a principle factor driving the increased utilization of shoulder arthroplasty. Our study is the first to report decreasing rates of hemiarthroplasty on a national level. Rates of hemiarthroplasty had been previously reported to be steadily increasing from 1990 and 2004. Between 2002 and 2011, the utilization of hemiarthroplasty decreased by 12.5%. We believe the growing acceptance of RSA may be contributing to coincidently declining HA volumes. Patient populations, especially the elderly, who were previously HA candidates may now be better treated with RSA.

Our findings also demonstrate significant differences in patient characteristics between patients undergoing RSA, TSA, and HA. Previous reports suggest RSA should be reserved for elderly patient (>70 years old) with low functional demands. The mean age of patients undergoing RSA in the US in 2011 was 72.7 years. This was significantly higher than patients undergoing TSA or HA. Then mean ages of patients who underwent shoulder arthroplasty in our cohort are comparable to previous reports. The United States has an aging population. The RSA is ideal for low demand, elderly patients who previously may not have been candidates for HA or TSA. In our series, RSA was more commonly performed in females (63.8%), however this was not true for TSA (50.6%) p<0.001 and this is consistent with previous reports.

Our findings demonstrate varying indications between RSA, TSA, and HA. In general, RSA carried a wider array of indications when compared to TSA and HA. RSA's are more commonly performed in the setting of rotator cuff associated conditions due to mechanical advantages of implant design. Our data suggests 28.5% of patients underwent RSA with a primary diagnosis of rotator cuff disease. In 2007, Wall et al. reported good outcomes for patients undergoing RSA for massive rotator cuff tears, primary rotator cuff arthropathy, and osteoarthritis. These indications represent of approximately 72.2% of the volume of RSA observed in the 2011. In addition, RSA has been described for treatment of proximal humerus fractures. Prosthetic replacement of the proximal humerus may be appealing in certain fracture patterns where the incidence of avascular necrosis of the humeral head is high with open reduction and internal fixation; also, tuberosity resorption is common in hemiarthroplasty. In 2011, surgeons in the US were 7 times more likely to choose RSA over a conventional TSA for prosthetic treatment of a proximal humerus fractures. HA remains the most common shoulder arthroplasty option for management of proximal humerus fractures. In addition, RSA has been described for treatment of proximal humerus fractures (5,402 cases). Furthermore, surgeons were more likely to choose RSA or HA to address posttraumatic sequelae after proximal humerus fractures (malunion or nonunion). Therefore broad indications for RSA in the 2011 cohort may be due in part to an aging population, and relatively increased utilization in the setting of rotator cuff disease, fracture and post-traumatic sequelae.

Reports of complications after reverse total shoulder arthroplasty vary greatly. According to our findings, RSA was associated with higher rates of in-hospital complications overall. Approximately half of these complications were post-operative anemia. In-patient peri-operative mortality was nearly five times higher after RSA and HA compared with TSA (0.2%, 0.26% versus 0.04%, p=0.014). Previous reports indicate that in-hospital morbidity and mortality is highly dependent on patient comorbidities in arthroplasty populations. Also, patient age has been well established as an independent risk fac-
tor for complications in the acute perioperative period. Patients undergoing RSA were found to be significantly older than those undergoing TSA or HA (72.71 versus 67.44 and 66.84 years, p<0.001). As we did not control for patient factors, we are unable to tell if the true incidence of complications differs between groups.

Our findings represent the first national estimates of RSA within the United States. The national volume of RSA was 21,692 cases in 2011. Overall, the volume of shoulder arthroplasty in the US continues to rise; a phenomenon driven, likely in part, by the expanding use of RSA. Conditions traditionally managed with HA in older populations appear to now be more commonly managed with RSA. Importantly, patients undergoing RSA and TSA differ significantly in their demographics, comorbidities, surgical indications and inpatient complications. Given the burden of shoulder disease within the United States, this data will help define a baseline for studying the role of RSA. Future epidemiological studies should continue analyzing the temporal trends of shoulder arthroplasty.

**REFERENCES**


ABSTRACT

Background: Rupture of the pectoralis major muscle (PMM) is an uncommon injury that occurs during physical exercise and high-impact contact sports; it may result in pain, weakness, and disability. Surgical repair is currently the preferred treatment of PMM rupture. Our study assesses subjective and functional outcomes of patients following repair of acute and chronic PMM ruptures.

Methods: Retrospective review identified twenty patients who underwent PMM repair by the senior author (BRW) between 2003 and 2011. Injury and surgical data was reviewed for all 20 patients. Six patients were assessed minimum 1-year post-operatively for clinical outcomes, (SF-36, DASH, and ASES), physical exam (ROM & cosmesis), and Cybex isokinetic strength testing.

Results: All patients were men with an average age of 30 years (range 20-55) at time of injury. The average time from injury to surgical repair was 3.8 months (range <1-28 months), and average follow up was 16.5 months (range 0-99). The majority of patients suffered injury while bench pressing (12/20; 60%) or wrestling (3/20; 15%). The most common intra-operative findings were partial sternal tears (9/20; 45%) followed by complete sternal tears (4/20; 20%). Six (30%) of twenty patients consented for on-site follow-up and clinical assessment. Average preoperative physical component scores from SF-36 improved from 43 (range 37.8-52.7) to 53.1 (range 48.1-55.8) at follow up. Average preoperative DASH scores decreased from 74 points (range 68.7-83.3) to 5.3 points (range 1.7-8.3) at follow-up. Average pre-operative ASES scores improved from 82.8 points (range 71.7-96.7) to 96.7 points (range 91.7-98.3) at follow up. Average isokinetic strength deficiency in horizontal adduction at 60°/s was 15% (range 16%-29%) and average at 120°/s was 9% (range 2%-21%). According to the Bak criteria, overall results were excellent in two patients (33%), good in two (33%), while two (33%) had a fair result.

Conclusion: Surgical repair of PMM rupture by suture anchor fixation provides high patient satisfaction and predictable return of strength, cosmesis, and overall function. Suture anchor fixation produced similar clinical outcomes and return of strength when compared to other surgical repair methods. Our results demonstrate isokinetic strength deficiency similar to historical results.

Level of Evidence: Level 4: Retrospective Case Series

INTRODUCTION

Rupture of the pectoralis major muscle (PMM) is an uncommon injury. There are less than 400 reported cases in the literature. Injuries typically occur during strenuous exercise and high-impact sports. As participation in these activities increases, the incidence of PMM ruptures has increased as well. Rupture or avulsion of the pectoralis major can lead to pain, weakness, and disability, especially in athletically active persons. Clinical presentations include ecchymosis, swelling, and asymmetric webbing of the axillary fold. Surgical repair is currently the preferred method of treatment.

Pectoralis major muscle ruptures occur most frequently when the arm is extended and externally rotated, specifically when the pectoralis major muscle is eccentrically contracting. This motion is most common while lifting weights during a bench press exercise. Due to this mechanism of injury, it is almost exclusive to males in their 20s to 40s. Rupture or avulsion is often associated with an audible pop, tearing sensation, and immediate pain. Musculotendinous junction and intramuscular ruptures often result from direct trauma.

Ultrasound and MRI are often used to identify patients that would benefit most from surgical repair. Operative examination of tears reveals tendon avulsion as the most common rupture type (65% frequency) followed by musculotendinous junction rupture (27% frequency). Due to the unique PMM morphology (sternocostal and clavicular muscle heads, overlapping and variable
length muscle fibers), tear classification can be difficult to determine especially when considering variance in timing, location and extent of injury. While complete function of the pectoralis major muscle is not necessary for activities of daily living, repair of ruptures increase patient satisfaction, strength, cosmesis, and shortens return to competitive sports. Prognosis is unrelated to the age of the patient or to the location of the rupture. Surgical treatment of pectoralis major ruptures is associated with lower incidence of strength deficiency as compared to non-surgical treatments. In particular, athletes have a better functional result after surgical treatment than after nonsurgical treatment. Decreased strength has been associated with operative and non-operative treatment. Most evidence suggests that surgical treatment within 8 weeks of injury provides significantly better outcome than nonsurgical treatment or delayed repair. The two main surgical treatment options for complete pectoralis major tendon rupture are transosseous sutures and suture anchors. Bone troughs, bone tunnels, screw and washers, and endobuttons are other repair options that have been used as well. All methods have excellent postoperative results, which allow surgeons to choose their preferred technique. To date, no comparison of different surgical techniques has been published. Currently, transosseous sutures and anchor sutures are most commonly reported techniques in the literature and have both demonstrated a relatively reliable return to sports, a fast recovery, and a low complication rate. There is no statistical difference found between the strengths of transosseous sutures and anchor sutures techniques in tests on human cadavers, both methods had comparable failure loads.

Nonsurgical treatment consists of physical therapy after the injured arm has been immobilized for three weeks in a sling. Passive-assistive physiotherapy is performed for three weeks followed by muscle strengthening exercises for several months. Non-operative treatment is often recommended for less active patients who are having minimal pain or functional disability and for tears that occur at the musculotendinous junction or in the pectoralis muscle belly. The goal of this study is to assess subjective and functional outcomes of patients following repair of acute and chronic PMM ruptures by suture anchor fixation.

**METHODS**

After IRB approval, a retrospective review identified twenty patients who underwent PMM repair by the senior author (BRW) between 2003 and 2011. All operative repairs were performed at the University of Iowa Hospitals and Clinics in Iowa City, IA.

Data on the age, sex, mechanism of injury, rupture location and type, length of time since treatment, pre-operative cosmetic appearance, pre-operative exam, diagnostic studies, operative technique, involved side, and primary follow-up were obtained from hospital records. No mentions of anabolic steroids were recorded or investigated in this study.

The operative repair was performed with patients in a beach-chair position. 18/20 repairs were performed with Mitek 2.4 mm suture anchors (DePuy, Raynham, MA). The two other repairs were performed using Arthrex corkscrew anchors (Arthrex Inc. Naples, FL). Patients were kept immobilized in slings for two to three weeks, at which point they were advanced to pendulum exercises and physiotherapy. Light resistance activity was allowed starting at six weeks. Full activities were generally resumed at three to four months.

All patients were contacted to consent for follow up clinical assessment. Six of twenty (30%) patients consented for follow up and were assessed at minimum 1-year post operatively for clinical outcomes. Outcomes were evaluated using a variety of validated health surveys including Standard Form – 36 (SF-36), Disability of Arm, Shoulder and Hand (DASH), and American Shoulder and Elbow Surgeons shoulder survey (ASES). Clinical assessment by the senior author (BRW) evaluated range of motion (ROM) and cosmesis. Pectoralis major muscle strength was assessed compared to contralateral side for peak torque at 60°/s and at 120°/s in horizontal abduction and adduction using Cybex isokinetic strength testing according to the Bak criteria. Cybex strength testing software captured torque curves and measured peak torque as patients moved through horizontal abduction.

**Table 1: Bak Criteria**

<table>
<thead>
<tr>
<th></th>
<th>Excellent</th>
<th>Good</th>
<th>Fair</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pain</td>
<td>Free</td>
<td>Free</td>
<td>With activity</td>
<td>Persistent</td>
</tr>
<tr>
<td>Range of Motion</td>
<td>Full</td>
<td>Slight Decrease</td>
<td>Slight Decrease</td>
<td>Restricted</td>
</tr>
<tr>
<td>Cosmesis</td>
<td>No complaints</td>
<td>Minor</td>
<td>Minor</td>
<td>Unsatisfactory</td>
</tr>
<tr>
<td>Return to Activity</td>
<td>Full function</td>
<td>Slight impairment</td>
<td>Impaired</td>
<td>Complications</td>
</tr>
<tr>
<td>Strength</td>
<td>&lt;10% Isokinetic loss</td>
<td>&lt;20% Isokinetic loss</td>
<td>&gt;20% Isokinetic loss</td>
<td>&gt;20% Isokinetic loss</td>
</tr>
</tbody>
</table>
and adduction. Angle of peak torque was also measured but not used as an objective outcome measurement in this study. The outcome of the treatment at follow-up was graded as excellent, good, fair, or poor, according to the Bak criteria as described in Table 1.

**RESULTS**

In our series of 20 anatomically repaired ruptures, all patients were men. Average age was 30 years (range 20-55) at time of injury, average time from injury to surgical repair was 3.8 months (range <1-28 months), and average follow up time was 16.5 months (range 0-99). The majority of ruptures (13/20; 65%) were repaired acutely (<6 weeks from time of rupture). The majority of patients (12/20; 60%) suffered injury while bench pressing with the second most common injury occurring during wrestling (3/20; 15%). Other mechanisms of injury include jet skiing, fall from height, closing bolt cutters, trimming bull horns, and throwing a football. The sternal portion of the pectoralis major tendon was involved in 16/20 ruptures, 3/20 ruptures involved both sternal and clavicular heads, and 1/20 ruptures involved only the clavicular head (Table 2).

All patients who returned for follow up ≥6 months from surgery reported returning to activities of daily living (13/20; 65%). Some patients (6/20, 35%) were lost to follow up by 4 months from surgery (Table 2). One patient suffered a re-injury before his 1 month follow up and reported no return to function (Table 2). Our study was not powered to detect differences in clinical outcomes between patients with acute tears (<6 weeks between injury and repair) compared to chronic tears (>6 weeks between injury and repair).

Six (30%) of twenty patients consented for further clinical assessment (Table 3). Of these patients, three underwent acute repair and three had delayed repair (>6 weeks from time of rupture). Both groups showed improved health outcomes post-operatively. Average preoperative physical component scores from SF-36 improved from 43.1 (range 37.8-52.7) to 53.1 (range 48.1-55.8) at follow up. Average preoperative DASH scores decreased from 73.9 points (range 68.7-83.3) to 5.3 points (range 1.7-8.3) at follow up. Average pre-operative ASES score improved from 82.8 points (range 71.7-96.7) to 96.7 points (range 91.7-98.3) at follow up.

---

**Table 2: Combined Patient Data**

<table>
<thead>
<tr>
<th>Case #</th>
<th>Age, y</th>
<th>Trauma Mechanism</th>
<th>Injury to Surgery, wk</th>
<th>Intra-Op Tear Findings</th>
<th>Operation Method</th>
<th>Follow-up, m</th>
<th>Resumed Activity at Follow up</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>22</td>
<td>Throwing Football</td>
<td>6</td>
<td>Complete Avulsion</td>
<td>Mitek suture anchors</td>
<td>8</td>
<td>Yes</td>
</tr>
<tr>
<td>2</td>
<td>32</td>
<td>Bench Press</td>
<td>2</td>
<td>Avulsion Sternal</td>
<td>Mitek suture anchors</td>
<td>99</td>
<td>Yes</td>
</tr>
<tr>
<td>3</td>
<td>27</td>
<td>Wrestling</td>
<td>11</td>
<td>Partial Sternal</td>
<td>Arthrex corkscrew anchor</td>
<td>3</td>
<td>Limited</td>
</tr>
<tr>
<td>4</td>
<td>23</td>
<td>Bench Press</td>
<td>7</td>
<td>Partial Sternal</td>
<td>Mitek suture anchors</td>
<td>4</td>
<td>Yes</td>
</tr>
<tr>
<td>5</td>
<td>25</td>
<td>Wrestling</td>
<td>3</td>
<td>Complete Sternal</td>
<td>Mitek suture anchors</td>
<td>1</td>
<td>No</td>
</tr>
<tr>
<td>6</td>
<td>19</td>
<td>Bench Press</td>
<td>6</td>
<td>Partial Sternal</td>
<td>Mitek suture anchors</td>
<td>2</td>
<td>Limited</td>
</tr>
<tr>
<td>7</td>
<td>27</td>
<td>Bench Press</td>
<td>4</td>
<td>Partial Musculotendinous Sternal</td>
<td>Mitek suture anchors</td>
<td>3</td>
<td>Yes</td>
</tr>
<tr>
<td>8</td>
<td>34</td>
<td>Bench Press</td>
<td>&lt;1</td>
<td>Complete Avulsion</td>
<td>Mitek suture anchors</td>
<td>2</td>
<td>Limited</td>
</tr>
<tr>
<td>9</td>
<td>28</td>
<td>Bench Press</td>
<td>111</td>
<td>Partial Sternal</td>
<td>Mitek suture anchors</td>
<td>9</td>
<td>Yes</td>
</tr>
<tr>
<td>10</td>
<td>42</td>
<td>Fall accident</td>
<td>17</td>
<td>Partial Sternal</td>
<td>Mitek suture anchors</td>
<td>4</td>
<td>Limited</td>
</tr>
<tr>
<td>11</td>
<td>36</td>
<td>Bench Press</td>
<td>13</td>
<td>Partial Sternal</td>
<td>Arthrex corkscrew anchor</td>
<td>52</td>
<td>Yes</td>
</tr>
<tr>
<td>12</td>
<td>55</td>
<td>Closing Bolt Cutter</td>
<td>60</td>
<td>Complete Avulsion</td>
<td>Mitek suture anchors</td>
<td>43</td>
<td>Yes</td>
</tr>
<tr>
<td>13</td>
<td>21</td>
<td>Bench Press</td>
<td>2</td>
<td>Complete Sternal</td>
<td>Mitek suture anchors</td>
<td>0</td>
<td>Limited</td>
</tr>
<tr>
<td>14</td>
<td>29</td>
<td>Jet Skiing</td>
<td>4</td>
<td>Partial Sternal</td>
<td>Mitek suture anchors</td>
<td>1</td>
<td>Limited</td>
</tr>
<tr>
<td>15</td>
<td>22</td>
<td>Wrestling</td>
<td>&lt;1</td>
<td>Complete Sternal</td>
<td>Mitek suture anchors</td>
<td>45</td>
<td>Yes</td>
</tr>
<tr>
<td>16</td>
<td>22</td>
<td>Bench Press</td>
<td>1</td>
<td>Partial Sternal</td>
<td>Mitek suture anchors</td>
<td>2</td>
<td>Yes</td>
</tr>
<tr>
<td>17</td>
<td>52</td>
<td>Trimming Bull Horn</td>
<td>19</td>
<td>Complete Clavicular</td>
<td>Mitek suture anchors</td>
<td>20</td>
<td>Yes</td>
</tr>
<tr>
<td>18</td>
<td>20</td>
<td>Bench Press</td>
<td>1</td>
<td>Complete Sternal</td>
<td>Mitek suture anchors</td>
<td>17</td>
<td>Yes</td>
</tr>
<tr>
<td>19</td>
<td>22</td>
<td>Bench Press</td>
<td>1</td>
<td>Partial Avulsion Sternal</td>
<td>Mitek suture anchors</td>
<td>2</td>
<td>Yes</td>
</tr>
<tr>
<td>20</td>
<td>40</td>
<td>Bench Press</td>
<td>5</td>
<td>Partial Sternal</td>
<td>Mitek suture anchors</td>
<td>13</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Two patients (33%) had minimal pain on exertion and decrease in range of motion (Table 4). No patients had cosmetic complaints. Average isokinetic strength deficiency in horizontal adduction at 60°/s was 15% (range 16%-29%) and average at 120°/s was 9% (range 2%-21%). According to the Bak criteria, overall results were excellent in two patients (33%), good in two (33%), and two (33%) had a fair result. As a group, those who underwent acute repair fared better according to the Bak criteria than those undergoing delayed repair, with one excellent and two good results compared to one excellent and two fair results, respectively.

### DISCUSSION

There are a total of 365 PMM ruptures reported in the literature that occurred between 1822-2010, and 274 of them occurred in the last 20 years. The increased number of reported injuries in the past 20 years has been attributed to increasing activity in high impact sports, competitive weight lifting, and extreme sports. Few case studies, less than 100, have reported clinical outcomes following surgical repair of the PMM using suture anchor fixation.

Pectoralis major muscle rupture is an uncommon injury that can have a positive clinical outcome if diagnosed early and surgically repaired. Unlike other injuries where a delay in surgical treatment can lead to decreased strength, range of motion, and overall function, in PMM rupture, delays in surgical treatment have not been shown to have decreased clinical outcomes when compared to acute repairs, although the repair technically is much easier in the acute setting. More information regarding acute vs chronic repairs is needed to guide clinical decisions and provide patient education. Our study was not significantly powered to show differences between these two groups, but our study did find that patients who underwent acute repair had slightly better health outcomes and functional return according to the Bak criteria when compared to those who had delayed repairs.

The demographics of the patients in the present study are consistent with the literature, males in their 2nd to 4th decade of life. Historically patients suffer full thickness tears to the sternal head while bench pressing and our series showed similar results with the majority of tears involving only the sternal head. PMM ruptures can be difficult to classify due to the unique tendon morphology consisting of sternocostal and clavicular heads, anterior and posterior tendon layers, and variable muscle fiber length. Also, variance in presentation based on chronicity, location and extent of injury can complicate rupture classification. Determining tear classification by MRI, ultrasound, and intra-operative finding is essential to guiding surgical repair. Two main classification schemes

---

**Table 3: Final Outcome Six Patients**

<table>
<thead>
<tr>
<th>Case</th>
<th>Pain free</th>
<th>Range of motion</th>
<th>Cosmetic complaints</th>
<th>Activity restrictions</th>
<th>Peak Torque 60°/s*</th>
<th>Peak Torque 120°/s*</th>
<th>Outcome</th>
<th>Repair Timing</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Yes</td>
<td>Full</td>
<td>None</td>
<td>None</td>
<td>17%</td>
<td>5%</td>
<td>Excellent</td>
<td>Acute</td>
</tr>
<tr>
<td>11</td>
<td>Pain on exertion</td>
<td>Full</td>
<td>None</td>
<td>None</td>
<td>-29%</td>
<td>-21%</td>
<td>Fair</td>
<td>Delayed</td>
</tr>
<tr>
<td>12</td>
<td>Yes</td>
<td>Full</td>
<td>None</td>
<td>None</td>
<td>-22%</td>
<td>-8%</td>
<td>Excellent</td>
<td>Delayed</td>
</tr>
<tr>
<td>17</td>
<td>Pain on exertion</td>
<td>Abduction limited to 130°</td>
<td>None</td>
<td>None</td>
<td>-17%</td>
<td>-2%</td>
<td>Fair</td>
<td>Delayed</td>
</tr>
<tr>
<td>18</td>
<td>Yes</td>
<td>Full</td>
<td>None</td>
<td>None</td>
<td>-23%</td>
<td>-19%</td>
<td>Good</td>
<td>Acute</td>
</tr>
<tr>
<td>20</td>
<td>Yes</td>
<td>Internal rotation limited to 45°</td>
<td>None</td>
<td>None</td>
<td>-16%</td>
<td>-9%</td>
<td>Good</td>
<td>Acute</td>
</tr>
</tbody>
</table>

* Isokinetic peak torque of horizontal arm adduction of the injured arm is compared to the contralateral side and presented as a percent deficit. Physiologic variance shows <10% variance in horizontal adduction strength in un-injured individuals [2].

**Table 4: Average Health Outcomes of Acute vs Delayed Repairs**

<table>
<thead>
<tr>
<th></th>
<th>Pre-operative</th>
<th>Post-operative</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SF-36 PCS</td>
<td>SF-36 MCS</td>
</tr>
<tr>
<td>Acute Repair (&lt;6 weeks)</td>
<td>46.9</td>
<td>46.5</td>
</tr>
<tr>
<td>Delayed Repair (&gt;6 weeks)</td>
<td>41.8</td>
<td>49.7</td>
</tr>
</tbody>
</table>
exist for PMM ruptures (Tietjen and ElMaraghy), however these classifications only guide surgical management, rehabilitation, and research; there is no evidence that PMM rupture classification correlates with surgical outcomes.1,12

Our case series had several unique mechanisms of injury varying from trimming bull horns to closing bolt cutters not noted elsewhere in the literature. Of the patients who underwent further clinical follow-up, all patients reported improvements in subjective outcomes and would elect to undergo surgery again. Factors associated with decreased outcomes were limited range of motion, slight impairment with return activities, and minimal pain on exertion.

The strengths of our study include complete reporting of mechanism of injury, intra-operative tear descriptions, repair technique, and activity level at follow-up. Weaknesses of our study include small sample size and 30% follow-up at a minimum of one year for clinical assessment, which introduces the possibility of selection or survivorship bias. Our study also reports follow up data from variable points in time after surgery, which may lead to reporting bias. Ideally, all patients would have a set schedule for follow-up prior to enrollment in the study. Our patients undergoing Cybex strength testing may have suffered from Hawthorne effect while being observed performing strength testing. Lastly, our study did not evaluate study participants for anabolic steroid use, which has been associated with increased rates of tendon rupture and improved healing.11

CONCLUSION

Surgical repair of PMM rupture by suture anchor fixation provides high patient satisfaction and predictable return of strength, cosmesis, and overall function. Suture anchor fixation produced similar clinical outcomes and return of strength when compared to other surgical repair methods.6,12

REFERENCES

ABSTRACT

Background: The medial patellofemoral ligament is the primary soft-tissue restraint to lateral patella translation. Medial patellofemoral ligament reconstruction has become a viable surgical option to provide patellar stability in patients with recurrent instability. The primary goal of this study was to determine the effect of medial patellofemoral ligament reconstruction on the lateral force-displacement behavior of the patella using finite element analyses.

Methods: A finite element model of the knee was created using cadaveric image data. Experimental testing was performed to validate the computational model. After validation, the model was modified to study the effect of various medial patellofemoral ligament reconstruction insertion sites, allowing comparison of patellofemoral contact force and pressure.

Results: For the intact anatomic model, the lateral restraining force was 80.0 N with a corresponding patellar contact area of 54.97 mm². For the anatomic reconstructed medial patellofemoral ligament model, the lateral restraining force increased to 148.9 N with a contact area of 71.78 mm². This compared favorably to the corresponding experimental study. The force required to laterally displace the patella increased when the femoral insertion site was moved anteriorly or distally. The lateral restraining force decreased when the femoral insertion site moved proximally and the patellar insertion site moved either proximal or distal by 5 mm.

Conclusion: The line of action was altered with insertion site position, which in turn changed the amount of force it took to displace the patella laterally. Considering the model constraints, an anterior femoral attachment may over constrain the patella and increase cartilage wear due to increase contact area and restraining force.

Clinical Relevance: A malpositioned femoral tunnel in MPFL reconstruction could increase restraining forces and PF contact pressure, thus it is suggested to use intra-operative fluoroscopy to confirm correct tunnel placement.

INTRODUCTION

Patellar stability is maintained by the bony architecture, soft tissue restraints, and dynamic action of the quadriceps throughout knee motion. The medial patellofemoral ligament (MPFL) is the primary soft tissue restraint to lateral translation of the patella1-3, acting as a check-rein to lateral translation during the first 30° of knee flexion prior to the patella engaging the trochlear groove4,5. Following acute lateral patellar dislocation, the MPFL is the most consistently injured ligamentous structure6-8. Nonoperative management of acute lateral patellar dislocation frequently results in recurrent instability9,10. Proximal soft tissue procedures, such as MPFL reconstruction or repair, are indicated in patients with normal bony alignment and a deficient MPFL4,7,11. Due to poor outcomes following MPFL repair12-14, MPFL reconstruction, which aims to restore the form and function of the native MPFL, has become the procedure of choice for this patient population.

Although MPFL reconstruction is a popular technique, relatively few studies have investigated the behavior of the patellofemoral joint after MPFL reconstruction. While MPFL reconstruction aims to restore the native properties of the ligament, experimental studies have shown that variations in insertion sites may over constrain the patella and lead to premature osteoarthritis due to increased medial patellofemoral contact pressures or result in recurrent instability due to graft failure5,15.
Therefore, the primary goal of this study was to determine the effect of MPFL reconstruction on the lateral force-displacement behavior of the patella using finite element analyses. Additionally, our objective was to study the affect MPFL reconstruction insertion site has on patellofemoral contact force, area and pressure.

METHODS

A single finite element (FE) model of the knee was created to gain a better understanding of MPFL reconstruction. The model was validated with corresponding experimental data. After model validation, the FE model was modified to study what effect MPFL reconstruction insertion site has on patellofemoral biomechanics.

Finite Element Model

A magnetic resonance (MR) image of a cadaveric knee joint was obtained and used to define the bone and soft tissue anatomy. The bones (tibia, femur, and patella) and soft tissues (cartilage, patellar tendon (PT), and quadriceps tendon (QT)) were manually segmented using BRAINS2 software. Surfaces were generated from the traced regions of interest using Gaussian image based smoothing, similar to the techniques described by DeVries et al.

A finite element model was created using IA-FEMesh (Figure 1). IA-FEMesh allows meshes to be created based on anatomical surfaces generated from medical image segmentation. The bones were modeled using three-dimensional rigid elements since bone is significantly stiffer than the soft tissues, which were the structures of interest, not the bone. The model did not include the fibula, similar to previous computational models of patellofemoral biomechanics. The cartilage, PT, and QT were modeled using 8-noded hexahedral elements. The MPFL and the medial patellotibial ligament (MPTL) were also modeled using hexahedral elements. Since the ligaments, specifically the attachment sites, were difficult to define on MR images due to their thin anatomy, they were modeled based on the insertion sites and dimensions (i.e. width, thickness) previously reported in anatomic studies.

The viscoelastic nature of the cartilage was simplified to linear elastic material properties (E=12 MPa, ν=0.45). The tendon and ligaments were modeled as hyperelastic with the material properties adapted from stress-strain and force-displacement curves reported in literature. The reconstructed MPFL assumed material properties characteristic of the tibialis tendon. The anatomic reconstruction insertion site and dimensions were considered to be the same as the intact model, which was based on anatomical data reported in literature.

To ensure model accuracy, a convergence study was conducted on the MPFL, since this was the primary tissue of interest. Meshes were created for the isolated MPFL, with varying mesh densities ranging from two elements to 4160 elements. A 100 N force was applied along the long axis of the MPFL, and stresses were monitored at three locations. Based on convergence, a mesh density of 520 elements was chosen to model the MPFL. A similar mesh element size was used throughout the entire knee model.

For both the intact and reconstructed models, the knee was positioned at 30° of flexion, with the femur fixed in all directions and the tibia free to translate and rotate about the z-axis, allowing anterior-posterior translation and varus-valgus rotation. The patella was free to rotate and displace in all directions. The quadriceps was physiologically loaded to 178 N, along the three main muscle groups. With the quadriceps loaded, the tibia and femur were fixed in all directions and the patella was displaced laterally 10 mm. The resultant patellar restraining force, contact pressure, and contact area were compared for the intact and reconstructed MPFL. Analyses were completed using Abaqus/Standard (Version 6.12-1; Dassault Systèmes Simulia, Providence, RI).
Model Validation/Experimental Study

To validate the computational models, corresponding experimental testing was conducted. Four fresh-frozen knees were obtained from two cadavers (95 year old male; 57 year old female). Prior to testing, magnetic resonance images were obtained to ensure continuity of the MPFL in all specimens. All soft tissues were dissected with the exception of the distal quadriceps extensor mechanism, MPFL, and capsular tissue surrounding the knee. The distal quadriceps was separated into three muscle groups (vastus medialis (VM), vastus lateralis (VL), and rectus femoris and vastus intermedius (RF+VI)). Cloth strips were attached to each muscle group to allow loading through the extensor mechanism. The femur and tibia were fixed in a polymer resin, allowing for attachment to the custom testing fixture.

The knee specimen was fixed at 30° of flexion using a custom fixture, with the femur and tibia firmly held in all directions. Next, the components of the quadriceps were loaded with a total of 178 N, accounting for physiological loading directions and cross-sectional areas. The patella was connected to a loading rod using a ball joint, allowing for patella rotation about the anterior-posterior and proximal-distal axes. Figure 3 shows the testing setup. Using a biaxial servo-hydraulic materials testing machine, the patella was cyclically displaced 10 mm laterally from its neutral position at 100 mm/min. The force to displace the patella 10 mm laterally (restraining force) was recorded, with the fourth cycle used for analyses.

After intact MPFL testing, the MPFL was sectioned and an MPFL reconstruction performed using a split anterior tibialis allograft. For additional information on the MPFL reconstruction procedure, refer to the study by Duchman et al.

The FE model was validated using the results from the experimental study by comparing the patellar restraining force for both the intact MPFL and MPFL reconstruction at anatomical insertion. The stiffness was also compared. The stiffness of the MPFL in response to lateral patella displacement for both the intact and reconstructed MPFL was calculated for the first 1.5 mm of displacement (S1) and from 1.5 mm to 10 mm of displacement (S2). Stiffness was defined as the slope of the linear regression that was fit to each region of the load-displacement curve.

Reconstructed MPFL – Insertion Sites

The validated model was used to study multiple MPFL reconstruction insertion sites. Specifically, the insertion sites were repositioned in increments of 5 mm from the anatomic position on both the femur and patella. For the validated model, the femoral and patellar insertions assumed the anatomic position. Thereafter, the femoral insertion was modeled at 5 mm and 10 mm anterior, proximal, and distal to the anatomic position (Figure 2), with the patellar insertion remaining at the anatomic site. Additionally, the patellar insertion site was positioned 5 mm proximal and distal to the anatomic site, with the femoral insertion site remaining in anatomic position, thus creating nine unique insertion scenarios (Figure 2). Note, the initial tension (0 N) in the graft remained the same for the different insertion sites.

RESULTS

For the intact FE model, the lateral restraining force was 80.0 N with a corresponding patellar contact area of 54.97 mm². For the reconstructed MPFL FE model, the lateral restraining force increased to 148.9 N with a contact area of 71.78 mm². The biomechanical data for
A the finite element model is summarized in Table 1. The model predicted restraining forces were greater than the forces measured during the experimental study, where the average lateral restraining force was 69.0 (5.9) N for the intact MPFL, increasing to 110.2 (17.5) N for the reconstructed MPFL. The ratios between intact and reconstructed MPFL restraining forces were similar, however.

In the intact FE model, S1 was 17.39 N/mm and S2 decreased to 6.15 N/mm. Comparatively, the experimental average S1 was 24.5 (5.0) N/mm; S2 decreased to 5.0 (1.6) N/mm. The stiffness for the reconstructed MPFL model was higher than the intact model. S1 was 18.97 N/mm and S2 decreased to 14.12 N/mm. Experimentally,

the average S1 for the MPFL reconstruction was 23.1 (4.2) N/mm; S2 average stiffness was 11.2 (1.8) N/mm.

Comparing the different reconstruction insertion site models to the anatomic MPFL insertion model, the lateral restraining force increased when the femoral insertion site was moved anteriorly or distally. The force decreased when the femoral insertion site moved proximally. Additionally, the lateral restraining force decreased when the patellar insertion site moved either proximally or distally by 5 mm relative to the anatomic insertion. Table 1 summarizes the biomechanical results for patellar lateral displacement of 10 mm, comparing the various insertion site models. Figure 4 shows the contact pattern and the corresponding contact pressure for each model. Similar to the lateral restraining force, the contact force increased for femoral insertion sites that were anterior, but decreased for femoral insertion sites proximal to the anatomical insertion. Additionally, the contact force decreased with the patella insertion site moving either proximal or distal by 5 mm.

**DISCUSSION**

Previous authors have highlighted the importance of anatomic graft position during MPFL reconstruction, but there have been relatively few studies that describe patellofemoral contact force and area after reconstruction. This finite element study provides insight into the changes in patellofemoral biomechanics due to medial patellofemoral ligament reconstruction, including the effect of reconstruction insertion site.

The finite element model was compared to the experimental study by Duchman et al. The model predicted similar, although slightly larger, forces to displace the patella 10 mm laterally for both the intact and reconstructed MPFL. The difference between experimental

<table>
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<tr>
<th>Table 1: The biomechanical data for lateral patella displacement of 10 mm determined by the finite element model</th>
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<tr>
<td>Force at the Patella (N)</td>
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<tr>
<td>-------------------------</td>
</tr>
<tr>
<td>Anatomical Intact</td>
</tr>
<tr>
<td>Anatomical Reconstructed</td>
</tr>
<tr>
<td>Femur Anterior 5mm</td>
</tr>
<tr>
<td>Femur Anterior 10mm</td>
</tr>
<tr>
<td>Femur Distal 5mm</td>
</tr>
<tr>
<td>Femur Distal 10mm</td>
</tr>
<tr>
<td>Femur Proximal 5mm</td>
</tr>
<tr>
<td>Femur Proximal 10mm</td>
</tr>
<tr>
<td>Patella Distal 5mm</td>
</tr>
<tr>
<td>Patella Proximal 5mm</td>
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</table>
forces and the model predicted forces could be due to the large variability in patellofemoral anatomy. Also, the models had similar stiffness predictions with a greater initial stiffness (0-1.5 mm range) than S2 (1.5-10 mm range). This was true both experimentally and theoretically. Since the experimental and finite element model results were comparable for both force and stiffness and followed a general trend, the anatomical model was considered validated.

For additional validation, the model was compared to experimental studies focusing on patellofemoral contact area. Although there is no direct comparison due to different loading conditions and varying techniques to define contact area, the contact pattern for the current study was similar to previous studies. The femoral contact pattern at 30° was comparable to the study by Yamada et al., like the current study, the contact was primarily isolated to the proximal portion of the femoral trochlear cartilage. Additionally, the patellar contact pattern was similar to that reported in the experimental study by Lee et al. The contact pattern was centered on the patella itself. For the current study, the contact occurred on the distal edge of the cartilaginous portion of the patella, but central overall on the patella (Figure 5).

Using this validated anatomical model, the effects of MPFL reconstruction insertion sites were studied, comparing the alternate insertion sites to the anatomically reconstructed MPFL. For this model, the initial graft tension did not vary with insertion site; the graft was not pre-tensioned and had the same material properties. It was determined that the insertion site does have an effect on the biomechanics of the patellofemoral joint. Anterior placement on the femur resulted in the greatest increase in patellar restraining force (a difference of 28.1 N at 10 mm anteriorly) compared to the anatomical MPFL reconstruction. This also resulted in a 32.7% increase in contact area with little decrease in contact pressure, both peak pressure (8.4%) and total pressure (1.5%). The larger contact area with minimal change in pressure may result in increased cartilage wear, suggesting that clinicians should avoid anterior graft positioning during reconstruction.

On the other hand, when the femoral insertion site was shifted proximally, the patellar force decreased by 34.8 N. The proximal insertion also had a lower patella contact force and contact area, which resulted in forces and contact area that are between the anatomically intact and reconstructed MPFL. The decrease in contact area and lateral restraining force may be due to the line of action of the reconstructed MPFL ligament based on the insertion site. The different ligament line of action may make it easier to laterally displace within the trochlear groove. Since the goal of MPFL reconstruction is to provide additional stability, proximal insertion may provide inadequate stability.

There are limitations to this study. First, the model is based on a single specimen; with high variability in trochlear groove depth and patella anatomy, it may be beneficial to extend this study to several models to account for anatomical differences. Also, for this model the MPFL and medial patellotibial ligament were modeled based on anatomic data reported in literature and were not specimen specific. Although defining these ligaments from medical images would be ideal, it is a challenge due to the thin anatomy and complex nature of the attachment site. With advances in medical imaging, future models may be able to define all soft tissues on a specimen-specific basis, as opposed to average anatomical data. Additionally, this model did not incorporate the meniscus since static loading options were considered. To study various loading conditions and angles of flexion, the meniscus should be added to the model. Also, the model boundary conditions do not capture in vivo scenarios; however, do mimic in vitro loading conditions. The model boundary constraints should be considered when applying these predicted trends to clinical situations. This study was restricted to one angle of flexion and graft tension. Future work should look at different flexion angles and different graft tensions. Additionally, the model will be used to look at different combinations of MPFL reconstruction insertion sites, where both the patellar and femoral insertion are not anatomic.

Although the model has limitations and constraints, it affords insight into overall patellar biomechanics, comparing intact MPFL to MPFL reconstruction. Additionally, the study addresses the effects of MPFL reconstruction insertion sites. Corresponding with experimental studies, MPFL reconstruction increases the patella lateral restraining force. Considering the constraint condition and model restrictions, the study
predicts that placement anterior to the femoral anatomical insertion could increase the contact force and area, whereas an insertion proximal to the anatomical position may reduce the contact force and area.

ACKNOWLEDGEMENTS
The authors would like to thank Dr. Mark McCarthy and Justin Kuiper for their assistance with the experimental setup and testing.

REFERENCES


ABSTRACT

Background: Recent literature has shown that posterolateral corner injuries of the knee have poor results when treated with repair, when compared to reconstruction. Our study sought to compare outcomes of posterolateral knee injuries treated with repair versus reconstruction and report results from our institution, with the hypothesis that acute repairs have comparable results to reconstructions.

Methods: We identified patients with posterolateral knee reconstruction or repair from January 1, 2000 to March 1, 2012. Patients returned for outcome measures, clinical exam and varus stress radiographs. Further, each patient underwent a chart review. Varus stress radiographs were obtained in 20 control knees, with no history of knee trauma, to our two cohort groups.

Results: 26 knees in 25 patients (17 reconstructions and 9 repairs) were evaluated in clinic at mean of 42 months postoperatively for repairs and 38 months postoperatively for reconstructions. Average IKDC scores for reconstruction and repair were 68 and 71, respectively. Average Lysholm scores for these groups were 83 for reconstructions and 83 for repairs. No statistically significant differences existed. Average varus gapping at zero degrees was 8.21 and 8.84 millimeters (mm) for reconstructions and repairs, respectively. Average varus gapping at 20 degrees knee flexion was 11.25 mm for reconstructions and 10.34 mm for repairs. No statistically significant differences were observed in varus gapping between the two groups.

Each patient chart was reviewed for complications. There were 2 failures in the 44 patient reconstruction group (4.7%) and 2 failures in the 18 patient repair group (11.1%). We noted a high rate (10/19 patients) of primarily distally-based injuries in our repair group. All failures were treated with revision reconstructions.

Conclusion: We found low failure rates in both groups. All knees in the repair group were operated within three weeks of injury. Our repair knees had a high rate of distally based avulsion and, were felt to have acceptable tissue that could be successfully repaired. We recommend posterolateral knee repair in cases with distally based avulsions that can be operatively treated within 3 weeks of injury, and have good tissue quality at the time of surgery.

Level of Evidence: IV

INTRODUCTION

Much research has gone into understanding the anatomy and biomechanics of the posterolateral corner (PLC) of the knee1. Both the complexity of the anatomic structures and concomitant ligament injuries can make diagnosis of posterolateral knee injuries difficult. Over the last 10 years, there have been many advances in the clinical and radiologic identification of these injuries2-4. Incompetent posterolateral knee structures can lead to significant instability and it has been clear that these injuries are best managed when diagnosed early5. There is a high rate of anterior and posterior cruciate reconstruction failures in the setting of unrecognized posterolateral corner injuries6-8.

There has been much debate on whether to repair or reconstruct the injured structures. In the setting of chronic instability or poor quality tissue, many authors have recommended reconstruction9-18. When acute injuries can be treated in a timely fashion, and tissue quality is appropriate, many authors recommend repair of these structures with good results5,9-11,19.

Previous studies showed poor results with acute repair20-22, necessitating revision reconstruction. Further, cadaveric and clinical studies have used varus stress radiography to assess PLC injuries. The purpose of our study is two-fold: one is to compare the outcomes of posterolateral corner reconstruction versus repair and, two, evaluate varus stress radiographs at final outcome, using matched controls as comparison. Our hypothesis was that our failure rates, outcomes scores, and varus stress opening would be comparable between the repair and reconstruction groups.
Posterolateral Knee Reconstruction Versus Repair

METHODS

After obtaining institutional review board approval, a chart review was performed to identify patients who underwent a posterolateral corner reconstruction or repair from January 1, 2000 to March 1, 2012 at a single institution. Inclusion criteria were 1) patients with confirmed PLC injury 2) minimum 6 month follow-up. We included both isolated PLC and patients with any concomitant ligamentous injuries. Patients with psychiatric comorbidities and patients who were prisoners were excluded from the study.

Demographic data, mechanism of injury, high vs low energy, number of ligaments injured, neurovascular injury, treatment, and complications were recorded. We reviewed each patient’s chart for any other major orthopaedic injuries, as well as any head, chest, abdomen or pelvis injuries.

We also collected information on preoperative and postoperative activity level. We reviewed our clinical outcome database to obtain IKDC and Lysholm scores, and obtained outcome measurements at each patient’s final follow up visit.

Patients returned to our sports medicine clinic for physical examination, outcome scores, and varus stress radiography. Physical exam included range of motion (ROM), quadriceps strength, evidence of recurvatum, and ligamentous evaluation. Varus stress radiographs were obtained at 0 and 20 degrees and measured in millimeters to assess varus gapping at the time of last follow up. These were compared to control knees with no history of knee trauma and/or surgery. We enlisted 20 healthy control subjects with no prior history of knee injury and measured lateral compartment opening with varus stress testing at 0 and 20 degrees.

In our reconstruction cohort, 27 knees underwent a dual femoral, transfibular reconstruction, 14 patients underwent anatomic reconstruction, with femoral, fibular and tibial tunnels, and two patients had isolated FCL injuries and subsequent reconstructions. Our approach in repairing PLC structures involved suture anchors for proximally and/or distally based avulsion injuries. The two midsubstance tears (two midsubstance popliteus tendon injuries) were repaired with end-to-end sutures.

RESULTS

Sixty-one knees in 60 patients were included in this study. Forty-four knees in 43 patients underwent reconstruction, while 18 knees in 18 patients underwent repair. In the repair group, the average age was 35 years (range, 19-68), with 13 men and 5 women. The reconstruction group’s average age was 33 years (range, 21-58), 35 men and 8 women. Average BMI in both groups was 29. For those that returned to participate in the study, mean follow up was 42 months in the repair group (range, 6-108) and 38 months in the reconstruction group (range, 6-94).

Table 1: Demographics of Repair and Reconstruction cohorts

<table>
<thead>
<tr>
<th></th>
<th>Total #</th>
<th>Ave Age (Range)</th>
<th>Ave BMI</th>
<th>M:F</th>
<th>Ave follow up-months (Range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repair</td>
<td>18</td>
<td>35 (19-68)</td>
<td>29</td>
<td>13:5</td>
<td>42 (6-108)</td>
</tr>
<tr>
<td>Recon</td>
<td>43</td>
<td>33 (21-58)</td>
<td>29</td>
<td>35:8</td>
<td>38 (6-94)</td>
</tr>
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Table 2: Mechanism of injury, time from injury (TFI) to surgery and other major injuries in both cohorts

<table>
<thead>
<tr>
<th></th>
<th>High Energy (%)</th>
<th>Low Energy (%)</th>
<th>Average TFI (wks)</th>
<th>Vascular Injuries (%)</th>
<th>Peroneal n. Injuries (%)</th>
<th>Other Injuries (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repair</td>
<td>7/18 (38.9)</td>
<td>11/18 (61.1)</td>
<td>2.1</td>
<td>0/18 (0)</td>
<td>4/18 (22.2)</td>
<td>4/18 (22.2)</td>
</tr>
<tr>
<td>Recon</td>
<td>18/43 (41.9)</td>
<td>25/43 (58.1)</td>
<td>25.7</td>
<td>2/43 (4.7)</td>
<td>10/43 (23.4)</td>
<td>13/43 (30.2)</td>
</tr>
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Mechanism of injury in the reconstruction group was recorded as high energy in 18/43 (41.9%) and low energy in 25/43 (58.1%). In the repair group, 7/18 (38.9%) sustained high energy injuries, and 11/18 (61.1%) had low energy injuries. Time from injury to surgery was 2.1 weeks in the repair group and 25.7 weeks in the reconstruction group. It should be noted that all repair patients were operatively treated within three weeks of their injury.

There were four patients in the repair group and 13 in the reconstruction group that sustained other major traumatic injuries, either trauma to the head, chest abdomen and/or pelvis, or sustained an additional severe orthopaedic injury. We reviewed each patients chart for neurovascular injuries, and the treatment for these injuries. The repair group had four patients (22.2%) with peroneal nerve injuries, zero vascular injuries. The reconstruction group had 10 peroneal nerve injuries (23.4%) and two popliteal artery injuries (4.7%). (Table 2)

Both groups were subdivided into isolated and concomitant ligament injuries. In the reconstruction group,
injury patterns were as follows: two isolated PLC injuries, 19 ACL/PLC, 6 PCL/PLC, 14 ACL/PCL/PLC, and 2 ACL/PCL/MCL/PLC. (Table 3) The repair group injury patterns were: 5 isolated PLC, 9 ACL/PLC, 1 PCL/PLC, 2 ACL/PCL/PLC and 1 ACL/PCL/MCL/PLC. (Table 4) The repair group was also reviewed to assess for which PLC structures were damage, along with their anatomic location. We noted a high rate of distally-based avulsion type injury patterns, with 10/19 (52.6%) having fibular collateral ligament (FCL) and biceps avulsion injuries off the fibula. Two patients had isolated FCL avulsion injuries off the fibula and another two patients sustaining FCL/biceps avulsions off the fibula with midsubstance popliteus tendon injury. (Table 5)

Average IKDC scores were 71 (range, 27-94) and 68 (range, 43-99) for the repair and reconstruction groups, respectively, and not statistically significant (p=0.72). Average Lysholm scores were 83 for both groups, ranges 56-95 for repair and 39-95 for reconstructions (p=0.97). Through direct follow up, patient phone calls or chart review, we assessed 28 patients in the reconstruction group and 13 in the repair for pre- and post-operative activity level. These were divided as outlined above. In the reconstruction group, all but three patients (10.7%) were able to return to their preoperative activity level, or one level below. These three patients went from a designation of “heavy” activity preoperatively, such as strenuous manual labor, heavy lifting or sports involving cutting / twisting, to “light” activity postoperatively, including finding jobs that required less physical work (intermittent walking, limited lifting) or inability to return to certain sporting activity (one unable to return to soccer, one unable to return to basketball). In the repair group, every patient either returned to their preoperative level, or one level below. (Table 6)

Varus stress radiographs were obtained on each patient that participated in the study. In the repair group, average varus gapping was 8.8 millimeters (mm) and 10.3 mm at 0 and 20 degrees respectively. The reconstruction group average varus gapping was 8.2 and 11.3 mm at 0 and 20 degrees. Comparing both groups, statistical significance was not met at either 0 (p=0.52) or 20 (p=0.42) degrees. Control knees had an average varus gapping of 5.3 mm and 6.5 mm at 0 and 20 degrees. When compared to control knees, both groups had statistically significant increased varus gapping at both degrees of measurement (p<0.001). Average mm difference in control vs repair group was 3.6 mm at 0 and 3.8 mm at 20 degrees. Average difference comparing control to reconstruction group was 2.1 mm and 4.3 mm at 0 and 20 degrees, respectively.
Each patient chart was reviewed for any failures and subsequent secondary procedures. In the reconstruction group, there were two failures in 43 patients (4.7%), each undergoing successful revision reconstruction. The repair group had two failed repairs as well (11.1%). Here, each repair failure was treated with revision PLC reconstruction. In one case, suture anchors pulled out of an “en bloc” reconstruction of the PCL structures on the femur. In the other failed PLC repair case, where the FCL avulsed off the fibula and popliteus off the femur, the suture anchor pulled out from the fibula. When comparing the failure rates of each group, we did not find a statistically significant difference ($p = 0.57$).

**DISCUSSION**

Posterolateral corner injuries remain difficult injuries to assess and treat for orthopaedic surgeons. The complex anatomy has now been well delineated. Cadaveric studies have aided in defining three structures vital to posterolateral stability: the fibular collateral ligament, popliteus tendon and popliteofibular ligament. Biomechanically, these structures have been shown to primarily resist varus stress and external rotation, but also, secondarily, act as an anterior-posterior stabilizer.

Various techniques of reconstruction have been described and evaluated in the literature, both in acute and chronic cases of posterolateral instability. Previous outcomes in PLC repair when compared to reconstruction have favored reconstruction, with repair having high failure rates. Further, a recent systematic, evidence based review of multiligament knee injuries, along with other review articles, have suggested that acute reconstruction be strongly considered, given the reported high failure rates of repairs in the literature.

Stannard, et al compared repair versus reconstruction of PLC injuries, and they noted a failure rate of 13/35 (37%) of their repairs, versus 2/22 (9%) of PLC reconstructions in their patients. The authors cite soft tissue not of high enough quality for successful repair on a consistent basis. Further, they reported 11/13 failures within the tendon and/or ligament itself; and not at the site of suture anchor placement in the setting of avulsion injury patterns.

Levy, et al, also evaluated PLC repair vs reconstructions and also discovered high failure rates in their series. Their series had a 40% failure rate for PLC repairs, versus 6% for their reconstructions. The authors noted no correlation between site of injury and repair failure, citing the repair itself as causative. Despite this, their time to surgery, in some repair cases, was greater than 3 weeks, with their upper limit of time from injury to operative repair being 33 days.

Varus stress radiographs have been evaluated as a diagnostic tool for PLC injury assessment previously. More recently, it has been used to assess for PLC repair and reconstruction in the postoperative interval. Rios, et al, evaluated 24 patients with PLC injuries, using varus stress radiographs postoperatively as a measure of outcomes. Here, at an average follow up of 39 months, showed that varus stress radiographs taken in 20 degrees of knee flexion had an average side-to-side difference of 0.2 mm. Geeslin and LaPrade evaluated outcomes of 30 Grade III isolated and combined PLC injuries, repairing avulsed structures and reconstructing mid-substance tears, along with concurrent cruciate reconstructions when applicable. Side-to-side comparisons of the injured and uninjured knees were obtained preoperatively and postoperatively. The authors noted an average 6.2 mm difference in varus gapping in preoperative radiographs, compared to 0.1 mm at final follow up. Further, in nine patients that underwent at least one posterolateral knee structure repair, the authors reported no failure of their repairs.

Our study showed improved outcomes in PLC repair than has been previously reported. Many of our repair PLC patients had avulsion-type injuries, which may have portended to increased success of the repairs than has been previously reported. In Stannard, et al, many failures were reported as mid-substance tears, perhaps increasing the rate of failure in this cohort. Levy, et al, had operative care in their repair cohort past 3 weeks from injury, which may have led to their high failure rate. All of our repair cohort patients had surgery within 21 days of their injury, and many had distally-based, avulsion type injuries. Tissue at the time of each repair surgery was deemed appropriate for repair.

We found substantial varus gapping in both repair and reconstruction group on stress radiographs; however, no differences were found between groups. In varus stress radiographs of control knees, we did find significant difference in varus gapping compared to both PLC repair and reconstruction patients. However, despite increased varus gapping on stress radiographs, no patients reported instability and clinical exam was unremarkable for instability.

Weaknesses of our study include a small cohort of patients in each group with low percentage of patients returning for follow up and participation in the study. The cohort size is comparable, however, to previously reported studies. Despite our average follow up being 42 and 36 months for the repair and reconstruction cohorts, respectively, some patients had follow up as short as six months, which may not be long enough to appropriately assess outcome measurements or need for revision surgery. Three surgeons were involved in...
In conclusion, our study showed improved results with PLC repair than previously reported. PLC repair may be a viable option in select patients based on location of structures, i.e., avulsions vs midsubstance tears, as well as timing of surgery and local tissue quality. Distally-based avulsion injuries that can be operatively treated within three weeks of injury may show improved results, provided adequate tissue quality at the time of surgery. Midsubstance tears, tears that have occurred greater than three weeks prior to surgery, or tears with poor-appearing tissue at the time of surgery may have improved outcomes if they are reconstructed. We recommend following these guidelines in deciding between posterolateral corner repair versus reconstruction.

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MEDIAL PATELLA SUBLUXATION: DIAGNOSIS AND TREATMENT

Mark A. McCarthy, MD, Mathew J. Bollier, MD

ABSTRACT
Medial patella subluxation is a disabling condition typically associated with previous patellofemoral instability surgery. Patients often describe achy pain with painful popping episodes. They often report that the patella shifts laterally, which occurs as the medial subluxed patella dramatically shifts into the trochlear groove during early knee flexion. Physical examination is diagnostic with a positive medial subluxation test. Nonoperative treatment, such as focused physical therapy and patellofemoral stabilizing brace, is often unsuccessful. Primary surgical options include lateral retinacular repair/imbrication or lateral reconstruction. Prevention is key to avoid medial patella subluxation. When considering patellofemoral surgery, important factors include appropriate lateral release indications, consideration of lateral retinacular lengthening vs release, correct MPFL graft placement and tension, and avoiding excessive medialization during tubercle transfer. This review article will analyze patient symptoms, diagnostic exam findings and appropriate treatment options, as well as pearls to avoid this painful clinical entity.

INTRODUCTION
Medial patella subluxation is defined as excessive medial patella translation that re-creates a sense of pain, popping or instability. This entity was first described by Hughston and Deese in patients with previous arthroscopic lateral retinacular release (and associated vastus lateralis release)1. The entity is typically iatrogenic, with common causes including a previous lateral release, detachment of the vastus lateralis from the patella, previous medial tibial tubercle transfer, or an overly tight and/or malpositioned medial patella femoral ligament (MPFL) graft. Underlying hyperlaxity, trochlear dysplasia, and deficient vastus lateralis musculature may also play a role in the development of medial patella subluxation. Often a difficult diagnosis, this article reviews cases, clinical evaluation, and treatment options. We will also provide tips and technical pearls to avoid medial patella subluxation in patients with patellofemoral symptoms.

CASE EXAMPLES
Case 1:
A 39 year old female underwent a lateral retinacular release, tibial tubercle transfer and vastus medialis advancement for patellofemoral instability 2 years prior to presenting to our office. One year prior, she had an MPFL reconstruction and hardware removal. She presented to our office with achy pain at rest and acute episodes of patella shifting and popping. On exam, she had a positive medial subluxation test, medial patella tilt and a tight MPFL graft. A lateral radiograph and MRI were obtained (Figures 1, 2) which showed an anterior and proximally positioned femoral tunnel. After a long discussion, we decided to proceed with revision surgery to address her medial patella subluxation. At the time of arthroscopy, she was found to have a tight medial retinaculum, medial patella tilt, and evidence of medial patellofemoral joint overload (Figure 3). She was treated with a medial retinaculum release, chondroplasty and lateral retinaculum imbrication, which alleviated her symptoms.

Case 2:
A 33-year-old woman underwent a tibial tubercle transfer with MPFL allograft reconstruction for patellofemoral instability at an outside institution. She presented to our office with continued pain and instability. She was found to have a positive medial subluxation test, medial patella tracking and tilt, and pain over the medial retinaculum. MRI revealed an anteriorly placed MPFL femoral tunnel (Figure 4). After failing non-operative treatment, she was taken to surgery to address her medial patella subluxation. At the time of arthroscopy, she had medial patella tilt and extensive medial facet cartilage loss.
Figure 1: Lateral radiograph of Case 1 patient with continued symptoms after MPFL reconstruction. Femoral tunnel placement is anterior and proximal.

Figure 2: Axial MRI of same patient showing anteriorly placed MPFL graft.

Figure 3: Arthroscopic view of Case 1 patient with evidence of medial patellofemoral overload.

Figure 4: Axial MRI of Case 2 patient with anteriorly placed tunnel.
She was treated with medial release and chondroplasty, but eventually required a patellofemoral arthroplasty to achieve pain relief (Figure 5).

**Case 3:**
A 19-year-old woman with Ehlers-Danlos disease had undergone bilateral lateral retinaculum releases for patellofemoral instability. Due to continued symptoms, she had a left MPFL reconstruction with autograft. A few months later, she presented to our office with medial retinaculum pain and acute episodes of dramatic popping. A lateral radiograph (Figure 6) showed an anteriorly placed MPFL femoral tunnel. She underwent an MPFL graft release, debridement of her medial patella chondral lesion and lateral patella stabilization, and achieved relief of her symptoms.

**Etiology**
Medial patella subluxation is frequently related to previous patellofemoral surgery. Hughston and Deese first reported medial patella subluxation in 54 patients (60 knees) who had worsening symptoms or failure to improve after a lateral retinacular release. Of the 60 knees, 30 developed medial subluxation postoperatively1. 144 of 154 (94%) reported cases of medial patella subluxation were in patients who previously had a lateral reticular release, with or without a tibial tubercle transfer2. Nonweiler and DeLee reported on five cases of medial patellar subluxation after isolated lateral retinacular release3. Bollier, et al, reported five patients having disabling symptoms after malpositioned MPFL grafts, which led to medial subluxation and medial patellofemoral articular overload in three cases4. Less commonly, hyperlaxity, trochlear dysplasia and deficient musculature can lead to medial patella subluxation5.

Spontaneous medial patellar subluxation is a very rare and limited to case reports5.

**Patient History**
Patients typically complain of a dramatic, painful patellofemoral popping sensation with certain knee movements. There often is a history of previous patellofemoral surgery. Often, they are worse after surgery and the timing, extent and description of symptoms need to be carefully sorted out. This condition can be quite disabling and can severely limit activities. Patients are apprehensive and avoid activities and knee positions that may reproduce their symptoms or instability. Often, they report that the patella shifts laterally and this condition can easily be mistaken for lateral patellofemoral instability. However, the patella is subluxed medially in full extension. As the knee flexes, the patella jumps laterally into the trochlear groove. Other reported symptoms are anterior knee pain, swelling, “giving away” episodes, and difficult navigating stairs.

Patients are substantially disabled by this condition. Hughston et al, found that 85% of patients were unable to perform light recreational activities, 69% reported severe or disable knee pain and only five of 65 patients could participate in competitive sports6.

**Physical Exam**
Static medial patella subluxation, notable vastus lateralis atrophy, or a visible and palpable lateral patella void may be observed1. Standard patellofemoral exam should be performed including assessment of patella glide, crepitus, lateral apprehension, tracking, and alignment. Medial patella translation greater than 2 quadrants indicates loss of lateral patellofemoral restraints or underlying hyperlaxity7. Although increased laxity suggests the
diagnosis, the key is to reproduce the patient’s symptoms or apprehension with the medial patella subluxation test. With the knee in full extension, the examiner applies a medial translational force to the patella. The knee is then flexed. In the first 30 degrees of knee flexion, pain, instability or dramatic reproduction of the patient’s symptoms occurs as the patella snaps laterally into the trochlear groove.

Nonweiler and DeLee described the gravity subluxation test. The patient is placed in the lateral decubitus position, with the affected leg abducted in the air. Patients are then asked to contract their quadriceps. A positive test is shown by the inability to pull the subluxed patella laterally into the trochlear groove and indicates laxity of the lateral retinaculum and/or detachment of the vastus lateralis from the patella.

**Imaging**

Standard knee radiographs are obtained, including weight-bearing AP, lateral, notch and Merchant views. Merchant views, obtained to measure the congruence angle, can show static patellar subluxation at a specific knee flexion angle. Trochlear dysplasia can be assessed on lateral radiographs looking for the “crossing sign.” The lateral view can also assess for patella alta. Gravity AP radiographs, taken with the leg abducted, have been described as a dynamic picture of the patella during non-contracted and contracted states of the quadriceps.

MRI has been used to assess the status of medial and lateral soft tissue restraints, the patella cartilage, and to measure tibial tubercle to trochlear groove, or TT-TG, distance. Dynamic MRI has been proposed to better assess patellar instability. However, confounding factors (patient position, motion, and muscle firing patterns) can change the position of the patella in various degrees of knee flexion.

Imaging studies are often nonspecific for the diagnosis of medial patella dislocation. This is usually a diagnosis made by history and physical exam.

**Nonoperative Management**

Physical therapy, specifically vastus lateralis strengthening, or the use of a patellofemoral brace during activities can be tried. Unfortunately, nonoperative management is often unsuccessful. Patients with continued symptoms after 3-6 months of non-operative treatment can be indicated for surgical intervention.

**Operative Management**

Most techniques involve repairing or reconstructing the lateral patellar stabilizers.

**Open Lateral Repair**

Direct repair of the lateral retinaculum fascia was described by Hughston and Brinker. When good tissue is present, a side-to-side anastomosis technique can be used to reapproximate the tissues (Figure 7). If the vastus lateralis has been released or retracted, it should be mobilized and repaired. Nonweiler and DeLee reported on 5 patients who had imbrication and vastus lateralis advancement. At an average followup of 3.3 years, four of the five patients had no instability symptoms with negative gravity subluxation tests. Three patients had excellent and two had good results. Heyworth, et al, reported results in 22 patients with previous lateral retinacular releases who underwent open lateral retinacular closure. Each patient had symptoms of anterolateral pain, a palpable lateral defect and positive medial apprehension test. Average follow up was 3.2 years, with 82% of patients rating their outcome as good or excellent and 14% as fair. Preoperatively, 86% of patients rated themselves as poor. Good tissue is necessary to perform repair or imbrication.

**Open Lateral Reconstruction**

When tissue quality is poor or insufficient, reconstruction should be considered. Various techniques have been described, utilizing iliotibial (IT) band, tensor fascia lata or patellar tendon for the reconstruction. Hughston described using an anterior strip of iliotibial band. With this technique, the surgeon dissects a one centimeter strip of tissue 3-4 cm in length. The distal aspect of the IT band is left attached to the lateral aspect of Gerdy’s tubercle. The strip is then used to close the lateral deficit by attachment to the lateral patella (Figure 8). The IT band can be either sewed to the soft tissues or placed through a patellar tunnel.

Hughston also described using the patellar tendon to reconstruct the lateral restraints. The lateral 1/4th of the patella tendon is detached distally from the tibial tubercle and left intact proximally, either with or without...
M. A. McCarthy, M. J. Bollier

a bone block attachment (Figure 9). The patellar tendon can be secured to the tibia through bone tunnels, suture anchors, or with direct suturing to the soft tissues.

Reconstruction using both IT band and patellar tendon can also be performed. The IT band graft is rotated toward the patella and patellar tendon rotated toward Gerdy's tubercle. The patella tendon is secured at Gerdy's tubercle and the IT band is fixed to the patella.

Regardless of surgical intervention chosen, the retracted vastus lateralis should be mobilized for transfer, and attached to the patella or quadriceps mechanism.

Hughston et al evaluated outcomes after lateral reconstruction with the patella tendon. They reported on 65 knees. At an average follow up of 53.7 months, 44 patients (68%) reported improvement in their functional levels and 49 patients (75%) were subjectively improved. Fifty patients (80%) rated their outcome as good or excellent. A second surgical reconstruction was required in six knees secondary to index surgical failure, re-injury, or failure to improve.

Postoperative recommendations for either repair or reconstruction consist of full weight-bearing with a knee immobilizer for 6 weeks. Quadriceps sets and straight leg raises are allowed the day after surgery. Immediate full knee ROM is allowed when seated.

Arthroscopic Medial Retinacular Release

Arthroscopic medial release has also been described to address medial subluxation of the patella. Shannon et al reported seven patients (nine knees) with history and exam consistent with medial subluxation and all of whom failed an extensive rehabilitation course and a trial of bracing. A diagnostic arthroscopy was performed on each patient, followed by the medial release using an arthroscopic electrode. The medial retinaculum was divided, beginning at the superior pole of the patella and traverses distally to the anteromedial portal. Once this was done, the authors grasped and tilted the patella laterally 50 to 70 degrees on its lateral edge to ensure any remaining retinacular tissue was divided. Final palpation over the medial undersurface of the patella was done to confirm a complete release. At an average follow up of 2.7 years, all seven patients had alleviation of their symptoms, with 6 excellent and 3 good results. There were no complications or need for further surgical intervention.

Avoidance of Medial Patella Subluxation

The key to avoiding medial patella subluxation is careful attention to initial surgical indications and technique. Lateral release should not be performed as the sole procedure to treat patellofemoral instability. Indications for isolated lateral release include a tight lateral retinaculum and/or lateral facet overload. Lateral release is often performed in conjunction with MPFL reconstruction or tibia tubercle transfer in the setting of patellofemoral instability surgery. In this setting, a lateral release may be indicated when the patella has lateral patella tilt less than neutral.
In lieu of a release, surgeons can consider a lateral retinacular lengthening\(^{16}\). In a recent prospective study, 28 patients were randomized to lateral release (14) or lengthening (14)\(^{16}\). The lateral lengthening group was found to have less quadriceps atrophy, less medial instability and improved outcomes at two years compared to the lateral release group. To perform, the superficial and deep retinacular layers are split sequentially and patellar tilt performed. The superficial layer is then sutured to the deep layer under no tension (Figure 10).

MPFL reconstruction is a common procedure to address patellofemoral symptoms. When performing MPFL reconstruction, it is important to have appropriate graft length/tension, and an anatomic femoral tunnel position. The native MPFL acts as a checkrein during the first 30 degrees of knee flexion, guiding the patella into the trochlear groove. The trochlea then becomes the primary restraint at deeper flexion angles. The MPFL remains isometric from extension to 60 degrees of flexion\(^{17}\). With further flexion, tension declines, with no measureable tension in deep knee flexion\(^{18}\). Appropriate graft placement and tension are keys to avoid medial patella subluxation\(^4\). An incision large enough to allow palpation of the MPFL insertion between the medial epicondyle and adductor tubercle is recommended (Figure 11)\(^{19}\). Palpating the adductor magnus tendon can assist in defining surgical anatomy (Figure 12). A suture can be used to connect the proposed femoral insertion site to the patella and isometry can be determined. If the suture tightens in flexion, the proposed femoral attachment site is too anterior or proximal. Finally, lateral fluoroscopic landmarks should be used to confirm accurate guidewire placement (Figure 13). The guidewire should be placed 1 millimeter anterior to the posterior cortical line of the femur, just proximal to Blumensaat’s line\(^{20}\) (Figure 14).


When tensioning the graft, the surgeon can flex the knee 45-60 degrees so that the patella is centered in the trochlea. Another option is to hold the patella flush with the lateral trochlea with the knee flexed to 30 degrees during final graft fixation. Either way, the end result should have some lateral patella translation with the knee extended and solid endpoint. The patella should pull into the groove when the knee is flexed.

Tibial tubercle transfer is another common operative treatment for patellofemoral symptoms. However, in patients with lateral malalignment and medial patella chondral lesions, caution should be taken to avoid over-medialization of the patella. Normal TT-TG is 10 mm\(^2\). If the measured pre-operative TT-TG distance is 20 mm, then tubercle transfer should be limited to 10 mm\(^2\). This will help avoid over medialization and the potential for develop of medial patella subluxation.

**CONCLUSION**

Medial patella subluxation should be considered in any patient with patellofemoral pain, popping, or instability who has had previous patellofemoral surgery or lateral retinacular release. The diagnosis is clinical and, while a constellation of signs and symptoms are typical, the medial patella subluxation test is diagnostic. Unfortunately, non-operative treatment is usually unsuccessful. Operative options include lateral retinacular repair or imbrication and lateral reconstruction. Operative intervention can yield good outcomes in most patients. Awareness of this relatively rare entity can lead to not only earlier intervention but also decrease the incidence through careful surgical indications, procedures and techniques employed.
REFERENCES
ABSTRACT

Background: Patients with femoral trochlear dysplasia are at risk for chronic recurrent patellofemoral dislocations, with extreme cases often requiring a surgical procedure. Anteromedialization of the tibial tubercle with intraoperative femoral nerve stimulation and concurrent medial patella-femoral ligament (MPFL) reconstruction is a previously reported method of maximizing patello-femoral congruency. We hypothesize the Fulkerson osteotomy with intraoperative femoral nerve stimulation and concurrent MPFL reconstruction in patients with severe trochlear dysplasia provides equivalent postoperative clinical outcomes to the same procedure in patients with low level trochlear dysplasia.

Methods: 48 knees underwent Fulkerson osteotomy with intraoperative femoral nerve stimulation and concurrent MPFL reconstruction for recurrent lateral patellar dislocations. MRI, surgeon intraoperative assessment, and X-ray were used to assess degrees of trochlear dysplasia; inter-observer and intra-observer error were measured. The knees positive for severe dysplasia on MRI, intraoperative assessment, and X-ray were considered as a comparison cohort to the rest of the study population. We considered postoperative dislocation events and patellar tracking kinematics as outcome measures. Independent student t tests and Fisher exact tests were used to evaluate differences between groups. Significance was set at P<0.05.

Results: 11 knees were positive for severe dysplasia (SD) by combined MRI, surgeon intraoperative assessment, and X-ray with the remaining 37 knees categorized as low dysplasia (LD). No patients in either group exhibited apprehension or required re-operation. Mean sulcus angle in the SD group was 175.8 ±2.45 degrees (95% CI 171.0-180.6); the LD group mean sulcus angle was 154.3 ± 0.98 degrees (95% CI 152.4-156.2) (P<.001). Postoperatively there was no significant difference in dislocation events between the SD group (0/11) and the LD group (2/37) (P>0.999). Patellar maltracking decreased in both groups and there were no significant differences in estimates of patellofemoral congruency between the SD (2/11) and LD (8/37) (P>0.999) groups.

Conclusion: The Fulkerson osteotomy with femoral nerve stimulation aimed at maximizing patellofemoral congruency may be an equally effective procedure for patients with either severe or mild trochlear dysplasia.

Level of Evidence: Level III, Retrospective comparative study

INTRODUCTION

Previous authors have described various etiologies of patellar maltracking and instability including an imbalance between soft tissue, muscular action and bone morphology. The medial patellofemoral ligament (MPFL) contributes approximately 50–60 % of the total restraining force against lateral patellar displacement. The trochlea can be described as a concave trough at the distal end of the femur with an average sulcus angle of 138±6° and the shallowness of this groove is described as trochlear dysplasia. A sulcus angle of greater than 145 degrees is suggestive of trochlear dysplasia and has been found to be an important risk factor for recurrent patellar dislocation. Similarly, a lateral trochlear inclination (LTI) of less than 11 degrees has been described as 93% sensitive and 87% specific for trochlear dysplasia.

Previous authors identified that 96% of patients with a prior history of a patellar dislocation had evidence of trochlear dysplasia radiographically.

Various imaging modalities and techniques have been described in an effort to characterize the bony architec-
ture and pathology associated with patellofemoral instability. A computed tomography (CT) scan or magnetic resonance imaging (MRI) can be used to determine the lateral offset of the tibial tubercle relative to the trochlear groove (TT-TG distance). Patella alta has been described as a risk factor for recurrent patella dislocation. The Caton-Deschamps method is a recognized method of assessing Patella alta and is defined as the ratio between the patellar articular facet length and the distance between the facet and the anterior corner of the superior tibial epiphysis. A Caton-Deschamps ratio of > 1.2 is suggestive of Patella alta and may indicate a disruption of the engagement between the proximal trochlea and the patella. Dejour proposed a classification system of trochlear dysplasia based on 2-dimensional radiographs and 3-dimensional computed tomography (CT) scans with type A described by a fairly shallow trochlea, Type B described as a flat or convex trochlea with a supra-trochlear spur creating a prominence and type C as demonstrating an asymmetry of trochlear facets with a hypoplastic medial condyle. Finally, type D is described as an asymmetry of trochlear facets plus a vertical join and cliff pattern.

Physical exam maneuvers including palpation, range of motion and provocative maneuvers can be used to evaluate the patient with suspected patella instability. The most widely used is the apprehension test where the examiner attempts to elicit an apprehensive response from the patient by pushing the patella laterally. Other kinematic tests of patellofemoral congruency are also employed. A positive J-sign describes the movement of the patella over the lateral femoral condyle when the knee is extended during active quadriceps contraction. A J-sign measuring greater than 5 mm may have clinical value in predicting the amount of medialization required during a Fulkerson osteotomy. The J-sign is very common in the population of patients with lateral patellar dislocations and can be used as a gross measure of patellar tracking. An “S-sign” has also been previously described as the initial medial movement of the patella prior to the lateral movement over the lateral femoral condyle during active extension.

There are a variety of conservative and surgical methods that have been used to treat patients with lateral patellar dislocations. Conservative treatment of patellofemoral instability includes immobilization, muscle re-education (quadriceps isometrics, straight leg raises, and single-plane motion exercises) bracing, and taping. Patellar instability manifested by recurrent dislocations that have failed conservative treatment can be treated by various surgical interventions including soft tissue balancing, tibial tubercle transfer, trochleoplasty, as well as rotational osteotomy of the femur. Most notably, lateral retinaculum release, MPFL reconstruction, trochleoplasty and various bony realignment procedures have all been discussed in the literature with varying degrees of success. In the face of poor patellofemoral congruency, isolated MPFL reconstruction has been shown to be inadequate and result in a high rate of patellar redislocation. Previous work has cited indications for a sulcus deepening trochleoplasty as reserved for severe cases that includes a prominent supratrochlear spur, high-grade trochlear dysplasia, and patellar instability or abnormal tracking. Fulkerson et al previously described a technique that we commonly use at our institution involving surgical anteromedialization of the tibial tubercle to align the extensor mechanism of the knee thus allowing the patella to move appropriately within the confines of the trochlear groove. Additionally, the senior author of this study has previously used intraoperative femoral nerve stimulation to estimate the amount of correction required to achieve congruency of the patella tracking from 0° to 30° of flexion when performing a Fulkerson osteotomy. This technique is based on achieving maximal patellofemoral congruency during active quadriceps extension when the femoral nerve is stimulated intraoperatively. This technique also takes into consideration the TT-TG distance to help guide placement of the tibial tubercle, however, the final placement of the tibial tubercle attempts to achieve complete congruency in the dynamic condition of active quadriceps contraction. Finally, the technique used by the senior author utilizes MPFL reconstruction concomitantly with anteromedialization of the tibial tubercle to correct the loss of the medial soft tissue checkrein restraints sustained in recurrent lateral patellar dislocations.

The aims of this study are to evaluate the preoperative imaging and postoperative outcomes of patients who underwent Fulkerson osteotomies with intraoperative femoral nerve stimulation and MPFL reconstruction for trochlear dysplasia. We hypothesize there will be no difference in postoperative patellar maltracking and re-dislocation events between patients with severe trochlea dysplasia and patients with low level dysplasia after undergoing Fulkerson osteotomy with intraoperative femoral nerve stimulation and MPFL reconstruction.

METHODS

This study is a retrospective comparative study of 48 knees (42 patients: 18 males, 24 females; range 16 to 54 years old) who underwent Fulkerson osteotomies for recurrent lateral patellar dislocations. Exclusion criteria included patients without adequate MRI scans or those with insufficient information in the pre- and postoperative clinical notes. Lateral trochlear inclination (LTI;
Figure 1) and Sulcus angle (Figure 2) were determined on the most proximal image of an axial MRI in which the entire width of the femoral trochlea was observed. Our methods for measuring sulcus angle and lateral trochlear inclination index have been previously described with good reliability previously demonstrated. Patellar height was measured using the Caton-Deschamps method on lateral MRI and TT-TG distance using axial MRI. Inter-observer error was measured between three observers and intra-observer error was measured by each observer repeating the measurements in a different order after a one month period. We used axial MRI slices and a two group classification for trochlear dysplasia which differentiated type A (Figure 3) low-level dysplasia...
from types B (Figure 4), C, and D (Figure 5) which were all considered to represent severe trochlear dysplasia. This two grade analysis has been previously described using the Dejour trochlear dysplasia classification. Additionally, the senior author examined and described the intraoperative appearance of each trochlear groove in a graphic illustration of the trochlear contour from the most superior contact point for the patella from through the first 30 degrees of flexion of the knee. Trochlear grooves that were described intraoperatively as flat or having a bump were categorized as severely dysplastic; all others as low-level dysplasia. For each trochlea that was both classified as severely dysplastic (types B, C, or D) on MRI and described intraoperatively as either flat or having a bump, a lateral X-ray was assessed for the presence of an obvious supratrochlear bump or crossing sign. To be classified into the severe dysplasia group (SD) a knee must have been classified as type B, C, or D on axial MRI in at least 66% of observations, described intraoperatively as flat or having a bump, and shown to have a supratrochlear bump or crossing sign on a true lateral X-ray. The remainder of knees that did not meet all three of these criteria were considered as the low-level dysplasia group (LD). Pre-operative and post-operative clinical notes were assessed for the presence of patellar maltracking and re-dislocation. Patellar maltracking was characterized as a clinically gross J-sign, a clinically gross S-sign, or a J-sign of >5mm if measured. Simple kappa coefficients were calculated to describe intra observer and inter observer agreement when determining two group axial MRI classification of trochlear dysplasia. Independent student t tests and Fisher exact tests were used to evaluate differences between groups. Significance was set at P<0.05.

### RESULTS

The SD group consisted of 11 knees which were positive for severe dysplasia by combined MRI, intraoperative assessment, and lateral view plain X-rays. The remaining 37 knees were placed into the LD group. Mean follow up time was 8.96+/-.141 months for SD group and for 13.02+/-.197 months for the LD group. Minimum followup was 1 month and maximum followup was 45 months. Mean sulcus angle was 175.8 +/- 2.45 (95% CI 171.0-180.6) degrees and lateral trochlear inclination was -4.8 +/- 1.87 (95% CI -8.4- -1.1) degrees in the SD group. The LD group mean sulcus angle was 154.3 +/-0.98 (95% CI 152.4-156.2) and with a lateral trochlear inclination of -11.0 +/- 0.80 (95% CI 9.4-12.6) degrees. Both the mean sulcus angle and mean lateral trochlear inclination differed significantly between the SD and LD groups (P<.001). Mean Caton-Deschamps index was 1.25 +/- 0.23 and 1.28 +/- 0.182 in the SD and LD groups respectively (P<0.42). 7 out of the 11 knees in the SD group surpassed the cutoff for patella Alta (Caton-Deschamps ratio >1.2) while 21 out of the 37 knees in the LD group had an index of >1.2. TT-TG distances were 21.25 +/- 3.06 mm and 19.44 +/- 3.77 mm in the SD and LD groups respectively (P=0.059). Simple kappa coefficients were calculated to describe intra observer and inter observer agreement when determining two group axial MRI classification of trochlear dysplasia (Table 4). Intra observer agreement analysis was as follows: Rater 1 (Kappa coefficient [KC], 0.7500 (95% confidence interval [CI], 0.5635-0.9365); rater 2 (KC,}

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**Table 1. Pre and postoperative clinical findings in patients with severe trochlear dysplasia (SD) and low-level or absent trochlear dysplasia (LD).**

<table>
<thead>
<tr>
<th>Clinical Finding</th>
<th>SD Group (n=11)</th>
<th>LD group (n=37)</th>
<th>p-value</th>
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<tr>
<td>Total Pre-operative Maltracking</td>
<td>11</td>
<td>34</td>
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<tr>
<td>Post-operative J-sign &gt; 5 mm</td>
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<tr>
<td>Post-operative Gross S-sign</td>
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<tr>
<td>Total Post-operative Maltracking</td>
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<td>8</td>
<td></td>
</tr>
</tbody>
</table>

**Table 2. Imaging findings in patients with severe trochlear dysplasia (SD) and low-level or absent trochlear dysplasia (LD).**

<table>
<thead>
<tr>
<th>MRI Measurements</th>
<th>SD group</th>
<th>LD group</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulcus Angle (degrees)</td>
<td>175.8 +/- 2.45</td>
<td>154.3 +/- 0.98</td>
<td>1.15x10^-4</td>
</tr>
<tr>
<td>Lateral Trochlear Inclination (degrees)</td>
<td>-4.8 +/- 1.87</td>
<td>11.0 +/- 0.80</td>
<td>1.2x10^-5</td>
</tr>
<tr>
<td>Caton-Deschamps Index</td>
<td>1.25 +/- 0.23</td>
<td>1.26 +/- 0.182</td>
<td>0.42</td>
</tr>
<tr>
<td>TT-TG Distance (mm)</td>
<td>21.25 +/- 3.06</td>
<td>19.44 +/- 3.77</td>
<td>0.059</td>
</tr>
</tbody>
</table>
Table 3. Intraobserver error in measurements assessing the two group axial MRI classification of trochlear dysplasia

<table>
<thead>
<tr>
<th></th>
<th>Rater 1</th>
<th>Rater 2</th>
<th>Rater 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kappa Value</td>
<td>0.7500</td>
<td>0.4615</td>
<td>0.4621</td>
</tr>
<tr>
<td>(95% CI)</td>
<td>0.5635-0.9365</td>
<td>0.2615-0.6616</td>
<td>0.2175-0.7067</td>
</tr>
</tbody>
</table>

Table 4. Interobserver error in measurements assessing the two group axial MRI classification of trochlear dysplasia

<table>
<thead>
<tr>
<th></th>
<th>Rater 1 – Rater 2</th>
<th>Rater 1 – Rater 3</th>
<th>Rater 2 – Rater 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kappa Value Run 1</td>
<td>0.4167 (95% CI 0.1677-0.6657)</td>
<td>0.5833 (95% CI 0.3568-0.8099)</td>
<td>0.3913 (95% CI 0.1269-0.6557)</td>
</tr>
<tr>
<td>Kappa Value Run 2</td>
<td>0.4857 (95% CI 0.2032-0.7283)</td>
<td>0.7600 (95% CI 0.6177-0.9042)</td>
<td>0.4507 (95% CI 0.2077-0.6937)</td>
</tr>
</tbody>
</table>

0.4615; 95% CI, 0.2615-0.6616); rater 3 (KC, 0.4621; 95% CI, 0.2175-0.7067). Interobserver agreement for Time 1 are as follows: Rater 1 versus rater 2 (KC, 0.4167; 95% CI, 0.1677-0.6657); rater 1 versus rater 3 (KC, 0.5833; 95% CI, 0.3568-0.8099); rater 2 versus rater 3 (KC, 0.3913; 95% CI, 0.1269-0.6557) (Table 3). Interobserver agreement for Time 2 were as follows: Rater 1 versus rater 2 (KC, 0.4857; 95% CI, 0.2432-0.7283); rater 1 versus rater 3 (KC, 0.7909; 95% CI, 0.6177-0.9642); rater 2 versus rater 3 (KC, 0.4507; 95% CI 0.2077-0.6937). There were no dislocation events in the SD group (0/11) after surgical intervention while two patients from the LD group had a dislocation of the patella postoperatively (2/37) (P>0.999). Patellar maltracking decreased from 11 to 2 in the SD group and from 34 to 8 in the LD group; there was no difference between groups (P>0.999).

DISCUSSION

Femoral nerve stimulation is a previously described successful method for intraoperative assessment of patellar tracking when performing anteromedialization of the tibial tubercle; however its effectiveness in those with severe femoral dysplasia has not been directly assessed. Our work primarily focused on the ability of our unique method of maximizing patellofemoral congruency to stabilize even the most dysplastic femoral trochlea. However, in doing so we also included measurements for many of the known radiographic risk factors for lateral patellar dislocations including sulcus angle, lateral trochlear inclination, TT-TG distance, and Caton-deschamps index in addition to qualitative indices of pre- and post-operative patellofemoral function. We also describe intra and interobserver differences when using the 2-grade analysis for trochlear dysplasia. In the setting of anteromedialization of the tibial tubercle with intraoperative femoral nerve stimulation and MPFL reconstruction, we report there were no significant differences in postoperative dislocation events or patellar tracking between patients with severe trochlear dysplasia and low-level dysplasia.

Trochlear dysplasia has been found to be an important risk factor for recurrent patellar dislocation with a sulcus angle of greater than 145 degrees suggestive of trochlear dysplasia. Authors have also reported a Caton-Deschamps ratio greater than 1.2 and LTI less than 11 degrees are suggestive of patella maltracking and dysplasia. Previous authors identified that 96% of patients with a prior history of a patellar dislocation had evidence of trochlear dysplasia radiographically. Previous work has also shown intraobserver and interobserver reliability using the two group axial classification of trochlear dysplasia to be 70-90% and 62-86% respectively indicating good to excellent agreement.

We report sulcus angle and LTI differed significantly in the SD versus LD groups of our cohort. The mean sulcus angle for the SD group was 175.8 +/-2.45 degrees while the LD group mean sulcus angle was 154.3 +/- 0.98 degrees. LTI was -4.8 +/- 1.87 and 11.3 +/- 0.8 degrees in the SD and LD groups respectively (p<0.001). The LTI LD group mean was close to the numeric cutoff of 11 degrees for trochlear dysplasia. The LTI SD group mean was calculated to be negative reflecting the extreme amount of subluxation and lateral tilt that often moved the patella completely outside of the femoral trochlea. TT-TG distances were not significantly different between the two groups (P=0.059), however, the distances were greater in the severely dysplastic group. The mean Caton-Deschamps indices were 1.25 +/-0.23 and 1.26 +/-0.82 for the SD and LD groups respectively with no significant difference between groups. Using a standard cutoff of >1.2 for Caton-Deschamps index both groups had a majority of knees reaching the radiographic cutoff for patella alta. We speculate that variation in LTI measurements are due to the observed difficulty in measuring angles in extremely dysplastic trochleas as well as differences between observers in choosing the most proximal image of the entire trochlea. The majority of values for intraobserver (Table 3) and interobserver (Table 4) kappa coefficients were calculated between 0.4 and 0.6 indicating moderate agreement which is slightly lower than previous reports. While direct visualization of the trochlear surface by surgeons will provide the most information, radiographs and MRIs can provide important planning information regarding the architecture of the femoral trochlea before any operation is initiated.
done. Axial MRI measurements reveal the architecture of the trochlea, evidence of articular damage, and allow the surgeon to estimate the amount of anteromedialization needed. Still, the placement of the tibial tubercle is finalized after direct observation of active quadriceps contraction using intraoperative femoral nerve stimulation. The utility of sulcus angle, LTI, and the Dejour grading method should be further assessed. While we have described significant differences in both sulcus angle and LTI between those with severely dysplastic trochleas and those with low-grade dysplasia, we have not qualified these data into clinically useful measures.

Femoral nerve stimulation allows for the reproduction of active forces and increases a surgeon’s ability to simulate patellofemoral tracking intraoperatively. The tibial tubercle placement is often modified after quadriceps stimulation as the lateral forces on the patella become apparent and increased medialization is required. Our described technique allows for the surgeon to avoid damaging the trochlear cartilage or underlying tissue as may be necessary in sulcus deepening trochleoplasty. Our results demonstrate that no knee in the SD group (n=11) and only 2 knees in the LD group (n=37) experienced a patellar dislocation following surgery (P>0.999). In addition, total patellar maltracking decreased from 11 to 2 in the SD group and from 34 to 8 in the LD group following surgery (P>0.999). The absence of dislocations in the SD group suggests that the Fulkerson Osteotomy with intraoperative femoral nerve stimulation and concurrent MPFL reconstruction may be as effective in stabilizing the patellofemoral joint in cases of severely dysplastic trochlear architecture as compared to cases of mild dysplasia. We also note the resolution of gross patellar maltracking in 9 of the 11 knees in the SD group which was not significantly different from the LD group; we report there was an improved kinematic patellofemoral relationship in both the SD and LD groups after our surgical technique. Our results suggest that the Fulkerson Osteotomy with intraoperative femoral nerve stimulation and MPFL reconstruction is as effective in stabilizing the patellofemoral joint in those with severe trochlear dysplasia as it is in those with low or absent trochlear dysplasia.

Limitations of the present work include the retrospective nature of this study. Patients were not contacted to obtain any new information and follow up times were variable. As previously discussed, axial MRI analysis was done by choosing the most proximal part of the trochlea in which the entire trochlear surface could be visualized. Difficulty was encountered between observers in choosing similar axial MRI cuts to make measurements. This may account for some of the variability in grades of dysplasia as well as angle measurements between observers. In addition, highly dysplastic trochleas often had no true sulcus to measure. The convex and laterally displaced trochlear surface often had sulcus angles of greater than 180 degrees and lateral trochlear inclinations of less than 0 degrees when referencing to a line through the posterior condyles. Additionally, information was derived from clinical notes written by different orthopaedic clinicians at different levels of training who presumably had varying exam techniques, skill level, clinical knowledge and thresholds for determining certain clinical characteristics. In particular, some clinicians reported patellar tracking as a gross J- or S-sign while others measured the J-sign objectively. The clinical cutoffs for a gross J- or S-signs for these particular clinicians are therefore not possible to ascertain. Lastly, our followup is limited, with some patients completing only 1 month. It is possible that some patients might go on to have late dislocations, and thus further follow-up is warranted in the future.

CONCLUSION

We report sulcus angle, lateral trochlear inclination, Caton-Deschamps Index, and TT-TG distance measurements in a cohort of 48 knees that underwent Fulkerson osteotomy with femoral nerve stimulation and MPFL reconstruction for patellar instability. The SD group consisted of 11 patients with severe dysplasia that have been reported to be candidates for the extreme measure of reshaping the trochlea. We report moderate intraobserver and interobserver reliability for the two group axial MRI classification of trochlear dysplasia. We find significant differences in both sulcus angle and lateral trochlear inclination between the SD and LD groups. We find no difference in dislocation events or patellar tracking between severely and mildly dysplastic trochleas after Fulkerson osteotomy with femoral nerve stimulation and MPFL reconstruction. We report that Fulkerson osteotomy with femoral nerve stimulation and MPFL reconstruction may be an equally effective procedure for those with both severe and mild trochlear dysplasia. The restricted chart review follow-up of this cohort will require functional outcome and activity based assessments in the setting of a long term follow-up to confirm the success of this approach.

REFERENCES


Effectiveness of Fulkerson Osteotomy with Femoral Nerve Stimulation

ABSTRACT

Background: Dysplasia epiphysealis hemimelica (DEH), or Trevor’s disease, is a developmental disorder of the pediatric skeleton characterized by asymmetric osteochondral overgrowth.

Methods: We present the case of a five year old boy with a two year history of right knee pain and evidence of DEH on imaging who underwent initial arthroscopic resection of his lesion with subsequent recurrence. The patient then underwent osteochondral allograft revision surgery and was asymptomatic at two year follow-up with a congruent joint surface.

Results: To our knowledge, this is the first reported case of a DEH lesion treated with osteochondral allograft and also the youngest reported case of osteochondral allograft placement in the literature.

Conclusions: Osteochondral allograft may be a viable option in DEH and other deformities of the pediatric knee.

Level of Evidence: Level V

INTRODUCTION

Dysplasia epiphysealis hemimelica (DEH), or Trevor’s disease, is a developmental disorder of the skeleton most often characterized by asymmetric osteochondral overgrowth. DEH was initially reported in 1926 and was further described by Trevor in 1950. The disease is rare with a reported incidence of one per million and a male predominance with a male: female ratio ranging from 2:1 to 3:1. The distal femur, distal tibia and fibula, talus and calcaneus are most often affected with lesions involving the carpal bones, bones of the midfoot, scapula, acetabulum and elbow also reported. DEH can affect either the medial or lateral epiphysis, though the medial epiphysis is most commonly involved. Clinical findings typically include deformity, pain, limb-length discrepancy, muscle wasting, swelling, and limitations in joint range of motion. Histologically the lesion is similar to an osteochondroma, however, DEH lacks the EXT1 and EXT2 gene mutations seen in osteochondroma. DEH is also classically an epiphyseal lesion whereas osteochondroma is more commonly metaphyseal in location. On plain radiographs the typical appearance of DEH is asymmetric epiphysal cartilaginous overgrowth, containing more than one ossification center, with varying patterns of epiphyseal chondral calcification. Computed tomography can be used for the detection of small foci of early calcification within the cartilaginous mass of a DEH lesion and can identify cortical and medullary continuity between the lesion and the neighboring bone. Additionally, MRI can be useful in characterizing the size and dimensions of the lesion before it begins to ossify. Management options of DEH include observation, surgical excision, and corrective osteotomy.

Surgical removal is indicated if the lesion is causing deformity, pain, compromising function, or resulting in an intraarticular loose body. Osteochondral allograft (OCA) is an accepted method of treatment for restoring large chondral and osteochondral defects on the femoral condyles. Previous work has found survival rates of OCA in cases of idiopathic, focal chondral or osteochondral lesions of the femoral condyles ranged from 85%-100% at 5 years, 71%-89% at 10 years, 74%-76% at up to 15 years, and 66% at up to 20 years. In cases of osteochondritis dissecans (OCD) and steroid associated osteonecrosis, OCA survival rates of 79% to 94% have been seen at less than five years follow-up. There is limited data regarding OCA use in the pediatric knee. Published results have shown that 82% of patients returned to full sporting activities by twelve months and a graft survivorship of 90% at ten years.

We present the case of a five year old boy who underwent arthroscopic resection for a symptomatic left medial femoral condyle DEH lesion and subsequent...
Figures 1a, 1b. Initial preoperative radiographs of the left knee which demonstrate an irregular radiodensity of the condylar surface along the posterior aspect of the medial femoral condyle.

Figures 2a, 2b. Radiographs of the articular surface of the left knee immediately after initial arthroscopic debridement of the DEH lesion. Of note, there is approximately 10% of the anterior portion of the lesion that was not removed as it was in the weightbearing zone of the medial femoral condyle.

repeat resection and placement of OCA due to lesion recurrence. The patient’s course with two year follow-up including history, exam, radiology findings, and treatment are discussed.

**CASE REPORT**

A five year old boy was referred to orthopaedics clinic by his local pediatrician with a two year history of worsening left knee pain and limp. Radiographs of the knee were consistent with DEH of the left medial femoral condyle (Figures 1a, 1b). During initial arthroscopic resection, there was noted to be a prominence of the articular surface on the posterior aspect of the medial femoral condyle. The cartilage overlying the lesion was taken down with a shaver and the bony prominence within the epiphysis was identified and resected. Approximately 80-90% of the lesion was removed while the anterior-most portion of the lesion was left undisturbed.
as it was distinctly in the weightbearing zone of the knee (Figures 2a, 2b). At the patient’s four-month postoperative visit he was complaining of pain with daily activities and imaging studies showed a recurrence with increased size of the lesion (Figures 3a, 3b).

The patient was subsequently taken to the operating room for a second surgical resection and planned OCA approximately eight months after his index procedure.

A medial parapatellar arthrotomy was performed and the knee was hyper-flexed, revealing a crown-shaped lesion that had projections both anteriorly and posteriorly and was approximately 15mm in its largest dimension. The lesion was removed with a curette, a burr, and a rongeur until on fluoroscopy the lesion was completely resected. A 15-mm, fresh, adult, press fit medial femoral condyle allograft plug was then placed, filling 95% of the lesion.
(Figures 4a, 4b). Standard clinical and radiographic follow-up was performed (Figures 5a, 5b; 6a, 6b). At 27 months follow-up after placement of the OCA, plain films (Figures 7a, 7b) and MRI (Figures 8a, 8b) demonstrated a cartilage surface of the medial femoral condyle that was grossly congruent without significant step-off. Additionally, the patient was pain free, had symmetric range of motion to the contralateral knee, and was participating in full activities.

**DISCUSSION**

We present the case of a five year old boy with a two year history of right knee pain and evidence of DEH who underwent initial arthroscopic resection and subsequent revision surgery with further resection and placement of an OCA. To the best of our knowledge, this is the first reported case of a DEH lesion treated with osteochondral allograft and also the youngest reported case of osteochondral allograft placement in the literature.
The patient’s clear history of worsening pain and limp over a two year period prompted surgical intervention as it was determined in discussion with the patient’s family that continued non-operative management was no longer appropriate; however, previous authors have reported three cases of treating medial femoral condyle DEH lesions non-operatively with good outcomes (Ages 1yo, 2yo, 13yo). Our initial approach was surgical resection. In our patient’s case, the index procedure was complicated by a portion of the lesion being located in a more anterior position on the femoral condyle. As such, the decision was made not to remove this aspect of the lesion as it was positioned in a weight-bearing portion of the knee. We acknowledge that incomplete removal of the DEH lesion in the index procedure may have contributed to the disease recurrence, though previous reports have indicated that partially resected lesions have not returned. Fasting et al. reported treating two medial femoral condyle DEH lesions with resection through bone. In the case of a four year old female at time of resection, the patient had no complaints regarding her knee, radiographic exam showed some flattening of the joint surface of the knee and the involved limb was two cm longer than the contralateral limb at 19 year follow-up. In the other case (five year old male), the patient was asymptomatic at one year follow-up. Keret et al. showed that simple excision of extra-articular lesions yielded favorable results, whereas surgical osteotomy may be required to correct angular deformities in cases of intra-articular lesions. In their case series of nine patients, Kuo et al. reported good outcomes with surgical removal of juxta-articular lesions; however, they reported fair to poor outcomes with removal of articular lesions and recommended against removal of these lesions unless they became loose bodies. Skripitz et al. reported two cases (ages two and four years old) of symptomatic medial femoral condyle DEH lesions that were treated with excision chondroplasty. At 4.5 years follow-up, the two-year-old boy was found to have moderate restriction of range of motion in the operative knee and a leg length discrepancy of 1.5 cm lengthening in the operative leg, without pain. At four years follow-up, the four-year-old patient was found to have a slight valgus deformity, normal range of motion, and a leg length discrepancy of one cm of lengthening of the operative side.

In the revision procedure, a complete resection of the DEH lesion recurrence was performed and a bony allograft was placed. Due to the size of the lesion removed, it was determined that placement of a graft was necessary to maintain appropriate joint congruity. As no juvenile allograft options were available, we used an adult fresh osteochondral allograft that had recently been processed by a hospital tissue vendor. Standard testing was completed and the graft was implanted less than 28 days after harvest. At 27 month follow-up after his second procedure, the patient was found to be walking and running with no pain and only occasional left knee stiffness. Plain radiographs (Figures 7a, 7b) and MRI (Figures 8a, 8b) showed near symmetric incorporation of the OCA at 27 months.

There is limited data regarding knee OCA use in the pediatric and adolescent populations. Murphy et al. reported on 39 patients (43 knees) under the age of 18 (range 11-17.9 years old) who underwent knee

![Figures 7a, 7b. Radiograph images at 27-month follow-up from OCA placement. Graft shows congruent joint surface of the medial femoral condyle.](image-url)
OCA procedures (18 medial femoral condyle, 15 lateral femoral condyle, 3 patella, 2 trochlea, 1 tibial plateau, 4 multiple sites) where 12% of the knees had failure of the allograft at a median of 2.7 years (range 1.0-14.7 years)\(^2\). These five failed allografts underwent salvage OCA transplantation with 80% of the revision grafts still in place at last follow-up (follow-up range 2.3-8.8 years)\(^2\). Overall, allograft survivorship was 90% at 10 years and at final follow-up 88% of patients reported they were either “extremely satisfied” (74%) or “satisfied” (14%) with their outcome\(^2\). In their case series of 11 patients (age range 13-20 yo; 4 medial femoral condyle, 7 lateral femoral condyle, 1 trochlea, 1 patella) who underwent OCA procedures after failed initial treatment for OCD, Lyon et al. reported no graft failures and found that 82% of patients had returned to full sporting activities between 9-12 months after surgery and that all patients had returned to full daily activity levels with decreased pain\(^2\). Notably, we were unable to find any previous reports of using OCA in cases of DEH. Osteochondral autograft transplantation and autologous cartilage implantation were other potential options considered.

Previous reports have described nonoperative and operative treatment for DEH lesions of the pediatric knee. We report a case of DEH of the medial femoral condyle treated with osteochondral allograft. At two year follow-up after OCA placement, the patient is asymptomatic, has returned to full activity, and has a largely normal radiographic exam. We submit OCA is a potential treatment option for patient with intra-articular DEH requiring extensive surgical excision.

Figures 8a, 8b. MRI images at 27-month follow-up from OCA placement demonstrate gross congruity of cartilagenous surface.

REFERENCES


ABSTRACT

Background: High tibial osteotomy (HTO) is a well-established and commonly utilized technique in medial knee osteoarthritis secondary to varus malalignment. Accurate measurement of the preoperative limb alignment, and the amount of correction required are essential when planning limb realignment surgery. The hip-knee-ankle angle (HKA) measured on a full length weightbearing (FLWB) X-ray in the standing position is considered the gold standard, since it allows for reliable and accurate measurement of the mechanical axis of the whole lower extremity. In general practice, alignment is often evaluated on standard anteroposterior weightbearing (APWB) X-rays, as the angle between the femur and tibial anatomic axis (TFa). It is, therefore, of value to establish if measuring the anatomical axis from limited APWB is an effective measure of knee alignment especially in patients undergoing osteotomy about the knee.

Methods: Three independent observers measured preoperative and postoperative FTa with standard method (FTa1) and with circles method (FTa2) on APWB X-rays and the HKA on FLWB X-ray at three different time-points separated by a two-week period. Intra-observer and inter-observer reliabilities and the comparison and relationship between anatomical and mechanical alignment were calculated.

Results: Intra- and interclass coefficients for all the three methods indicated excellent reliability, having all the values above 0.80. Using the mean of paired t-student test, the comparison of HKA versus TFa1 and TFa2 showed a statistically significant difference (p<.0001) both for the pre-operative and post-operative sets of values. The correlation between the HKA and FTa1 was found poor for the preoperative set (R=0.26) and fair for the postoperative one (R=0.53), while the new circles method showed a higher correlation in both the preoperative (R=0.71) and postoperative sets (R=0.79).

Conclusions: Intra-observer reliability was high for HKA, FTa1 and FTa2 on APWB x-rays in the pre- and post-operative setting. Inter-rater reliability was higher for HKA and TFa2 compared to FTa1. The femoro-tibial angle as measured on APWB with the traditional method (FTa1) has a weak correlation with the HKA, and based on these findings, should not be used in everyday practice. The FTa2 showed better correlation with the HKA, although not excellent.

Level of Evidence: Level III, Retrospective study.

INTRODUCTION

Medial knee osteoarthritis is a common disease frequently caused by additional load on the medial compartment due to varus deformity. It has been shown that varus alignment increases the risk of medial OA progression, and valgus alignment increases the risk of lateral OA progression, with the severity of malalignment predicting the decline in physical function. Young active patients with medial compartment osteoarthritis of the knee combined with a varus deformity can be treated with a high tibial osteotomy (HTO), a well-established and commonly used technique. HTO is performed to reduce pain, diminish the progression of OA perhaps to postpone or avoid total knee arthroplasty. Accurate measurement of limb alignment, and the amount of correction required are essential when planning a limb realignment surgery. HTO is performed to reduce pain, diminish the progression of OA perhaps to postpone or avoid total knee arthroplasty. Accurate measurement of limb alignment, and the amount of correction required are essential when planning a limb realignment surgery. As suggested by Miniaci et al, Noyes et al, and Dugdale et al, the optimal outcome would be achieved transferring the weight bearing line to a point around 62.5% of tibial plateau width from medial to lateral (usually just lateral to the lateral tibial spine), aiming for a mechanical axis comprised between 3° and 5° of valgus. Significant under- or overcorrection of the mechanical axis may lead to disappointing clinical results. Possible factors affecting the outcomes after an HTO are inaccurate preoperative planning of the desired correction, inadequate correction during surgery and loss of correction in the post-operative period. The hip-knee-ankle
angle (HKA) measured on a full length weightbearing (FLWB) X-ray made in standing position is considered the gold standard, since allows for reliable and accurate measurement of the mechanical axis of the whole lower extremity. This method is however time consuming, requires special equipment, involves significant radiation exposure and generates extra costs. In general practice, alignment is often evaluated on a standard anteroposterior weightbearing (APWB) X-rays, as the angle between the femur and tibial anatomic axis (TFa). It is, therefore, of value to establish if measuring anatomical axis from limited APWB is an effective measure of knee alignment especially in patients undergoing to HTO. We asked two research questions: (1) Is the measurement of limb alignment reliable in both FLWB and APWB? (2) Do the HKA and TFa correlate in patients with medial knee OA secondary to varus alignment?

MATERIALS AND METHODS

Film series of thirty-six consecutive patients, undergoing isolated HTO by the same experienced surgeon (A.A.) from 2010 to 2013, were retrospectively reviewed. The indication for surgery for all the subjects was symptomatic medial compartmental knee osteoarthritis with varus deformity. The surgical technique was performed according to the former description by the senior author. Each patient underwent to a standard anteroposterior weightbearing (APWB) X-ray and full length weightbearing (FLWB) X-ray, both preoperatively and postoperatively. Full-limb radiographs were obtained using a long length vertical cassette holder containing four 14x17 inches graduated cassettes. The X-ray beam was centered at the knee at a distance of 94 inches. The beam was parallel to the floor and the machine’s settings were 100 to 200 mA-s and a kilo voltage of 90, depending on limb size and tissue characteristics. The APWB films were obtained on a 17 x 17 inch cassette. The X-ray beam centered at the knee at a distance of 45 inches with the patients having the back of their knees in contact with the vertical cassette. The beam was parallel to the floor and the machine’s settings were 3.2 mA-s and a kilo voltage of 55. For both the X-ray types, the subjects were asked to stand without footwear, with tibial tubercles facing forward. Both limbs were radiographed. The same protocol was applied in performing both types of radiological exams in all the patients. Both knees and both legs were scanned in full extension and with full weightbearing for every examination. In FLWB X-rays the alignment was measured as the angle between femoral and tibial mechanical axes. Femoral and tibial mechanical axes run from the midpoint of tibial spines, respectively to the center of hip and ankle joint (HKA). In APWB x-rays, alignment was assessed by measuring the angle between femoral and tibial anatomical axes (femur-tibial angle, FTa). Two different methods were used to measure the FTa. The first one (TFa1), has been previously used by many authors: a line running from the midpoint of tibial spines to a point located midway between medial and lateral cortical bone surface, 10 cm above the tibial spine for the femur and 10 cm below for the tibia (Figure 1). The second one (TFa2) is based on a method recently described by Veljkovic et al. to define the position of the talus as it relates to the anatomic tibial axis. In this method, on the same type of X-ray, two different circles were fitted between medial and lateral cortices of femur and tibia, 5 and 10 cm far from the joint line (Figure 2 Point A and B). A joint
Assessing Lower Limb Alignment

Table 1: Hip-Knee-Ankle angle (HKA) intra- and inter-tester reliability

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<td>Intra-tester reliability</td>
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<td>preop</td>
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<td>postop</td>
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<tr>
<td>Inter-tester reliability</td>
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<tr>
<td>preop</td>
<td>0.89</td>
</tr>
<tr>
<td>postop</td>
<td>0.95</td>
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Table 2: Tibio-femoral angle as measured on APWB x-rays: intra- and inter-tester reliability of the traditional method (TFa1)

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<tr>
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<td>0.91</td>
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<tr>
<td>postop</td>
<td>0.92</td>
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<tr>
<td>Inter-tester reliability</td>
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<tr>
<td>preop</td>
<td>0.81</td>
</tr>
<tr>
<td>postop</td>
<td>0.84</td>
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Table 3: Tibio-femoral angle as measured on APWB x-rays: intra- and inter-tester reliability of the circles method (TFa2)

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<tr>
<td>Inter-tester reliability</td>
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<tr>
<td>postop</td>
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</tbody>
</table>

Table 4: Comparison of pre-operative and post-operative Mechanical axis (HKA) versus Anatomical axis (TFa1). Mean difference between the values and standard deviation are given in degrees.

<table>
<thead>
<tr>
<th></th>
<th>HKA VS TFa1: PAIRED T-TEST BETWEEN THE AVERAGE OF THE HKA and TFa1 MEASUREMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean difference ± SD</td>
</tr>
<tr>
<td>Preop</td>
<td>2.85°± 3.05°</td>
</tr>
<tr>
<td>Postop</td>
<td>1.99°±3.2°</td>
</tr>
</tbody>
</table>

Table 5: Comparison of pre-operative and post-operative Mechanical axis (HKA) versus Anatomical axis (TFa2). Mean difference between the values and standard deviation are given in degrees.

<table>
<thead>
<tr>
<th></th>
<th>HKA VS TFa2: PAIRED T-TEST BETWEEN THE AVERAGE OF THE HKA and TFa2 MEASUREMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean difference ± SD</td>
</tr>
<tr>
<td>Preop</td>
<td>2.48°±2.73°</td>
</tr>
<tr>
<td>Postop</td>
<td>2.01°±1.81°</td>
</tr>
</tbody>
</table>

STATISTICAL ANALYSIS

The intra-observer and inter-observer reliabilities for continuous measurements were calculated with the Intra-Class Correlation Coefficient ICC (3, 1). Since a formula to calculate the sample size based on ICC (3, 1) is not available, the ICC (2, 1)-based sample size formula described by Doros and Lew was used as a reference. Assuming that ICC is at least 0.7, then 32 (or more) subjects used by each of the three raters would be sufficient to assure an ICC 95% confidence interval smaller than 0.3. The comparison and relationship between anatomical and mechanical alignment were calculated by Paired t-test and Pearson’s correlation/linear regression.

RESULTS

All the patients had varus alignment. The preoperative average HKA was 172.9°, while FTa1 was 175.7° and FTa2 was 175.3°. The postoperative average HKA was 181.3°, while the FTa1 was 183.3° and FTa2 was 182.7°. Intra- and inter-tester intraclass coefficients for all the three methods indicated excellent reliability, having all the values above 0.80 (Tables 1-3). The comparison of HKA versus TFa1 and TFa2 showed, by mean of paired t-student test, a statistically significant difference (p<.0001) both for the pre-operative and post-operative values (Table 4 and 5). The correlation between the extended, mid-diaphyseal line was drawn for femur and tibia at intersection of the center of the circles at points A and B. Fta2 was obtained at the intersection of the two diaphyseal lines. In order to assess the reliability of the above mentioned methods, three independent observers measured preoperative and postoperative APWB and FLWB views at three different time-points separated by a two-week period, with dedicated software. The measures were recorded in degrees, and angles lower than 180° were considered as varus alignment and those higher than 180° valgus alignment.
HKA and FTa1 was found poor for the preoperative set (R=0.26) and fair for the postoperative one (R=0.53), while the new method showed a higher correlation either in the preoperative set (R=0.71) and in the postoperative one (R=0.79) (Scattered plots, Fig 3 - 6).

**DISCUSSION**

The gold standard for measuring knee alignment is represented by mechanical axis of the lower limb, measured on FLWB X-ray. This is not routinely performed on patients in the pre and postoperative clinical setting, because of greater cost and increased radiation exposure. FLWB X-ray involves exposure of the pelvis to radiation, with effective radiation from one film at 73-fold higher than a standard APWB x-ray. The first research question asked whether the two methods (HKA and TFa) were reliable. Results from intra- and inter-tester reliability shows as both methods have acceptable intra-tester reliability. The inter-tester reliability was satisfactory for the FLWB X-ray both in the pre- and post-operative sets of x-rays, while it was just fair for APWB x-ray. These outcomes are in agreement with the current available literature. The second research question asked is if the HKA and TFa correlate in a population affected by medial knee OA secondary to varus deformity. The results from this study show that there is a very low correlation with statistically significant differences between the HKA and the TFa1. Compared to our results, previous studies showed a better correlation between mechanical and anatomical axes (r= 0.66 to 0.93)\(^1\).\(^2\),\(^3\),\(^4\),\(^5\),\(^6\),\(^7\),\(^8\),\(^9\),\(^10\),\(^11\),\(^12\). One other study had comparable results to this study. Van Raaij found high intra- and inter-observer reliability for FTa but low correlation with the HKA angle (r = 0.34) in cohort of 68 patients with painful medial knee OA. A possible explanation for such conflicting results may be related to the differences in the methods used to measure the TFa in the study populations in the various studies. Most of the previous studies used the same FLWB x-rays to measures both the HKA and the TFa, allowing any variance in patient positioning in terms of rotation and weight bearing to be non-existent. Two studies with a dedicated standard AP x-ray in flexion to measure the TFa, used a specific leg holder (Synaflex). This is another factor that could help in reducing the variability of patient positioning. In addition, a clear description of the patients' population...
in terms of OA severity was not clearly stated in all the previous studies. It has been shown that the difference between mechanical and anatomical axes varies with gender and presence of advanced OA. In this study, patients were indicated and underwent to HTO for symptomatic medial knee OA. Kraus et al. identified a mean offset for the anatomical axis of 4.21° valgus from the mechanical axis (3.5° in women, 6.4° in men) using fixed flexion posteroanterior (PA) knee x-rays. We used fully extended knee radiographs and found no evidence of an offset angle or constant relationship. One possible explanation for these results is the crossing point of the tibial and femoral anatomical angles. The FT angle or anatomical axis does not pass through the center of the knee joint due to the physiological valgus of femur, intersecting the knee joint line slightly medial to the joint center. The knee joint center is regarded as a landmark for FTa measurement. Thus, accepting the joint center as the landmark for the FTa measurement might diminish our ability to find the true anatomical axis and its relationship with the HKA angle. Sheeny et al. showed as the longer were the landmark on the femur and tibia to calculate the FTa, the higher was the correlation with the HKA, therefore suggesting that a longer x-rays would be necessary to have a closer measurement of the actual FTa, though this would defeat the advantages of standard AP knee x-rays. The same authors showed that the offset of FTa measurements from standard AP x-rays varies depending on direction and degree of knee deformity. They found that in varus limbs the shorter the shaft length for measuring FTa, the wider was the offset magnitude between HKA and FTa values. The opposite goes for valgus alignment. The patients in our study also changed from a varus alignment to a neutral or valgus alignment after HTO surgery, this could explain why the correlation between HKA and TFa improved from pre- to post-operative assessment. Since the TFa showed a low correlation with the HKA, in order to find and alternative method to measure the lower limb alignment, we studied in addition the reliability and the correlation of a new method, the TFa2, developed on the basis of a previously described method to define the position of the talus as it relates to the anatomic tibial axis. This new method showed high reliability for both intra- and intertester intraclass coefficient and it showed a good correlation with the HKA (R up to 0.79). The authors explanation is that when using the circles, the femoral and tibial anatomical axis are measured independently from the joint center, therefore allowing for a closer measurement to the true anatomical axis, as opposite to the traditional method (TFa1). Though the correlation was improved compared to the traditional method, it’s still not excellent. The same factors that influenced negatively the correlation between HKA and TFa (varus alignment of the study population, variability in patient positioning from FLWB to APWB) could play a detrimental role in the relationship between HKA and TFa2. The weaknesses of this study includes the following: it is a retrospective study; the FLWB and APWB x-rays were not always taken the same day, thus increasing the variability in patient positioning; we did not evaluate the relationship between the two angles separately for men and women, since its known that the offset varies depending on sex. However this study does assess the reliability of APWB x-rays, and the correlation between HKA and FTa in a cohort of patients with varus alignment of the knee that underwent a HTO in a common clinical setting.

CONCLUSION

In summary it was found that intra-observer reliability is high for HKA, FTa1 and FTa2 on APWB x-rays in the pre- and post-operative setting. Inter-rater reliability was higher for HKA and TFa2 compared to FTa1. The femorotibial angle as measured on APWB with the traditional method (FTa1) has a weak correlation with the HKA, and based on these findings, should not be used in everyday practice. The FTa2 showed higher correlation with the HKA, though not excellent. Further studies are necessary to better understand the correlation between HKA and the TFa as measured by the new method. Thus, at the time being, substituting full leg x-rays with standard AP may cause inaccuracy, which is undesirable in patients undergoing corrective knee surgery.

BIBLIOGRAPHY


ABSTRACT

Background: Many types of projectiles, including modern hollow point bullets, fragment into smaller pieces upon impact, particularly when striking bone. This study was performed to examine the effect on time to union with retained bullet material near a fracture site in cases of gunshot injury.

Methods: All gunshot injuries operatively treated with internal fixation at a Level 1 Trauma Center between March 2008 and August 2011 were retrospectively reviewed. Retained bullet load near the fracture site was calculated based on percentage of material retained compared to the cortical diameter of the involved bone. Analyses were performed to assess the effect of the lead-cortical ratio and amount of comminution on time to fracture union.

Results: Thirty-two patients (34 fractures) met the inclusion criteria, with an equal number of comminuted (17) and non-comminuted fractures (17). Seventeen of 34 fractures (50%) united within 4 months, 16/34 (47%) developed a delayed union, and 1/34 (3%) developed a nonunion requiring revision surgery. Sixteen of 17 fractures (94%) that united by 4 months had a cumulative amount of bullet fragmentation retained near the fracture site of less than 20% of the cortical diameter. Nine out of 10 fractures (90%) with retained fragments near the fracture site was equal to or exceeding 20% of the cortical diameter had delayed or nonunion. Fracture comminution had no effect on time to union.

Conclusions: The quantity of retained bullet material near the fracture site was more predictive of the rate of fracture union than was comminution. Fractures with bullet fragmentation equal to or exceeding 20% of the cortical width demonstrated a significantly higher rate of delayed union/nonunion compared to those fractures with less retained bullet material, which may indicate a local cytotoxic effect from lead on bone healing. These findings may influence decisions on timing of secondary surgeries.

Level of Evidence: Level III

INTRODUCTION

Gunshot wounds are a common cause of trauma in the United States\(^1\). According to the Centers for Disease Control and Prevention, more than 73,000 injuries resulted from firearms in 2011\(^2\). Recent data has shown an increase in the use of higher velocity semiautomatic weapons as well as an increase in the average bullet caliber and type of ammunition involved in metropolitan violent assaults\(^6,7\). Such statistics demonstrate a changing landscape of gunshot injuries and also correlate with a substantial increase in pre-admission fatality rates\(^8\).

Although there is abundant literature on the treatment of high and low energy gunshot wounds (GSW), minimal clinical data is available pertaining to modern hollow point projectiles. This type of ammunition is designed to expand in the body cavity, increasing stopping power by making a larger cavity in soft tissue, and prevent over penetration of the intended target. However, when such projectiles hit bone, they may fragment into multiple smaller pieces that are often retained near the fracture site (Fig. 1). It has been our observation that fractures with a substantial amount of retained bullet fragments near the fracture site are at risk for delayed or nonunion. This study was performed to examine the effect on time to union of retained bullet material near the fracture site in cases of gunshot injury.

MATERIALS AND METHODS

After obtaining institutional review board approval, all operatively treated gunshot injuries treated at a Level 1 Trauma Center between March 2008 and August 2011 were retrospectively reviewed. Inclusion criteria consisted of: 1) patient age > 18 years; 2) operative fracture fixation; and 3) minimum follow up of 4 months or fracture union. Study data was recorded by two collaborative reviewers using digital radiographic images. Retained bullet load near the fracture site was calculated based on percentage of material retained compared to the cortical diameter of the involved bone. The length of these frag-
ments (if laid end-to-end) was calculated as a percentage of the cortical diameter, described as the lead-cortical ratio (Fig. 2). For a fragment to be counted in this calculation it had to be within 5 mm of the fracture site on both the anterior-posterior (AP) and lateral radiographs (Fig. 3). To generally assess the energy imparted to bone, fractures were grouped as simple or comminuted. Demographic information was recorded, as well as the location of each fracture. All available post-operative imaging was used to determine fracture union. Radiographic evidence of healing was determined by bridging callus on three of four cortices on AP and lateral views. Delayed union was defined as lack of radiographic union by 4 months from surgery, and nonunion as failure to heal by one year.

Data sets were statistically analyzed using a two-variable Pearson correlation. Fracture union was compared to delayed/non-union as the measure of outcome. Variables of analysis were fracture comminution and the lead-cortical ratio, compared above and below threshold increases at 5% increments. An outcome was considered statistically significant for \( p \leq 0.05 \). Data analysis was performed using statistical software XLSTAT version 2011.4.2 Copyright Addinsoft 1995-2011 software.

RESULTS

Seventy-five patients underwent internal fixation of a fracture secondary to GSW. Forty-three patients were excluded due to insufficient follow-up data. Thirty-two patients (34 fractures) had minimum four month follow up or fracture union and comprised the study group as shown in Table 2. There were an equal number of comminuted and non-comminuted fractures in the study group.
Fig. 3a-e  These images show a comminuted femur fracture with a 5% lead-cortical ratio. By assessing the multiple views available after presentation in 3a-c, it can be seen that very little of the retained bullet load is actually within 5 mm of the fracture. Most of the metal is in the surrounding tissue. This fracture is seen healed on day 78 in 3d-e.
Mean follow up was 4.5 months (range 2-15 months). Seventeen of 34 fractures (50%) united within four months, 16/34 (47%) developed a delayed union, and 1/34 (3%) developed a nonunion requiring revision surgery. Of the fractures united by four months, 16/17 (94%) had a cumulative amount of bullet fragmentation retained near the fracture site of < 20% of the cortical diameter, while only 1/17 (6%) had retained fragments near the fracture site of > 20% of the cortical diameter \( (p = 0.001) \). Fracture comminution had no effect on time to fracture union \( (p = 0.372) \).

Fractures taking greater than four months to reach union are represented in Table 2. A visual comparison of all study variables on fractures that healed within four months and those that went on to delayed or non-union is shown in Figure 4.

**DISCUSSION**

This study found that the quantity of retained bullet material near the fracture site inversely correlated with the rate of fracture union \( (p = 0.001) \), independent of the degree of comminution. Fractures with bullet fragmentation equal to or exceeding 20% of the cortical width demonstrated a significantly higher rate of delayed union/ nonunion compared to those fractures with less retained bullet material at the fracture site. These results indicate that additional physiologic factors involved in ossification and remodeling, beyond bone and tissue disruption, may be disturbing fracture union in gunshot injuries.

Most previous literature has suggested that the severity of gunshot wounds is related to the muzzle velocity of the inflicting weapon correlating to the degree of energy dissipation to the tissues\(^{1,9-14}\). The complete set of factors involved in tissue damage by ballistic projectiles is actually more intricate. These include the diameter of the bullet, also known as caliber, its shape, weight distribution, velocity, tumbling characteristics and propensity to deform or fragment. Kinetic energy of an impacting bullet is lost to the projectile-tissue interaction through tissue destruction and recoil, dependent on the elasticity of the tissues involved, as well as heat, projectile deformation and a sonic pressure wave\(^{15-17}\). The resulting damage to osseous tissue is therefore multifactorial and similar weapons may produce dissimilar cortical injuries. The ballistic injury literature has focused on factors effecting tissue and bone healing including local effects on microvasculature, pro-inflammatory cytokines, growth factors and oxygenation\(^{17-23}\). It has not been previously suggested in human studies that lead from retained bullets or fragments may affect healing, although retained projectile lead has been well documented as a cause of lead poisoning\(^{24,26}\).
Minimal investigations pertaining to modern hollow point projectiles have been conducted. Hollow point bullets, which use a soft, pliable core with a pit at the bullet point, allow for rapid expansion of the bullet upon impact and a significantly larger destructive path, magnified up to four times in the generation of the temporary cavity\(^1\). By making a larger cavity in soft tissue, this type of ammunition expends more energy in the target and prevents over penetration. However, when such projectiles hit bone, they often fragment into multiple smaller pieces that are often retained in the fracture site. Figures 1a and 1b show radiographic evidence consistent with a hollow point bullet injury. Although investigations have clearly shown increased fragmentation and resulting tissue destruction from expanding bullets, even certain jacketed ammunition has been notorious for fragmenting within tissue. The M-16 5.56 mm round may lose one-third of its mass through bullet fragments within its target\(^15\). Additionally, the bullet path and its collision with bone or other solid structures, such as clothing articles, increase the tendency to fragment.

Nearly all bullets used today are composed of lead or a lead-alloy composition. Although the local effects of lead particles on bone formation have never been studied in humans, previous studies in animals have revealed that bone lead levels significantly impact bone healing. Several authors have published the adverse effects of lead on bone formation and resorption by demonstrating its effect on osteoblast and osteoclast activity\(^27\,28\). One study by Carmouche et al investigated the response lead levels had on tibial fractures treated with intramedullary fixation in mice\(^29\). A dose dependent inverse correlation was observed between callus formation and bone lead levels increasing from zero to an approximately environmentally relevant level of human exposure. With increasing lead level, fracture calluses showed a significant delay in endochondral ossification with a greater amount of unmineralized cartilage, several times that of the unexposed calluses. At lower lead levels exposure did not completely inhibit fracture healing, but delayed the ossification process. However, a second group was exposed to a dose ten times higher than what would correlate with environmental exposure levels in humans. In this group, 75% of the subjects exhibited fibrous non-unions, suggesting that lead can completely inhibit fracture healing at very high doses.

The current study is consistent with the aforementioned literature. Nearly all fractures went on to heal, albeit at a slower rate when more bullet particles were retained. Although the underlying cause of this correlation is unknown at this time, we hypothesize that it may reflect a local cytotoxic effect of lead from bullet fragments on fracture healing. Whether this is a product of reduced osteoprogenitor cell formation or an unknown biologic impact of the metal debris requires further research.

This study included only operative cases as we were primarily concerned with the effect this data would have on predicting outcomes for the surgeon. Regardless of the underlying cause, the correlation found between bullet load at the fracture site (lead-cortical ratio \(> 20\%\)) and delayed union provides prognostic information on union time with respect to retained bullet load. Although fractures with more retained bullet fragments required more time to heal, almost all eventually achieved union. This may have implications on a surgeon’s decision and timing for secondary surgery, as well as expectations for the patient. At this time, further studies would be necessary to show that fragment removal outweighs the risk of inducing iatrogenic damage to healthy tissue in the vicinity of a fracture solely for the purpose of aggressively removing any metal fragments.

Limitations of this study include a relatively short follow-up period and the lack of three-dimensional imaging to more accurately quantify fragment load at the fracture site. Utilizing anteroposterior and lateral views, the lead-cortical ratio is only an estimation of the retained bullet load. Although this estimation can provide prognostic value regarding time to union, CT imaging may be a useful tool to better quantify the amount of retained fragments for future studies. Additionally, due to the limited number of fractures meeting the criteria for the study, this study compared fractures from multiple sites using a single metric for union times. To account for this, the authors used a value that was considered conservative for all included fractures based on the senior authors’ experience. Another shortcoming of the current study is its < 50% follow-up. However, In the population currently under study, followup is frequently poor and in order to further our understanding of these complex injuries we have used our available clinical data to raise new questions and to examine the current dogma that retained bullet fragments in the soft tissues of the extremities is without consequence.

The clinical significance of this study is to provide prognostic information on union time with retained lead. Although fractures with more retained bullet fragments required more time to heal, almost all eventually went on to union. This may have implications on a surgeon’s decision and timing for secondary surgery, as well as expectations for the patient. Despite findings of a positive correlation between retained bullet material and delayed union, at this time we do not recommend additional dissection for bullet removal at the fracture site for purposes of improving fracture union.
REFERENCES


EXPEDITED OPERATIVE CARE OF HIP FRACTURES RESULTS IN SIGNIFICANTLY LOWER COST OF TREATMENT

Kyle T. Judd, MS, MD¹, Eric Christianson, BA²

ABSTRACT

Background: There are an estimated 150,000 hip fractures per year in the United States, with estimated costs of care between $10.3 billion and $15.2 billion. With such high costs and an increasing burden of care, there has been interest in newer methods to increase efficiency of care. One such method is expedited fracture care, with earlier operative intervention. The purpose of this study was to determine if intervention within six hours of admission decreased costs with no change in the rate of major complications.

Methods: A retrospective review of all patients age >65 undergoing operative intervention for a proximal femur fracture over a two year period were identified. Patients were divided into two groups: those undergoing operative intervention < six hours after admission (early) and those undergoing operative intervention > six hours after admission. Patient age, average length of stay, and complication rates were determined for the two groups.

Results: Our study identified 657 patients, 111 of which underwent early intervention with the remaining 546 undergoing late intervention. The average length of stay for the early intervention group was 4.11 days, compared to 5.68 days for the late intervention group (p=0.0005). There was a significant difference in average cost between the two groups. The average cost of the early intervention was $49,900, with the average cost of late intervention being $65,300 (p = 0.0086). There was no significant difference in incidence of major complications between the two groups.

Conclusion: Programs emphasizing early intervention for hip fractures have the potential for large healthcare savings, with an average savings of $15,400.

Level of Evidence: Level IV, therapeutic case series.

INTRODUCTION

The population of Americans older than age 65 is increasing and with this increase the incidence of hip fractures is also expected to rise¹. Hip fractures occur at an estimated rate of 150,000 per year in the United States and account for 7% of all osteoporosis related fractures²,³. With such a high prevalence, hip fracture care has been thought to reach costs estimated to be $10.3 billion to $15.2 billion dollars annually⁴. As hip fracture care places such a large burden on the healthcare system, methods to increase efficiency of care and safely decrease the costs associated with the care of these patients have become particularly attractive.

Multiple investigations have evaluated the timing of hip fracture surgery⁵⁻⁸. Despite ongoing controversy, there is a trend toward expedited surgical intervention as outcomes have been shown to improve with surgical intervention within 48 hours of admission⁹. Some centers have even proposed intervention within six hours of admission¹⁰, as there is some data to indicate that this may be safe for properly selected patients. In addition to being associated with improved outcomes, expedited surgical intervention for fractures has also shown some promise for decreasing the costs associated with fracture care¹¹,¹². With these ongoing controversies there is a paucity of data in the literature regarding the financial implications of expedited hip fracture care.

We present a series of two cohorts of geriatric hip fracture patients. One cohort undergoing surgical intervention within six hours (early) of admission and a second cohort in which surgical treatment was delayed greater than six hours (late) from the time of admission. Our hypothesis was that early surgical intervention would significantly decrease the costs associated with inpatient treatment. Our null hypothesis was that there would be no change in the rate of major complications between the early and late intervention groups.

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Expedited Operative Care of Hip Fractures Results

METHODS

Institutional review board (IRB) approval was obtained prior to initiation of the study. All patients age > 65, undergoing operative intervention for a proximal femur fracture at a community based level II trauma center over a two year period (2011-2013), were identified using current procedural terminology codes. Patient age, average length of stay, direct variable and direct fixed expenses as well as major complication rates were determined for two groups of patients, those undergoing early surgical intervention and those undergoing late surgical intervention.

Direct variable and direct fixed expenses were defined in a similar fashion as previously done by Klewen et al. in which direct variable expenses consisted of those costs pertaining to patient care that vary with patient volumes, i.e. length of stay, supplies, pharmacy, operating room time, laboratory, radiology and therapy. Direct fixed expenses were defined as those pertaining to patient care, but not varying with patient volume i.e. managerial salaries, overhead.

STATISTICAL ANALYSIS

Cost and length of stay were compared independently for the early and late intervention groups using $X^2$ methods. Costs and length of stay were further examined using analysis of variance for comparison. Values were log-transformed in order to stabilize variances. 95% confidence interval values were computed for each group.

RESULTS

A total of 657 patients were included, of those 111 underwent surgical intervention within six hours of admission, with the remaining 546 undergoing intervention at a time greater than six hours from the time of admission. Average age for the early intervention group was 79 years. Average age for the late intervention group was 81 years.

No Transient Ischemic Attack (TIA) or Deep Vein Thrombus (DVT) occurred in either group.

DISCUSSION

Review of the current data shows a significant difference in cost for two groups of patients, those undergoing early and late operative fixation of hip fractures. An average cost savings of $15,400 was present for each patient treated within 6 hours of admission when compared to those treated in a more delayed fashion. This translates to an overall cost savings of over $1.7 million dollars between the two cohorts when controlling for the greater number of patients in the late intervention group.

Average length of stay for the two groups was also significantly different which may explain a portion of the discrepancy between the two groups. It has been shown that approximately 29% of direct variable expense can be attributed to length of stay. Our results are in agreement to studies that have identified cost savings for treatment of femoral shaft fractures and pelvic ring injuries as the length of hospital stay decreases. Specifically, Vallier et al showed increased profitability for treatment of pelvic ring disruptions, when operative intervention was undertaken within 72 hours after admission. Similarly, Dy et al evaluated two systems based strategies designed to increase the likelihood of operative intervention occurring within 48 hours of admission. They found that when between 88 and 93% of patients underwent intervention within the given time frame fracture care remained cost effective. Our data differs from previous reports as our average direct costs for both cohorts was found to be higher than those previously described. Despite these differences in cost, the overall cost effectiveness with early intervention is maintained and similar to those previously presented.

Timing of hip fracture surgery continues to be controversial despite reports of improved patient outcomes.

Table 1. Average length of stay (LOS) in days for the early and late treatment groups. (F=12.26, p=0.0005)

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Ave LOS (days)</th>
<th>p-value</th>
</tr>
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<tr>
<td>Early(0-6hrs.)</td>
<td>111</td>
<td>4.11</td>
<td>p=0.0005</td>
</tr>
<tr>
<td>Late(&gt;6hrs.)</td>
<td>546</td>
<td>5.68</td>
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Table 2. Sum of direct variable and direct fixed expenses for inpatient surgical treatment of hip fractures between the early and late groups (F=6.95, p=0.0086).

<table>
<thead>
<tr>
<th></th>
<th>Average Cost (CI=95%)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early(0-6hrs.)</td>
<td>$49,900 ($41,400-$60,300)</td>
<td>P=.0086</td>
</tr>
<tr>
<td>Late(&gt;6hrs.)</td>
<td>$65,300 ($61,100-$69,600)</td>
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Table 3. Rates of major complication between the early and late intervention groups.

<table>
<thead>
<tr>
<th>Complication</th>
<th>Early(0-6hrs.)</th>
<th>Late(&gt;6hrs.)</th>
<th>n</th>
<th>%</th>
<th>n</th>
<th>%</th>
<th>p-value</th>
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<tbody>
<tr>
<td>CVA</td>
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<td>9</td>
<td>0.9</td>
<td>1.6</td>
<td>0.3191</td>
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<tr>
<td>Hemorrhage</td>
<td>0</td>
<td>4</td>
<td>3.5</td>
<td>0.7</td>
<td>0.5719</td>
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</tr>
<tr>
<td>PE</td>
<td>0</td>
<td>6</td>
<td>0.2</td>
<td>0.7</td>
<td>0.8303</td>
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<td></td>
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<tr>
<td>Prosthetic</td>
<td>1</td>
<td>1</td>
<td>0.9</td>
<td>0.2</td>
<td>0.3910</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sepsis</td>
<td>1</td>
<td>6</td>
<td>1.1</td>
<td>4.1</td>
<td>0.1312</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>2</td>
<td>23</td>
<td>1.8</td>
<td>4.1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Average length of stay (LOS) in days for the early and late treatment groups. (F=12.26, p=0.0005)

Table 2. Sum of direct variable and direct fixed expenses for inpatient surgical treatment of hip fractures between the early and late groups (F=6.95, p=0.0086).

Table 3. Rates of major complication between the early and late intervention groups.
with expedited surgical intervention\textsuperscript{5,8,9}. Some centers have advocated intervention within six hours as a mode to improve mortality after hip fracture surgery\textsuperscript{9}. Review of our data shows no increase in major complications for those patients treated within six hours of admission, lending support to argument that expedited surgical intervention for hip fractures is likely safe.

Limitations of our study include the fact that selection bias may exist between the two groups, as the early intervention group may have had fewer co-morbidities and undergone fewer diagnostic interventions prior to undergoing surgical fixation. These differences would have potentiated the higher costs for the late intervention group. Healthier patients would also be expected to have an average length of stay that is shorter than those with a higher number of comorbidities as this has been shown to be a determinant of length of stay\textsuperscript{18}. This increased length of stay, also may have perpetuated the cost difference between the two groups.

CONCLUSION

Programs emphasizing expedited hip fracture surgery have the potential to produce large healthcare savings. Patients undergoing hip fracture surgery within 6 hours have decreased cost of treatment with no difference in major complications.

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REFERENCES

OUTCOMES FOLLOWING LOW-ENERGY CIVILIAN GUNSHOT WOUND TRAUMA TO THE LOWER EXTREMITIES: RESULTS OF A STANDARD PROTOCOL AT AN URBAN TRAUMA CENTER

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ABSTRACT

Background: Lower extremity injuries secondary to low-energy gunshot wounds are frequently seen in the civilian populations of urban areas. Although these wounds have fewer complications than high-energy gunshot injuries, the functional and psychological damage is still significant making appropriate timely orthopaedic treatment and follow-up imperative.

Purpose: The purpose of this study is to present our outcomes in the treatment of low-energy gunshot wounds in a civilian population at an urban, level one trauma center in patients treated by a standard protocol.

Methods: One hundred and thirty three patients who sustained 148 gunshot wound injuries were treated at our level one trauma center between January 1st, 2009 and October 1st, 2011. Following IRB approval, we extracted information from medical records regarding hospital course, length of stay and type of operative or non-operative treatment. If available, injury and post-operative radiographs were also reviewed. Patients were contacted by telephone to obtain Short Musculoskeletal Function Assessment (SMFA) surveys, pain on a scale of 0-10 and for the determination of any adverse events related to their shooting.

Results: There were 125 men (94.0%) and 8 women (6.0%) with an average age of 27.1 years (range: 15.2- 56.3). Seventy-six patients (57.1%) did not have any health insurance upon admission. The average length of stay in the hospital was 4.5 days (range: 0.0-88.0). Fifty-one gunshot shots (34.5%) resulted in fractures of the lower extremities. Patients underwent a total of 95 lower extremity-related procedures during their hospitalization. Twenty-two patients (16.5%) experienced a complication related to their gunshot wounds. 38% of the cohort was available for long-term functional assessment. At a mean 23.5 months (range: 8-48) of follow up, patients reported mean Functional and Bothersome SMFA scores of 19.6 (SD: 15.9) and 10.9 (SD: 15.6) suggesting that these patients have poorer function scores than the general population. These patients still had pain related to their gunshot injury with an average pain score of 2.16 (range 0-8).

Conclusions: Gunshot injuries to the extremities may involve bone, soft tissue, and neurovascular structures. Execution of appropriate therapeutic methods in such situations is critical for treating surgeons given the potential for complications. At our level one trauma center, gunshot victims were predominantly young, uninsured adult men. Complications included infection, compartment syndrome, and arterial injuries. Functional data collected demonstrated that patients continued to have difficulties with ADL’s at long-term follow-up.

Keywords: Gunshot wounds, Lower extremity, Soft tissue damage, Comminution

INTRODUCTION

Civilian gun violence rates have decreased since 1993, but still accounts for around 500,000 violent crimes per year1. Civilian gun violence rates are steadily increasing in the United States with each passing decade. Lower-energy weaponry, such as handguns and shotguns, typically inflict most of these injuries2.

A lower severity of tissue damage is expected as opposed to injuries inflicted by higher velocity weapons. However, depending on how missile mechanical factors interact, variations in the extent of damage may be appreciated. Damage caused by gunshots directed to the lower extremities can be especially extensive owing to the anatomical structure of lower extremities.

At our center, the orthopaedic and trauma surgeons tend to be more aggressive in treating extremity gunshot wounds than many of centers in our local area. The purpose of this paper is to present and discuss our experience in the treatment of low-energy gunshot wounds to the lower extremities.

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METHODS AND MATERIALS

Institutional review board (IRB) approval was obtained and we retrospectively reviewed cases of low-energy gunshot wounds to the lower extremities in a civilian setting over a 22-month span. One hundred and thirty three patients with gunshot wounds to the lower extremities were identified in the trauma database of our level one center. Medical records were obtained and information regarding hospital stay, management course, and insurance methods were recorded. The appropriate operative details and radiographic imaging studies were collected and assessed. At our institution, a standard protocol was developed for the management of all gunshot wounds to the extremities as follows: Soft tissue wounds superficial to the fascia were washed out and debrided in the emergency room without antibiotic treatment. Injuries that appeared to have deep muscle or bony involvement were taken for operative I & D and given IV antibiotics for 24-48 hours depending upon the extent of injury noted in the OR. Operative irrigation and debridement was our most commonly used treatment modality. Hennessy et al regards this procedure necessary for the removal of surface contaminants and debris. Burg et al also supports this method as standard protocol for all gunshot injuries to assist with complication prevention i.e., infection.

We attempted to contact each patient by telephone to obtain long-term outcome information. Fourteen patients (10.6%) were currently incarcerated or expired and unable to be contacted. Outcomes were evaluated and scored using the Short Musculoskeletal Function Assessment (SMFA) at long-term phone follow-ups.

RESULTS

Injury and Treatment

A total of 133 patients with 14 low-energy gunshot wounds to the lower extremities were identified as eligible for this study. Nine patients sustained bilateral injuries, which were counted as 2 wounds. The mean age of the study group population was 27.1 years (range: 15.2-56.3). There were 125 men (94.0%) and 8 women (6.0%). Patients underwent a total of 95 procedures during their hospitalization. Mean hospitalization time was 4.52 days (range: 0-88). Gunshot wounds caused 51 total fractures, with 6 patients (11.7%) receiving multiple fractures (counted as sustaining 1 gunshot injury or wound). Six fractures locations were identified, 1 fracture site was unknown due to amputation. The exact distribution is depicted in Figure 1a. The remaining 9 injuries (65.5%) consisted of soft tissue damage only. Forty-three patients underwent operative treatment. Figure 1b displays the definitive treatment modality distribution for all operative injuries. Twenty-eight percent of all patients underwent formal irrigation and debridement in the operating room as a definitive treatment, while 21% of patients had additional fracture fixation (intramedullary nailing, external fixation and open reduction internal fixation procedures utilizing plates and screws). Forty-six percent of operative patients underwent fixation with an intramedullary nail. Of the 6 (11.8%) fractures treated with external fixation devices, 3 (50.0%) of these devices were converted to intramedullary nailing, whereas the remaining 3 (50.0%) were treated definitively with the original external fixator. In addition, 6.3% of patients had an extremity angiogram procedure for questionable vascular status. Of the patients who went to the OR, foreign body removal was performed in 6.3% of the cohort.
Complications

The overall complication rate in the series was 15% (22 complications out of 148 injuries). See Table 1 for complete breakdown of complications. Of the 9 injuries associated with vascular injury to the lower extremity, 5 (55.6%) were associated with bony fractures. Two (1.4%) gunshot wounds were associated with nerve damage. One of the 2 injuries was complicated by nerve injury was associated with a fracture of the femoral shaft. Neither of these nerve injuries were concomitant with vascular injury. The patient who developed vasospasm was managed with heparin to salvage the limb. Patients who developed compartment syndrome were successfully treated with a fasciotomy. One patient with a comminuted tibia fracture underwent a below the knee amputation five days after placement of an external fixator due to focal necrosis of bony and soft tissue. One patient required a revision surgery for an infected non-union of the tibia; the patient’s intramedullary nail was replaced with an antibiotic nail and subsequently healed after several subsequent procedures.

Hospital Details

The average length of hospital stay in days varied according to the type of injury sustained by patients. Forty-three out of 97 (44.3%) patients with soft tissue injuries only were discharged on the day of admission, most of which underwent non-operative treatment. The average length of hospital stay for soft tissue injuries without vascular damage was 1.2 days (range 0-10). Patients who sustained bony injuries along with soft tissue injuries average length of hospital stay was 7.1 days (range 0-88). The average length of stay for patients who sustained vascular injuries along with other soft tissue injuries was 11.7 days (range 0-24). Those injuries that included a combination of vascular, bony and soft tissue injuries stayed for an average 17.0 days (range 0-35, 0 = died same day of admission). Patients who sustained multiple organ injuries had hospital stays at an average of 13.5 days (range 2-33). The average cost of hospital stay for the different gunshot inflicted injuries is listed in Table 1.

Outcomes

Out of the 133 patients enrolled, 14 were incarcerated or expired and 55 patients were unable to be contacted and therefore lost to follow up. Fifty patients (37.6%) successfully completed the Short Musculoskeletal Function Assessment Questionnaire. Scores were obtained at a mean of 24 months (range: 8-48) of follow up. Patients reported a mean total standardized SMFA score of 10.1 (SD: 12.7). Pain related to gunshot injuries were at an average pain score of 2.16 (range 0-8). Thirteen (9.8%) patients are currently incarcerated and one (0.8%) patient expired shortly after injury.

DISCUSSION

The treatment of low-energy gunshot wounds is contingent on the degree of tissue damage generated by the bullet. Typically, damage is classified according to bullet speed as low-velocity gunshot injuries (<2000 ft/s) or high velocity gunshot injuries (>2000 ft/s); however, the amount of harm one bullet is capable of causing is in fact related to a variety of factors. Flight, behavior, and projectile effects in combination with bullet type, velocity and mass are all significant elements. Thus, decisions pertaining to the management of gunshot wounds should not be based solely on weapon velocity.

The primary survey addresses emergencies related to airway, breathing and circulation (ABC). Once issues regarding these parameters have resolved a thorough physical exam is done as part of the secondary survey. Entrance and exit wound patterns can then be appreciated. Physician recognition of characteristic wound patterns may hasten treatment implementation and heighten suspicion for probable associated injuries which will be further aided by imaging obtained.

In our study population, the infection rate was low with 7 (5.3%) patients developing primary superficial infections and 1 (0.8%) patient a deep soft tissue infection. Our infection rate was similar to most studies analyzing lower-velocity injuries treated without prophylactic antibiotic treatment. Marcus et al's data demonstrated that patients who did not receive antibiotics prophylactically in the emergency department fared no worse or better in terms of early or late infections compared to those who had prophylactic treatment. Dickey and Howland et al also concluded that antibiotics were not necessary in the routine management of lower-velocity injuries. Conversely, Patzakis and Wolosyn et al both felt that prophylactic antibiotic treatment was beneficial for patients with these types of injuries. Furthermore, Melenev et al stated that 3 days of intravenous antibiotic
therapy is optimal for infection prevention of contaminated wounds. In terms of treatment following establishment of infection, all seven acute infections in our cohort resolved with appropriate antibiotic treatment and surgery. However, the one case with the deep infection associated with a non-union ended up undergoing a revision surgery in which an intramedullary nail was exchanged for an antibiotic nail.

The standard of care for gunshot fractures at our institution begins with primary stabilization of the patient and ends with fracture analysis. In the emergency department, a complete physical examination is followed by neurological exam; open fractures are covered with sterile dressings to separate the wound from environmental bacteria. Once any emergencies have been addressed, radiographs of the fracture site are taken (including the joint above and below the fracture site) for delineation of the extent of bony and soft tissue injury.

In the recent literature, intramedullary nailing has been labeled as the primary treatment method for low-velocity femoral fractures. The most commonly used fixation method in our cohort was intramedullary nailing. Weil et al reported intramedullary nailing as their most common modality for gunshot inflicted fractures followed by external fixation. Conversely, Burg et al reported external fixation (36%) as their primary fixation tool and intramedullary nailing (28%) as second. Our experience with low-velocity gunshot wounds demonstrate that select bony injuries can be treated operatively with immediate internal fixation rather than extended external fixation as Burg et al reported.

Tissue swelling is to be expected in extremity fracture, thus, fasciotomies should be performed when concern for the development of compartment syndrome is present. Three patients (2.3%) developed compartment syndrome in our cohort, and all were treated with fasciotomy without long-term complication.

Arterial damage in the lower extremity can be a limb or life-threatening situation and demands immediate attention. Dorlac et al reviewed the cause of death for gunshot victims at their institution and found that over half of their patients died from excessive loss of blood secondary to arterial damage within the lower extremity. To help expedite the treatment of such critical injuries, Smith et al proposed specific hard signs to look for when vascular injury is suspected; no palpable pulses, signs of ischemia, excessive bleeding, and pulsating or expanding hematoma. Burg et al also reported on a sensitive test for identification of vascular damage; an ankle brachial index (ABI) of 0.9 or less.

In this series, when arterial damage was suspected, an angiogram (6.3%) and/or surgical exploration (5.3%) was performed. Knudson et al found that the use of Duplex Doppler Ultrasonography as a replacement to angiography was equal in sensitivity in detecting vascular injury and yet non-invasive. Ziperman et al supports the use of surgical exploration in these situations and recommends that it be done for all gunshot injuries. Overall, angiography and exploration have been accepted in the literature as the mainstay of investigation when vascular injury suspicion is high. Nerve injury can present as numbness, tingling, paralysis or any combination of those three. Two (1.4%) gunshot wounds at our institution were associated with peripheral nerve damage. These neurological injuries were treated non-operatively. It has been reported that neurological deficits associated with lower-velocity gunshot injuries may resolve without surgical intervention.

Outcomes of gunshot wound patients were measured using the SMFA questionnaire. Compared to valid normative SMFA data (baseline of musculoskeletal health of the general population), functional, daily, and mobility indexes of gunshot wound patients all proved to be worse at latest follow-up compared with the general population. Interestingly, both mean bothersome and emotional standardized scores were better in the gunshot patients compared to the general population.

In conclusion, with thorough physical examination and fracture analysis, primary stabilization, irrigation and debridement in the emergency room, appropriate fixation, and proper follow-up care, low-velocity gunshot wounds can be successfully treated with high patient satisfaction rates. With better recognition of these types of injuries, substantial improvements can be made to patient lives and the healthcare system alike.

REFERENCES
ASYMMETRIC BILATERAL HIP DISLOCATIONS:
A CASE REPORT AND HISTORICAL REVIEW OF THE LITERATURE
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ABSTRACT
Background: Asymmetric bilateral hip dislocations are a rare injury pattern in which one hip dislocates posteriorly, and the contralateral hip dislocates anteriorly. We report a case of bilateral asymmetric hip dislocations and provide a comprehensive review of all available reports, identifying 104 total cases, which is 70 more than previously reported.

Purpose: To review and evaluate the total body of literature regarding bilateral asymmetric hip dislocations.

Methods: Comprehensive literature review and analysis of all reports of bilateral asymmetric hip dislocations with concurrent case report.

Results and Conclusions: Bilateral, asymmetric represent approximately 0.01%-0.02% of all joint dislocations. There has been a substantial increase in the number of case reports in the literature in the last 10 years. Males are more likely than females to incur this injury pattern and the most common mode of injury is motor vehicle accident. Urgent closed reduction should be attempted in an efficient and safe manner to avoid potential complications, and open reduction should be considered in irreducible dislocations. Post reduction management should include stability assessment and CT to assess for associated injuries and intra-articular fragments; although no clear guidelines for post-reduction treatment emerged. Common complications include: nerve palsies, AVN and heterotopic ossification.

INTRODUCTION
Asymmetric bilateral hip dislocations are a rare injury pattern in which one hip dislocates posteriorly, and the contralateral hip dislocates anteriorly, representing approximately 0.01%-0.02% of all joint dislocations. The first published case report appeared in the international literature in 1845, with a right posterior superior dislocation and a left anterior-inferior dislocation after an accidental overturning of wagon loaded with furniture. Since that original case report, there have been 104 reports of this rare injury with discussions focused on the mechanism of the injury, treatment of injury and outcomes associated with the injury; the most recent case series identifying only 34 total cases in the English language. We report a case of bilateral asymmetric hips dislocations and a critical review of 104 available reports of asymmetric bilateral hip dislocations focused on the mechanisms and patterns injury, associated injuries, complications and contemporary management and outcomes.

CASE REPORT
Patient AT is a 23-year old woman with no previous history of pelvic trauma, abnormal hip development or ligamentous laxity who was the unrestrained passenger in the front of a motor vehicle traveling at highway speeds. The patient was riding on the front console and was not in a proper seat at the time of accident. She was air-lifted to a regional hospital where initial physical exam and imaging indicated an open right proximal humerus fracture (FIGURE 1a) and chest/abdomen pelvis CT demonstrated a right posterior-superior hip dislocation and left anterior-inferior hip dislocation (FIGURE 2). After initial assessment and stabilization, patient was subsequently air-lifted to our hospital where the General Surgery Service performed a complete trauma evaluation. Notably, no reduction of the known hip dislocations was attempted prior to secondary transfer.

Upon arrival 4 hours from injury, patient was alert and conversive reporting right upper extremity pain, left chest wall pain and bilateral hip pain. Right upper extremity examination revealed an open fracture of the
Asymmetric Bilateral Hip Dislocations

Figure 1. (a) AP radiograph of right shoulder demonstrating open proximal third humerus fracture. (b) AP radiograph of the right shoulder at 16 months post-operatively, demonstrating healed fracture status post open reduction, internal fixation.

Figure 3. (a) AP radiograph of pelvis demonstrating right posterior, superior and left anterior, inferior hip dislocations. (b) AP radiograph of pelvis after reduction of both hips demonstrating concentric reductions.

Figure 2. 3-dimensional CT reconstructions of pelvis prior to reduction of bilateral, asymmetric dislocations. (a) AP view. (b) Lateral view of left hip demonstrating anterior, inferior dislocation. (c) Right lateral view of the right hip demonstrating posterior superior dislocation. (d) Right obturator oblique view demonstrating bilateral dislocations.

Asymmetric Bilateral Hip Dislocations

right humerus without gross contamination in an otherwise neurovascularly intact limb.

Examination of the lower extremities revealed a shortened and externally rotated right lower extremity while the left lower extremity was in a position of relative internal rotation and appeared longer than the contralateral side, consistent with asymmetric bilateral hip dislocations. Both lower extremities were found to be neurovascularly intact with appropriate strength, sensation and palpable distal pulses. Patient reported pain with attempted internal and external rotation of both hips. An AP pelvis radiograph (FIGURE 3a) was obtained to verify asymmetric dislocations and verify no obvious femoral neck fractures or acetabular fractures.

After completion of the full trauma workup, the patient was consciously sedated with ketamine, propofol and fentanyl in the emergency department. With adequate sedation, an attempt was made at reducing the right posterior-superior hip dislocation using standard in-line traction technique with stabilization of the pelvis with hip and knee flexion, gentle traction and adduction and internal rotation of the hip. After an initial attempt was unsuccessful, attention was turned to the left anterior-inferior dislocation, which was reduced with in-line axial and external rotation and abduction. After successful relocation of the anterior-inferior hip dislocation, attention was then turned back to the right posterior-superior hip dislocation. Again using the aforementioned in-line traction, the hip was easily located. Leg lengths appeared symmetric and she maintained her pre-reduction neurovascular status. Gentle manual traction was applied while the AP pelvis was obtained (FIGURE 3b).

A post-reduction CT was obtained indicating concentric reduction of both hips with no evidence of intra-articular fragments (FIGURE 4). Patient was placed on posterior hip precautions and taken to the operating room to address the open right humerus fracture. Given the predicted weight bearing demands in the upper extremity the humerus fracture was fixed with plate and screws (FIGURE 1b) and stability of the hip reductions was tested under anesthesia in the operating room (FIGURE 5). Post-operatively the patient continued on posterior hip precautions bilaterally, with weightbearing as tolerated on the right lower extremity, and toe-touch weightbearing on the left due to the small posterior wall.
fracture. She was discharged from the hospital 2 days postoperatively and remained on weightbearing restrictions for 2 weeks then was transitioned to weightbearing as tolerated bilateral lower extremities. Patient did well after discharge and at 16-month followup she was found to be doing well with no complications. Specifically patient had no pain with ambulation or weightbearing, no restrictions to movements, and no radiographic evidence of complications (FIGURE 1b & 6).

REVIEW OF LITERATURE

Introduction

The following is a review of previous reports of asymmetric, bilateral hip dislocations identified in both the English- and non-English literature. We feel that a comprehensive evaluation of the available literature offers perspective on this unique traumatic entity. Previous reviews have often overlooked non-English language studies; we feel this is a shortcoming as many of the original reports of bilateral, asymmetric hip dislocation were reported in the international literature.

In our literature review, we identified a total of 104 cases of asymmetric, bilateral hip dislocations, including the case presented herein, stemming from 92 total publications; 72 cases were identified in the English-language literature and another 32 cases from the International non-English language literature (APPENDIX 1). It is possible that one case was reported twice in the interdependent reports of Thompsen and Epstein and Epstein. We thoroughly reviewed each of these articles to identify salient information such as: direction of dislocations, gender, age at dislocation, mechanism of injury, associated injuries, time to reduction, treatment, outcomes and complications. In many of the cases reviewed, there is accurate documentation of the details of the case. However, in some cases details are lacking, and thus specific entities are reported as unknown. All reported dislocations were of native hips; there were no

![Figure 4](image4.png)

Figure 4. 3-dimensional CT reconstructions of pelvis after reduction of bilateral, asymmetric dislocations. (a) AP view. (b) Lateral view of left hip demonstrating reduction of dislocation. (c) Right lateral view of the right hip demonstrating reduction of dislocation. (d) Right obturator oblique view demonstrating reduction of both dislocations.

![Figure 5](image5.png)

Figure 5. Intraoperative fluoroscopic images demonstrating stability (a) AP right hip in neutral position. (b) Right obturator oblique, outlet view with hip in 90° of flexion. (c) AP left hip in neutral position. (d) Left obturator oblique, outlet view with hip in 90° of flexion.

![Figure 6](image6.png)

Figure 6. (a) AP radiograph of pelvis at 16 months post-reduction demonstrating continued stability without obvious complications. (b) Left iliac oblique view. (c) Right iliac oblique view.
Asymmetric Bilateral Hip Dislocations

A total of 95 cases were identified that detailed the directions of the asymmetric dislocations. Nine cases did not report direction of dislocation, whereas 50 (53%) cases were right posterior, left anterior and 45 (47%) cases were right anterior, left posterior.

We found a total of 93 cases that reported gender. Seventy-six (81%) were found to be males and 18 (19%) were females. The first reported asymmetric dislocation in a female was reported in 1889, and there was not another reported incidence of female asymmetric dislocation until 1954, nearly 65 years later. Since 1997, there have been 16 more cases of female asymmetric dislocations, including the case reported here, representing a total of 32% of the cases since 1997.

Ninety cases reported the age at dislocation. Ages range from 11 – 65 years of age, with an average age of 32.9 years. When analyzing the age of dislocation by gender, the average age of dislocation in men was 32.2 years and women 32.7 years.

We divided the method of injury into one of five categories: motor vehicle collision (includes motorcycle collision), weight from above (e.g. collapsing wall), fall from height, pedestrian struck by motor vehicle and other (airplane crash). Of the 104 cases reported, 91 cases reported mechanism of injury. The majority of the reported cases (n=54, 59%) occurred from motor vehicle collisions. The second most common mode of injury was weight from above (n=17, 19%), followed by pedestrian struck by motor vehicle (n=14, 15%), fall (n=5, 5%) and airplane crash (n=1).

Taylor first reported motor vehicle collisions resulting in asymmetric, bilateral dislocation in 1940. He reported a 50 year-old male who was the passenger in a truck involved in a head on collision. Since that report, there have been 54 reported cases of asymmetric, bilateral dislocation as a result of motor vehicle collision, including motor cycle collisions, accounting for 59% of the cases in which the mechanism was reported. Of the 54 reported cases, 16 cases were the driver, 21 cases were reported as passengers, 13 cases did not report position of patient at time of accident, and 4 cases were the result of motorcycle accidents.

Although the reported mode of injury presumably resulted in the bilateral dislocations, it is not always apparent if the bilateral, asymmetric dislocation occurred simultaneously or occurred in two, temporally separate instances. For example, one hip dislocation occurred at the time of injury; then the second, asymmetric contralateral dislocation occurred during attempted extrication.

Other injuries are common with asymmetric bilateral hip dislocations. This is likely due to the fact that for both hips to dislocate a great deal of force is required. Of the 104 cases reviewed, 62 cases reported additional injuries, 23 reported no additional injuries and 19 cases made no mention of additional injuries. For purposes of analysis, we categorized fractures of the proximal femur and acetabulum as associated injuries and all other injuries as non-associated injuries.

Associated fractures of proximal femur and acetabulum

Associated fractures include fractures of the acetabulum or proximal femur including femoral head, neck and peritrochanteric fractures. Of the 104 cases analyzed, 46 (44%) cases reported associated fractures, for a total of 71 associated proximal femur or acetabular fractures. The majority (n=53) of these associated fractures were of the acetabulum (75%), with 18 fractures of the proximal femur representing 25% of the associated fractures. Of the 53 acetabular fractures, 39 (74%) were associated with posterior dislocation and 12 (26%) were associated with anterior dislocation. According to the Letournel classification, the type of acetabular fracture was not reported in enough of the cases to make analysis relevant; many of the cases analyzed were reported prior to the modern classification system.

Of the 18 fractures of the proximal femur, 12 (66%) were associated with anterior dislocations and 6 (43%)
were associated with posterior dislocations. A total of 4 hips had ipsilateral acetabular and proximal femur fractures and 1 case reported bilateral acetabular and proximal femur fractures\(^6\).

**Non-associated injuries**

The documentation of non-associated injuries is variable. However, of the reported non-associated injuries 17 cases reported non-associated lower extremity injuries e.g. knee or ankle injuries; 15 cases reported upper extremity injuries including hands; 5 cases reported concomitant spine injuries; 10 cases reported abdominal injuries; 10 cases reported lacerations or superficial skin injuries; 10 cases reported patient was in unspecified shock on presentation, and 2 cases reported facial or head injury. Levine\(^{21}\) described the "floating pelvis" with bilateral, asymmetric hip dislocations and a three column lumbar spine injury, which effectively results in a pelvis that is disconnected the axial and appendicular skeleton and poses a unique treatment dilemma.

**Time to reduction**

A total of 53 cases reported time to reduction, with 42 cases (79%) reporting reduction of both hips with 6 hours of injury. An additional 4 cases reported reduction of both hips within 24 hours (7.5%) for a total of 46 of 53 cases (87%) reporting reduction within 24 hours. The remaining 7 cases (13%) reported reduction greater than 24 hours from time of injury.

**Method of Reduction**

We also analyzed site of the reduction (emergency room setting versus the operating room). A total of 70 cases reported location of the reduction attempt. Twenty of these 70 (29%) had both hips reduced in the emergency room, 40 patients (57%) had both hips reduced in the operating room, and 10 patients (11%) had 1 hip reduced in the emergency room and 1 hip reduced in the operating room. No specific details regarding number of reduction attempts were identified.

Additionally, 93 cases reported whether open or closed reduction methods were employed. Eighty-three of the 93 (88%) reported closed reduction, 10 cases (12%) reported closed reduction of 1 hip and open reduction of the other hip, and no cases reported open reduction of both hips. Open or surgical reduction methods were only utilized in the operating room setting. Analysis of the closed reduction technique or maneuver utilized was not possible as most papers did not directly identify the method of reduction.

**Post-reduction Management**

We analyzed post-reduction management including post-reduction precautions, weightbearing status and heterotopic ossification prophylaxis. Forty-three identified some type of post-reduction traction treatment with an average treatment time of 4 weeks. Of these 43 cases, 23 specified skeletal traction, 16 utilized skin traction, and 4 cases did not identify type of traction. 42 cases mentioned a post-reduction period of non-weight bearing with an average of 6.7 weeks of non-weight bearing. Only 8 cases identified Indomethacin at standard dosing as heterotopic ossification prophylaxis\(^{8,22-27}\).

**Radiographic Documentation**

Of the 104 total cases reported, 80 have radiographic documentation of asymmetric, bilateral dislocations. This first radiographically documented asymmetric, bilateral hip dislocation was by Hill and Penn\(^{28}\) in 1929. Since that time, most case reports have included radiographic evidence with the exception of several cases\(^{2,4,29}\).

**Outcomes**

Eighty cases reported some sort of outcome, without any type of standardized outcome measures. In cases reporting return to full strength, no pain, and full ROM, cases were classified as "Excellent", while if patients had minor abnormalities (soreness, small change in ROM, or some loss of strength or sensation) not detrimental to their life they were given a “Good” classification. Patients with any detriment or change in lifestyle due to long term complications were given a “Poor” rating. Forty-nine cases (61%) reported excellent outcomes, 25 cases (31%) reported good outcomes, and 6 cases (8%) reported poor outcomes.

**Complications**

We analyzed reported complications related to the dislocation, and found the highest complication was nerve palsy, with 6 reported sciatic nerve palsies, 1 peroneal nerve palsy, 1 tibial nerve palsy and 1 obturator nerve palsy. Five cases reported avascular necrosis of the femoral head, 5 cases reported heterotopic ossification, 2 cases reported re-dislocation of the reduced hips and 1 case reported post-traumatic osteoarthritis. Other complications that were not directly related to the dislocation included: reported DVT/PE, lung infection, femoral hernia, and one death.

**DISCUSSION**

**Historical Demographics**

In the review of the literature regarding bilateral hip dislocations, the first reported case of bilateral anterior dislocation was by Singowitz in 1830\(^{30}\). Nearly a half-century later, in 1883, the first review of bilateral hip dislocations was published by Packard\(^{31}\), who identified a total of 13 reported cases, 8 of which were asymmetric, 3 were bilateral posterior and 2 were bilateral anterior. Within the next decade, two literature reviews emerged
Asymmetric Bilateral Hip Dislocations

The first published case report of asymmetric, bilateral hip dislocation occurred in 1845 by Andreini, in which he identified and documented the case of a 30-year-old male who sustained a right posterior superior dislocation and a left anterior-inferior dislocation after an accidental over-turning of wagon loaded with furniture. Since that initial case report there was a steady number of reported cases until approximately 1985, when the number of bilateral, asymmetric hip dislocations dramatically increased. That trend has continued, such that in the last 10 years there have been more cases reported than in the previous 20 years. This increase in case reports does not likely reflect a true increase in the incidence of bilateral, asymmetric hip dislocations, but more likely an increase in publishing of case reports (FIGURE 8).

In his treatise on fractures and dislocations published in 1907, Stimson reported that of the 26 cases of bilateral hip dislocations reported at that time, the dislocations were usually asymmetric with one backward upon the ilium and one forward upon the obturator or pubis. He reported the asymmetry was commonly caused by a direct posterior blow while bending forward and twisting.

Classification and Descriptions

Classification systems for hip dislocations have existed for a long time and have evolved over the years. Many of the original systems are based on the direction of the femur, or force vector, at time of dislocation. Others are based on the final resting position of the femoral head in relation to the pelvis. The various nomenclatures have led to confusion regarding the description of hip dislocations, making direct comparisons difficult.

Hippocrates initially described four principal directions of dislocation of the hip: outward, inward, forward and backward. This basic schema was based on the direction of the force vector of the proximal femur at the time of dislocation and was utilized for centuries, until many authors developed a classification systems based on the resting position of the femoral head after dislocation. Thus, the terms upon the ilium (iliac), upon the ischium (ischial), upon the pubes (pubic), and upon the foramen ovale (ovale) were introduced. Several variations on these terms were later introduced including suprapubic, sub- or infrapubic, sacro-sciatic.

Rosen and Nélaton independently introduced the concept of the ilio-ischiatic line, which was a line between the Anterior Inferior Iliac Spine (AIIS) and ischial spine and effectively created a line for relative anterior and posterior dislocations. Bigelow advanced the classification system by basing his system not only on the direction of the dislocation and where it came to rest, but also on the position of the head in relation to the surrounding muscles, the joint capsule and chiefly the Y-ligament or ilio-femoral ligament. His descriptions of incomplete and

Figure 8. Incidence of case reports of bilateral, asymmetric hip dislocations in 20-year intervals. Note the dramatic increase in reported cases in the last ten years.

including those by Niehaus in 1888, documenting 25 cases of known bilateral hip dislocations, 10 of which were reported as asymmetric, and Six in 1891, which identified 30 bilateral dislocations, again identifying the same 10 asymmetric dislocations noted by Niehaus. In 1936, Marquardt provided the most up-to-date reviews of bilateral hip dislocations, identifying a total of 54 bilateral hip dislocations, 17 asymmetric bilateral dislocation, 20 bilateral posterior and 7 bilateral anterior dislocations. In his thesis on bilateral hip dislocation in 1991, Scharplatz identified 120 reported cases of bilateral hip dislocations, 40 of which were asymmetric, accounting for 33.3% of all bilateral dislocations.

The combined works of Thompson and Epstein and Epstein’s series of 583 traumatic hip dislocations, they identified 10 total bilateral dislocations, 8 total asymmetric bilateral dislocations, 1 of which may represent a duplicate case. Marotte reported the incidence of posterior bilateral dislocation at 50%, anterior bilateral dislocation at 10% and asymmetric bilateral dislocation at 40%. According to Brav’s review of 517 patients, in which he identified 6 total bilateral dislocations, 3 of which were asymmetric, hip dislocations account for 2-5% of all joint dislocations.

Based on the large populations based studies of Epstein, Thompson and Epstein, and Stewart and Milford, in 1991, Shannak estimated the incidence of bilateral hip dislocations to be approximately 1.25% of all hip dislocation; thus, the incidence of bilateral hip dislocation was 0.025%-0.05% of all dislocations. Additionally, if we extrapolate further and estimate 40% of all bilateral hip dislocations are asymmetric based on work by Marotte, asymmetric, bilateral hip dislocations account for 0.01%-0.02% of all joint dislocations.
complete dislocations have led to a better understanding of hip dislocations and attempts at reduction as well as the fracture patterns of the proximal femur. Thompsen and Epstein introduced a 5-type classification system for only posterior hip dislocations based on associated injuries of the acetabulum and proximal femur. This classification has proven useful for management as it related to outcomes.

In modern practice, physicians tend to favor descriptions of dislocations in relation to the resting position of the femoral head after dislocation and thus prefer to use the simpler terms, anterior or posterior. These terms are roughly based in relation to the Rosen-Nélaton line. If the femoral head comes to rest below the Rosen-Nélaton line, it is thought to be anterior and if it rests above the Rosen-Nélaton line it is considered posterior. This distinction can further be differentiated into superior and inferior with anterior superior dislocations termed pubic and inferior anterior dislocation commonly called obturator. Posterior superior dislocations are most commonly called iliac, while inferior posterior dislocations are called ischiadic. Perineal dislocations are anterior dislocations that rest below the obturator foramen and are still considered anterior dislocations. Part of the difficulty in identifying previously reported dislocations is that the nomenclature has changed as well as the use of radiographs. The terms suprapubic, infrapubic, obturator, or thyroid dislocation refers to an anterior dislocation and the terms ischiadic, sciatic or iliac refer to posterior inferior and superior dislocations respectively. As noted in the textbook of Key and Conwell, central dislocations of the hip joint are more appropriately classified as fractures of the pelvis as they are always associated with disruption of the acetabular dome, and thus are not discussed in this article.

**Patient Evaluation and Initial Management**

A thorough patient evaluation is required of any hip dislocation. With bilateral, asymmetric hip dislocations the mechanism of injury is likely high-energy. Thus, the suspicion of other injuries, especially concomitant lower extremity injuries, should be high, and a full trauma workup should be performed. Initial evaluation on presentation should include the basics of Advanced Cardiovascular Life Support (ACLS), including management of airway and necessary life resuscitating measures. If the patient is stable, evaluation should proceed with basic imaging labs which include AP pelvis, chest x-ray, C-spine films or CT, and musculoskeletal imaging of any other areas.

The initial AP pelvis will likely demonstrate the bilateral dislocation. The direction of the dislocation is not always obvious on the 2-dimensional AP pelvis and should be correlated with clinical exam. However, there are several keys to identifying direction of location on the AP pelvis. First, the majority of posterior dislocations are superior, and the majority of anterior dislocations are inferior. Associated fractures of the acetabulum may also be useful in identifying the direction of the dislocation. Anterior wall fractures are more likely to be associated with anterior dislocation and posterior wall dislocations are more likely to be associated with posterior dislocations. Despite these hints, the direction of dislocation may still be difficult to determine on AP radiograph. Measuring the diameter of the femoral head can be useful in determining the position of the femoral head in relation to the x-ray beam. With an anterior dislocation, the femoral head will be relatively larger than the femoral head of a posterior dislocation.

The AP pelvis should be thoroughly evaluated to rule out obvious femoral neck fracture. If a femoral neck fracture is observed on initial AP pelvis, do not proceed with attempted reduction in the emergency room, and consider operative reduction of the dislocation status post fixation of femoral neck fracture. Reduction of a hip dislocation with a non-displaced or minimally-displaced femoral neck fracture may lead to significant displacement of the femoral head, making surgical reduction necessary and potentially more difficult. If a femoral neck fracture can be ruled out on the AP pelvis radiograph, it is safe to proceed with a reduction attempt.

A chest abdomen and pelvis CT is often obtained to rule out intra-abdominal injury as part of the initial trauma workup. As in the case presented herein, this imaging is often obtained prior to consultation of orthopedics or transfer to a primary trauma center; therefore the hips are often not reduced prior to initial CT. Every effort should be made to reduce hips prior to initial CT imaging, as CT imaging is indicated postreduction to evaluate for intra-articular fragments, femoral head or neck fractures and to classify associated fractures of the acetabulum.

After patient stabilization and initial imaging, a thorough physical exam should be performed. Specifically, a complete neurovascular examination of the lower extremities should be conducted. The femoral vasculature run anterior to the hip joint are rarely injured in hip dislocation, although given the proximity and force required for dislocation, a full vascular exam should be performed. The sciatic nerve exits the pelvis posterosuperior to the hip joint and traverses directly posterior to the posterior acetabular rim. The nerve may be damaged in a simple posterior dislocation of posterior wall fracture dislocation. Basic nerve function should always be assessed prior to reduction attempts, as repeated reduction attempts may damage the nerve per se.

If the AP pelvis is negative for femoral neck fractures and a full neurovascular exam has been completed, a closed reduction attempt is indicated with conscious sedation in the emergency room setting. If there is a
femoral neck fracture or other injuries that necessitate intubation or hemodynamic monitoring, it may be advisable to transfer the patient to the operating room for a closed reduction attempt. Similarly, if reduction attempts in the emergency room setting are unsuccessful, consider transfer to the operating room for closed reduction with full relaxation and possible open procedure.

Reduction Techniques

According to the translated work of Hippocrates48: “In some the thigh is reduced with no preparation, with slight extension directed by the hands, and with slight movement; and in some the reduction is effected by bending the limb at the joint and making rotation. “ This basic understanding of the potential difficulties in hip reduction led to the development of several techniques or maneuvers that are often used to aid in hip reduction.

Allis45 and Bigelow60 advanced our understanding of the anatomy and technical aspects of closed hip reduction maneuvers, generally involving axial traction with varying degrees of flexion, abduction and adduction depending on the location of the femoral head in relation to the pelvis. Although Bigelow described prone positioning for difficult hip reductions, the majority of closed reductions can be attempted in the supine position. First, most patients present in the supine position and attempting to flip a patient with bilateral hip dislocations and possible other injuries is a difficult task. Therefore, if at all possible both anterior and posterior hip reductions should be attempted in the supine position.

Generally, initial reduction of posterior dislocations should include axial traction with hip and knee flexion and some degree of adduction, followed by internal rotation as the femoral head clears the posterior wall of the acetabulum. These maneuvers may be augmented with counter traction applied to the pelvis by an assistant. For anterior dislocations, the reduction maneuver includes axial traction with hip flexion with external rotation or lateral translation of the hip. Similarly, stabilization of the pelvis by an assistant may help with reduction. Often with reduction of the hip, a palpable or audible “chunk” is appreciated. After apparent reduction of one hip, gentle manual traction should be applied while the reduction of the second hip is attempted. Once both hips are reduced, stability should be assessed with range of motion testing. This is an important step in the reduction maneuver as it will dictate post-reduction management. If the hip is felt to be grossly unstable upon reduction, it is acceptable to not test range of motion immediately after reduction. One should also check leg lengths, as well as relative internal or external rotation for symmetry as this can clinically indicate reduction. If there is a significant acetabular fracture, shortened femur fracture, or gross instability one may consider application of skeletal traction at this point.

With bilateral asymmetric dislocations, there does not appear to be any indication to reduce the anterior or posterior hip first. There is no clear biomechanical advantage to reducing one first over the other. In the case presented here, an attempt was made to reduce the posterior dislocation first, which was unsuccessful. Then, the anterior hip was successfully reduced. A second attempt on the posterior hip was then successful and noted to be substantially easier than the first attempt at the posterior hip reduction. It is possible that there is some sort of paracrine or endocrine effect after reduction of one hip that allows for more muscle relaxation and effectively easier relocation of the second hip.

After presumed reduction an immediate AP pelvis should be obtained to verify reduction. It may facilitate obtaining the post-reduction radiograph to have the image plate placed underneath the patient prior to the reduction attempt. This effectively eliminates the need to move the patient after reduction attempt and before radiographic verification of reduction. If the AP pelvis verifies reduction, a post-reduction pelvis CT should be obtained to identify and classify possible acetabular fracture; look for intra-articular fragments or eccentric reduction as the presence of either will dictate further treatment and guide surgical planning. Additional plain films including: inlet, outlet and Judet oblique views should be obtained at this point to further assess pelvic injury and serve as primary comparison films for clinical follow up. If intra-articular fragments are encountered or there is evidence of eccentric reduction, hip arthroscopy may be considered to remove fragments and achieve concentric reduction45.

Effects of Gender

The first apparent reported asymmetric, bilateral hip dislocation occurring in a women, was reported in 1889 by Kirn45. He describes a woman who is struck by a collapsing wall with a right anterior and left posterior hip dislocation. Interestingly, this also appears to be the first report of surgical reduction of asymmetric bilateral hip dislocation using the approach described by Fiorani47 in the literature.

As mentioned previously, after the initial reports of a female, asymmetric dislocation was reported in 188945, there was not another reported incidence of female asymmetric dislocation until 19544, nearly 65 years later. Since 1997, there have been 16 more cases of female asymmetric dislocations, including the case report presented here27,37. Analysis since 1997 indicates that the number of women with asymmetric, bilateral hip dislocations is 32% of the total reported cases. The increase in incidence of bilateral asymmetric dislocations in the last 20 years likely reflects a simple increase in reporting, as well as increase in the total number of motorists and the number of female
motorists in particular. There are still an overwhelmingly greater number of male asymmetric dislocations, representing 81% of the total cases reported (FIGURE 7).

The majority of male bilateral asymmetric dislocations may be related to relative differences in anatomy between males and females. Specifically, posterior dislocations are more likely to occur in patients with reduced femoral anteversion or increased retroversion. Women generally have more femoral anteversion as well as more anteverted acetabuli which allows acceptance of greater axial femoral load.

Mechanism of Injury
Bray reported nearly 85% of hip dislocations were attributed to motor vehicles and Sah and Marsh provide a thorough discussion of the mechanism of asymmetric, bilateral hip dislocations that occur in motor vehicle accidents. In our review of the literature, the majority of bilateral asymmetric hip dislocations occurred in motor vehicle accidents (59%); the majority of those reported injuries occurred in passengers. Regardless of the mechanism of injury, the dislocations can only occur if each hip joint is subjected to two separate force vectors. For posterior dislocations, the force vector is directed posteriorly through the hip joint, for anterior dislocations the force vector is directed anteriorly through the hip joint. The relative position of the hip at the time the force is applied may enable the dislocation and determine the extent of associated injuries. For example, if the hip is in extreme abduction with an anteriorly directed force vector, the hip is likely to dislocate anteriorly without significant injury to the anterior rim of the acetabulum or femoral head. However, if the hip is adducted with the same anteriorly directed force vector, the femoral head may blow through the anterior rim of the acetabulum causing an anterior wall fracture or femoral head fracture. Similarly, a posteriorly directed force with the hip in relative adduction may result in a simple posterior dislocation, whereas a posteriorly directed force with a hip in relative abduction may result in a posterior wall fracture. Furthermore, slight variations in the degree of force vector may result in differences in associated fractures. The magnitude of the force also affects the dislocations; the greater the magnitude of force vector, the more likely to encounter dislocation and associated injuries.

As theorized in Sinha, one of the force vectors may be applied by a stationary object as the passengers themselves are thrown forward creating a posterior vector on one hip. It is also possible that the dislocations do not occur at the same moment; one hip dislocation may occur during the trauma event and the second, contralateral dislocation may occur with the extrication or subsequent trauma.

Effects of Age of Dislocation
According to populations studies, after the age of 15, age at time of dislocation does not affect outcome. Economu reported 2 cases of adolescent dislocations: a 12-year old with no long term sequelae and an 11-year old with recurrent dislocations. Sahin reported longer term follow up of a 12-year old with minimal arthritic changes of the right hip and sclerosis of left acetabular roof in a child with simultaneous central fracture dislocation of one hip and posterior dislocation of the other hip. Donnelly reported two cases of a 12 year old and 14 year old; the 14 year old with no complications and the 12 years old developed avascular necrosis and segmental collapse of the right femoral head. Thus, it appears that bilateral, asymmetric dislocations in a younger population suffer the same risks of AVN and PTOA as older patients. It should also be noted that the hip articulation of the child or adolescent differs significantly from the adult. Specifically, the hip joint is more pliable in a child or adolescent secondary to the nature of the developing bone and increased ability of the cartilage to absorb energy. Furthermore, with an open tri-radiate cartilage at the time of injury, the potential for growth disturbance and functional complications of the hip are greater.

The average age of dislocation in this review of the literature was 32.7 years of age with a range from 11 to 65. The mean age of dislocations indicates that this injury is more likely to occur in a more active, younger population.

Anatomy
Posterior dislocations are more common than anterior dislocations and often cited as 90% of all hip dislocations based on the work of Epstein, Thompsen and Epstein and Stewart and Milford. The reason that posterior dislocations occur more frequently is two-fold. First, and most importantly, the direction of dislocation is related directly to anatomy. Almost all posterior dislocations will leave the acetabulum in the inferior posterior portion of the joint. This is due to the weakness in both the joint capsule and the thinness of the acetabulum in this region. Additionally, the strong iliofemoral ligament, or Y-ligament of Bigelow is the primary restraint to anterior dislocation and the pubofemoral ligament and ischiofemoral ligaments provide restraint to dislocation inferiorly and posteriusuperiorly, respectively. Thus, the area of greatest anatomic weakness with the hip joint, from a soft tissue and bony perspective, is the posterior inferior region. It should also be noted, that the iliofemoral ligament is considered the strongest ligament near the hip. The transverse fibers of the ligament, or the base of the Y, are thought to be the strongest as they are oriented in-line with the obliquity of the hip joint. The superior and inferior branches of the Y-ligament insert respectively on the superior and inferior portions of the intertrochanteric
The nature of the inverted Y inherently creates a region of weakness in the axilla of the Y. Moreover, the anterior capsule is thought weakest at this location. Thus, anterior dislocations are most likely to result in disruption of the superior or inferior branches of the iliofemoral ligament or by fracture of the femur or acetabulum.

The second reason that posterior dislocations are more common than anterior dislocation is related to the force vector required for dislocation. The force vector for a posterior dislocation is typically an axial load with the hip in a neutral or flexed position. With this type of load, the femur is likely to dislocate posteriorly. Moreover, as motor vehicle collisions are the most common mechanism for dislocation and passengers and drivers are likely to be in a seated position with hip flexed, the resultant posterior dislocation is the most likely outcome. For anterior dislocation the force vector is commonly applied from behind the patient with the hip in a neutral or slightly extended position, resulting in a force vector the forces the femoral head anteriorly. Remember that in order to dislocate anteriorly, the strong iliofemoral ligament must be disrupted, either by fracture near its origin on AIIS and rim of acetabulum or near its insertion on the intertrochanteric ridge.

It should be noted that associated fractures of the acetabulum both anteriorly or posteriorly may render the strong soft tissue restraints weaker and thus account for the high rate of associated fracture with dislocations.

**Treatment, Complications & Outcomes**

In our review of the literature, treatment was quite varied. However, several principles merged that guide modern practice. Outcomes of large population based studies, indicate that urgent reduction of the femoral head within 24 hours, and within 6 hours if possible. The majority of cases reviewed indicated reduction within 24 hours, although a direct relationship between time to reduction and outcomes could not be established. Once the hip is reduced, stability should be tested clinically and stable range of motion documented. If fluoroscopy is available, whether in the emergency room or operating room, this may be used to better visualize the stability of the hip, especially in concomitant pelvic fractures. The gold standard is to obtain a pelvic CT status post reduction to fully evaluate the concentricity of reduction as well as evaluate for occult fracture of the acetabulum or proximal femur. If the hip is not concentrically reduced and there appears to be interposed material, hip arthroscopy or open reduction may be attempted. Although no clear guidelines exist in this regard, there is mounting evidence of significant intra-articular injury with traumatic hip dislocations, and hip arthroscopy after traumatic dislocation may allow for better understanding, definition, and ultimately treatment of the injury.

The decision whether to relocate the hips in the emergency room versus the operating room was not clearly delineated in this review and likely depends on the resources available to the practitioner at time of presentation. If full muscular sedation is available in a safe manner in the emergency room and there are no other contraindications to attempted reduction, e.g. femoral neck fracture, reduction can be performed in a safe and timely manner in the emergency room setting. In cases where reduction attempts are unsuccessful or there are direct contraindications to closed reduction, the patient should be moved to the operating room for a safe and effective reduction, despite possible delay in reduction. There are several reported cases the required open reduction with tenotomy secondary to interposed soft tissue.

After successful, concentric reduction no specific conclusions about treatment regimen could be established from review and analysis. In general, traction, either skeletal or skin, was temporarily to reduce intra-capsular pressure and pain associated with dislocation and was not used as primary treatment. Weightbearing does not appear to affect outcome; however, weightbearing should be based on the nature of the injury. Our analysis revealed no clear trends regarding weight bearing status after reduction, however, most of the modern papers limited weight bearing for some period of time if there was a concomitant posterior wall fracture. Moreover, cases that involved ORIF of the pelvis or femur were managed with modifications in weight bearing that did not appear to follow any specific trend. The use of NSAIDs of radiation to prevent heterotopic ossification after dislocation was not standardized. The analysis of complications associated with asymmetric bilateral hip dislocations was difficult due to the fact that the majority of the literature reviewed was level V evidence, reported as a single case report or case series. It is likely that the number and nature of complications reviewed herein would be substantially larger if the publication had longer follow up and more accurate measures of outcomes. Specifically, the development of PTOA and need for hip arthroplasty was not addressed in any of the reviewed literature. Nonetheless, the reported complications of nerve palsy and avascular necrosis fit with current understanding of the complications related to simple dislocations of the hip. Namely, the sciatic nerve is at risk for injury, in particular with posterior dislocations. Similarly, the tenuous blood supply to the femoral head is at risk as the hip capsule is disrupted during the dislocation moment. In an effort to relieve potential pressure on the sciatic nerve and attempt to restore blood supply to the femoral head, reductions are attempted as soon as safely possible.
In general, the reported outcomes from this bilateral injury are good to excellent. The outcomes that were described as poor were generally found in multiply injured patients and were more dependent on the initial injury severity as opposed to the bilateral asymmetric nature of the hip dislocations.

CONCLUSIONS
This comprehensive review of asymmetric, bilateral hip dislocation revealed several conclusions. The incidence of asymmetric, bilateral hip dislocations accounts for approximately 0.01%-0.02% of all joint dislocations. Males are more likely than females to incur this injury pattern and the most common mode of injury is motor vehicle accident. Urgent closed reduction should be attempted in an efficient and safe manner to avoid potential complications, and open reduction should be considered in irreducible dislocations. Post reduction management should include stability assessment and CT to assess for associated injuries and intra-articular fragments; although no clear guidelines for post-reduction treatment emerged. Common complications include: nerve palsies, AVN and heterotopic ossification.

AUTHOR CONTRIBUTIONS
Joseph Buckwalter, MD, Ph.D is the corresponding author and primary author of this publication. He reviewed all the reported literature and wrote the majority of the manuscript. Brian Westerlind is a research assistant who aided with translation of non-English case reports and assisted with preparation of the manuscript. Matthew Karam, MD is the senior author for this publication. He provided the framework for the publication and assisted with the writing and preparation of the manuscript.

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<table>
<thead>
<tr>
<th>#</th>
<th>Lead Author</th>
<th>Year</th>
<th>Sex</th>
<th>Age</th>
<th>Mechanism/Description</th>
<th>R</th>
<th>L</th>
<th>Injuries</th>
<th>Time</th>
<th>Treatment/Management</th>
<th>Outcome/Complications</th>
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<tbody>
<tr>
<td>1</td>
<td>Andreini</td>
<td>1845</td>
<td>M</td>
<td>30</td>
<td>Crushed by Overturned Wagon</td>
<td>P</td>
<td>A</td>
<td>Arm laceration</td>
<td>3 d</td>
<td>Multiple attempts 3 days in hospital</td>
<td>Did Well, No complications</td>
</tr>
<tr>
<td>2</td>
<td>Hodgen</td>
<td>1855</td>
<td>M</td>
<td>--</td>
<td>Crushed by Overturned Wagon</td>
<td>P</td>
<td>A</td>
<td>Cotyloid Laceration Scrotum laceration</td>
<td>-</td>
<td>Strict bed rest Splint and traction (left)</td>
<td>Good @ 2.5 mo Re-Dislocation, short left leg</td>
</tr>
<tr>
<td>3</td>
<td>Warren</td>
<td>1857</td>
<td>M</td>
<td>--</td>
<td>Crushed by House Collapse</td>
<td>A</td>
<td>P</td>
<td>Proximal Femur Fracture L rib fractures</td>
<td>-</td>
<td>Closed reduced with ether Observed for 2 mo.</td>
<td>Good @ 2 mo Chest congestion</td>
</tr>
<tr>
<td>4</td>
<td>Boisnot</td>
<td>1867</td>
<td>M</td>
<td>40</td>
<td>Crushed by Wool Bale</td>
<td>A</td>
<td>P</td>
<td>None</td>
<td>-</td>
<td>closed reduced with ether/chloro 29 days of observation</td>
<td>Excellent @ 25 d No complications</td>
</tr>
<tr>
<td>5</td>
<td>Pollard</td>
<td>1872</td>
<td>M</td>
<td>53</td>
<td>Crushed by Earth Collapse</td>
<td>A</td>
<td>P</td>
<td>None</td>
<td>2 h</td>
<td>Closed reduced with Chloroform</td>
<td>Good @ 75 d</td>
</tr>
<tr>
<td>6</td>
<td>Packard</td>
<td>1878</td>
<td>M</td>
<td>40</td>
<td>Crushed by House</td>
<td>A</td>
<td>P</td>
<td>R Arm fracture</td>
<td>&lt;6 h</td>
<td>Closed reduced with ether 6 weeks hospital</td>
<td>Excellent @ 5 wks No complications</td>
</tr>
<tr>
<td>7</td>
<td>Alls</td>
<td>1879</td>
<td>M</td>
<td>42</td>
<td>Crushed by Ship’s Ballast</td>
<td>P</td>
<td>A</td>
<td>None</td>
<td>R 81 d L 90 d R, then L 2 hours later</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Schinzinger</td>
<td>1879</td>
<td>M</td>
<td>40</td>
<td>Dragged by Horse Wagon</td>
<td>P</td>
<td>A</td>
<td>Acetabular Roof Fracture</td>
<td>-</td>
<td>Closed reduced on floor 18 months on crutches</td>
<td>Poor @ 18 mo R Sciatic Nerve Palsy</td>
</tr>
<tr>
<td>9</td>
<td>Roberts</td>
<td>1882</td>
<td>M</td>
<td>65</td>
<td>Struck by Wooden Planks</td>
<td>P</td>
<td>A</td>
<td>-</td>
<td>&lt;6 h</td>
<td>Closed reduced with Ether/Chloroform Bryant’s traction for 1 month, FWB @ 2 months</td>
<td>Poor @ 57 d Blood in urine</td>
</tr>
<tr>
<td>10</td>
<td>James</td>
<td>1883</td>
<td>M</td>
<td>44</td>
<td>Crushed by Earth Wall</td>
<td>A</td>
<td>P</td>
<td>R 4th rib dislocation Clavicle fracture Pelvis fracture</td>
<td>&lt;6 d</td>
<td>Closed reduced at home Skin traction 5 days</td>
<td>Good @ 6 mo No complications</td>
</tr>
<tr>
<td>11</td>
<td>Fiorani</td>
<td>1887</td>
<td>F</td>
<td>--</td>
<td>Buried Under Wall</td>
<td>A</td>
<td>P</td>
<td>-</td>
<td>40 d</td>
<td>Closed reudction Right Open reduction Left</td>
<td>Excellent No complications</td>
</tr>
<tr>
<td>12</td>
<td>Six</td>
<td>1891</td>
<td>M</td>
<td>27</td>
<td>Trapped Between Trains</td>
<td>A</td>
<td>P</td>
<td>Inguinal Hematoma Internal Injuries</td>
<td>-</td>
<td>Closed reduction with alcohol</td>
<td>Dead next morning</td>
</tr>
<tr>
<td>13</td>
<td>Tschmarke</td>
<td>1905</td>
<td>M</td>
<td>40</td>
<td>Fall from Tram</td>
<td>P</td>
<td>A</td>
<td>Multiple wounds</td>
<td>24-48 h</td>
<td>closed reduced at home Skin traction 5 days</td>
<td>Good @ 6 mo No complications</td>
</tr>
<tr>
<td>14</td>
<td>Bousquet</td>
<td>1913</td>
<td>M</td>
<td>52</td>
<td>Crushed by Pile of Wood</td>
<td>A</td>
<td>P</td>
<td>None</td>
<td>12 h</td>
<td>Closed reduced at home Skin traction short time</td>
<td>Good @ 1 mo No complications</td>
</tr>
<tr>
<td>15</td>
<td>Hill &amp; Penn</td>
<td>1929</td>
<td>M</td>
<td>40</td>
<td>Fall from Roof</td>
<td>A</td>
<td>P</td>
<td>Skull fractures T12 compression fractures L rib fractures</td>
<td>-</td>
<td>Closed reduced with light anesthetic plaster cast from axilla to knees with abduction for 1 week bed rest for 12 weeks</td>
<td>Excellent @ 6 mo no complications</td>
</tr>
<tr>
<td>16</td>
<td>Wolff</td>
<td>1935</td>
<td>M</td>
<td>59</td>
<td>Crushed by Earth</td>
<td>A</td>
<td>P</td>
<td>-</td>
<td>&lt;24 h</td>
<td>Closed reduction 11 days of traction 4 weeks of crutches</td>
<td>Excellent @ 2 mo No complications</td>
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<tr>
<td>17</td>
<td>Marquardt</td>
<td>1936</td>
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<td>40</td>
<td>Crushed by Fallen Wall</td>
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<td>P</td>
<td>L Acetabular Fracture</td>
<td>-</td>
<td>Closed reduction with sedation 6 weeks NWB</td>
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<tr>
<td>No.</td>
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<td>Year</td>
<td>Age</td>
<td>Gender</td>
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<td>18</td>
<td>Taylor†</td>
<td>1940</td>
<td>50</td>
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<td>L Acetabular Fracture</td>
<td>Closed reduced with GA Tibial traction 3 weeks, left No traction, Right Good @ 7 mo L Hip pain with flexion</td>
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<td>19</td>
<td>Thompson &amp; Epstein†</td>
<td>1951</td>
<td>23</td>
<td>M</td>
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<td>A</td>
<td>P</td>
<td>L Femoral Shaft Fracture L Acetabular Rim Fracture</td>
<td>Closed reduction with sedation Excellent, Right @ 5 y 10 mo Left hip arthritis @ 5 y 10 mo</td>
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<td>Speed†</td>
<td>1953</td>
<td>38</td>
<td>M</td>
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<td>A</td>
<td>P</td>
<td>L Posterior Acetabular Fracture R Acetabular Rim Fracture Multiple abrasions</td>
<td>Open reduced in OR, right, Left 10 days later 1 1/2 hip spica, then, double spica cast 20 days PWB for 4 mo Poor @ 6 y</td>
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<td>21</td>
<td>Ellingshausen†</td>
<td>1954</td>
<td>27</td>
<td>F</td>
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<td>P</td>
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<td>None</td>
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<td>22</td>
<td>Brunner &amp; Bühler†</td>
<td>1958</td>
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<td>Pedestrian Crushed by Car</td>
<td>A</td>
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<td>23</td>
<td>Economu†</td>
<td>1958</td>
<td>12</td>
<td>M</td>
<td>Buried by Landslide</td>
<td>P</td>
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<td>-</td>
<td>Closed reduction with spinal block 17 days in hip cast Good @ 45 d NWB No complications</td>
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<td>24</td>
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<td>1958</td>
<td>11</td>
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<td>P</td>
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<td>L Trochanter Fracture L forearm fracture</td>
<td>Closed reduction with GA 15 days in bed Re-dislocation treated with cast Re-Dislocation @ 2 &amp; 4 y</td>
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<td>Hofmeister†</td>
<td>1958</td>
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<td>Bilateral talus fractures &lt;6 h closed reduced with GA and curare</td>
<td>Excellent @ 2 y Bilateral Ankle Pain</td>
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<td>26</td>
<td>Riedlinger†</td>
<td>1961</td>
<td>35</td>
<td>M</td>
<td>Dragged Under Train</td>
<td>A</td>
<td>P</td>
<td>R Traumatic BKA</td>
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<td>30</td>
<td>Nelson†</td>
<td>1965</td>
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<td>R Posterior Acetabular Rim Fracture</td>
<td>4 h closed reduced with GA Right posterior overcorrected to anterior before reduction skin traction 3 weeks, left skin traction 6 weeks, right PWB 12 weeks Excellent @ 2 y NWB No complications</td>
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<td>31</td>
<td>Kinnamon†</td>
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<td>R Acetabular Fracture L Acetabular Fracture</td>
<td>Closed reduced with sedation Bedrest for 3 weeks, PWB 6 weeks Good @ 5 y NWB No complications</td>
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<td>32</td>
<td>Lyddon &amp; Hartman†</td>
<td>1971</td>
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<td>R Femoral Neck Fracture R Femoral Shaft Fracture R Acetabular Fracture L Femur Fracture Facial fractures Pneumothoraces</td>
<td>L 1 d R 19 d Closed reduction with GA, left skeletal traction for femur fractures IM nail L femur, R THA @ 2 weeks traction 3 1/2 months, right Good @ 2 mo NWB No complications</td>
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<td>Closed reduction with GA, left Open reduction OR, right after failed closed reduction traction for 2 months</td>
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</table>

Chotigavanichayaya & Rugsapaulmuang | 1974 | 20  | MVC Passenger | A P | R Femoral Head Fracture | Closed reduced with GA in OR skin traction for 3 days double hip spica | Excellent @ 18 mo |

Ethisham | 1976 | 19  | MVC | P A | L Proximal Femur Fracture | Open reduced after failed closed, left ORIF next day, right 6 weeks Skeletal Traction | Excellent @ 28 mo R sciatic nerve palsy |

Civil & Tapsel | 1981 | 59  | MVC | A P | R Acetabular Fracture Facial fractures | Closed reduction with GA Hamilton-Russel traction for 4 weeks PWB till 8 weeks | Excellent @ 28 mo No complications |

Sinha | 1985 | 38  | Airplane Crash | P A | Diastasis of Pubic Symphysis Diastasis of L SI Joint | Closed reduced with GA pelvic sling for 6 weeks bilateral tibial traction for 4 weeks PWB till 8 weeks | Excellent @ 12 wks |

Alonso | 1986 | 25  | MVC | P A | R Acetabular Fracture L femur fracture | Closed reduced with GA in OR skin traction for 3 days double hip spica | - |

Shannak | 1987 | 29  | MVC Passenger | A P | L Acetabular Fracture R femur fracture Facial fractures L ankle fracture | Closed reduced while patient unconscious skeletal traction for 6 weeks, NWB till 3 mo, PWB till 7 months | - |

Rocha Sole | 1987 | 24  | MVC Passenger | A P | L Acetabular Fracture | Closed reduced with GA in OR 4 Weeks skeletal traction | Excellent @ 2 y No complications |

Hill & Chmell | 1990 | 24  | Fall into Canyon | P A | L Femoral Head Fracture | Closed reduced with spinal block several weeks of traction | - |

Nadkarni | 1991 | 22  | MVC Driver | P A | R Ilium Fracture | Closed reduction with GA Bilateral skin traction for 6 weeks Gradual weight bearing | Excellent @ 3 y No complications |

Bansal & Mehta | 1991 | 32  | MVC Passenger | A P | L Acetabular Fracture | Closed reduction with GA 4 weeks tibial traction PWB till 6 weeks | Excellent @ 30 mo No complications |
<table>
<thead>
<tr>
<th>No.</th>
<th>First Name &amp; Last Name</th>
<th>Year</th>
<th>Age</th>
<th>ME</th>
<th>Inj. Location</th>
<th>Inj. Type</th>
<th>Time</th>
<th>Treatment</th>
<th>Outcome</th>
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<tr>
<td>51</td>
<td>Gittins &amp; Serif⁹⁶†</td>
<td>1991</td>
<td>28</td>
<td>MVC Driver</td>
<td>P</td>
<td>A</td>
<td>Facial fractures</td>
<td>&lt;6 h</td>
<td>Closed reduction with sedation in ER, left Closed reduction in OR with GA, right skeletal traction on right for 12 d skin traction on left dor 12 d PWB till 10 weeks</td>
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<tr>
<td>52</td>
<td>Shukla⁹⁷†</td>
<td>1993</td>
<td>25</td>
<td>MVC Driver</td>
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<td>P</td>
<td>R Acetabular Fracture R Hip Avulsion Fracture Hand abrasions</td>
<td>8 h</td>
<td>Closed reduction in ER with sedation left femoral traction NWW 10 weeks</td>
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<td>Aristide⁹⁸</td>
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<td>P</td>
<td>Skin wounds</td>
<td>2 h</td>
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<td>54</td>
<td>Maqsood &amp; Walker⁹⁹†</td>
<td>1996</td>
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<td>Run Over by ATV</td>
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<td>A</td>
<td>L Proximal Femur Fracture L humerus fracture</td>
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<td>Blanco⁹⁰†</td>
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<td>A</td>
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<td>Loupasis &amp; Morris⁹⁹†</td>
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<td>1 h</td>
<td>Closed reduction in OR with GA Skin traction for 3 weeks PWB till 10 weeks</td>
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<td>Kaleli &amp; Alyüz⁹⁰†</td>
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<td>28</td>
<td>MVC Driver</td>
<td>P</td>
<td>A</td>
<td>R Acetabular Fracture</td>
<td>1.5 h</td>
<td>Closed reduction in OR with GA, left Open reduction in OR with GA, right 3 weeks skeletal traction for left 6 weeks skeletal traction for right NWB for 9 weeks of left hip</td>
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<td>Levine⁹¹†</td>
<td>1999</td>
<td>27</td>
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<td>A</td>
<td>R Acetabular Fracture Lumbar spine fracture “Floating Pelvis”</td>
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<td>Closed reduction in ER with sedation ORIF Right acetabulum L4-L5 PSF</td>
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<td>Dudkiewicz⁹²†</td>
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<td>A</td>
<td>R Acetabular Fracture Metacarpal fractures</td>
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<td>P</td>
<td>L Acetabular Fracture Left Patella Fracture</td>
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<td>Closed reduction in OR with GA Skin traction right leg for 3 weeks skeletal traction left leg ORIF left acetabulum PWB at 4 weeks on right PWB at 10 weeks on left</td>
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<td>P</td>
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<td>P</td>
<td>R Acetabular Fracture L Acetabular Fracture</td>
<td>6 h</td>
<td>Closed reduced in OR with GA skeletal traction for 7 weeks PWB till 18 weeks</td>
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Asymmetric Bilateral Hip Dislocations
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<td>63</td>
<td>2000</td>
<td>33</td>
<td>MVC</td>
<td>Closed reduced in ORR with GA skeletal traction, bilateral casting for 45 days</td>
<td>L Acetabular Fracture R Acetabular Fracture</td>
<td>2 h</td>
<td>Excellent @ 26 mo No complications</td>
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<td>2001</td>
<td>26</td>
<td>Pinned by Tractor</td>
<td>Closed reduction in ER with sedation, Right Open reduction in OR with GA, left 2 weeks skin traction PWB at 4 weeks</td>
<td>P A</td>
<td>4 h</td>
<td>Excellent @ 5 y No complications</td>
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<td>2001</td>
<td>18</td>
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<td>Closed reduction in OR with GA 3 weeks skeletal traction NWB for 9 weeks</td>
<td>P A None</td>
<td>&lt;6 h</td>
<td>-</td>
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<td>A P None</td>
<td>&lt;5 h</td>
<td>Excellent @ 1 y No evidence of AVN</td>
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<td>67</td>
<td>2002</td>
<td>29</td>
<td>Mine Collapse</td>
<td>Closed reduction in ER with sedation abduction brace for 1 week PWB till 2 mo</td>
<td>P A None</td>
<td>4 h</td>
<td>Excellent @ 2 mo Right sciatic nerve palsy</td>
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<td>68</td>
<td>2002</td>
<td>30</td>
<td>Pedestrian hit by Car</td>
<td>Closed reduction in ER with sedation skeletal traction for 4 weeks Left Bigelow, Right Allis</td>
<td>P A Pelvis Fractures</td>
<td>30 m</td>
<td>Good-Ex @ 2 y DVT @ 10 days AVN @ 6 mo</td>
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<td>Closed reduction in OR with GA IM nail Right femur ORIF left acetabulum, skeletal traction</td>
<td>A P</td>
<td>&lt;3 h</td>
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<td>P A Right Supracondylar Femur Fracture</td>
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<td>Closed reduction in OR with GA Skeletal traction 3 weeks PWB till 4 months Indomethacin 75 mg Bigelow method</td>
<td>A P Left LisFranc dislocation</td>
<td>90 m</td>
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<td>A P Dental avulsions</td>
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<td>Closed reduced with GA skin traction for 6 weeks</td>
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<td>Good @ 30 mo Trendelenburg Gait, Slight Flexion Contractures AVN @ 17 mo</td>
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<td>Ran over by Semi Truck</td>
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<td>A P R Acetabular Fracture L Acetabular Fracture L femur fracture L ankle fracture</td>
<td>R&lt;3h L9d</td>
<td>Excellent @ 16 mo</td>
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<td>No.</td>
<td>Author &amp; Year</td>
<td>Gender</td>
<td>Age</td>
<td>Mechanism</td>
<td>Type 1</td>
<td>Type 2</td>
<td>Time</td>
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<tr>
<td>75</td>
<td>Sahin†</td>
<td>M</td>
<td>45</td>
<td>MVC Passenger</td>
<td>A</td>
<td>P</td>
<td>&lt;6 h</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>R Anterior Column Fracture</td>
<td></td>
<td></td>
</tr>
<tr>
<td>76</td>
<td>Sraj &amp; Lakkis†</td>
<td>F</td>
<td>20</td>
<td>MVC Driver</td>
<td>P</td>
<td>A</td>
<td>5 h</td>
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<td></td>
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<td></td>
<td></td>
<td>L Acetabular Fracture</td>
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</tr>
<tr>
<td>77</td>
<td>López-Sánchez &amp; Kovacs-Kovacs†</td>
<td>F</td>
<td>19</td>
<td>MVC Passenger</td>
<td>P</td>
<td>A</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td>Pubic Symphysis Widening</td>
<td></td>
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</tr>
<tr>
<td>78</td>
<td>Sanders &amp; Tejwani†</td>
<td>F</td>
<td>31</td>
<td>MVC Passenger</td>
<td>P</td>
<td>A</td>
<td>2 h</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>R Acetabular Fracture</td>
<td></td>
<td></td>
</tr>
<tr>
<td>79</td>
<td>Pascarella†</td>
<td>M</td>
<td>23</td>
<td>MVC Driver</td>
<td>P</td>
<td>A</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td>R Femoral Head Fracture</td>
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<td></td>
<td></td>
<td></td>
<td>L Femoral Head Fracture</td>
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</tr>
<tr>
<td>80</td>
<td>Pascarella†</td>
<td>F</td>
<td>16</td>
<td>MVC Passenger</td>
<td>P</td>
<td>A</td>
<td>--</td>
</tr>
<tr>
<td>81</td>
<td>Sah &amp; Marsh†</td>
<td>F</td>
<td>19</td>
<td>MVC Driver</td>
<td>P</td>
<td>A</td>
<td>2 h</td>
</tr>
<tr>
<td>82</td>
<td>Zhou‡‡ †</td>
<td>F</td>
<td>42</td>
<td>Impaled by Forklift</td>
<td>P</td>
<td>A</td>
<td>1 h</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>R Femoral Head Fracture</td>
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<td></td>
<td></td>
<td>L Pubis Fracture</td>
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<td>L Femoral Head Fracture</td>
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<td>L Acetabular Fracture</td>
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<td>L Ischiium Fracture</td>
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<td>Pubic Symphysis Widening</td>
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<td>Diastasis</td>
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<td></td>
<td></td>
<td></td>
<td>R Tibial plateau fracture</td>
<td></td>
<td></td>
</tr>
<tr>
<td>83</td>
<td>Bilsel†</td>
<td>F</td>
<td>42</td>
<td>MVC Passenger</td>
<td>P</td>
<td>A</td>
<td>--</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>R Femoral Head Fracture</td>
<td></td>
<td></td>
</tr>
<tr>
<td>84</td>
<td>Peshin‡</td>
<td>F</td>
<td>65</td>
<td>Crushed by Earth</td>
<td>A</td>
<td>P</td>
<td>1 h</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>R Superior Pubis Ramus Fracture</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td>L Inferior Pubis Ramus Fracture</td>
<td></td>
<td></td>
</tr>
<tr>
<td>85</td>
<td>Verma‡‡ †</td>
<td>M</td>
<td>60</td>
<td>Fall from Train</td>
<td>P</td>
<td>A</td>
<td>2 h</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Right Femur Fracture</td>
<td></td>
<td></td>
</tr>
<tr>
<td>86</td>
<td>Mahajan‡‡ †</td>
<td>M</td>
<td>20</td>
<td>MVC Passenger</td>
<td>P</td>
<td>A</td>
<td>&lt;1 h</td>
</tr>
<tr>
<td>Case</td>
<td>Year</td>
<td>Age</td>
<td>Sex</td>
<td>Mechanism</td>
<td>Fractures</td>
<td>Initial Treatment</td>
<td>Outcome</td>
</tr>
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<tr>
<td>87</td>
<td>2010</td>
<td>47</td>
<td>M</td>
<td>MVC</td>
<td>R Acetabular Fracture</td>
<td>Closed reduction in ED, left &lt;br&gt;Closed reduction in OR, right ORIF right acetabulum</td>
<td>Poor &lt;br&gt;Right PTOA Requiring THA &lt;br&gt;Subsequent Implant Failure</td>
</tr>
<tr>
<td>88</td>
<td>2010</td>
<td>21</td>
<td>M</td>
<td>Crushed by Landslide</td>
<td>R Acetabular Fracture</td>
<td>Closed reduction with GA in OR&lt;br&gt;Spica cast for 3 weeks&lt;br&gt;NWB till 6 weeks, PWB till 3 months</td>
<td>Excellent @ 10.5 y&lt;br&gt;arly Post-Op Problem Not Specified</td>
</tr>
<tr>
<td>89</td>
<td>2011</td>
<td>31</td>
<td>M</td>
<td>Crushed by Earth</td>
<td>R Acetabular Fracture&lt;br&gt;R Pubis Fractures&lt;br&gt;L Superior Pubis Ramus Fracture</td>
<td>Closed reduction with GA in ER&lt;br&gt;Tibial traction&lt;br&gt;right acetabular ORIF</td>
<td>Excellent @ 4 y&lt;br&gt;H0 on right @ 4 y</td>
</tr>
<tr>
<td>90</td>
<td>2011</td>
<td>55</td>
<td>M</td>
<td>Crushed by Wall</td>
<td>Scalp laceration</td>
<td>Closed reduced in ER with sedation&lt;br&gt;NWB till 3 week, PWB till 3 mo walk</td>
<td>Excellent @ 6 mo</td>
</tr>
<tr>
<td>91</td>
<td>2011</td>
<td>17</td>
<td>M</td>
<td>MCC</td>
<td>None</td>
<td>R Closed ER, L GA OR Open Reduction</td>
<td>Good @ 3 mo&lt;br&gt;decreased ROM on left</td>
</tr>
<tr>
<td>92</td>
<td>2011</td>
<td>24</td>
<td>F</td>
<td>MVC Driver</td>
<td>L Acetabular Fracture&lt;br&gt;R rib fracture</td>
<td>Closed reduced in ED with sedation&lt;br&gt;Bilateral tibial traction&lt;br&gt;ORIF Left acetabulum&lt;br&gt;PWB till 8 mo</td>
<td>Excellent @ 2 y&lt;br&gt;Left Obturator Nerve Palsy</td>
</tr>
<tr>
<td>93</td>
<td>2012</td>
<td>30</td>
<td>M</td>
<td>MVC Passenger</td>
<td>L Acetabular Fracture&lt;br&gt;R rib fracture</td>
<td>Closed reduced in ED with sedation&lt;br&gt;Bilateral tibial traction&lt;br&gt;ORIF Left acetabulum&lt;br&gt;PWB till 8 mo</td>
<td>Good @ 8 mo&lt;br&gt;Left Peroneal palsy</td>
</tr>
<tr>
<td>94</td>
<td>2012</td>
<td>34</td>
<td>M</td>
<td>MVC Driver</td>
<td>L Acetabular Fracture&lt;br&gt;R Acetabular Fracture&lt;br&gt;Sub-arachnoid hemorrhage&lt;br&gt;R tibial avulsion fracture</td>
<td>Closed reduced with sedation in ER&lt;br&gt;ORIF Right acetabulum&lt;br&gt;NWB 2 months</td>
<td>Good @ 2 mo&lt;br&gt;Right Tibial Nerve Palsy</td>
</tr>
<tr>
<td>95</td>
<td>2012</td>
<td>30</td>
<td>M</td>
<td>MVC Driver</td>
<td>R Trans PW Acetabular Fracture&lt;br&gt;L Femoral Head Fracture&lt;br&gt;Right Fibula Fracture&lt;br&gt;Pulmonary Contusions&lt;br&gt;Bilateral Rib Fractures</td>
<td>Closed reduction in ED with sedation&lt;br&gt;Right hip re-dislocation reduced in OR with GA&lt;br&gt;ORIF left feoral head, acetabulum&lt;br&gt;NWB 3 months&lt;br&gt;PWB till 6 months</td>
<td>Excellent @ 6 mo&lt;br&gt;Bilateral HO @ 6 mo</td>
</tr>
<tr>
<td>96</td>
<td>2012</td>
<td>30</td>
<td>M</td>
<td>MVC Passenger</td>
<td>R Transverse PW Acetabular Fracture&lt;br&gt;Pneumothoraces&lt;br&gt;Splenic laceration</td>
<td>Closed reduction in ER with sedation&lt;br&gt;ORIF right acetabulum&lt;br&gt;25 mg Indomethacin 3x per day</td>
<td>Excellent @ 3 mo&lt;br&gt;weight bearing AMA</td>
</tr>
<tr>
<td>97</td>
<td>2012</td>
<td>57</td>
<td>M</td>
<td>Fall from Tree</td>
<td>L Acetabular Fracture&lt;br&gt;R should dislocation</td>
<td>Closed with GA&lt;br&gt;Skeletal traction&lt;br&gt;ORIF left acetabulum</td>
<td>-</td>
</tr>
<tr>
<td>98</td>
<td>2012</td>
<td>28</td>
<td>M</td>
<td>MVC</td>
<td>R AW Acetabular Fracture&lt;br&gt;L PW Acetabular Fracture</td>
<td>Closed reduction in OR with GA&lt;br&gt;Bigelow method&lt;br&gt;Bilateral skeletal traction for 3 weeks&lt;br&gt;PWB till 4 mo</td>
<td>Excellent @ 32 mo&lt;br&gt;No complications</td>
</tr>
</tbody>
</table>
### Appendix 1. List of all reported bilateral, asymmetric hip dislocations. Cases are listed in order by year and identify the lead author, year of publication, gender of patient, age of patient, direction of dislocations, other injuries, time to reduction, treatment/management and complications/outcomes. * indicates non-English language publication, † Indicates radiographic evidence of reported dislocations.

<table>
<thead>
<tr>
<th>Case</th>
<th>Lead Author</th>
<th>Year</th>
<th>Gender</th>
<th>Age</th>
<th>Direction</th>
<th>Other Injuries</th>
<th>Time to Reduction</th>
<th>Treatment/Management</th>
<th>Complications/Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>99</td>
<td>Gupta</td>
<td>2012</td>
<td>M</td>
<td>40</td>
<td>A</td>
<td>None</td>
<td>&lt;1 h</td>
<td>Closed reduction in ER with sedation, Allis Method, bilateral skin traction for 3 weeks, NWB for 6 weeks, PWB till 4 months, Indomethacin 3 month</td>
<td>Excellent @ 2 y No complications</td>
</tr>
<tr>
<td>100</td>
<td>Suresh</td>
<td>2012</td>
<td>M</td>
<td>19</td>
<td>P</td>
<td>MVC Passenger</td>
<td>2 h</td>
<td>Closed reduction in OR with GA, Skin traction for 6 weeks, NWB for 10 weeks</td>
<td>Excellent @ 18 mo No complications</td>
</tr>
<tr>
<td>101</td>
<td>Kanojia</td>
<td>2013</td>
<td>M</td>
<td>45</td>
<td>A</td>
<td>Fall Chasing Bus</td>
<td>&lt;3 h</td>
<td>Closed reduced with GA in OR, Allis method, Skin traction for 3 weeks, NWB for 6 weeks</td>
<td>Excellent @ 35 weeks No complications</td>
</tr>
<tr>
<td>102</td>
<td>Lo</td>
<td>2013</td>
<td>M</td>
<td>36</td>
<td>P</td>
<td>MVC Driver</td>
<td>-</td>
<td>Closed reduction with GA in OR</td>
<td>-</td>
</tr>
<tr>
<td>103</td>
<td>Yildirim</td>
<td>2013</td>
<td>M</td>
<td>26</td>
<td>A</td>
<td>Pedestrian hit by Car</td>
<td>-</td>
<td>Closed reduction in OR with GA, ORIF left femur, bilateral skeletal traction 4 weeks</td>
<td>Good @ 3 mo Left sciatic nerve palsy</td>
</tr>
<tr>
<td>104</td>
<td>Buckwalter</td>
<td>2015</td>
<td>F</td>
<td>23</td>
<td>A</td>
<td>MVC Passenger</td>
<td>&lt;6 h</td>
<td>Closed reduced in ER with sedation, PWB 2 weeks, right</td>
<td>Excellent @ 7 mo No complications</td>
</tr>
</tbody>
</table>

* Indicates non-English language publication
† Indicates radiographic evidence of reported dislocations
IMPACT OF AGE, GENDER AND ANESTHESIA MODALITY ON POST-OPERATIVE PAIN IN TOTAL KNEE ARTHROPLASTY PATIENTS

David Pope, MD, Mouhanad M. El-Othmani, MD, Blaine T. Manning, BS, Mykel Sepula, BS, Stephen J. Markwell, MA, Khaled J. Saleh, BSc MD MSc FRCS(C) MHCM

ABSTRACT

Background: Optimizing pain control following total knee arthroplasty is of utmost importance to the immediate post-operative course. Various anesthesia modalities are available, but studies comparing multiple anesthesia modalities, patient age, and sex are limited.

Questions/Purpose: The purpose of our study was to examine the impact of patient age, gender, and perioperative anesthesia modality on postoperative pain following primary total knee arthroplasty.

Methods: 443 patients who underwent primary total knee arthroplasty by 14 surgeons with some combination of general anesthesia, spinal anesthesia, femoral nerve block, and intrathecal morphine were identified. Anesthesia route and type, length of surgery, post-operative patient-reported pain measures using the Visual Analog Scale, opioid consumption, and length of hospital stay were recorded for each patient and used to compare differences among study groups.

Results: No significant differences were noted between anesthesia groups with regards to postoperative pain or length of hospital stay. Patients receiving spinal anesthesia and femoral nerve block without intrathecal morphine were significantly older than other groups. Patients receiving general anesthesia required significantly more daily intravenous morphine equivalents than patients receiving spinal anesthesia. Patients receiving spinal anesthesia with femoral nerve block and intrathecal morphine consumed the least amount of morphine equivalents. When comparing males and females among all groups, females had significantly higher pain ratings between 24-36 and 24-48 hours post-operatively.

Conclusion: Although no significant differences were noted on pain scores, patients who received spinal anesthesia with intrathecal morphine and femoral nerve block used less narcotic pain medication than any other group. Females reported significantly higher pain between 24-48 hours post-op compared with males but not significantly greater anesthetic usage.

Level of Evidence: Level III, Therapeutic Study, (Retrospective Comparative study)

Keywords: Total knee arthroplasty, Pain control, Anesthesia, Gender

INTRODUCTION

By 2030, the demand for total knee arthroplasty (TKA) in the United States is projected to reach 3.48 million procedures annually\(^1,2\). While the efficacy and safety of TKA is well-known, adequate postoperative pain relief is essential in order to ensure a rapid recovery\(^3,4\). In order to achieve maximum benefit from primary TKA, proper pain management begins during perioperative anesthesia.

However, a variety of anesthesia modalities for TKA are available for patients and physicians. General anesthesia has long been the standard regimen for TKA pain management and affords significant patient benefits. With general anesthesia, patients are allowed amnesia of the entire procedure while physicians maintain complete control over the airway and circulation of the patient. However, general anesthesia has long been the standard regimen for TKA pain management and affords significant patient benefits. With general anesthesia, patients are allowed amnesia of the entire procedure while physicians maintain complete control over the airway and circulation of the patient. However, general anesthesia is associated with higher postoperative pain and longer postoperative rehabilitation when compared to regional anesthesia/analgesia\(^5\).

In response to the shortcomings of general anesthesia, regional anesthesia has become a viable option for pain management in TKA patients. Spinal anesthetics offer rapid onset, minimal systemic toxicity, and a prolonged duration of anesthesia into the postoperative period\(^6\). The use of femoral nerve block (FNB) as a supplement to general or spinal anesthesia has also been explored for TKA use. Studies have found that patients receiving an FNB with general anesthesia used less postoperative morphine and had significant pain relief compared to those who did not\(^7\). In addition to combining spinal anesthesia with a FNB, it is also pos-
sible to combine spinal anesthesia, FNB, and intrathecal morphine. Fischer et al. showed that rescue analgesic use was lower in patients who received spinal anesthesia with an opioid supplement. 

Currently, there is a lack of literature regarding the impact of gender and anesthesia modality on post-operative pain in patients undergoing TKA. The purpose of our study was to determine if anesthesia modality and patient gender impact postoperative pain following primary TKA. We hypothesized that the use of intrathecal morphine with FNB would have the greatest analgesic efficacy as shown through patient-reported pain scores and opioid consumption. We also hypothesized that there would be no difference between pain scores and morphine consumption between males and females in the immediate post-operative period.

**MATERIAL AND METHODS**

Investigational Review Board (IRB) approval was obtained by the Committee for Research Involving Human Subjects for this study. Using CPT code 27447, 443 patients who had undergone primary total knee arthroplasty at Memorial Medical Center in Springfield, IL from March 2010 through September 2010 were retrospectively identified. Fourteen different surgeons performed the operations. Using the patient's hospital identification number, baseline demographic information was extracted, including: age, gender, and comorbidities. Inpatient information, including: anesthesia route and type, length of surgery, post-operative patient-reported pain measures using the Visual Analog Scale (VAS), opioid consumption (which included IV-PCA, IV nurse given, and oral), and length of hospital stay were also collected.

Nurses obtained the VAS scores, post-operatively, before opioid administration. Patients were asked to designate what magnitude of pain they were experiencing with zero representing no pain and ten representing the worst possible pain. The VAS was administered by nursing staff at 21:00 hours (+/-5 hours) on post-operative day one, as this is the time when the anesthesia is typically out of the patient’s system. However, TKA patients are often sleeping during the post-operative timeframe of 21:00 hours +/- 5 hours. Therefore, average VAS scores between 24-36 hours and 24-48 hours postoperative were also calculated for analysis.

Due to the expected variation in opioids given to patients, the morphine equivalent was calculated. Initially, the total amount of a specific IV opioid was multiplied by its conversion factor to find an equianalgesic equivalent with 10mg of morphine as the standard. All drug equivalents were then totaled to determine the total IV opioid equianalgesic dosage. Oral opioid equianalgesic dosage was calculated using conversion factors specific to oral medications. After multiplying the total amount of a specific narcotic by its conversion factor, that number was multiplied by the morphine oral-to-IV conversion factor to obtain the IV equivalent. The drugs' IV equivalents were summed to obtain a final equivalent value. The final step was to add the total IV opioid equianalgesic dosage to the total oral opioid equianalgesic dosage. This final number is the total amount of opioids delivered to the patient in IV equivalents. In accordance with hospital policy, the Duramorph group did not receive any oral narcotics until 16 hours postoperatively, and no IV narcotics were given until post-op day one.

The data was de-identified, using sequential study numbers, prior to any data analysis. Means and standard deviations or medians and interquartile ranges (IQR) are reported for continuous variables, while frequencies and percentages are reported for categorical variables. Analyses of variance (ANOVAs) were used to compare the three groups on age, length of surgery, length of stay and the ratings of pain. Because of distributional characteristics, non-parametric Kruskal-Wallis tests were used to compare the groups on their daily usage of morphine equivalents. Chi-square tests of independence were used to compare the groups on gender and on comorbidities. Results were considered statistically significant for p < 0.05. Pair-wise follow-up comparisons were performed in the presence of statistically significant overall tests. All analyses were performed using SAS v9.2 software (SAS Institute Inc., Cary, NC, USA).

**3.0 Results**

Of the 443 TKA patient charts that were reviewed, 27 received general anesthesia without intrathecal morphine (DURAMORPH®; Baxter, Deerfield, IL, USA) or femoral nerve block, 37 received general anesthesia and femoral nerve block without intrathecal morphine, 17 received spinal anesthesia without intrathecal morphine or femoral nerve block, 77 received spinal anesthesia and femoral nerve block without intrathecal morphine, 18 received spinal anesthesia and intrathecal morphine without femoral nerve block, and 267 received spinal anesthesia with intrathecal and femoral nerve block.

**Intergroup Comparisons**

No significant differences were noted between the anesthesia groups with regards to postoperative pain or length of hospital stay. Patients receiving spinal anesthesia and femoral nerve block without intrathecal morphine were significantly older (69.8±10.8) than those receiving general anesthesia without intrathecal morphine or femoral nerve block (62.3±10.2), and those receiving spinal anesthesia with intrathecal morphine and femoral nerve block (65.8±9.9) (p<0.05).
Of the 27 patients receiving general anesthesia without intrathecal morphine or femoral nerve block, 11 were male (40.7%). Twelve of the 37 patients (32.4%) receiving general anesthesia and femoral nerve block without intrathecal morphine were male. Seven of the 17 patients (41.2%) receiving spinal anesthesia without intrathecal morphine or femoral nerve block were male. Twenty-four of the 77 patients (31.2%) receiving spinal anesthesia and femoral nerve block without intrathecal morphine were male. Seven of the 18 patients (38.9%) receiving spinal anesthesia and intrathecal morphine without femoral nerve block were male. Of the 267 patients undergoing spinal anesthesia with intrathecal morphine and femoral nerve block, 107 were male (40.1%).

Table 1: The prevalence of comorbidities and other factors that may contribute to post-operative pain within each group are listed.

<table>
<thead>
<tr>
<th>Comorbidity</th>
<th>General (n=27)</th>
<th>General with Femoral nerve block (n=37)</th>
<th>Spinal (n=17)</th>
<th>Spinal with Femoral nerve block (n=77)</th>
<th>Spinal with Intrathecal morphine, (n=18)</th>
<th>Spinal with Intrathecal morphine and Femoral nerve block (n=267)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardiac Disease</td>
<td>23 (85.2%)</td>
<td>35 (94.6%)</td>
<td>15 (88.2%)</td>
<td>66 (85.7%)</td>
<td>13 (72.2%)</td>
<td>237 (88.8%)</td>
<td>0.262</td>
</tr>
<tr>
<td>Sleep Apnea</td>
<td>7 (25.9%)</td>
<td>6 (16.2%)</td>
<td>9 (53.0%)</td>
<td>13 (16.9%)</td>
<td>4 (22.2%)</td>
<td>57 (21.6%)</td>
<td>0.038</td>
</tr>
<tr>
<td>Mental Disorder</td>
<td>7 (26.0%)</td>
<td>7 (19.0%)</td>
<td>4 (23.5%)</td>
<td>14 (18.2%)</td>
<td>6 (33.3%)</td>
<td>51 (19.1%)</td>
<td>0.695</td>
</tr>
<tr>
<td>Pulmonary Disorder</td>
<td>9 (33.3%)</td>
<td>12 (32.4%)</td>
<td>4 (23.5%)</td>
<td>20 (26.0%)</td>
<td>2 (11.1%)</td>
<td>73 (27.3%)</td>
<td>0.614</td>
</tr>
<tr>
<td>Obesity</td>
<td>11 (40.7%)</td>
<td>10 (27.0%)</td>
<td>4 (23.5%)</td>
<td>20 (26.0%)</td>
<td>6 (33.3%)</td>
<td>73 (27.3%)</td>
<td>0.726</td>
</tr>
<tr>
<td>Endocrine Disorder</td>
<td>11 (40.7%)</td>
<td>16 (43.2%)</td>
<td>6 (35.3%)</td>
<td>34 (44.2%)</td>
<td>3 (16.7%)</td>
<td>90 (33.7%)</td>
<td>0.232</td>
</tr>
<tr>
<td>Male Patients</td>
<td>11 (40.7%)</td>
<td>12 (32.4%)</td>
<td>7 (41.2%)</td>
<td>24 (31.2%)</td>
<td>7 (38.9%)</td>
<td>107 (40.1%)</td>
<td>0.751</td>
</tr>
</tbody>
</table>

Table 2: The primary outcomes listed by anesthesia group

<table>
<thead>
<tr>
<th>Outcome</th>
<th>General (n=27)</th>
<th>General with Femoral nerve block (n=37)</th>
<th>Spinal (n=17)</th>
<th>Spinal with Femoral nerve block (n=77)</th>
<th>Spinal with Intrathecal morphine, (n=18)</th>
<th>Spinal with Intrathecal morphine and Femoral nerve block (n=267)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total surgery time (min)</td>
<td>89.6±24.7</td>
<td>80.2±24.5</td>
<td>87.4±29.4</td>
<td>65.4±18.7</td>
<td>98.8±29.4</td>
<td>82.5±22.4</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Age (years)</td>
<td>62.30±10.15</td>
<td>66.92±10.65</td>
<td>64.00±11.83</td>
<td>69.81±10.81</td>
<td>64.44±10.95</td>
<td>65.73±9.90</td>
<td></td>
</tr>
<tr>
<td>Length of hospital stay (days)</td>
<td>2.9±1.1</td>
<td>3.1±1.2</td>
<td>2.8±0.8</td>
<td>2.8±0.9</td>
<td>3.3±1.0</td>
<td>2.8±1.0</td>
<td>0.223</td>
</tr>
<tr>
<td>Average daily IV morphine eq. consumption (mg) – median (IQR)</td>
<td>13.7 (2.9-53.4)</td>
<td>10.0 (0.0-106.7)</td>
<td>3.7 (0.0-18.5)</td>
<td>3.0 (0.0-64.5)</td>
<td>0.8 (0.0-55.3)</td>
<td>0.3 (0.0-405.3)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Average daily oral morphine eq. consumption (mg) – median (IQR)</td>
<td>13.8 (2.1-54.6)</td>
<td>18.2 (0.0-178.8)</td>
<td>17.1 (7.7-38.1)</td>
<td>17.2 (0.0-417.7)</td>
<td>11.1 (1.7-53.0)</td>
<td>10.8 (0.0-50.8)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Average total daily morphine eq. consumption (mg) – median (IQR)</td>
<td>31.6 (4.6-62.9)</td>
<td>28.3 (0.0-193.4)</td>
<td>23.3 (7.7-42.6)</td>
<td>22.1 (0.0-621.4)</td>
<td>18.8 (3.1-65.5)</td>
<td>11.6 (0.0-456.4)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>VAS Score (21:00 ± 5 hrs postoperative day 1) – median (IQR)</td>
<td>4.00±2.13</td>
<td>3.93±2.02</td>
<td>3.50±1.76</td>
<td>3.40±2.20</td>
<td>3.67±3.04</td>
<td>3.38±2.06</td>
<td>0.855</td>
</tr>
<tr>
<td>Average VAS Score, 24-36 hours postoperative – median (IQR)</td>
<td>6.17±1.61</td>
<td>5.68±1.62</td>
<td>5.36±1.56</td>
<td>5.65±1.46</td>
<td>6.07±2.05</td>
<td>5.70±1.63</td>
<td>0.585</td>
</tr>
<tr>
<td>Average VAS Score, 24-48 hours postoperative – mean±std</td>
<td>5.94±1.57</td>
<td>5.49±1.47</td>
<td>5.59±1.13</td>
<td>5.51±1.26</td>
<td>5.76±1.87</td>
<td>5.48±1.43</td>
<td>0.687</td>
</tr>
</tbody>
</table>
patients receiving spinal anesthesia and femoral nerve block without intrathecal morphine (16.9%, \(p=0.038\)).

Furthermore, as shown in Table 2, there were significant differences between groups with regards to skin to skin operative time. Follow-up statistical tests indicated that patients receiving spinal anesthesia and femoral nerve block without intrathecal morphine had significantly shorter operative times (65.4±18.7 min) than TKA patients receiving: general anesthesia without femoral nerve block or intrathecal morphine (89.6±24.7 min), general anesthesia and femoral nerve block without intrathecal morphine (80.2±24.5 min), spinal anesthesia without intrathecal morphine or femoral nerve block (87.4±29.4 min), or spinal anesthesia and intrathecal morphine without femoral nerve block (98.8±29.4 min) \(p<0.001\). Follow-up statistical tests revealed that patients receiving spinal anesthesia with intrathecal morphine and femoral nerve block had significantly shorter surgery times (82.5±22.4 min) than those receiving spinal anesthesia and intrathecal morphine without femoral nerve block (98.8±29.4 min) \(p<0.001\).

Table 2 also shows that postoperative pain medication usage in terms of daily IV morphine equivalents differed statistically between the groups \(p<0.001\). Follow-up comparisons indicated that patients receiving: general anesthesia without femoral nerve block or intrathecal morphine (13.7 mg, range 2.5-53.4); and general anesthesia and femoral nerve block without intrathecal morphine (10.0 mg, range 0.0-106.7), required significantly more daily IV morphine equivalents than patients receiving: spinal anesthesia and femoral nerve block without intrathecal morphine (3.0 mg, range 0.0-65.7), spinal anesthesia and intrathecal morphine without femoral nerve block (0.8 mg, range 0.0-55.3), and spinal anesthesia with intrathecal morphine and femoral nerve block (0.3 mg, range 0.0-140.3) \(p<0.001\). Patients receiving general anesthesia without femoral nerve block or intrathecal morphine required significantly more daily IV morphine equivalents than patients receiving spinal anesthesia without intrathecal morphine or femoral nerve block (13.7 (2.5-53.4) mg vs. 3.7 (0.0-18.5) mg, \(p<0.001\)). Additionally, patients receiving spinal anesthesia with intrathecal morphine and femoral nerve block consumed significantly fewer daily IV morphine equivalents (0.3 (0.0-140.3) mg) than those receiving: spinal anesthesia without intrathecal morphine or femoral nerve block (3.7 (0.0-18.5) mg); and spinal anesthesia and femoral nerve block without intrathecal morphine (3.0 (0.0-65.7) mg).

Daily average oral morphine equivalent consumption among patients receiving spinal anesthesia with intrathecal morphine and femoral nerve block (10.8 (0.50.8) mg) was significantly lower than patients receiving: general anesthesia and femoral nerve block without intrathecal morphine (18.2 (0-178.8) mg), spinal anesthesia without intrathecal morphine or femoral nerve block (17.1 (7.7-38.1) mg), and spinal anesthesia and femoral nerve block without intrathecal morphine (17.2 (0-417.7) mg) \(p<0.001\).

Daily average total morphine equivalent consumption also differed significantly among anesthesia groups. Patients receiving spinal anesthesia with intrathecal morphine and femoral nerve block consumed significantly less daily morphine equivalents (11.6 (0-456.4) mg) than those receiving: general anesthesia without femoral nerve block or intrathecal morphine (31.6 (4.6-62.9) mg), general anesthesia and femoral nerve block without intrathecal morphine (28.3 (0-193.4) mg), spinal anesthesia without intrathecal morphine or femoral nerve block (23.3 (7.7-42.6) mg), and spinal anesthesia and femoral nerve block without intrathecal morphine (22.1 (0.6-421.4) mg) \(p<0.001\).

**Intragroup Comparisons**

(Table 3). Among patients receiving general anesthesia without intrathecal morphine or femoral nerve block, females reported significantly higher mean VAS scores than males between 24-48 hours postoperatively (6.5±1.7 vs. 5.1±1.1, \(p=0.057\)) and 24-36 hours postoperatively (7.1±1.6 vs. 5.1±0.8, \(p<0.001\)). Females receiving general anesthesia and femoral nerve block without intrathecal morphine consumed significantly more daily average morphine equivalents (21.5 (0.0-178.8) mg) than males (10.0 (2.5-25.7) mg, \(p=0.027\)).

Compared to females, males receiving spinal anesthesia and intrathecal morphine without femoral nerve block experienced significantly shorter surgery times (115.6±29.2 min vs. 88.1±25.2 min, \(p<0.05\). Surgery time for males receiving spinal anesthesia and intrathecal morphine without femoral nerve block (87.7±26.1 min) was significantly longer compared to respective female patients (79.1±18.9 min, \(p<0.05\). Furthermore, among patients receiving spinal anesthesia and intrathecal morphine without femoral nerve block, mean VAS ratings were significantly higher for females than males in both 24-48 hours postoperatively (5.7±1.5 vs. 5.2±1.2, respectively, \(p<0.05\)) and from 24-36 hours postoperatively (5.9±1.7 vs. 5.4±1.5, respectively, \(p<0.05\)).

Female patients across all anesthesia groups were similar with regards to length of stay and age. The only significant difference in VAS scores was found in average pain ratings during 24-36 hours postoperative, where females receiving general anesthesia without intrathecal morphine or femoral nerve block reported significantly more pain (7.0±1.6) than females receiving spinal anesthesia and femoral nerve block without intrathecal morphine (5.6±1.4, \(p<0.05\). Females receiving spinal anesthesia and femoral nerve block without intrathecal
morphine had significantly shorter surgery times (63.7 ± 17.0 min) than those female patients receiving: general anesthesia without femoral nerve block or intrathecal morphine (86.5 ± 26.3 min), general anesthesia and femoral nerve block without intrathecal morphine (78.2 ± 27.1 min), spinal anesthesia without intrathecal morphine or femoral nerve block (88.4 ± 27.0 min), spinal anesthesia and intrathecal morphine without femoral nerve block (88.1 ± 25.2 min), and spinal anesthesia with intrathecal morphine and femoral nerve block (79.1 ± 18.9 min) (p<0.0001).

Significantly more daily IV morphine equivalents were required among female patients receiving general anesthesia without femoral nerve block or intrathecal morphine (12.1 (2.5-53.4) mg) and general anesthesia and femoral nerve block without intrathecal morphine (10.3 (0.0-27.8) mg) compared to those female patients receiving: spinal anesthesia and femoral nerve block without intrathecal morphine (3.0 (0.0-23.0) mg), spinal anesthesia without intrathecal morphine or femoral nerve block (2.0 (0.0-11.0) mg), spinal anesthesia and intrathecal morphine without femoral nerve block (0.7 (0.0-55.3) mg), and spinal anesthesia with intrathecal morphine and femoral nerve block (0.3 (0.0-405.5) mg), (p<0.0001). Daily IV morphine equivalent was significantly higher among females receiving spinal anesthesia and femoral nerve block without intrathecal morphine (3.0 (0.0-23.0) mg) compared to those receiving spinal anesthesia with intrathecal morphine and femoral nerve block (0.3 (0.0-405.5) mg), (p<0.0001). Female patients receiving spinal anesthesia with intrathecal morphine and femoral nerve block consumed significantly less daily oral morphine equivalents (10.8 (0.0-50.8) mg) than those receiving general anesthesia and femoral nerve block without intrathecal morphine (21.5 (0.0-178.8) mg) or spinal anesthesia and femoral nerve block without intrathecal morphine (17.2 (0.0-417.7) mg) (p<0.0001).

Finally, females receiving spinal anesthesia with intrathecal morphine and femoral nerve block consumed significantly fewer daily total morphine equivalents (11.4 (0.0-456.4) mg) compared to those receiving general anesthesia without femoral nerve block or intrathecal morphine (31.8 (13.1-62.9) mg), general anesthesia and femoral nerve block without intrathecal morphine (30.9 (0.0-193.4) mg), or spinal anesthesia and femoral nerve block without intrathecal morphine (22.6 (0.0-405.5) mg) (p<0.0001).

Across anesthesia groups, there were no differences between males regarding VAS scores, length of stay, or age. Surgery time was significantly shorter for males receiving spinal anesthesia and femoral nerve block without intrathecal morphine (69.3 ± 21.8 min) compared to those receiving general anesthesia without femoral nerve block or intrathecal morphine (115.6 ± 29.2 min) or spinal anesthesia with intrathecal morphine and femoral nerve block (87.7 ± 26.1 min) (p=0.001).

With regard to daily IV morphine equivalent consumption, males receiving spinal anesthesia with intrathecal morphine and femoral nerve block consumed significantly less (0.2 (0.0-90.9) mg) compared to those receiving: general anesthesia without femoral nerve block or intrathecal morphine (69.3 ± 21.8 min) compared to those receiving spinal anesthesia and intrathecal morphine without femoral nerve block (115.6 ± 29.2 min) or spinal anesthesia with intrathecal morphine and femoral nerve block (87.7 ± 26.1 min) (p=0.001).

With regard to daily IV morphine equivalent consumption, males receiving spinal anesthesia with intrathecal morphine and femoral nerve block consumed significantly less (0.2 (0.0-90.9) mg) compared to those receiving: general anesthesia without femoral nerve block or intrathecal morphine (69.3 ± 21.8 min) compared to those receiving spinal anesthesia and intrathecal morphine without femoral nerve block (115.6 ± 29.2 min) or spinal anesthesia with intrathecal morphine and femoral nerve block (87.7 ± 26.1 min) (p=0.001).
IV morphine equivalents (14.7 (2.5-27.7) mg) than those receiving spinal anesthesia and femoral nerve block without intrathecal morphine (3.3 (0.0-65.7) mg) (p<0.0001).

Daily oral morphine equivalent consumption was significantly greater among males receiving spinal anesthesia and femoral nerve block without intrathecal morphine (18.1 (0.0-121.3) mg) compared to those receiving spinal anesthesia with intrathecal morphine and femoral nerve block (11.0 (0.0-43.0) mg) (p<.05). Total daily morphine equivalent consumption was significantly less among males receiving spinal anesthesia with intrathecal morphine and femoral nerve block (12.8 (0.4-117.9) mg) compared to those receiving: general anesthesia without femoral nerve block or intrathecal morphine (28.4 (4.6-59.1) mg), spinal anesthesia without intrathecal morphine or femoral nerve block (26.5 (19.3-42.6) mg), and spinal anesthesia and femoral nerve block without intrathecal morphine (19.5 (8.6-187.0) mg) (p<0.0001).

**DISCUSSION**

Data exploring post-operative pain control after total knee arthroplasty with regard to anesthesia modality and gender remains limited. Pain control after surgery is vital for both patient satisfaction and early rehab. This study's aim was to answer which anesthesia modality provides for optimal pain control post-operatively as well as if gender or age plays a role in post-operative pain control.

Femoral nerve blocks and intrathecal morphine in isolation have been proven effective in post-operative pain control. There is limited literature on combining both intrathecal morphine and femoral nerve blocks in concert with spinal anesthesia. In our study, patients receiving spinal anesthesia with FNB and intrathecal morphine injections used the least amount of morphine equivalents in the post-operative period. Consistent with previously reported results, patients receiving general anesthesia required more pain medication post-operatively than those receiving spinal anesthesia. This, along with the fact that the literature seems to indicate a higher complication rate with general anesthesia when compared to spinal, suggests spinal anesthesia should be favored. Both femoral nerve blocks and intrathecal morphine injections are inexpensive and safe procedures that will diminish pain in the post-operative period, and our study would indicate that using both of these adjuncts to spinal anesthesia will provide the best post-operative pain control, or at the very least, diminished use of post-operative narcotics.

Limited studies examining the effect of gender on post-operative pain were available. Liu et al found female gender to be an independent risk factor for persistent pain after TKA but was more focused on long-term outcomes. In our study, females reported significantly higher pain post-operatively when compared to males but did not consume greater amounts of pain medication. The fact that females did not consume more pain medication although it was available suggests that the post-operative pain medication protocol does not need to be adjusted, but patients should be encouraged to use the medication that is available to them if necessary.

No significant differences were noted between anesthesia groups with regards to postoperative pain or length of hospital stay. Patients receiving general anesthesia required significantly more daily IV morphine equivalents than patients receiving spinal anesthesia. On average, patients receiving both FNB and intrathecal morphine after spinal anesthesia consumed the least daily IV morphine equivalents, daily oral morphine equivalents, and daily average total morphine equivalents. In this study, patients receiving spinal anesthesia and femoral nerve block without intrathecal morphine had significantly shorter operative times compared with the other groups. One hypothesis is faster surgeons preferred this type of anesthesia and the average surgical time is therefore shorter. It is also possible that selection bias lead to more straightforward knees receiving this type of anesthesia, but it is beyond the scope and design of this study to accurately answer this question.

There are limitations with this study that must be considered. There were 14 surgeons included in the study. Subtle differences in technique could affect pain post-operatively and this would not be accounted for in this study. We searched for patients using a CPT code, but not all primary total knee arthroplasties are the same. We did not control for level of pre-operative pain or deformity. Furthermore, anesthesia type was not randomly assigned, leaving the present study open to selection bias based on anesthesia type. Also, patients received different pain medications post-operatively. Calculation of morphine equivalents will minimize the negative impact of this, but it must be considered.

**CONCLUSION**

In conclusion, our study supports the use of spinal anesthesia with both FNB and intrathecal morphine as the anesthesia regimen most effective in minimizing post-operative narcotic use. Length of stay and pain scores were not different among anesthesia groups. General anesthesia should be used only when spinal anesthesia is contraindicated. Females reported higher pain in the immediate post-operative period but did not use more morphine equivalents.
REFERENCES


ABSTRACT

Background: Medial protrusio is a recognized complication of total hip arthroplasty, but it is not known if a medial wall breach during cup implantation increases the risk. We thus investigated the effect of up to a 2 cm defect in the medial acetabular wall in a cadaveric model. Separately, we investigated the ability of acetabular screws to rescue the construct.

Methods: Nine human fresh-frozen hemipelves were reamed medially to create the defect, implanted with acetabular cups, and then loaded to failure. The nine contralateral hemipelves were reamed in a standard fashion and served as controls. Separately, nine hemipelves with a medial defect were augmented with two acetabular screws each, then loaded to failure, with the contralateral side as a control. Load-to-failure, stiffness, and energy were recorded.

Findings: The presence of a medial wall defect decreased the load-to-failure by a mean of 26% (5710 v. 4221 N, p=0.024). The addition of two acetabular screws did not rescue the construct (mean 27% decrease, 4082 v. 2985 N, p=0.024). The majority of specimens failed in a supra-physiologic range of force. Bone density correlated with failure loads (R² range of 0.54-0.78), and osteoporotic specimens were more likely to fail at a physiologic range, consistent with forces experienced during minor stumbles or falls.

Interpretation: Osteoporotic patients with a medial wall defect after hip arthroplasty may be susceptible to fracture during activities of daily living. Protected weight bearing with an assistive device may be reasonable in order to minimize fall risk until cup ingrowth is achieved.

INTRODUCTION

Prosthetic acetabular protrusio is a medial migration of the acetabulum cup past Kohler’s line and into the pelvis, and is a known complication of total hip arthroplasty. The mechanism usually involves a periprosthetic fracture and subsequent pelvic discontinuity, with the incidence reported to be as high as 0.9%. The defect typically causes pain and dysfunction necessitating revision arthroplasty, and severe cases with disruption of the intra-pelvic vessels and the bladder have been reported. Furthermore, disruption of the intra-pelvic structures by the acetabular component can lead to sepsis if left untreated.

The risk factors for this complication include patient factors such as poor medial bone stock, pre-existing protrusio, and rheumatoid arthritis, as well as operative factors including both under and over-reaming of the acetabulum. Under-reaming the acetabulum increases the contact stress between the acetabular rim and the prosthesis, thus increasing the risk of iatrogenic fracture at the time of cup impaction. In contrast, excessive medial reaming causes a breach in the medial acetabular wall, and presumably predisposes the patient to fracture during activities of daily living post-operatively. However, to the best of our knowledge only two prior biomechanical studies have investigated any effect of a medial wall breach, with one being in canine pelves and the results were conflicting. Some authors have proposed that the majority of the stability of the acetabular component comes from contact with the acetabular rim, and thus small medial defects might not have clinical significance. Overall, the effect of a medial wall breach remains controversial, and very little biomechanical data exists to help guide decision making.
There are multiple treatment modalities available for the treatment of medial acetabular wall defects encountered at the time of a revision total hip arthroplasty, including trabecular metal buttons, revision cages, bone graft, and washers. However, these treatment modalities are usually reserved for massive acetabular bone loss in revision cases. Ideally, if a small medial defect occurred during a primary hip arthroplasty, the surgeon should have an effective treatment modality to prevent the need for revision surgery entirely. At our own institution, a patient was recently referred with protrusio acetabuli, secondary to fracture, that developed only two weeks after her primary total hip arthroplasty (Figure 1). The initial treating surgeon had breached the acetabular wall during reaming, causing a two centimeter defect. After reviewing her case, we hypothesized that the medial wall disruption was responsible for the rapid failure, and that the use of well-placed acetabular screws may have strengthened the construct and prevented the subsequent medial displacement. After reviewing her case, we hypothesized that the medial wall disruption was responsible for the rapid failure, and that the use of well-placed acetabular screws may have strengthened the construct and prevented the subsequent medial displacement. To the best of our knowledge, no study has investigated the use of prophylactic acetabular screws for restoring the strength of the acetabular construct after a breach in the medial wall has occurred.

The purpose of this study was to test the biomechanical effect of a medial wall breach in a human cadaveric pelvis model, and to investigate the use of acetabular screws as an intra-operative treatment for this complication. We hypothesized that the presence of a medial breach would significantly decrease the load-to-failure strength. Furthermore, we hypothesized that adding two points of acetabular screw fixation would restore the stability of the construct.

MATERIALS AND METHODS

The devices and treatments described in this article have been approved by the Food and Drug Administration, and our article is compliant with the IRB requirements at our institution.

Specimens:

We obtained 20 cadaveric pelvis specimens (40 hemipelves from Anatomic Gifts Registry (Hannover, MD)) with information regarding donor age, gender, and cause of death. Patients with known metastatic disease to the pelvis, or known traumatic pelvis injury were excluded. We also excluded two specimens after testing. The first was a 47 year-old female with a bone mineral density (BMD) of 643 mg/cm³, which was 185% higher than the mean BMD for the overall cohort. No results could be obtained because this specimen’s load at failure exceeded the maximum force that could be applied by our materials testing machine (15,000 N). The second excluded specimen was incorrectly potted, causing mechanical testing to prematurely abort. Overall, this left 18 specimens (36 hemipelves) that formed our study cohort. The average age of the included specimens was 75 years and the mean BMD was 327 mg/cm³ (Table 1).

The specimens were dissected free of all soft tissue attachments and wrapped in saline-soaked gauze to keep them moist when not being tested. All specimens were stored in plastic bags at -5 degrees Celsius, and were allowed to thaw overnight to room temperature prior to use. After being separated from the contralateral half, each hemi-pelvis was inspected with a lateral radiograph in order to look for fractures, tumors, malformations, or pre-existing deformity. No specimen had an obvious radiographic deformity. In addition, each specimen was scanned with a peripheral quantitative computed tomography scanner, which allowed precise measurements of bone mineral density (BMD).

Experimental Groups:

Specimens were stratified according to BMD and assigned to one of two treatment groups (Table 2), with assignment done in a block fashion in order normalize BMD between both groups. After stratification, the mean BMD in treatment group A was 320 mg/cm³ and in treatment group B was 334 mg/cm³, with no significant difference between groups (p=0.67). In both experimental groups, the treatment side was over-reamed medially until up to a two cm defect was created in the medial acetabular wall. The exact dimensions of the defect were measured for each specimen prior to testing (Table 1). The mean area of the created defect was similar between the two groups (299 mm² v. 331 mm², p=0.52). A goal defect of two cm in diameter was chosen because that size of defect has previously been reported.
Table 1: Description of Pelvic Specimens.

<table>
<thead>
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<th>Specimen Name</th>
<th>Side</th>
<th>Sex</th>
<th>Race</th>
<th>Age (yr)</th>
<th>Cause of Death</th>
<th>BMD (mg/cm³)</th>
<th>Testing Group</th>
<th>Medial Wall Defect Size</th>
<th>Cup Size (mm)</th>
<th>Screws Implanted?</th>
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<td>R</td>
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<td>201</td>
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Table 2: Description of Treatment Groups

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<tr>
<th>Treatment Groups</th>
<th>Defect Side</th>
<th>Control Side</th>
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<tbody>
<tr>
<td>Group A</td>
<td>Over Reamed, No Acetabular Screws</td>
<td>Normal Acetabular Cup Placement</td>
</tr>
<tr>
<td>Group B</td>
<td>Over Reamed, Two Acetabular Screws</td>
<td>Normal Acetabular Cup Placement</td>
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</table>

in patients with this complication, and is consistent with the size of the defect seen in our own recent cases. On the contralateral, control side, the acetabulum was reamed line-to-line up to the medial acetabular wall with careful visual inspection and manual palpation to verify that no breach had occurred. Reaming was generally 1mm greater than the total diameter of the cup. The contralateral hemipelvis was chosen as the control for each experimental specimen in order to minimize...
variations in specimen age, bone mineral density, or bone morphology, and is a commonly used method of control\textsuperscript{5,17-19}. In group A, no additional points of fixation were added on the over-reamed side. In group B, we used two acetabular screws to strengthen the construct on the over-reamed side. The screws were placed into the posterior-superior acetabular safe zone as defined by Wasielewski et al\textsuperscript{20}. Screw depth was measured at the time of implantation and an appropriate length was chosen for each specimen. No additional points of fixation were added on the control side for either experimental group. The acetabular cups were inserted with 45 degrees of abduction and 15 degrees of anteversion, with local anatomic landmarks used to verify cup positioning. Wright Medical acetabular implants were used (Dynasty implant system, Wright Medical Technology, Inc., Arlington, TN). Cups ranging in size from 46mm to 60mm were available, and each specimen was custom fit with an appropriately sized implant (Table 1).

**Biomechanical Testing:**

For each hemipelvis, the table of the ilium and the pubic symphysis were separately potted with polymethylmethacrylate (PMMA), with the bones supplemented with multiple screws to increase PMMA purchase (Figure 2). To obtain uniform orientation of each specimen, a bubble level was screwed into the acetabular component (Figure 2 Left), to direct the potting of the ilium such that the ultimate force vector was positioned with the hip in 15 degrees of abduction and 20-30 degrees of flexion, which correlates with the direction of the maximum load experienced during regular walking as defined by Bergman et al\textsuperscript{21}. The pubic symphysis was then potted, with a stainless steel ball bearing on the undersurface to allow for multi-planar motion and rotation of the symphysis, separate from the ilium, during testing (Figure 2 Right).

Each hemipelvis was attached to the load cell of an MTS Bionix 858 Materials Testing Machine (MTS Systems Corp., Eden Prairie, MN), through an x-y table. The acetabular cup was loaded through a femoral component attached to the actuator of the MTS (Figure 2 Right). We used a size 28mm femoral head with a Dynasty (Wright Medical Technology, Inc., Arlington, TN) femoral implant to deliver the load to the acetabulum, and the same femoral component was used in each test. Each specimen was first preconditioned with five cycles of axial loading at 0.5 Hz from 5 to 100 N, to ensure seating of all components. Each specimen was then loaded to failure at a rate of 0.2 mm/s; this loading rate was consistent with the rate chosen by other biomechanical studies of the acetabulum\textsuperscript{5,22-24}. The tests were video recorded to assist with determination of failure modes. A load-displacement curve was generated for each specimen, and the maximum (failure) load was recorded (Figure 3). The displacement measurement of the MTS actuator was used in our calculations of energy-to-failure and initial stiffness for each test.

![Figure 2. (Left) A right sided specimen is shown prior to potting, with the positioning measured by the bubble level. (Right) A left sided specimen is shown in the MTS machine, with the ilium (A) and symphysis (B) both potted in PMMA.](image-url)
Table 3: Experimental Results

<table>
<thead>
<tr>
<th>GROUP A</th>
<th>Control Failure Load (N)</th>
<th>Defect Failure Load (N)</th>
<th>Percent Control</th>
<th>Control Stiffness (N/mm)</th>
<th>Defect Stiffness (N/mm)</th>
<th>Percent Control</th>
<th>Control Energy (J)</th>
<th>Defect Energy (J)</th>
<th>Percent Control</th>
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<tr>
<td>(No screws)</td>
<td>Mean</td>
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<td>4221</td>
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<td>1630</td>
<td>1220</td>
<td>75</td>
<td>13</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Std Dev</td>
<td>3565</td>
<td>2477</td>
<td></td>
<td>907</td>
<td>524</td>
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<td>6</td>
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<td>P value</td>
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<td>0.124</td>
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<table>
<thead>
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<th>GROUP B</th>
<th>Control Failure Load (N)</th>
<th>Defect Failure Load (N)</th>
<th>Percent Control</th>
<th>Control Stiffness (N/mm)</th>
<th>Defect Stiffness (N/mm)</th>
<th>Percent Control</th>
<th>Control Energy (J)</th>
<th>Defect Energy (J)</th>
<th>Percent Control</th>
</tr>
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<td>(Two screws on the defect side)</td>
<td>Mean</td>
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<td>2985</td>
<td>73</td>
<td>1239</td>
<td>903</td>
<td>73</td>
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<tr>
<td></td>
<td>Std Dev</td>
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<td>1351</td>
<td></td>
<td>296</td>
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<tr>
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<td>P value</td>
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<td>0.124</td>
<td></td>
<td>0.554</td>
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</table>

Figure 3: Sample Load to failure curve from experimental group A.

Figure 4: Relationship between bone density and ultimate failure load.

**Statistical Analysis:**
Specimens were compared against their control side with a paired-sample Wilcoxon signed rank test. Statistical significance was considered to be p<0.05.

**Funding Source:**
The cost of purchasing the cadaveric specimens was supported by the Orthopaedic Research and Education Foundation. Supplemental funding was provided through a general donation to biomechanical research at the University of Iowa, made by Dr. Dan Fitzpatrick. Wright Medical (Wright Medical Technology, Inc., Arlington, TN) donated the implants.

**RESULTS**
In treatment group A, the creation of a 2 cm medial wall defect resulted in a 26% decrease in mean load-to-failure (5710 v. 4221 N, p=0.024), and a 23% mean decrease in the energy (13 v. 10 Nm, p=0.033). There was also a 25% decrease in mean stiffness, but this did not achieve statistical significance (1630 v. 1220 N/mm, p=0.124) (Table 3).
In treatment group B, the addition of two acetabular screws to posterior-superior safe zone on the defect side did not successfully restore the load-to-failure of the construct relative to the control (mean 27% decrease, 4082 v. 2985 N, p=0.024). Similar to treatment group A, the mean stiffness and energy trended lower when a defect was present, but these did not achieve statistical significance (Table 3).

There was a moderate linear correlation between the specimen’s bone density and its ultimate failure load in both group A ($R^2$ of 0.78 for defect side, and $R^2$ of 0.74 for the control side) and in group B ($R^2$ of 0.55 for defect side, and $R^2$ of 0.55 for the control side), as measured by Pearson’s correlation coefficient (Figure 4). Mechanistically, the acetabulum appeared to fracture before the cup displaced and the screws engaged. Two failure modes were observed. Specimens without a defect developed a transverse type acetabular fracture (Figure 5). In specimens with a defect, the cup failed through the defect itself, resulting in a fracture with significant medial cup displacement and enlargement of the defect (Figure 6). In both cases, the fracture appeared to go directly through the medial wall, which is outside the posterior-superior zone in which screws were placed.

**DISCUSSION**

Medial acetabular prosthesis migration is a rare, but known complication of total hip arthroplasty. A medial wall breach has been proposed to be a significant risk factor, but few studies have investigated either the biomechanical effect of a medial breach, or treatment methods...
to prevent medial prosthesis migration once the defect has occurred. Thus, the purpose of this study was to investigate the effect of up to a two centimeter medial wall defect on load-to-failure in a cadaveric model, and to determine the ability of acetabular screws to restore strength to the construct. Overall, we found that the presence of a breach decreased the load-to-failure by a mean of 26% relative to controls, and that the addition of two acetabular screws in the posterior-superior safe zone did not successfully restore the strength of the construct.

The primary aim of this study was to determine the biomechanical effect of a medial acetabular wall defect caused by over-reaming. Previously, the risks related to creation of an isolated medial wall defect have generally not been well recognized. Hadjadi et al reported that isolated central acetabular defects had no effect on initial implant stability under axial loads up to 1000 N. These authors reported that a medial wall defect allowed placement of a large implant with good rim coverage and excellent initial stability. In contrast, Desai et al reported one case of early pelvic discontinuity resulting from a transverse fracture in a patient with a 2 cm medial wall defect caused by over-reaming the pelvis. Similarly, Springer et al reported a series of 7 patients who developed transverse acetabular fractures and pelvic discontinuity early in the post-operative period after revision arthroplasty. The authors speculated that excessive reaming to allow the placement of a large revision type implant had weakened the medial bone stock. In this study, central defects of up to 2 cm in diameter decreased the load to failure strength by a mean of 26%. Thus, excessive removal of medial acetabular bone stock clearly weakened the construct.

However, it is not immediately clear whether or not this loss in load-to-failure is enough to be clinically significant or to produce fractures during activities of daily living in an in vivo setting. Results from in vivo investigations have reported that average hip joint reactive forces during common activities ranged from 238-260% body-weight. For a 70 kg (154 lb) patient this corresponds to 1,632-1,783 N and for a 100 kg (220 lb) patient this rises to 2,334-2,550 N. The mean failure loads in this study were well above these ranges, even in specimens with a breach.

Mechanistically we observed that, due to the tight rim fit, the force was primarily delivered through the implant and into the acetabular rim. Thus, the acetabulum fractured and the cup began to displace before the screws engaged, and acetabular screws placed into the posterior-superior safe zone were not sufficient to prevent fracture from occurring. In this study, we chose to mimic the most common clinical pattern of screw placement with two screws placed into the posterior-superior safe zone. However, it is possible that an alternative screw pattern would have had more success. In pelvic discontinuity cases screws are placed both into the posterior-superior safe zone, and also down into the ischium in order to bridge the defect. A construct that bridged the defect may have been more successful and would be an interesting area for further study.

Our study has several limitations. First, cadaveric bone does not have the same properties as living bone in terms of viscoelasticity and ability to heal or respond to local stressors, and this could feasibly limit the generalizability of our conclusions. Second, we attempted to control for variations between specimens (in terms of bone quality, amount of osteoarthritis, age of the specimen, and size of the acetabulum relative to the implant) by having each contralateral hemipelvis serve as its own internal control. Thus, our results are presented as a percent of the control side. Nonetheless, it is possible...
that small differences remained that we were unable to account for. Third, our study design allowed the investigation of only a single direction of force applied with increasing magnitude at a quasi-static loading rate in a single laboratory setting. Living patients are subjected to multiple axial and torsional loads in a cyclic fashion, and at higher loading rates. Thus, our experimental model best approximates the application of a large force, such as during a stumble or fall, but cannot accurately represent the results of cumulative stresses over time. Fourth, the ability of acetabular screws to resist torsional strains, seat the cup down to the acetabulum, or to resist micromotion which might prevent cup ingrowth was not studied. Clinically, the failures we had observed were transverse fractures resulting in medial cup displacement, and we thus designed the study to reproduce that mechanism. Prior authors have argued that acetabular screws increase the initial implant stability in response to torsional forces, and help to seat the cup, thus minimizing the distance between the bone and the implant\textsuperscript{6,8,9}. Thus, acetabular screws may have benefits beyond what we are able to comment on in this study, and our data should not be interpreted as generally discouraging their use. Fifth, the ultimate failure load of the specimens is likely dependent, in part, on the direction in which the force is applied. We implanted the cups using anatomic landmarks, and then directed the force in reference to the acetabular implants. Thus, it is possible that there was variability in the way the cups were implanted, and in the ultimate force direction. However, the use of anatomic landmarks for cup positioning is common during in vivo surgeries, and all of the surgeries were performed in a uniform fashion by a single individual. Thus, we feel that this is not a substantial source of bias.

CONCLUSIONS

Overall, our study has demonstrated that medial acetabular defects caused by medial reaming decreased the ultimate load-to-failure of the pelvis. Osteoporotic patients seem to be the most likely to develop a fracture as a result of this complication. Acetabular screws placed into the posterior-superior safe zone do not appear to be sufficient prophylaxis in our in vitro model. It seems feasible that once cup ingrowth has occurred the importance of a medial wall defect would likely be reduced. Thus, when this complication is encountered clinically, it may be reasonable to institute a period of protected weight bearing with an assistive device in order to minimize fall risk until cup ingrowth can be achieved. Further clinical follow-up is necessary, and future studies should focus on clinical outcomes of patients with medial wall breaches to determine if the incidence of fracture is substantively increased.

ACKNOWLEDGEMENTS

The authors would like to thank Dr. M. James Rudert for his contributions to the design and implementation of the biomechanical analysis. We would also like to thank Dr. Dan Fitzpatrick and the Orthopaedic Research and Education Foundation for providing funding for this study. Lastly, we would like to thank Wright Medical Technology Inc. for donating the implants used.

REFERENCES


ABSTRACT

Background: The purpose of this study was to determine the early outcomes of 599 cases of revision THA performed using a porous tantalum cup.

Methods: Clinical and radiographic data was sought in all patients at a minimum two years follow-up, after acetabular revision performed with a porous tantalum cup.

Results: Of the 599 cases identified, there were 51 re-operations in 47 patients (7.8 percent). Cup removal was required in 14 of these cases (2.3 percent). The most common cause for cup removal was a septic joint (12). No cups were revised for aseptic loosening during the study period. There was one case of early cup migration. There were 17 incomplete lucencies not initially seen on post-operative films, but identified later, all were non-progressive on subsequent x-rays.

Conclusions: Early results of porous tantalum acetabular components in the revision setting demonstrate good initial stability and low re-operation rates at two years follow-up.

Level of Evidence: Level 4: Case series

INTRODUCTION

Acetabular components for total hip arthroplasty (THA) made from the porous metal tantalum (TM; Zimmer/Impax, Warsaw, IN) have been in use since 1997. Clinical application of this material has grown due to remarkable bone in-growth properties\textsuperscript{1,3}. Additional unique features include high porosity with fully intercommunicating pores, which give it the potential to act as a conduit for local delivery of substrates such as antibiotics, bone growth factors, and bisphosphonates\textsuperscript{4}. A roughened surface micro-texture provides a higher coefficient of friction for increased initial stability upon implantation\textsuperscript{5,7}. Moreover, it has a lower modulus of elasticity than that seen previously with solid metals, which creates the potential for a more physiologic transfer of forces to the pelvis and reduces acetabular stress shielding\textsuperscript{7,9}. Interestingly, equivalent or lower bacterial adherence to porous tantalum has been demonstrated when compared with traditional surfaces\textsuperscript{10}.

Successful clinical applications of porous tantalum have been reviewed by a number of authors. Broad clinical applications to orthopaedics were demonstrated by Bobyn et al.\textsuperscript{11}, and more recently those specific to primary and revision THA\textsuperscript{12,13} have been examined and summarized. The technique for implantation of a porous tantalum cup and augments, and the associated clinical decision making was nicely reviewed by Drs. Gross, Backstein and colleagues who have extensive clinical experience with these tools\textsuperscript{14}.

In the present study we sought to determine the outcomes in the first 599 revision THAs performed with a porous tantalum acetabular component at 2 to 8-year follow-up from a single center, examining causes and details related to failures and revision surgery encountered over the study period.

METHODS

Institutional Review Board approval was obtained for this study.

Demographic Characteristics

599 trabecular metal cups were inserted during revision acetabular surgery in the period from December 1997 through January 2004. There were 577 patients, 20 of whom had bilateral revisions, and two patients each with two revisions on the same hip. A minimum two-year follow up was potentially available in all patients at the beginning of this study. All cases had been followed prospectively at regular intervals since surgery as part of an Institutional Joint Registry.
The average patient age at surgery was 65.5 years (22 to 94). 345 females and 254 males were enrolled. 276 left and 323 right hips underwent surgery. Mean height was 165.7 centimeters, and weight was 77.3 kilograms, yielding an average BMI of 28.0 (range 14.8 to 54.5). The primary diagnosis at the time of their index surgery was most commonly: osteoarthritis (201), developmental dysplasia (97), proximal femoral fracture (75), unknown (68), rheumatoid arthritis (46), avascular necrosis (37) and previous osteomyelitis or septic arthritis (13).

**Surgical Data**

Hips had undergone an average of 1.8 previous surgeries (range 1 to 9).

In the 599 revision cases performed, implants included 5 monoblock acetabular components, 1 cup with peripheral screw holes (an early design), and 593 revision shells with multiple screw holes and a cemented liner. The most common indications for acetabular revision were: wear, osteolysis and loosening (387), septic joint (98), failed uni or bipolar hemiarthroplasty (33), and recurrent dislocations (30).

**Clinical Follow-up**

All patients were followed prospectively, and data was entered into the Institutional Joint Registry. A review of all cases of re-operation, for any reason, was performed.

**Radiographic Evaluation**

Post-operative images were examined. The presence of radiolucent lines, and the zone in which they occurred was noted, as per the system of Charnley and Delee. Cup migration was evaluated using the criteria of Callaghan et al., and the development of any osteolysis was recorded. Minimum two-year follow-up images were reviewed and compared with the post-operative views.

Radiographic reviews were performed by one of three authors [WJL, NON, TAM]. In cases where there was concern regarding loosening defined as: cup migration, new or progressive lucencies, or progressive peri-articular osteolysis, a detailed review of all available images, and chart review of clinical notes was performed. These cases were also reviewed by one of the senior authors [DGL].

**RESULTS**

**Clinical**

**Re-operation and Revisions**

51 re-operations were performed. The most common indications for re-operation were instability (24) and septic joint (14) (Tables 1 & 2). Only 14 re-operations involved removal of the trabecular metal acetabular cup (Table 2). The average time to failure following cup insertion was 22.8 months (1 to 69 months). There were 5 males and 9 females, with an average age of 63.3 years (42 to 80 years), and average BMI of 29.1 (24.2 to 41.8). Ten right, and four left hips failed. Of the 14 revision cases where the cup was subsequently removed, the causes for failure were: 12 septic joints, and two malpositioned cups. There were no cases of re-operation for aseptic loosening during the study period.

**Radiographic**

599 cases were identified for inclusion. There were 44 patient deaths, in only two of these cases was a two-year follow-up x-ray obtained. The cup was cemented into a cage in one case. There were no radiographic signs of cup failure in any of these cases, though in some cases the postoperative radiograph was the only image available. Thirteen of the fourteen cases of cup removal did not have two-year follow-up.

The remaining 543 cases were reviewed. All patients had a minimum postoperative AP and lateral x-ray that was examined. 124 patients did not have a minimum two-year postoperative imaging (20.7 percent), which left 419 cases in which the postoperative x-ray and the most recent follow-up were reviewed and compared. Follow-up was thus obtained to two-years, cup removal, or patient death in 79.6 percent of cases. The average length of radiographic follow-up was 38 months (range 24 to 72 months).

Lucent lines were noted on 83 postoperative x-rays (Table 3). In 37 cases these lines had resolved on the most recent radiograph, and in 4 cases of initial 2 zone lucencies they were reduced but still present. In 26 cases, 18 of which involved isolated zone 3 lucencies, they persisted. The remaining 16 cases did not have complete two-year radiographic follow-up, but no cases of failure or loosening have been reported.

A new lucency was documented in 18 cases. 16 of these were isolated to zone 1 (3) and zone 3 (13). Review

### Table 1: 37 Cases of Revision Surgery with Cup Retention

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>Number of Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constrained liner</td>
<td>17</td>
</tr>
<tr>
<td>Abductor repair and constrained liner</td>
<td>2</td>
</tr>
<tr>
<td>Head and liner exchange</td>
<td>3</td>
</tr>
<tr>
<td>Femoral stem revision</td>
<td>4</td>
</tr>
<tr>
<td>ORIF peri-prosthetic femur fracture</td>
<td>1</td>
</tr>
<tr>
<td>Pelvic discontinuity cage/plate</td>
<td>5</td>
</tr>
<tr>
<td>Posterior column plate removal</td>
<td>1</td>
</tr>
<tr>
<td>Haematoma evacuation</td>
<td>1</td>
</tr>
<tr>
<td>Femoral cable removal</td>
<td>1</td>
</tr>
<tr>
<td>I&amp;D with cup retention</td>
<td>2</td>
</tr>
</tbody>
</table>

Abbreviations: ORIF open reduction internal fixation; I&D incision and debridement
A of these patients’ entire series of radiographs did not reveal any progression of the lucencies. One case of new zone 2 and 3 lucency was noted. This consisted of a 1-2 mm lucent line with an associated pelvic discontinuity that was treated non-operatively. Most recent follow-up imaging, two years following the identification of the pelvic discontinuity, showed healing of the discontinuity and a slight decrease in the thickness of the radiolucent line. The cup was clinically stable, though there was a broken locking ring on the constrained liner.

A single case of early cup migration occurred. Subsequent clinical and radiographic follow-up have not revealed any further migration and the hip was clinically stable and functioning well. The contralateral THA femoral component in this patient is symptomatic and has radiographic signs of loosening.

Table 2: 14 Revisions with Cup Removal

<table>
<thead>
<tr>
<th>Patient</th>
<th>Implant Type</th>
<th>Date of Insertion</th>
<th>Primary Diagnosis</th>
<th>Revision Diagnosis at time of PT cup insertion</th>
<th>Etiology of Cup Failure</th>
<th>Time to Removal (Months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Revision cup</td>
<td>7/31/2000</td>
<td>DDH</td>
<td>Aseptic loosening</td>
<td>Malposition</td>
<td>69</td>
</tr>
<tr>
<td>2</td>
<td>Revision cup</td>
<td>10/26/2000</td>
<td>OA</td>
<td>Recurrent instability</td>
<td>Septic joint</td>
<td>57</td>
</tr>
<tr>
<td>3</td>
<td>Revision cup</td>
<td>11/8/2000</td>
<td>OA</td>
<td>2nd stage post infection</td>
<td>Septic joint</td>
<td>16</td>
</tr>
<tr>
<td>4</td>
<td>Revision cup</td>
<td>2/18/2002</td>
<td>OA</td>
<td>2nd stage post infection</td>
<td>Septic joint</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>Revision cup</td>
<td>5/23/2002</td>
<td>OA</td>
<td>2nd stage post infection</td>
<td>Septic joint</td>
<td>21</td>
</tr>
<tr>
<td>6</td>
<td>Revision cup</td>
<td>7/16/2002</td>
<td>Post acetabular fracture</td>
<td>Chronic dislocation</td>
<td>Septic joint</td>
<td>22</td>
</tr>
<tr>
<td>7</td>
<td>Revision cup</td>
<td>7/16/2002</td>
<td>OA</td>
<td>Aseptic loosening acetabulum</td>
<td>Malposition</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>Revision cup</td>
<td>9/19/2002</td>
<td>AVN post steroids</td>
<td>2nd stage post infection</td>
<td>Septic joint</td>
<td>20</td>
</tr>
<tr>
<td>9</td>
<td>Revision cup</td>
<td>02/21/2003</td>
<td>OA</td>
<td>Aseptic loosening</td>
<td>Septic joint</td>
<td>39</td>
</tr>
<tr>
<td>10</td>
<td>Revision cup</td>
<td>2/27/2003</td>
<td>DDH, L4 myelomeningocele</td>
<td>Aseptic loosening revision acetabular reconstruction</td>
<td>Deep infection at periprosthetic femur fracture</td>
<td>29</td>
</tr>
<tr>
<td>11</td>
<td>Revision cup</td>
<td>6/17/2003</td>
<td>OA</td>
<td>Aseptic loosening acetabulum and periprosthetic femur fracture</td>
<td>Septic Joint</td>
<td>12</td>
</tr>
<tr>
<td>12</td>
<td>Revision cup</td>
<td>8/28/2003</td>
<td>OA</td>
<td>Aseptic loosening acetabular cage</td>
<td>Septic joint</td>
<td>13</td>
</tr>
<tr>
<td>13</td>
<td>Revision cup</td>
<td>9/22/2003</td>
<td>RA</td>
<td>Girdlestone and acetabular fracture post attempted THA</td>
<td>Septic joint</td>
<td>2</td>
</tr>
<tr>
<td>14</td>
<td>Revision cup</td>
<td>10/20/2003</td>
<td>OA</td>
<td>2nd stage post infection</td>
<td>Septic joint</td>
<td>17</td>
</tr>
</tbody>
</table>

Notes: New 3 zone lucency since removed due to sepsis
Reduced lines only recorded for 2 zone lucencies
1 case of early cup migration occurred but appeared stable at subsequent follow-up

Abbreviations: AVN avascular necrosis; DDH developmental dysplasia of the hip; OA osteoarthritis; RA rheumatoid arthritis

Table 3: Radiographic review and Radiolucent lines

<table>
<thead>
<tr>
<th>Zone</th>
<th>Post operative</th>
<th>Follow-up</th>
<th>Incomplete follow-up</th>
<th>New lines</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6</td>
<td>5 resolved</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>16</td>
<td>12 resolved; 1 persists</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>39</td>
<td>14 resolved; 17 persist</td>
<td>8</td>
<td>13</td>
</tr>
<tr>
<td>2 zones</td>
<td>22</td>
<td>6 resolved; 4 reduced; 8 persist</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>3 zones</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Totals</td>
<td>83</td>
<td>37 resolved; 4 reduced; 26 persist</td>
<td>16</td>
<td>18</td>
</tr>
</tbody>
</table>

Notes: New 3 zone lucency since removed due to sepsis
Reduced lines only recorded for 2 zone lucencies
1 case of early cup migration occurred but appeared stable at subsequent follow-up
One case of a complete radiolucent line was noted on our radiographic review. Subsequent analysis of this patient’s chart revealed a revision surgery to a constrained liner performed during the early post-operative course for instability. A single culture was obtained and was positive. The patient, initially lost to follow-up, had presented to an outside facility at 39 months post-operatively with a chronically infected THA. Staged revision was performed and cultures grew similar bacteria to the previous operative culture.

**DISCUSSION**

This study presents the largest series of TM acetabular cups used in the revision setting from a single center. Early clinical and radiographic results are presented at 2 to 8 years post operatively. These cases involved the majority of the most complex acetabular revisions performed over this time course, including 17 cup-cage constructs. Our clinical and radiographic results suggest excellent stability and a low rate of revision in these difficult cases. Though no cases of aseptic loosening occurred in this study group there have been a number of cases that fell outside the timeframe of this study, in the complex acetabular revision setting. This demonstrates that there are limits to the in-growth and stability of these reconstructions as demonstrated by other authors.

Trabecular metal cups continue to be used at our center with improved clinical results when compared with previous implant surfaces, particularly for the more complex revision acetabular reconstructions. Other authors have noted a similar reduction in revisions with a porous tantalum shell, where they also report that the discrepancy was greater in cases with more significant acetabular bone loss.

One early complication reported by Springer et al. with the use of a revision porous tantalum cup is the occurrence of an early postoperative transverse pelvic fracture. The average time to diagnosis was eight months, and in seven cases reported, five underwent revision surgery. In all cases solid in-growth of the porous tantalum cup into one of the fracture portions was noted. A cup cage, column plating or both were used to obtain fixation of the fracture with stable early results. It was felt that this complication was the result of cyclical loading on the reduced bone stock following revision reaming and cup placement. These cases are also included in this current review (Table 1).

A number of clinical reviews have been published. The largest to date is by Skytta et al. who reviewed the results of 827 porous tantalum cups in the Finish national registry. They reported a 3-year survivorship of 92% with an aseptic loosening rate of 2 percent.

Unger and associates reported on the use of monoblock cups for 60 cases of revision acetabular surgery. In five cases the constructs were augmented with peripheral screws. At a mean follow-up of 42 months, 4 cups were revised, one for ‘initial cup movement’, 2 for dislocations, and one for aseptic loosening associated with a pelvic discontinuity non-union. There were no other cases of cup loosening on radiographic review. At a mean 40-month follow-up Kim et al. noted one revision out of 46 patients with revision shells used for Paprosky 2 and 3 defects.

Studies reviewing the combined use of a porous tantalum cup, augments, and in some cases cages, in the complex revision setting with severe bone have demonstrated very low rates of migration and aseptic loosening at early to mid-term follow-up loss. In a paper by Kosashvili et al. of 26 acetabular reconstructions involving a cage-in-cup technique for pelvic discontinuity were noted to be stable at early follow-up. They also obtained stable revisions using porous tantalum cups in 12 of 15 cases involving failed acetabular cages.

Sporer and Paprosky presented 13 cases of porous tantalum cups for treatment of a pelvic discontinuity. No re-operations were performed, though one case showed possible signs of radiographic loosening.

Concerns associated with our clinical review include the retrospective nature of the review without a comparison group, our follow-up rate, and that clinical outcome scores were not included. Follow-up was incomplete for 20 percent of patients. This occurred despite a rigorous joint registry program with special emphasis on obtaining follow-up in these patients. No re-operations or complications were reported in the patients not reviewed, but it is difficult to obtain patient follow-up and x-rays when they are functioning well without symptoms, or have difficulty getting x-rays approved by payers. This review was intended as an examination of the use of this new porous metal acetabular component, and not as a functional review of the associated revision hip reconstruction and thus clinical outcome scores were not included.

With respect to our radiographic review, it can be difficult to assess the cup interface in complex revision cases involving augments, cages and plates and associated bone grafting. In these cases we reviewed all of the multiple views provided and came to a consensus amongst the reviewers regarding fixation status and presence or absence of lucent lines, though some occult lucencies may persist.

The strengths of this study are the large number of patients, and the fact that all cases were performed at a single center. These results suggest very successful
early clinical and radiographic outcomes with the use of a porous tantalum cup for revision acetabular surgery. Specifically, this study presents the largest series of porous tantalum acetabular cups from a single center, used in the revision setting. Early clinical and radiographic results show excellent ingrowth and stability of this new surface. The stable apparent bony in-growth seen clinically and radiographically at up to eight years from surgery is encouraging for the likely long-term success of these implants, but further longer-term studies will be necessary to confirm these findings.

REFERENCES


ABSTRACT

Background: Although lateral epicondylitis (LE) is a very common tendinopathy, we understand little about the etiology of the disease. Tobacco use has been associated with other tendinopathies, and the purpose of this study is to determine if there is an association between the incidence of lateral epicondylitis and tobacco use.

Methods: We performed a retrospective cohort study of adult patients diagnosed with lateral epicondylitis. Patients from a single orthopaedic surgeon’s practice with LE were matched to control patients with other common upper extremity conditions based on age, gender, and occupation. A total of 65 case patients and 217 control patients were included in the study. The incidence of smoking in patients with lateral epicondylitis was compared to the incidence of smoking in the control group.

Results: Of the LE patients, 30/65 (46.2%) were non-smokers, 23/65 (35.4%) were former smokers, and 12/65 (18.5%) were current smokers. Of the control patients, 121/217 (55.8%) were non-smokers, 45/217 (20.7%) were former smokers, and 51/217 (23.5%) were current smokers. The odds of LE patients being former or current smokers compared to control patients were 1.45 times higher, but this was not statistically significant. Among people who did not smoke at the time of presentation, the odds of being a former smoker were 2.28 times higher in LE patients than in controls, which was statistically significant.

Conclusions: The odds of being a former smoker were significantly higher in patients with lateral epicondylitis compared to patients with other upper extremity conditions. Although it did not reach statistical significance, the odds of being former or current smokers were also higher in the LE group. These results suggest a relationship between smoking history and incidence of lateral epicondylitis, though more research is needed to determine the exact nature of the relationship.

Level of Evidence: Prognostic, Level III

INTRODUCTION

Lateral epicondylitis (LE), or “tennis elbow,” is a common cause of elbow pain, affecting nearly 1% of working-age adults. Despite the prevalence of lateral epicondylitis, the etiology of the disease is not well understood. Several studies have evaluated the relationship between LE and patient factors such as occupational activities, sex, and age. These studies have shown a link between manual labor and LE as well as a higher incidence of LE in patients ages 45-54.

Biopsies of tendon tissue in patients undergoing surgery for lateral epicondylitis reveal a pattern of poorly organized collagen and invasion with abnormal vascular structures known as tendinosis. These changes are similar in appearance to tendon changes in other tendinopathies such as rotator cuff tears. Though there is not a wealth of data on the relationship between smoking status and LE, a link between tobacco use and rotator cuff tears has been shown in several recent studies. Kane et al. found an increased incidence and increased severity of rotator cuff tears in cadavers with a history of smoking. Likewise, Baumgarten et al. found an increased incidence of rotator cuff tears was associated with any history of smoking, a history of smoking within 10 years of onset of shoulder pain, and increased pack-years of tobacco use.

Because of the similarity in microscopic pathology between rotator cuff tears and LE, we questioned whether tobacco use was related to LE. We identified two published studies addressing this question. The first study, a cross-sectional study from Finland, found that patients with LE were more likely to be regular tobacco users (odds ratio [OR] 3.4). The second study, a case-control study from England that utilized diagnostic and demographic information from a database, found that previous smoking history was a risk factor for lateral
epicondylitis (OR 1.20) but that current smoking status was not\textsuperscript{11}. However, this study was limited in that there were no specific diagnostic criteria for LE.

Understanding the relationship between tobacco use and LE could have an important impact on treatment. Mallon et al. found that smokers had worse outcomes than non-smokers following open rotator cuff repairs\textsuperscript{12}. If tobacco use is related to tendinosis, evaluating the efficacy of various treatments in smokers vs. non-smokers could yield important direction for treatment of patients with LE. The goal of this study was to evaluate the relationship between tobacco use and incidence of lateral epicondylitis. We hypothesized that patients with lateral epicondylitis are more likely to regularly use tobacco than the general population. In this study, we compared the smoking rates in a group of LE patients to the smoking rates in a control group of patients with other upper extremity conditions. We also compared the smoking rates of the LE patients and control patients to the state average of the study population.

### PATIENTS AND METHODS

**Subject Selection:**

This was a retrospective case control study approved by the site’s institutional review board. We reviewed patients who presented to a single orthopaedic surgeon specializing in upper extremity conditions between 2009 and 2012. Patients were identified by query of billing codes (ICD9 codes) through hospital databases. Data was collected from the electronic medical record.

Eligible subjects for study were 18 years or older at the time of presentation, and had either a diagnosis of LE by ICD-9 code (case patients), or one of the ten common upper extremity injuries listed in Table 1 (control patients). Patients were excluded if their records contained incomplete smoking status or occupation information, or if the cause of LE was determined by the principal investigator to be due to high energy trauma. All patients were examined by a single orthopaedic surgeon. The diagnosis of LE was made based on the presence of tenderness over the lateral epicondyle and pain with resisted wrist extension with the elbow in extension. Because the pool of potential controls was large, a subset was selected using the random number generator (RAND) function in Excel (Microsoft Corporation, Redmond, WA, USA).

**Case-control match:**

Occupations were organized into three classes (light, moderate, and heavy) based on the perceived frequency that workers would engage in high risk activities identified by Van Rijn et al., Walker-Bone et al., and Haahr and Anderson\textsuperscript{25,13}. The high risk factors for lateral epicondylitis identified in the literature included forceful work, repetitive movements, working with hands or arms in a non-neutral position, working with the neck twisted, working with neck bent forwards >2h/day, handling tools > 1 kg, handling loads > 20 kg at least 10/day, use of hand/arm vibrating tools >1h/day, carrying weights on one shoulder, and lifting weights >5kg in one hand. Table 2 shows the classification of specific occupations and occupation fields according to the above criteria. A separate investigator independently assessed occupation class in a subset of 20 LE patients and 20 control patients for purposes of demonstrating inter-rater agreement. Each LE patient in the case cohort was matched with up to four controls using a greedy matching algorithm according to age, gender, and occupation class\textsuperscript{14}. In order to be considered a match, a control had to be within 5 years of age from a case, and have the same occupation class and gender. Any cases or controls that remained unmatched were not included in the analysis.
Data Analysis:

The sample was described in terms of mean age, proportion female and proportion of subjects reporting moderate or high occupational risks of injury. We used the AC-1 statistic for assessing the extent of agreement by multiple reviewers about a subject’s occupation class.

The primary hypothesis was tested using conditional logistic regression, which modeled the probability of having the exposure of smoking as a function of case/control status, conditional on the age, gender, and occupation cluster to which the individual patient was assigned by the matching algorithm. A priori, we decided to use two definitions of smoking exposure: (1) current smoking (CS) and (2) past or current smoking (ever smoking; ES). Comparisons of smoking rates with the current state averages were done using exact binomial tests, treating estimates from the 2010 [Blinded] Adult Tobacco Survey as known population values (16.7% current smokers, 27.3% former smokers, and 56.6% never smokers). In all cases, tests were two-sided, with α = 0.05. Thus, 95% confidence intervals (CI) are used in this manuscript to describe variability in our estimates. When describing the uncertainty around a sample proportion, the Clopper-Pearson confidence bounds are used. Analysis was done using SAS 9.2 (SAS Institute Inc., Cary, NC, USA).

RESULTS

A total of 65 patients with LE met our entry criteria. From 934 eligible control patients identified by ICD9 code, we randomly selected 408 of them to classify according to occupation intensity, in order to make them eligible for matching with cases. Out of these 408 subjects, 217 of them were matched and included in the study. Of the 65 LE patients, 33 were matched to four control subjects, 22 were matched to three controls, nine were matched to two controls each, and one LE patient could only be matched with a single control. Thus, the sample consisted of 282 subjects (Figure 1). In the 40 subjects for which occupational intensity was assessed by multiple investigators, the inter-rater reliability between the two investigators was high (AC1 0.971).

Lateral epicondylitis patients had a mean age of 49.4 years (CI: 47.0 – 51.0), with the observed range of ages spanning from 25 to 87 years. Of the 65 cases, 23 (35.4%) were male (CI: 23.9 -48.2%). Fifty-two LE subjects were classified as having light occupational activity (80%; CI: 68.2 - 88.9%), while seven were classified as having moderate occupational activity (10.8%; CI: 4.4 - 20.9%) and six were classified as having heavy occupational activity (9.2%, CI: 3.5 - 19.0%).

Thirty of the 65 LE patients (46.2%) were never-smokers, 23/65 (35.4%) were former smokers, and 12/65 (18.5%) were current smokers. Of the control patients, 121/217 (55.8%) were never-smokers, 45/217 (20.7%) were former smokers, and 51/217 (23.5%) were current smokers.

When analyzed within age, gender, and occupation-matched clusters, the odds of LE patients being ever smokers (current or former) were 1.45 (CI: 0.83 – 2.52, p = 0.194). LE patients were not more likely to be current smokers than controls (OR 0.71, CI 0.36 -1.41, p =0.327) (Table 3). However, LE patients were significantly more likely to be former smokers compared to controls (OR 2.28, CI 1.11- 4.68, p=0.024).

The 23.5% rate of current smoking in the control group was significantly higher than the state average of 16.7% (p=0.012). The rate of current smoking seen in LE pa-
DISCUSSION

Previous research has shown a link between tobacco use and tendinopathies. The purpose of this study was to determine if there was an association between patient smoking history and lateral epicondylitis. We hypothesized that patients with lateral epicondylitis were more likely to use tobacco than the general population. We did not find a statistically significant difference in current smokers between the LE patients and control cohorts for this study. The data did trend towards our hypothesis, but due to a small sample size, it did not reach statistical significance. However, there was a significantly higher rate of former smokers in the LE patients when compared with the control cohort and when compared with the state averages.

The lifetime smoking rate (ever smoking) was noticeably higher in LE patients compared to controls and the state average, but this was not statistically significant (Table 3). Failure to detect a statistically significant difference could have been due to the small sample size. A priori, we calculated that a study that obtained 60 cases and 180 age, gender, and occupational intensity-matched controls would allow for a conditional logistic regression to have 84% power to detect a true increase in odds ratio of 2.5. If we assume that the true underlying odds of lateral epicondylitis are equal to our best estimate from this data (OR = 1.52), then a sample of this size has approximately 37% power to detect such an effect. Thus, it should be noted that a true increase of LE odds among tobacco users may indeed exist, but the likelihood of obtaining a sample of this size that demonstrates such an effect with the typical level of statistical certainty (p<0.05) is poor. Further studies examining this effect in similar populations should recruit 200 or more cases, in order to have a type II error rate of <20%.

The results from our study are similar to the findings from Titchener et al, which used data from The Health Improvement Network, a large database of electronic medical records collected from general practices throughout the United Kingdom. They also found a statistically significant increase in risk of LE in former smokers, but not in current smokers. In our study population, we found a significant age difference in age between levels of smoking exposure. Former smokers were significantly older (two-sided Wilcoxon p value= 0.03) than current or never smokers (Table 4). One explanation for the higher odds of lateral epicondylitis occurring in a former smoker than a current smoker or non-smoker in our study is that the extra risk of lateral epicondylitis with smoking is one that accumulates over time.

Although our study includes fewer patients than Titchener, a strength of our study is that all patients were examined and diagnosed based on specific clinical criteria by a single orthopaedic surgeon fellowship trained in hand surgery.

Another limitation of this study is the failure to quantify tobacco exposure in our patients. Several studies support the dose dependent effects of tobacco on rotator cuff pathology, which may also be the case in regards to LE. In our study, there was an increased incidence of history of any tobacco use in patients with LE compared to the control patients. Although the rates of current smokers were very similar between the two groups, it is possible that the increased incidence of LE in former smokers could be because the damage from tobacco has already occurred prior to smoking cessation. Future research efforts should be made to examine the possible dose dependent relationship between lateral epicondylitis and tobacco use.

A limitation that this study shares with all other case-control studies is that, due to the fact that we do not know the size of the population being sampled (i.e., the denominator is unknown), we cannot make causal inferences about smoking upon lateral epicondylitis incidence. However, the design does allow us to observe and report associations (odds ratios) without assigning causality.

Another limitation of our study was that our control group had a higher rate of current smoking than the general population of the study state. We elected to use other clinic patients as our controls so that we could account for age and occupation, but a comparison to a control group from the general population may have yielded a larger difference between the LE patients and the control group with regard to tobacco use. A related limitation is that our study treats the estimated smoking rates reported in the 2010 Adult Tobacco Survey as known population values, rather than as proportions observed in a sample of roughly

<table>
<thead>
<tr>
<th>Smoking Status (Overall Sample)</th>
<th>N</th>
<th>Mean Age</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Never Smoker</td>
<td>151</td>
<td>49.5</td>
<td>47.9 – 51.1</td>
</tr>
<tr>
<td>Former Smoker</td>
<td>68</td>
<td>52.4</td>
<td>49.5 – 55.3</td>
</tr>
<tr>
<td>Current Smoker</td>
<td>63</td>
<td>48.0</td>
<td>45.9 – 50.0</td>
</tr>
</tbody>
</table>

Table 4: Differences in Age by Smoking Status

patients of 18.5% was not different at a statistically significant level from the [Blinded] state average (p = 0.803). Compared to the general state population, the rate of former smoking was significantly lower in controls (p=0.032), but not significantly different in LE cases (p=0.190). The rate of ever smoking was not different from state averages in either LE cases (p=0.141) or controls (p = 0.996).
7,000 interviewees. This assumption was used because in the format that the [Blinded] Adult Tobacco Survey results were presented, the exact numerators for current, former and never smokers were not available for use in a comparison such as Fisher's exact test\(^2\). We felt that the assumption was justifiable due to the large sample size of the survey, especially relative to our own data.

**CONCLUSION**

In conclusion, our study found a higher incidence of LE in patients with any history of tobacco use. Current smokers did not have an increased incidence of lateral epicondylitis in our study. Larger studies could better define the possible dose dependent nature of the relationship between tobacco and tendinopathies such as lateral epicondylitis.

**REFERENCES**

ABSTRACT

Background: Fracture of the scaphoid bone can be treated with cast immobilization or surgery. Historically, surgery was reserved for displaced fractures. However, because weeks of cast immobilization may result in stiffness, loss of strength, loss of bone density and an inability to work or participate in recreational activities for a prolonged period, operative treatment of non-displaced fractures has become increasingly common. Several surgical techniques for fixation have been described, but their risks and benefits have not yet been clearly elucidated. In a study in cadavers, we investigated whether one approach—volar percutaneous fixation—might pose a risk of injury to surrounding structures.

Methods: In 15 cadaver upper limbs with the wrist structures intact, a K-wire was inserted in a volar percutaneous manner under fluoroscopic guidance, distal to proximal and through the scaphoid waist into the center-center position. The volar aspect of the wrist and hand were then dissected around the K-wire, with isolation of surrounding structures. The distance between the K-wire and several individual structures was then measured with use of a digital caliper.

Results: The K-wire was at least 4 mm from the superficial radial nerve, the first dorsal extensor compartment, the recurrent motor branch of the median nerve, and the radial artery (RA) in all specimens. However, the K-wire may penetrate the flexor carpi radialis (FCR) tendon and the superficial volar branch of the RA during volar percutaneous scaphoid fixation. The possible long-term clinical implications of this finding require investigation.

Clinical Relevance: Our findings indicate that modification of the volar percutaneous approach to scaphoid fixation may be advisable to avoid damage to adjacent structures. We suggest use of a “mini-open” percutaneous procedure.

INTRODUCTION

Scaphoid fracture, the most commonly fractured carpal bone, frequently results from a fall on an outstretched hand with the wrist in extension1,2. Most scaphoid fractures occur in active men, often athletes, in their twenties or thirties3. The annual incidence is about 30 to 43 fractures per 100,000 people3. Approximately 70% of scaphoid fractures occur at the waist (middle third) of the bone4.

The scaphoid bone has unique characteristics that require special consideration when planning treatment of fractures. Normal carpal alignment depends partly on an intact scaphoid. The scaphoid spans both the proximal and distal carpal rows and is exposed to marked stress; therefore, immobilization is important in achieving union after fracture. About 70% to 80% of the intraosseous blood supply and the entire proximal pole of the scaphoid receive blood flow in a retrograde manner from branches of the radial artery (RA) that enter at the dorsal ridge5. The remaining 20% to 30% is provided by the volar RA branches at the distal tuberosity6. A scaphoid fracture may disrupt this tenuous blood supply, leading to delayed union, nonunion, or avascular necrosis and, ultimately, post-traumatic arthritis and carpal collapse7.

Early treatment of scaphoid fractures is important in preventing these complications. The principal treatment methods are cast immobilization and surgery. There is general agreement that unstable and displaced fractures require operative treatment, but the optimal treatment for stable, non-displaced fractures remains
somewhat controversial. Both cast immobilization and screw fixation have high, similar union rates (about 85% to 100%)\(^2\,8,9\), although some studies have found that the long-term complication rate is higher in patients who undergo surgery\(^9\,11\). In patients given a cast, however, fracture healing may require 12 or more weeks, during which time loss of muscle strength and bone density occurs, as does stiffness of the wrist, elbow, and hand\(^2\,8,12\). In addition, the young, active patients who are most likely to sustain a scaphoid fracture may find a cast particularly burdensome because it restricts recreational and occupational activities. Surgical treatment (screw fixation) of non-displaced fractures has therefore become increasingly common, and the mean time to union and return to work have been found to be significantly shorter in patients who have undergone surgery compared with those given a cast\(^12,13\).

Several surgical procedures for treating scaphoid fractures have been described, including open and percutaneous volar or dorsal techniques. Because open fixation involves dissection that damages the volar radiocarpal ligaments or dorsal capsular structures\(^8\), surgeons may choose a percutaneous approach.

Studies comparing the dorsal and volar percutaneous approach to screw fixation of scaphoid fracture have found little difference between the two procedures with respect to screw position, union rate, or functional outcomes\(^14\,17\). However, with any percutaneous technique, there is a risk of injury to anatomical structures during guide wire placement and screw advancement. This risk has been addressed in several cadaver studies. For example, investigations by Adamany et al\(^18\) and Weinberg et al\(^19\) found that dorsal percutaneous scaphoid fixation can damage the posterior interosseous nerve and the extensor indicis proprius, extensor pollicis longus, extensor carpi radialis, and extensor digitorum tendons. Kamieni and Lavy\(^20\) observed that the volar percutaneous approach risks injuring the superficial volar branch of the RA (SVBRA). In a study of screw positioning using the volar method, Vaynrub et al\(^21\) noted articular damage affecting an average of 7% of the articular surface in 6 of 10 wrists and “fraying” of 5% of the ulnar-most fibers of the abductor pollicis longus (APL) in one specimen and 10% of the radial-most fibers of the flexor carpi radialis (FCR) tendon in another specimen. Little other information on anatomical structures that may be at risk of injury during volar percutaneous fixation is available.

**METHODS**

Fifteen fresh-frozen cadaveric upper limbs (Science Care, Phoenix, AZ) were used in this study (mean age, 41 years [range, 27-54 years]). Seven (four male and three female) were matched pairs, and one was a single right arm (male). All structures in the wrist of the specimens were intact at the beginning of the study, and no specimen showed evidence of wrist trauma or prior surgery.

The specimens were placed in a supine position on a flat table with a bump to maintain wrist extension (Figure 1). Ulnar deviation was obtained by using manual traction through the thumb. A completely percutaneous procedure was then performed under direct mini-fluoroscopic guidance. A 1.58-mm (0.062-in) K-wire was advanced through the skin and thenar muscles into the scaphoid tuberosity in line with the first metacarpal in the coronal plane and positioned at a 45° angle in the sagittal plane. A starting point just radial to the distal pole of the scaphoid was attained within the scaphotrapezial joint. The K-wire was advanced through the scaphoid waist and into a central position in both the sagittal and coronal planes of the proximal pole (Figure 2A and Figure 2B).

The volar aspect of the wrist and hand in each specimen was then dissected around the K-wire, with isolation of the following anatomical structures: the RA, SVBRA, recurrent motor branch of the median nerve (RMBMN), superficial radial nerve (SRN), first dorsal extensor compartment (FDEC), and FCR tendon. The distance between the K-wire and the nearest portion of each anatomical structure in each specimen was measured to the nearest 0.1 mm by using a digital caliper. If the structure had been penetrated by the K-wire, a value of 0 was assigned. If the K-wire was directly adjacent to the structure, a value of 0.1 mm was assigned. Data were expressed as the mean ± SD distance between the K-wire and structure of interest and the number and percentage of specimens with 0 and 0.1-mm values for each structure.

Figure 1: Specimen positioning during volar percutaneous fixation of scaphoid fractures. The specimens were placed in a supine position on a flat table with a bump to maintain wrist extension.
Structures at Risk During Volar Percutaneous Fixation of Scaphoid Fractures

RESULTS

Table 1 shows the results of the measurements of the distance between the K-wire and structures in the 15 specimens. The K-wire was at least 4 mm from the SRN, FDEC, RMBMN, and main RA in all specimens and directly adjacent to the SVBRA in one specimen. In four specimens, the FCR had been penetrated by the K-wire (Figure 3). In another four, the K-wire was directly adjacent to the FCR (Figure 4). Therefore, for 8 of the 15 specimens (53%), the FCR is considered to be at risk of injury from the surgical procedure.

DISCUSSION

Both the dorsal and volar percutaneous approaches to scaphoid fixation have a low complication rate and allow an earlier return to normal activities than does cast immobilization. However, advantages and disadvantages

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Table 1. Distance between K-wire and wrist anatomical structures after placement of K-wire centrally in the proximal pole of the scaphoid in 15 cadaveric specimens

<table>
<thead>
<tr>
<th>Structure</th>
<th>Overall mean ± SD distance (range), mm</th>
<th>No. (%) of specimens with direct penetration</th>
<th>No. (%) of specimens with 0.1-mm distance†</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCR</td>
<td>2.5 ± 3.3 (0-9.8)</td>
<td>4 (27)</td>
<td>4 (27)</td>
</tr>
<tr>
<td>SVBRA</td>
<td>7.2 ± 3.3 (0.1-11.8)</td>
<td>0 (0)</td>
<td>1 (8)</td>
</tr>
<tr>
<td>SRN</td>
<td>11.5 ± 3.9 (4-19)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>FDEC</td>
<td>13.6 ± 4.1 (7.8-20)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>RMBMN</td>
<td>15.9 ± 4.6 (9.1-22)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>RA</td>
<td>16.6 ± 4.7 (9.2-23.7)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
</tbody>
</table>

FCR, flexor carpi radialis tendon; SVBRA, superficial volar branch of the radial artery; SRN, superficial radial nerve; FDEC, first dorsal extensor compartment; RMBMN, recurrent motor branch of the medial nerve; RA, radial artery.

† K-wire was directly adjacent to structure.

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Figure 2: Radiographic images showing K-wire advanced through the scaphoid waist and into a central position in both the sagittal and coronal planes of the proximal pole. A. anteroposterior view. B. lateral view.

Figure 3: The flexor carpi radialis tendon was penetrated by the K-wire in four specimens using the volar percutaneous approach. Approximately 25% of the width of the tendon was affected. This percentage would increase following insertion of the cannulated fixation screw used for repair.

Figure 4: The K-wire was directly adjacent to the flexor carpi radialis tendon in four specimens. Cannulated fixation screw placement would result in edge penetration of the tendon.
have been described for both methods. With the dorsal approach, central placement of the screw in the long axis of the scaphoid may be easier to achieve\cite{13,18,22,23}. Disadvantages of the dorsal technique include a risk of fracture displacement because of the maximal wrist flexion it requires\cite{14,19,24} and possible iatrogenic injury to the dorsal blood supply\cite{24} and radiocarpal joint\cite{25}. The volar approach does not require wrist hyperflexion\cite{14}. Disadvantages of this technique include the risk of iatrogenic injury to the scaphotrapezial joint\cite{26}, the difficulty of obtaining a central-axis screw position because of the anatomical hindrance of the trapezium\cite{25}, and the potential for volar ligament instability\cite{25}.

Although the clinical results of the two percutaneous approaches have generally been satisfactory, the findings of our study and previous cadaver investigations that identified structures at risk with each method\cite{18,21} raise questions about possible avoidable injury to surrounding structures during this procedure. For the volar approach, our findings and those of Kamineni and Lavy\cite{20} suggest that the SVBRA is at risk, and indeed, at least one injury of this vessel has been observed in a patient who underwent volar percutaneous scaphoid fixation\cite{20}. In contrast, Vaynrub et al\cite{25} observed no visible damage to vascular structures. The reason for this discrepancy in results among the three studies is unclear. None of the three studies detected a risk to nerves.

Injury to a tendon was observed only in our study and that of Vaynrub et al\cite{25}. Vaynrub et al reported “minor” damage to the APL and FCR. We found penetration of the FCR tendon with the K-wire in 27% of specimens and direct adjacency in another 27%. These results are concerning, especially in light of the fact that a cannulated screw is then advanced over the K-wire further increasing the diameter of the affected region. A case of a patient in whom FCR tenosynovitis and, eventually, FCR tendon rupture occurred after volar percutaneous scaphoid fixation has been described\cite{27}. At reoperation, irritation and inflammation of the FCR tendon, scar tissue, and pieces of metal in the tendon fibers were observed. Either K-wire placement, screw advancement, prominent hardware, or a combination of these factors may have been responsible for this outcome. The implications of damage to the FCR tendon require further investigation. The tendon is often harvested for grafting to treat common conditions, including osteoarthritis of the thumb carpometacarpal joint. Varitimidis et al\cite{20} reported no compromise in wrist function after FCR harvest. On the other hand, Naidu et al\cite{29} showed that wrist-flexion extension torque ratio and fatigue resistance decreased when the entire tendon was harvested. Our study had the usual limitations of a cadaver investigation in that the anatomical findings could not be correlated with outcomes in patients, including union rates, development of arthritis, or function. Moreover, the cadaver wrists we used had not sustained a fracture. Our results suggest that the usual “blind” volar percutaneous approach to scaphoid fixation may not be optimal. Therefore, like Kamineni and Lavy\cite{20}, we recommend use of a “mini-open” percutaneous technique to enhance the safety of the procedure. The mini-open method includes blunt dissection down to the scaphotrapezial joint through a 1-cm incision to allow direct visualization of the distal scaphoid. This modification may prevent injury to the FCR tendon and SVBRA during K-wire placement and screw advancement.

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DECLARATION OF CONFLICTING INTERESTS
Each author certifies no commercial associations (eg, consultancies, stock ownership, equity interest, patent/licensing arrangements, etc) that might pose a conflict of interest in connection with the submitted article.

REFERENCES
Structures at Risk During Volar Percutaneous Fixation of Scaphoid Fractures


OUTCOME OF SEMI-CONSTRAINED TOTAL ELBOW ARTHROPLASTY IN POSTTRAUMATIC CONDITIONS WITH ANALYSIS OF BUSHING WEAR ON STRESS RADIOGRAPHS

Jenniefer Y. Kho, MD, Brian D. Adams, MD, Howard O’Rourke, MD

ABSTRACT
Background: Total elbow arthroplasty for post-traumatic arthritis or nonunion has been associated with a high rate of complications. Bushing wear is a known complication, although the actual incidence is unknown because stress views of the elbow are not routinely performed. We evaluate incidence of bushing wear in total elbow arthroplasty using stress radiographs.

Methods: Eighteen patients underwent total elbow arthroplasty from 1997-2009 for posttraumatic arthritis or distal humerus nonunion using the third generation Coonrad-Moorey design. Eight patients met inclusion criteria and had an average age of 67 years and mean follow-up of 105 months. Radiographs were analyzed for bushing wear and implant loosening on standard and stress radiographs. Clinical outcome measures included the Disabilities of Arm, Shoulder, and Hand (DASH) questionnaire, Mayo Elbow Performance Score (MEPS), overall patient satisfaction, range of motion, and complications.

Results: Rate of bushing wear was high, and stress views were five times more sensitive in detecting bushing wear (63%) compared to non-stress views (12%). Seventy-five percent of patients had a good or excellent MEPS. Range of motion slightly improved from pre- to post-operatively. Minor complications were common, but there were no revisions and no cases with radiographic loosening. There was no correlation between bushing wear and the DASH or MEPS.

Conclusion: Incidence of bushing wear in total elbow arthroplasty is high, and under-diagnosed without stress views. Although minor complications are common, frequent loosening and revision do not occur as previously reported for other implants. Despite bushing wear, mid-term functional outcomes are good.

Level of Evidence – Therapeutic IV.

INTRODUCTION
Total elbow arthroplasty (TEA) for the treatment of post-traumatic conditions has historically been considered a salvage procedure due to unfavorable outcomes and frequent complications. Complications have included infection, ulnar neuropathy, triceps insufficiency, implant fracture, periprosthetic fracture, aseptic loosening, and bushing wear.

Bushing wear is a common reported concern for current TEA designs, however the true incidence is difficult to determine due to lack of consistency in the way it is defined and measured. For the Coonrad-Moorey implant, which is designed to have 7 degrees of ulno-humeral laxity, definitions of bushing wear have ranged from qualitative descriptions, such as “asymmetric tilt of the implant,” to specific grades of severity based on quantitative measurements. Wright et al recommended that bushing wear be measured on anteroposterior (AP) stress radiographs, with the elbow stressed from full varus to full valgus; if the entire arc measured 7-10 degrees, then the bushings were considered partially worn and if greater than 10 degrees, then believed to be completely worn. Unfortunately, most studies do not include stress views of the elbow and therefore the actual incidence of bushing wear is unknown.

The purpose of this study is to evaluate the incidence of bushing wear utilizing stress radiographs in patients treated with total elbow arthroplasty for a post-traumatic condition. We also report correlation between bushing wear and clinical outcome.

MATERIALS AND METHODS
Following institutional review board approval, a retrospective chart and radiographic review was performed for patients who underwent total elbow arthroplasty for post-traumatic arthritis (PTA) or nonunion from 1997-2009 by a single surgeon. Patients who qualified for the study were contacted by phone to return for a clinical and radiographic evaluation. Further effort to locate patients who were not found through the hospital database was done using the website http://www.intelius.com and the Social Security Death index. Inclusion criterion was primary total elbow arthroplasty for PTA or nonunion with stress radiograph follow-up of at least 2 years. Patients who had a prior resection arthroplasty were also
included. Exclusion criteria included acute elbow trauma less than 3 months prior to TEA, revision arthroplasty involving only 1 component, inflammatory or primary osteoarthritis, and malignancy about the elbow.

There were a total of 66 patients (75 elbows) who underwent primary or revision total elbow arthroplasty from 1997-2009, of which 18 elbows in 18 patients were for PTA or nonunion. Eight patients met inclusion criteria with an average follow-up of 105 months (range 33-173 months). There were 6 women and 2 men with an average age of 67 years (range, 53-74 years) at the time of the operation. Six patients were older than 65 years. PTA was the primary diagnosis in 2 patients and nonunion in 6 patients. Four patients had undergone previous surgeries for open reduction internal fixation or external fixation while three were primary arthroplasties. One patient had a reimplant after a resection arthroplasty for infection. Hardware placed for fracture fixation was removed in 3 elbows at the time of surgery. The dominant extremity was involved in 38% of the cases.

A single surgeon performed all the surgeries using the third generation Coonrad-Moorey (Zimmer, Warsaw, Indiana) semi-constrained linked implant system. The technique included triceps reflection and ulnar nerve transposition, if not previously transposed. Antibiotic-impregnated polymethylmethacrylate was used for fixation. Standard closure along with a subcutaneous drain and posterior slab splint was used. The patient was maintained on intravenous antibiotics for 24 hours post-operatively.

Radiographic evaluation
A musculoskeletal radiologist reviewed radiographs. Pre-operative radiographs were available for review in 4 elbows, while the others had been destroyed. All eight elbows had complete post-operative radiographic evaluations (anteroposterior [AP], lateral, and varus-valgus stress views). The standard AP view was taken with the elbow in maximum extension, and the lateral view with the elbow flexed to 90°. The AP stress views were obtained in maximum extension possible while stabilizing the humerus with 1 hand and applying maximum tolerable valgus or varus force to the forearm with the other hand. All stress radiographs were performed by one of the authors. Bushing wear was measured on both the AP view without applied stress and the AP varus-valgus stress views by a radiologist as previously described by Ramsey et al11. In this method, a line parallel is drawn parallel to the humeral yoke, and another line is drawn parallel to the medial or lateral edge of the ulnar component’s articular surface. A joint angle >10° on any single AP view indicates excessive tolerance of the bushings due to wear or plastic deformation, while angle ≥7-10° suggests mild to moderate wear, and ≤7° is considered normal.

Implant loosening was graded on AP and lateral radiographs according to the classification described by Morrey12. In this classification, radiolucency is graded as Type 0 if a radiolucent line is less than one millimeter wide and involving less than 50% of the interface, Type I if a radiolucent line is at least 1 millimeter wide and involving less than 50% of the interface, Type II if a radiolucent line is more than 1 millimeter wide and involving more than 50% of the interface, Type III if a radiolucent line is more than 2 millimeters wide and around the entire interface, and Type IV if there is gross loosening.

Clinical evaluation and chart review
Outcome measures included the Disabilities of Arm, Shoulder, and Hand (DASH) questionnaire, Mayo Elbow Performance Score (MEPS), patient satisfaction questionnaire, range of motion, and complications.

The DASH measures pain and function and is based on a 0 to 100 scale, with 0 indicating the best score. The MEPS has a maximum score of 45 points for pain, 25 points for daily functional activities, 20 points for motion, and 10 points for stability. An excellent outcome is defined as a score ≥90 points, good if between 75 and 89 points, fair if between 60 and 74 points, and poor if <60 points. The MEPS data were only collected post-operatively at the follow up for this study. The patient satisfaction score was based on a one-to-five Likert scale, with 1 indicating most satisfied.

Range of motion was measured using a goniometer. Complications were obtained from chart review and were divided into minor and major.

Statistical methods
Statistical analysis was performed using the paired Student’s t-test with 2-tailed distribution for clinical and radiographic parameters. Pearson’s correlation coefficient was calculated to assess correlations between bushing wear and questionnaire scores. Level of significance was set at less than 0.05.

RESULTS
Average joint angle was 5.6° without stress compared to 13.6° of total arc on the stress view (p=0.002) (Table 1). Joint angulation greater than 10° of total arc was noted in 5 out of 8 (63%) elbows, compared to 1 out of 8 (12.5%) elbows on the non-stress AP view (Figures 1, 2). Therefore, absolute bushing wear was detected 5 times more frequently with stress views than without. There was greater joint angulation with valgus (9.9°) versus varus stress (3.8°) (p=0.002). There was no correlation between bushing wear and DASH (R²=0.008, p=0.83) or MEPS (R²=0.04, p=0.63).

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Outcome of Semi-Constrained Total Elbow Arthroplasty
Seven elbows had type I, and one elbow had type 0 radiolucency changes (Figures 1, 2). All radiolucency changes were limited to the periarticular region, with none surrounding the stems of the implant (Table 1).

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>Age/Sex</th>
<th>X-ray follow-up (months)</th>
<th>Bushing angle (degrees)</th>
<th>Radiolucency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>AP</td>
<td>Varus stress</td>
</tr>
<tr>
<td>1 Nonunion</td>
<td>59F</td>
<td>173</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>2 Nonunion</td>
<td>70F</td>
<td>78</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>3 Nonunion</td>
<td>66F</td>
<td>127</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>4 Nonunion</td>
<td>70M</td>
<td>68</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>5 Nonunion</td>
<td>73F</td>
<td>103</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>6 PTA</td>
<td>53F</td>
<td>138</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>7 PTA</td>
<td>74M</td>
<td>124</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>8 Nonunion</td>
<td>70F</td>
<td>33</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>105</td>
<td>5.6</td>
<td>3.8</td>
</tr>
</tbody>
</table>

Clinical data
DASH score improved from 70 pre-operatively to 28 post-operatively (p=0.20) (Table 2). The mean MEPS was 85, with 75% having good to excellent results. Mean patient satisfaction score was 2 out of 5.
Mean flexion–extension arc of motion was overall unchanged from 99° (range, 50-145°) pre-operatively to 103° (range, 46-120°) post-operatively (p=0.99) (Table 2). Mean pronosupination arc improved from 127° (range, 40-170°) pre-operatively to 146° (50-170°) post-operatively (p=0.22).

Complications
There were 4 minor complications in 3 patients, which included a stitch abscess, recurrent olecranon bursitis, hematoma requiring intravenous antibiotics, and ulnar neuropathy that had worsened from pre-operatively. Two of the 3 patients with complications had prior surgery. The patient with a stitch abscess was treated with suture removal, and the olecranon bursitis was treated with IV and oral antibiotics and a compressive bandage with resolution at 1-year follow-up. The patient who had an exacerbation of his pre-existing ulnar neuropathy had improved symptoms at his most recent follow-up. There were no major complications and no deep infections. None of the patients had implant revision surgery.

DISCUSSION
The Coonrad-Moorey total elbow arthroplasty is a semi-constrained, linked implant with a hinged design that is claimed to reduce force at the prosthesis-bone interface. The implant has an important role in reconstruction for elbow conditions characterized by deformity, bone loss, and instability, with good patient satisfaction and functional scores. Bushing wear, however, is a known complication at midterm to long-term follow-up, particularly in patients with post-traumatic arthritis. Incidence of bushing wear is variable, and may be under-diagnosed in the absence of stress views.

Our study demonstrates that stress views are much more sensitive for detecting bushing wear compared to a standard AP view. This suggests that bushing wear may be under-reported in the literature, as most total elbow arthroplasty studies do not evaluate stress radiographs. Of note, we specifically limited our study to include only patients treated for a posttraumatic condition. Despite the high rate of bushing wear, none of the patients in our study required a bushing exchange or revision surgery.

There was also no correlation with clinical or functional outcome. This finding appears to be consistent with what is reported in the literature.

Throckmorton et al reported a 34% rate of bushing wear at 9-year follow-up of 69 patients with PTA. This was a radiographic finding in 41% of the cases and was treated conservatively. Bushing wear rate in another study by Cil et al was 37%, with one of 32 elbows requiring isolated bushing exchange. Lee et al at reported a 1.3% bushing exchange rate in 919 primary total elbow replacements at an average of 7.9 years. Indications for surgery were pain, crepitus, or squeaking but with a well-fixed implant by radiographic assessment. They did not state what percentage of patients had asymptomatic bushing wear, but did acknowledge that the absence of stress radiographs was a weakness of their study. At surgery for bushing exchange, no extensive osteolysis was found and all implants were well fixed. They concluded that when there was radiographic evidence of bushing wear but no symptoms, the patient should be offered surgery only if pain or mechanical squeaking develops.

On the other hand, Wright et al reviewed 10 patients who underwent bushing exchange and found that all patients had obvious osteolysis and metallic synovitis. They stated that particulate polyethylene and metal debris generated from bushing wear was common, and recommended early bushing exchange and synovectomy for patients with synovitis, bushing wear, or osteolysis. Findings from a retrieval study of 16 Coonrad-Moorey implants revised for pain, crepitus, implant fracture, or a grossly loose prosthesis, suggest that polyethylene deformation or wear could lead to metal-on-metal contact between the humeral and ulnar components resulting in osteolysis. So, although our study and several others suggest that asymptomatic bushing wear can be treated conservatively, there is evidence to support more aggressive intervention. Stress radiographs in this situation may assist the surgeon in making a decision on whether bushing exchange would be helpful.

We do acknowledge that obtaining stress views can be challenging, especially in patients with a flexion contracture. We only applied maximum tolerated varus and valgus stress with the elbow in as much extension
as possible to minimize patient discomfort. We suspect that the degree of flexion contracture may affect the ulnohumeral angle measurement.

Clinical outcomes in our small cohort were also consistent with what is reported in the literature, with an average MEPS of 85 at our 8-year follow-up. Average MEPS for a group of patients treated for non-union at 6.5 years was 81. Throckmorton et al reported average MEPS of 75 at 9-year follow-up of patients with PTA.

Our overall 38% complication rate was higher than in many previous studies, however all complications were minor. Two of three patients with complications had previous surgery, which is a known risk factor. One patient had worsening of his ulnar neuropathy. Ulnar neuropathy has been reported to be as high as 26%, with permanent injury ranging from 0 to 10%. Wound and soft tissue problems have reported to range up to 13%.

There were no deep infections in our cohort, although in the literature, rates range from 0 to 10%.

None of the patients in our cohort required a revision or explant. This may in part reflect an improved implant design introduced in 1981 that was used in our patients. In 1994, Kraay et al reported results of a linked semi-constrained arthroplasty for patients with non-union or PTA, and found a survival rate of 73% at 3 years and 53% at 5 years, which was worse than the rates found for their patients with inflammatory arthritis (92% and 90%, respectively). Cil et al reported results of TEA for nonunion, and at average 6.5 years, 23 of 92 elbows underwent revision or removal, resulting in a prosthetic survival of 82% at five years and 65% at 10 and 15 years. Complications included aseptic loosening, fractured components, and periprosthetic fractures, and occurred while using an implant design that had a precoated ulnar component and a c-ring locking mechanism. Ensuing design changes included a plasma-sprayed ulnar component and snap-fit articulation. Risk factors for implant failure were patient age less than 65 years, 2 or more prior surgical procedures, and a history of infection. Throckmorton et al reported 19% failure rate in 84 patients after linked semi-constrained TEA for post-traumatic conditions. Their incidence of loosening was 19%, with 25% of those cases being grossly loose. Survival rate was 92% at 5 years, 78% at 10 years, and 70% at 15 years. They also noted that 75% of the failures were in patients less than 60 years old at the time of index TEA. The majority of patients in our study were older than 65 years, which may have contributed to our better results.

The major weakness of our paper was the small cohort size. However, this is the first study to compare non-stress versus stress radiographs of total elbow arthroplasty, with clinically important findings.

In summary, stress views of the elbow are more sensitive in diagnosing radiographic bushing wear compared to non-stress views. Despite the high incidence of bushing wear, we did not detect any clinical correlation nor have complications related to bushing wear at 8-year follow-up in patients treated with a post-traumatic condition. Stress radiographs are relatively cheap and non-invasive and should be considered in evaluating bushing wear.

REFERENCES


MINIMALLY INVASIVE VERSUS OPEN LUMBAR FUSION:
A COMPARISON OF BLOOD LOSS, SURGICAL COMPLICATIONS,
AND HOSPITAL COURSE

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Barth A. Green, MD3, Allan D. Levi, MD, PhD, FACS3, Steven Vanni, DO, DC3, Seth K. Williams, MD4

ABSTRACT

Background: Perioperative blood loss is a frequent concern in spine surgery and often necessitates the use of allogeneic transfusion. Minimally invasive technique (MIS) is an option that minimizes surgical trauma and therefore intra-operative bleeding. The purpose of this study is to evaluate the blood loss, surgical complications, and duration of inpatient hospitalization in patients undergoing open posterolateral lumbar fusion (PLF), open posterior lumbar interbody fusion (PLIF) with PLF, or MIS transforaminal lumbar interbody fusion (MIS TLIF).

Methods: Operative reports and perioperative data of patients undergoing single-level, primary open PLF (n=41), open PLIF/PLF (n=42), and MIS TLIF (n=71) were retrospectively evaluated. Patient demographics, operative blood loss, use of transfusion products, complications, and length of stay were tabulated. Patient data was controlled for age, BMI, and gender for statistical analysis.

Results: Patients undergoing open PLF and open PLIF/PLF respectively experienced a significantly higher blood loss (p<0.001), higher volume of blood transfusion (p<0.001), higher volume of cell saver transfusion (p<0.001), and more surgical complications (dural injury, wound infections, screw malposition) (p=0.02) than those undergoing MIS TLIF. There was no statistically significant difference in duration of hospital stay (p=0.11).

Conclusions: MIS TLIF provides interbody fusion with less intraoperative blood loss and subsequently a lower transfusion rate compared to open techniques, but this did not influence length of hospital stay. MIS TLIF is at least as safe as open techniques with respect to dural tear, wound infection, and screw placement.

Level of Evidence: Level III, Therapeutic

INTRODUCTION

Lumbar spondylolisthesis with stenosis is a common ailment causing back pain, radiculopathy, and/or neurogenic claudication1. Patients who fail non-operative treatment are often treated surgically with decompression of the neural elements and stabilization with spinal fusion when indicated2. Many surgical techniques have been used to achieve this, most commonly via laminectomy and posterolateral instrumented fusion (PLF), which allows for direct decompression of the neural elements and arthrodesis across the posterior elements3. Posterior lumbar interbody fusion (PLIF), first described by Cloward and colleagues in 1953, is an alternate procedure that provides three-column stabilization and, in some cases, indirect decompression of the neural elements through restoration of disk space height4. PLIF has been shown to provide an increase in lumbar lordosis, high fusion rates, and overall excellent clinical outcomes5. In patients with spondylolytic spondylolisthesis, PLIF combined with PLF (PLIF/PLF) allows for structural support along with direct decompression and has been reported to have a greater reduction in listheses, a lower complication rate, and more excellent results compared to PLF alone6.

Transforaminal lumbar interbody fusion (TLIF), first described in 1982 by Harms and Rolinger, is an alternative to PLIF that implements a unilateral approach to the disc space and minimizes retraction of the neural elements7. Similar to PLIF, TLIF provides decompression, allows for correction of anterolisthesis, and achieves a circumferential fusion. Compared to PLIF, TLIF is associated with similar fusion rates and restoration of sagittal

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balance; however, TLIF is also technically demanding and may be associated with increased operating time, blood loss, and postoperative complications\(^3\).

With advances in surgical technique and instrumentation, minimally invasive surgical techniques (MIS) have been developed to perform decompression and interbody fusion. MIS for interbody fusion has been associated with less blood loss, less need for transfusion in the post-operative period, and earlier ambulation. However, MIS procedures are more technically demanding than open procedures and have reportedly been associated with higher complication rates\(^8\).

Perioperative blood loss is a frequent concern in spine surgery and often necessitates the use of allogeneic transfusion. Blood transfusion carries several well-known risks, including the transmission of blood-borne infections, transfusion-related immunomodulation, febrile reactions, and acute lung injury\(^9,10\). The need for blood product transfusion may be minimized with careful patient selection and improved surgical techniques. The purpose of this study is to evaluate the blood loss, need for transfusion, surgical complications, and duration of inpatient hospitalization of patients undergoing open PLF, open PLIF/PLF, and MIS TLIF.

**MATERIAL AND METHODS**

After Institutional Review Board (IRB) approval, we performed a retrospective cohort study using prospectively-collected data from the electronic medical record. Operative case logs were reviewed to query all patients undergoing primary, single-level MIS TLIF at the University of Miami Hospital and Jackson Memorial Hospital by four surgeons (ADL, SV, MYW, SKW) from January 2010 through December 2012. Separate cohorts during the same time frame were obtained for primary, single-level open PLF by three surgeons (BAG, NHL, SKW) and open PLIF/PLF by two surgeons (BAG, NHL). Cases were consecutive and reflected each surgeon’s surgical preference. Patients undergoing a combined anterior and posterior approach or a revision surgery were not included.

The electronic and paper records for the open PLF (n=41), open PLIF/PLF (n=42), and MIS TLIF (n=71) groups were reviewed. No patients had a history of a bleeding disorder.

Operative reports, discharge summaries, pre-operative and post-operative notes, and anesthesia records were reviewed. Patient demographics and perioperative data points were tabulated. Specifically, operative blood loss, amount of perioperative product transfused (packed red blood cells and cell saver), specific complications (dural injuries, wound complications, screw malposition, neurological deterioration), and length of stay were recorded. Anesthesia records were considered the most accurate for blood loss during the procedure. Estimates for blood loss were made from recording blood in the suction/ cell saver canisters and subtracting total irrigation used during the case. Cell saver and packed red blood cell transfused were recorded from anesthesia records as well. Total product transfused was defined as the sum of cell saver and packed red blood cells transfused. Other outcomes (i.e. radiculopathies, motor deficits, paresthesias) or complications after discharge were not recorded in the outpatient setting.

Statistical comparisons between the three groups were made using the one-way analysis of variance test for continuous variables, and statistical significance was defined as p<0.05. The Wald test was implemented for comparisons between MIS TLIF to all open procedures (open PLF and open PLIF/PLF). Age, BMI, and gender were controlled for this analysis. All analysis was conducted using R statistical software\(^11\).

**ACKNOWLEDGEMENTS**

The authors would like than Vivek Charu, BS for his assistance in the statistical analysis for this study.

**SOURCES OF FUNDING**

There were no sources of funding for this study.

**RESULTS**

There was no statistically significant difference for age, gender, or BMI amongst the open PLF, open PLIF/PLF, and MIS TLIF groups (Table 1). Blood loss and transfusion varied considerably amongst cohorts (Table 2). Open PLF and open PLIF/PLF were associated with significantly more blood loss (313 cc and 514 cc respectively) than the MIS TLIF group (136 cc). Subsequently, a blood product transfusion (including blood products or cell saver) was more likely to be administered and

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Table 1: Patient Baseline Characteristics

<table>
<thead>
<tr>
<th></th>
<th>Open PLF</th>
<th>Open PLIF/PLF</th>
<th>MIS TLIF</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>61.5 (30-89, 14.1)</td>
<td>54.6 (22-86, 15.3)</td>
<td>58.6 (26-85, 11.8)</td>
<td>0.066</td>
</tr>
<tr>
<td>Gender (% male)</td>
<td>39.0</td>
<td>40.5</td>
<td>39.4</td>
<td>0.99</td>
</tr>
<tr>
<td>BMI (kg/ m²)</td>
<td>27.6 (16.3-39.6, 4.9)</td>
<td>27.4 (20.4-45.3, 6.3)</td>
<td>27.4 (17.3-39.4, 4.6)</td>
<td>0.99</td>
</tr>
</tbody>
</table>

*Range and standard deviation listed in parenthesis*
using greater amounts with open PLF (61.0%, 163 cc) and (74.0%, 275 cc) than the MIS TLIF (4.2%, 6 cc). In particular, packed red blood cells were transfused in 29.0% (97 cc) of cases in the open PLF group, 42.9% (146 cc) in the open PLIF/PLF group, and never in the open MIS TLIF group. Intra-operative cell saver was used primarily or as an adjunct in several cases as well. Open PLF utilized cell saver in 39.0% (67 cc) of cases, open PLIF/PLF in 57.1% (135 cc) of cases, and MIS TLIF in 4.2% (6 cc) of cases. After controlling for age, BMI, and gender, patients with open PLF were more likely to have greater blood loss (Odds Ratio [OR] = 2.4, 95% Confidence Interval [CI] 1.9-3.1), a blood transfusion (OR= 67.9, 95% CI 16.8-395.6), and cell saver transfusion (OR = 4.2, 95% CI 3.3-5.3) compared to those undergoing MIS TLIF. Similarly, patients with open PLIF/PLF were more likely to have greater blood loss (OR = 16.7, 95% CI 4.8-80.8) compared to those undergoing MIS TLIF. Overall, there were significantly more complications (dural injuries, wound complications, screw malposition) associated with open PLF (14.6%) and open PLIF/PLF (9.5%) compared to MIS TLIF (1.4%) (Table 3). Adjusting for age, gender, and BMI, open PLF was associated with 14.4 (95% CI = 2.6-174.1) times more complications than MIS TLIF, and open PLIF/PLF was associated with 5.5 (95% CI = 0.8-72.2) times more complications than MIS TLIF. In the open PLF cohort, three patients experienced a dural injury intra-operatively, all of which were repaired without complication. In addition, two patients developed deep post-operative wound infections treated with an incision and debridement followed by intravenous antibiotics, and one other patient was found to have aberrant screw placement with post-operative neurological deficits requiring revision. In the open PLIF/PLF group, one patient had a post-operative wound infection requiring an incision and debridement and intravenous antibiotics. Three patients also had dural tears, two of which were found intra-operatively and repaired, and one diagnosed post-operatively and definitely treated with a lumbar drain. One patient who underwent a MIS TLIF experienced a superficial wound infection on post-operative day 5 and was treated with intravenous and later oral antibiotics; there were no infections requiring surgical debridement. There were no dural tears in patients who underwent MIS TLIF. No patients in any cohorts (except for the aberrant screw complication of the open PLF cohort) experienced gross neurological deterioration in the immediate post-operative period, and no patients experienced any other medical complications. There was also a non-significant trend (p = 0.11) towards greater lengths of stay with open PLF (4.3 days) and open PLIF/PLF (4.8 days) compared to the MIS TLIF group (4.1 days).

**DISCUSSION**

Lumbar fusion can be performed via several techniques, including PLF, PLIF, and TLIF. The advent of minimally invasive techniques provides an additional option that seeks to minimize surgical trauma caused by exposing the spine. Our results indicate that MIS TLIF can be performed with less intraoperative blood loss, lower blood product transfusion rates, and fewer

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Table 2: Surgical Outcomes

<table>
<thead>
<tr>
<th></th>
<th>Open PLF</th>
<th>Open PLIF/PLF</th>
<th>MIS TLIF</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated Blood Loss (cc)</td>
<td>313 (50-100, 189)</td>
<td>514 (200-1350, 250)</td>
<td>136 (25-600, 108)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Transfused? (%)*</td>
<td>61.0</td>
<td>74.0</td>
<td>4.2</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Total Product Transfused (cc)*</td>
<td>163 (0-720, 193)</td>
<td>275 (0-905, 259)</td>
<td>6 (0-200, 30.6)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Blood Transfused? (%)</td>
<td>29.0</td>
<td>42.9</td>
<td>0.0</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Blood Transfused (cc)</td>
<td>97 (0-500, 175)</td>
<td>146 (0-500,191)</td>
<td>0 (0)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Cell Saver Transfused? (%)</td>
<td>39.0</td>
<td>57.1</td>
<td>4.2</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Cell Saver Transfused (cc)</td>
<td>67 (0-470, 104)</td>
<td>135 (0-540, 146)</td>
<td>6 (0-200, 30.6)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Length of Stay (d)</td>
<td>4.3 (2-11, 1.5)</td>
<td>4.8 (2-16, 2.5)</td>
<td>4.1 (2-10, 1.4)</td>
<td>0.11</td>
</tr>
<tr>
<td>Complications** (%)</td>
<td>14.6</td>
<td>9.5</td>
<td>1.4</td>
<td>0.02</td>
</tr>
</tbody>
</table>

*Total product transfused is the sum of blood products and cell saver
**Includes dural injury, wound infection, and screw placement.
***Range and standard deviation listed in parenthesis

Table 3: Surgical Complications

<table>
<thead>
<tr>
<th></th>
<th>Open PLF</th>
<th>Open PLIF/PLF</th>
<th>MIS TLIF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dural Tear</td>
<td>3</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Wound Infection</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Screw Placement</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
surgical complications than the traditional open PLF and open PLIF/PLF procedures.

Recent reviews of the literature have been inconclusive regarding the perioperative outcomes of PLIF and PLF. One study demonstrated similar operative times and blood loss between the groups with a shorter length of stay associated with the PLIF group\(^\text{15}\). A recent meta-analysis by Liu et al. examined four randomized clinical trials and five comparative observational studies. The authors concluded that there was no difference between PLF and PLIF in regards to blood loss, complications, or operating time\(^\text{15}\). Comparisons between TLIF and PLIF have been inconclusive in the literature as well. Recent retrospective reviews have claimed that TLIF is generally associated with shorter operative times, less blood loss, and equivocal findings in regards to complications\(^\text{3,14}\). Studies regarding MIS techniques compared to open techniques have been more homogenous in their results. Dhall et al. retrospectively compared MIS TLIF and open TLIF and demonstrated a lower blood loss (194 cc vs. 505 cc), shorter length of stay (3.0 days vs. 5.5 days), and a higher rate of hardware-related complications with MIS TLIF\(^\text{15}\). Other studies have also demonstrated a lower blood loss and shorter length of stay with MIS TLIF when compared to open TLIF\(^\text{16,17}\). Our findings are most in accordance with the literature. The increased blood loss associated with the open PLIF/PLF is expected given greater dissection and more surgical procedures being performed; however, there was a slightly higher complication rate with open PLF compared to open PLIF/PLF. With a limited cohort size, this difference may be a result of type I error.

The additional costs associated with blood product transfusion should also be considered. In a recent cost-benefit outcome study, the average cost of cell saver was $512 per patient transfusion and $250 per unit of allogeneic blood replaced\(^\text{18}\). In another study examining the use of cell saver in single-level spine surgery, the authors concluded that with cell saver there was an additional cost of $722 per surgery and no significant reduction in blood loss or need for transfusion\(^\text{19}\). A systematic review by Elgafy et al. determined that the rate of blood transfusion with spinal fusion (including primary and revision procedures, anterior/posterior/combined approaches, and multi-level fusions) may be as high as 50-81%. The authors also noted that there is weak evidence to support the use of agents to reduce intra-operative blood loss, in particular cell saver, recombinant factor VIIa, activated growth factor platelet gel, or normovolemic hemodilution\(^\text{20}\). As such, the surgical technique is an important variable in minimizing the morbidity and cost associated with blood product transfusion.

There are limitations to this study. It is a retrospective review and patient treatments were not randomized. Surgeries were conducted by six surgeons across two hospitals. Our outcomes were limited to only length of stay, blood loss and transfusion, and certain complications during hospitalization. We chose to focus on four specific complications because we felt that they best represented potential differences between open and MIS techniques. Neither long-term outcome measures nor radiographic data were studied past the date of discharge from the hospital. However, the goal of this study was to examine the early post-operative outcomes, in particular blood loss and complications during hospitalization, from the listed procedures. Our study was properly controlled based on age, BMI, and gender, and all surgeries were single-level, primary fusions to minimize confounding variables.

Our results indicate that MIS TLIF has less blood loss, blood product transfusion, wound complications, dural injury, and screw malposition when compared to open procedures. With the lack of long-term clinical and radiographic data, it is not possible to state whether one procedure is superior to another, and this decision should be based on surgeon preference and experience. The data indicate that MIS TLIF is at least as safe as open PLF and open PLIF/PLF. These findings may help surgeons in planning their surgical approach in patients who may be candidates for lumbar decompression with fusion, and underscores the importance of learning and teaching MIS techniques during surgical training.

REFERENCES


ABSTRACT
Background: Few references are available describing the epidemiology of pediatric spine injuries. The purpose of this study is to examine the prevalence, risk factors and trends during the period from 1997 to 2009 of pediatric spine injuries in the United States using a large national database.

Methods: Data was obtained from the Kid’s Inpatient Database (KID) developed by the Healthcare Cost and Utilization Project (HCUP), for the years 1997-2009. This data includes >3 million discharges from 44 states and 4121 hospitals on children younger than 20 years. Weighted variables are provided which allow for the calculation of national prevalence rates. The Nationwide Emergency Department Sample (NEDS), HCUP.net, and National Highway Traffic Safety Administration (NHTSA) data were used for verification and comparison.

Results: A prevalence of 107.96 pmp (per million population) spine injuries in children and adolescents was found in 2009, which is increased from the 77.07 pmp observed in 1997. The group 15 to 19 years old had the highest prevalence of all age groups in (345.44 pmp). Neurological injury was present in 14.6% of the cases, for a prevalence of 15.82 pmp. The majority (86.7%) of these injuries occurred in children >15 years. Motor vehicle collisions accounted for 52.9% of all spine injuries, particularly in children >15 years. Between 1997 and 2009 the hospital length of stay decreased, but hospital charges demonstrated a significant increase.

Conclusions: Pediatric Spine Injuries continue to be a relevant problem, with rates exceeding those of other industrialized nations. Teenagers >15 years of age were at greatest risk, and motor vehicle collisions accounted for the most common mechanism. An increase in prevalence was observed between 1997 and 2009, and this was matched by a similar increase in hospital charges.

Level of Evidence III.

INTRODUCTION
There are very few references describing the epidemiology of spinal injuries in children and adolescents, and even fewer that are based on population studies. During this past decade, children have been increasingly exposed to high-speed recreational vehicles and high-velocity sports. During this same period, automobile safety regulations have gone through several modifications, at both the federal and state levels. This includes the enforcement of seat belts and new infant booster seat regulations. Furthermore, instant message texting has become an increasingly deadly habit, and organized competitive sports have also been subject to changes in regulations, fair-play and novel safety equipment.

Thus, an updated analysis of the epidemiology of pediatric spine injuries should be a valuable tool for multiple stakeholders, including physicians, policy makers, law enforcement, and the safety industry. Therefore, the purpose of this study was to examine the prevalence, risk factors and trends in pediatric spine injuries from a large national database.

MATERIALS AND METHODS
The Kids’ Inpatient Database (KID) is a data subset from the National Inpatient Sample, developed by the Agency for Healthcare Research and Quality (AHRQ), as part of the Healthcare Cost and Utilization Project (HCUP). This Federal-State-Industry partnership consists of the collaboration of data from 4121 hospitals in 44 states, and includes children younger than 20. The total number of non-birth discharges during this study period includes 3,380,676 discharges. The Kids’ Inpatient Database (KID) is the only all-payer pediatric inpatient care database in the United States. Its large sample size is ideal for developing national and regional estimates. The overall design objective was to select a sample of pediatric discharges that accurately represents the target universe of U.S. community, non-rehabilitation hospitals. Moreover, this sample was to be geographically dispersed, yet drawn exclusively from hospitals in
The estimated US population by July 1, 2009 was 306,553,824 and the states participating in the KID database include 96% of the US population, or 294,588,026. In that same year, the estimated population 0 – 19 years of age included 83,420,691 children. Proportionally, the 44 KID states represent a pediatric population of 80,167,284. The prevalence data that is presented has been adjusted for the US population estimates for different age group categories (Chart 1) by means of the discharge weight variable (DISCWT). This variable has been estimated to weight discharges in the KID core files to represent pediatric discharges from all U.S. community, non-rehabilitation hospitals.

To ensure that the weighted calculations are accurate, we compared the prevalence data to NIS data, as well as to National Emergency Department Sample (NEDS), using the HCUPnet online query system (http://www.hcupnet.ahrq.gov). The HCUPnet is a Web-based query tool for identifying, tracking, analyzing, and comparing statistics on hospitals at the national, regional, and State level.

The KID dataset was analyzed with the SAS (SAS Institute Inc. SAS Campus Drive Cary, NC) statistical software package. We searched for the International Classification of Diseases – 9th Revision – Clinical Modification (2009 ICD-9CM) diagnostic codes of cervical spine injuries, dorsal or thoracic spine injuries and lumbar spine injuries (see appendix 1), for the years 1997-2009. Procedural codes were also examined and included spine-injury specific treatment codes (see appendix 2). Data is presented as means and 95% Confidence Limits. Ordinal variables were compared with the Rao-Scott Chi-Square test, and means were compared with the student’s t-test. Statistical significance was considered for p<0.001.

RESULTS

A total of 6191 hospital discharges with an ICD9 diagnosis of spinal injury were identified in 2009. The corresponding weighted frequency is 9007, representing a national prevalence of 107.96 per million for the reference population under age 20 years, for the year 2009. The trend from 1997-2009 is presented in Chart 1.

The gender distribution consisted of 60.5% males and 39.5% females, and did not vary significantly across different age groups. Children between ages of 15 - 20 years accounted for 82.9% of all spinal injuries, reflecting significant variation in the prevalence of spine injuries across different age tiers: The group 0 – 4 years of age, presented with a prevalence of 9.80 per million population (pmp); between ages 5 – 9, the prevalence was 17.22 pmp; between ages 10 – 14, the prevalence increased to 50.22 pmp; and finally, in the group 15 years or older, the prevalence had a seven fold increase to 345.44 pmp (Chart 1).

Neurological Injury

Of the 6191 spine injuries, 905 resulted in neurological injury (14.6%) with a prevalence of 15.82 pmp. The majority of these injuries (86.7%) occurred in children older than 15 years of age, which is proportional to the overall prevalence of spinal injuries in this age group (82.9%).
Across all age groups, 53.8% of all neurological injuries occurred as a consequence of a cervical spine injury, followed by 29.5% in thoracic spine injuries and 16.7% in lumbar spine injuries. For patients with neurological injuries, there were also differences in the anatomical location of the injury by age group. The primary anatomical location resulting in neurological injury was cervical for the 0 – 4 year old patients (67%) followed by the 5 – 9 year old group (62%). Cervical injuries accounted for approximately half of the neurologic injuries in other age groups (Chart 3).

**Risk Factors**

The accidents that resulted in spinal injuries in children were related to alcohol abuse in 7.3% (472) of the cases, and to drug abuse in 5.6% (355) of the cases. Motor vehicle collisions accounted for 52.9% of all spine injuries. This was particularly relevant for children older than 15, where motor vehicle collisions accounted for 56.2% of all injuries in this age group (Chart 4). In fact, motor vehicle collisions in this age group represented the largest risk segment. Specifically, there were 2889 spinal injuries related to motor vehicle collisions in children over 15 years of age, which accounts for 46.6% of the total spine injuries combined for all age groups.

**Treatment**

Of the 6191 identified children with spine injuries, 40.9% (2529 cases) did not require any specific procedure or intervention beyond those required for diagnostic purposes or for the treatment of other concomitant injuries. Of the remaining 3662 patients, 14.8% (913 cases) required one procedure or intervention for the treatment of the spine injury, 8.0% (498 cases) required two procedures, and the remaining 36.3% (2251 cases) required three or more procedures. The specific type of procedural intervention was not reported.

The group of children with spine injuries that required at least one procedure for the treatment of this particular injury had a significantly longer length of hospital stay (LOS) (8.36 days (95% CI 7.97 – 8.74)) than that of the group that did not require any specific procedures (2.57 days (95% CI 2.45 – 2.70), p<0.0001. Similarly, the total hospital charges (TOTCHG) were also significantly higher for the group that required at least one procedure or intervention for the treatment of the spine injury ($104,675 (95% CI $100,239 - $109,110)), when compared to the group that was treated without requiring any intervention ($21,832 (95% CI $21,157 – $22,507)), p<0.0001 (Chart 5). The average length of hospital stay (LOS) was found to be progressively shorter over the years 1997 to 2009 for both groups: the group that required at least one procedure (9.46 days in 1997 vs. 8.36 days in 2009; p=0.0432) as well as the group that was treated without spine specific procedures (5.51 days in 1997 vs. 2.58 days in 2009; p<0.0001) (Chart 5). During the same period the average charges for each hospitalization increased significantly for both groups, but disproportionally more so for the group with spine specific procedures ($36,890 in 1997 vs. $104,675 in 2009; p<0.0001) when compared
to the group treated without spine specific procedures ($9,864 in 1997 vs. $21,832 in 2009; p<0.0001).

Comparison With Other Databases
To ensure the accuracy of our calculations, the adjusted frequency of injuries to the spine that we are currently reporting (9,007 cases) was corroborated with alternative data sources. A query of the HCUPnet dataset for the year 2009 identified a weighted frequency of 8,749 children with spinal injuries, closely resembling the frequencies described in the current report. Similarly, the Nationwide Emergency Department Sample (NEDS) reveals that there were 6,635 children (0 – 17 years of age) that were admitted to hospitals with the diagnosis of a spinal injury. This figure also closely resembles our findings.

DISCUSSION

Few population-based studies exist on spinal trauma and spinal cord injuries in children and adolescents. The present report is based on a large, representative sample of the US population under the age of 20, and demonstrates a prevalence of spine injuries in children of 107.96 pmp (per million population) during the year 2009. To our knowledge, the only previous reports based on national databases include a US (1997 – 2000) report on pediatric spinal cord injuries, and a recent national database study from Finland (Table 1) which reports a prevalence of traumatic spine injuries in children younger than 18 during the period 1997 – 2000 of 66 pmp. In contrast, our study suggests a prevalence that is 61.1% higher.

The prevalence of traumatic spine injuries with concomitant neurological injury in the current report is 15.82 pmp in 2009. This is slightly lower than the prevalence from the 1997 – 2000 KID report [4] of 19.9 pmp. Although this appears to be a positive trend, these figures are significantly higher than those reported in Finland (1.9 pmp), Canada (1.0 pmp) and Sweden (2.4 pmp) during similar time periods.

Teenage driving was found to be a significant component of spinal injuries in children and adolescents. Our data suggests that 52.9% of all spine injuries were related to motor vehicle collisions (MVC’s). MVC’s in teenagers >15 years of age accounted for 46.6% of all spine injuries, being the single most important risk factor for spinal injuries in children and adolescents (Chart 4). Previous report of spinal cord injuries in children and adolescents from the National Trauma Databank revealed that 56% of these injuries occurred as a consequence of a MVC, closely resembling the data from the current report. Similarly, a report from the Canadian National Trauma Registry (1998) shows that pediatric spinal cord injuries increase from 1pmp to 17pmp for young adults (15 – 40 years old), which coincides with the legal driving age in Canada (17 years of age).^4^ According with the National Highway Traffic Safety Administration (NHTSA), motor vehicle collisions are the leading cause of injuries and death for teenagers (15 – 20 years of age) in the United States. Teenage driving accounts for 35% of all deaths in the 15 – 20 year age group. Interestingly, the report from the U.S. Department of Transportation shows a marked spike in motor vehicle injury rates in the 15 – 20 year old age group, again, coinciding with the legal driving age. This spike in motor vehicle related injuries parallels the sharp increase in spine injuries in children and adolescents described in this report (Chart 6).

Inexperience, immaturity combined with speed, driving under the influence of alcohol or drugs, non-compliance with seatbelt use and distracted driving are the leading factors associated to this problem. In 2006, 25% of teenage drivers (15 – 20) who were killed in motor vehicle collisions had a blood alcohol levels >0.08. In fatal motor-vehicle crashes, the majority of teens (16 to 20 years old) continue to be unbuckled (56% in 2009). In our report, we found alcohol to be present in 7.3% of all traumatic spine injuries, and drugs to be present in 5.6% of the cases. We were unable to determine if these cases were also those with injuries related to motor vehicle collisions.

The anatomical distribution of the injuries varied accordingly with the different age groups. In patients 0 – 4 years of age, cervical spine injuries were the most common (53%), while in all other age groups, lumbar spine injuries were the most common. Similar results have been previously described. In a study from Finland^3^, the proportion of cervical spine injuries decreased from 64% in smaller children, to 25% after the age of 8. Similarly, Platzer^1^ reported from the Vienna General Hospital trauma registry, that 37% of the spinal injuries in children occurred in the cervical spine.
Even though the length of hospital stay (LOS) has decreased over the years (1997 to 2009) for patients with spine injuries the charges for these hospitalizations has increased significantly, particularly for those patients that required at least one procedure for the treatment of the spinal injury (Chart 5). Further research is needed to dissect the exact reasons for this trend. It may be related to a cost effect or to changes in healthcare utilization patterns. The children that were subject to procedures were not only costlier, but also required significantly longer Length of Hospital Stays. Also, it should be specifically noted that hospital charges are not the same as hospital costs. Charges represent the bill that is sent to the payor, and it is common for the hospital to be reimbursed only a small portion of the actual bill, or in some cases to receive no reimbursement at all. Thus, the charge data presented here may be useful in establishing an economic trend, but readers should realize that hospitals and physicians are not actually compensated these amounts, and the services do not actually cost as much as the charges that are presented here.

Although this study has the advantage of a large representative sample of the United States Population, it presents several limitations: First of all, the KID sampling frame has a disproportionate representation of the more populous states, which thus contain hospitals with more annual discharges. The frequencies represent hospital discharges, and not patients. The prevalence data may be affected by hospital coding, and is also affected by patients with multiple admissions. The KID sample does not include a uniform patient identifier that can allow a patient-level analysis. The database only contains 15 diagnosis codes for each case. In the case of multiple-trauma victims, there is a small likelihood that the spine injury was not represented in the codes. Finally, it must also be noted that spine injuries in fatal accident victims that did not reach the hospitals were not included. This effect is most likely minuscule due to the fact that pediatric injury victims are usually always coded and transported to the nearest hospital, even if they have been fatally stricken.

We conclude that Pediatric Spine Injuries continue to be a relevant problem, with exceedingly higher rates than those of other developed nations. The most relevant risk factor was found to be teenage driving. A sharp spike in the prevalence of these injuries after age 15 is paralleled by other data sources, such as the NHTSA for comparable time periods. Although the average length of stay has decreased, the overall hospital charges have increased.

REFERENCES
ABSTRACT
Chemotherapy derivatives of the rabbit posterolateral fusion model are considered a challenging environment in which to test bone graft materials. The purpose of this study was to determine the performance characteristics of SiCaP-30 as a bone graft substitute relative to autograft (iliac crest bone graft [ICBG]), Actifuse ABX and β-Tricalcium Phosphate-Bioactive Glass-Type I Collagen (βTCP-BG) in a rabbit posterolateral spine fusion model with concurrent chemotherapy treatment. This was a randomized, controlled study in a laboratory setting with blinded assessment of fusion by manual palpation and flexibility testing. Sixty rabbits were entered into the study with 45 used for analysis. Chemotherapeutic agents, doxorubicin and cisplatin (2.5 mg/kg), were administered one week prior to surgery, and one, two and three weeks post surgery. Bilateral posterolateral lumbar intertransverse process fusions were performed at L5-L6. The lateral two thirds of the transverse processes were decorticated and covered with 3cc/side of one of the following graft materials: autologous ICBG, Actifuse ABX (ApaTech Ltd, UK), Vitoss BA (Orthovita, USA) or SiCaP-30 (ApaTech Ltd., UK). Animals were euthanized 12 weeks post surgery. The ICBG group had a 45% (5/11) manual palpation fusion rate and correlated with motion analysis fusion results of 36% (4/11). The Actifuse ABX group had a 33% (4/12) manual palpation fusion rate and a motion analysis fusion rate of 25% (3/12). No motion segments in the Vitoss BA group (0/11) showed any signs of fusion. The SiCaP-30 group demonstrated a statistically higher manual palpation and motion analysis fusion rate of 82% (9/11; p<0.05) and produced superior bone formation compared with Actifuse ABX and βTCP-BG.

Key words: posterolateral fusion, silicate-substitute, lumbar spine, bone substitute, SiCaP-30

INTRODUCTION
Iliac crest autograft is considered the gold standard bone graft material for lumbar spinal surgery despite limitations in the quantity available and complications associated with the harvesting procedure. These disadvantages have motivated clinicians and investigators to seek alternative graft materials to extend, enhance and/or substitute for autograft sources. Numerous alternatives include: allografts, synthetic materials and recombinant human bone morphogenetic proteins (rhBMPs). Several synthetic bone graft substitutes have been developed that are designed to address the limitations associated with using human donor material. Recent concerns for BMP-related tumorigenesis have spurred investigators to consider osteoconductive materials as alternatives to traditional bone grafts. Silicate-substituted calcium phosphate (SiCaP) is a synthetic bone graft substitute which has demonstrated a similar efficacy to autograft material in ovine fusion models. A more recent study has reported similar fusion rates between SiCaP and iliac crest autograft in a rabbit posterolateral fusion model.

Synthetic bone graft substitutes based on hydrated calcium phosphate hydroxyapatite (HA; Ca$_{10}$(PO$_4$)$_6$(OH)$_2$) have been used in bone repair surgery for many years. Porous HA has a similar chemical composition and structural features to bone, and has been designed to have qualities that promote bone ingrowth after implantation. Numerous attempts have been made to identify the properties that promote the osteostimulatory and osteointegrative capacity of HA-based bone grafting material. For instance, partial substitution of phosphate with silicate (Si) within the HA lattice results in a significant enhancement in protein adsorption and subsequent osteoblastic cell attachment and proliferation compared with that seen on stoichiometric HA.
Furthermore, silicon-based HA (SiCaP) appears to direct the differentiation of mesenchymal stem cells towards an osteogenic lineage. SiCaP-30 differs from its direct control (Actifuse® ABX) in terms of the strut porosity (microporosity), but possessing similar macroporosity.

Chemotherapy derivatives of the rabbit posterolateral fusion model are considered a “step-beyond” the typical testing environment as they represent a greater challenge for bone formation and fusion, with the potential to push the limits of bone graft materials and may represent conditions of clinical co-morbidities. In this investigation we used a modified chemotherapy protocol described by Morcuende et al. that utilized multiple treatments of cisplatin and doxorubicin to slow the bone formation rate associated with healing grafts. Therefore, we hypothesized that a bone graft substitute with modified chemical and structural properties could increase bone formation in this challenging environment.

In this investigation, two silicon-based HA formulations (SiCaP-30 and Actifuse ABX) and a βTCP-bone graft material (Vitoss BA) were evaluated in a posterolateral spine fusion model with concurrent administration of chemotactic drugs.

**METHODS**

Sixty male skeletally mature New Zealand White rabbits weighing 4.5–5.5 kg were entered into the study. The number of animals in total and per group was determined by a power analysis to show a 20% difference in flexion/extension via biomechanical testing (alpha of 0.05 and a power of 90). All procedures were approved by the Institutional Animal Care Use Committee (#1003068) and conducted at The University of Iowa Department of Orthopaedics, Bone Healing Research Lab-Iowa Spine Research Center, USA. Throughout the study, animals were individually caged and monitored daily for signs of pain and discomfort.

The rabbits received cisplatin and doxorubicin intravenously (2.5 mg/kg) 7 days before surgery and again at 7, 14 and 21 days after the procedure. Blood was drawn from each rabbit prior to administration of cisplatin and doxorubicin. Complete blood panels and chemistries were used to assess the health status of the rabbits during the study. Rabbits in poor health were given 5% dextrose/lactated Ringers solution intravenously and other supplemental nourishment.

**Surgical procedure**

All operative procedures were performed in a surgical suite using inhalation anesthesia and aseptic techniques. A preanesthetic dose of Ketamine HCL 26 mg/kg, acepromazine maleate 0.15 mg/kg, and xylazine HCL 0.78 mg/kg was administered intramuscularly. Surgical anesthesia was maintained with 1.5–2.5% isoflurane delivered in oxygen. Cardiorespiratory monitoring was continued throughout the procedure.

A parenteral dose of cefazolin (20 mg/kg, intravenous) was administered for infection prophylaxis preoperatively and immediately postoperatively.

Rabbits were placed prone on the operating table and surgically prepped with 70% povidone-iodine solution. A single level posterolateral intertransverse process fusion was performed in 58 rabbits. A dorsal midline incision, approximately 15 centimeters long, was made from L1 to the sacrum and the soft-tissues overlying the transverse processes (TP) were dissected via separate bilateral fascial incisions. The transverse processes of L5 and L6 were decorticated with a high-speed burr. At no time were the vertebral bodies decorticated in the gutter of the motion segment.

For animals in the autograft group, approximately 2.5–3.0 cc of corticocancellous bone graft was obtained bilaterally from the iliac crest. This volume of graft is the maximum amount which can be harvested from the rabbit iliac crest without significant animal morbidity. This procedure typically results in fusion rates around 65% in healthy, non-treated rabbits and a 25–38% fusion rate when chemotactic drugs are administered prior to surgery. Investigational implant preparation of the SiCaP-30, Actifuse ABX and Vitoss BA was done according to manufacturer instructions. The implant materials were administered as stand-alone grafts that were not mixed with autologous bone nor autologous bone marrow aspirate. Approximately 3.0 cc of implant material was placed bilaterally. Animals were euthanized at 12 weeks post-surgery.

**Manual palpation analysis**

The primary outcome used to determine fusion was manual palpation and flexibility analysis. After removing the spine, fusion was graded by three independent blinded observers as ‘fused’ if no detectable motion was present at the treated segment when tested in flexion and extension. The fusion was graded as ‘not fused’ if motion was present. Final results were determined by agreement of at least two of the three observers.

**Mechanical testing**

Flexibility assessments of lumbar motion and stiffness involved biomechanical, non-destructive load testing. This was performed in flexion/extension, lateral bending and torsion to a pre-determined sub-failure load. Flexibility tests were conducted among five pure moments (0 Nm, 0.09 Nm, 0.18 Nm, 0.27 Nm, and 0.36 Nm) using a MTS 858 Bionix testing system, two MTS spine gimbals (six degrees of freedom devices) and an Optotak motion analysis system. During testing the specimens were kept moist with saline solution spray. Stiffness
was determined and compared with normal controls (10 normal rabbit lumbar columns), historic controls and literature. Motion segments were considered fused if motion was less than 5.5° in flexion/extension.

**Radiographic assessment**

All rabbits were radiographed at 0, 4, 6, 8 and 12 weeks post surgery. At the final interval, high resolution images of removed spines were judged by three blinded observers for radiographic fusion by evaluating for continuous trabecular bridging between the grafted transverse processes. The ability of the observers to accurately grade the fusion status was limited by the density of the grafts at the fusion sites and therefore radiographic fusion rates were not determined. Peripheral quantitative computer tomography analysis of all specimens was performed at 0 and 12 weeks (study end) to demonstrate quantitative change in bone mineral density over time.

**Histology**

Four specimens from each group were randomly selected for histological evaluation. Non-decalcified slides were prepared and stained with hematoxylin and eosin. Slides were evaluated for presence of inflammation, extent of graft remodeling, and general observations relevant to bone formation activity. New bone formation / bone maturation was scored on a scale of 0–4 where a score of 0 represented has less than 25% lamellar bone and a score of 4 greater than 75% lamellar bone in the paraspinal bed. Residual implant was also scored on a scale of 0–4 with 0 representing no remaining implant present and 4 having greater than 50% of the fusion mass containing residual graft. Fusion was scored using a scale of 1–10 where a score of 10 represented complete bridging of the TPs with mature bone.

### Statistical analysis

Fishers exact tests and T-tests were used to determine statistical differences between groups.

### Funding Source

An institutional grant was received from Apatech, LTD to support this research study.

## RESULTS

Fifteen rabbits were omitted from the study due to surgical and chemotherapy treatment complications, which included problems with graft harvest, low platelets, metabolic imbalances and infection. These complications appeared to be randomly distributed among the groups and were consistent with the type and rate of complications published previously by ourselves and others. The remaining 45 animals included in the analysis were evaluated by manual palpation, flexibility and histological criteria.

### Manual palpation assessment of fusion

At 12 weeks post surgery, manual palpation of the treated motion segment demonstrated successful fusion in 45% (5/11) of the autograft group, 33% (4/12) in the ACTIFUSE ABX group and 0% (0/11) in the Vitoss BA group. In contrast the SiCaP-30 group demonstrated successful fusion in 82% (9/11; Table 1). Incomplete fusions (pseudarthrosis) were highest in the Vitoss BA group, followed by the Actifuse ABX and autograft group and were lowest in the SiCaP-30 group.

### Mechanical testing of motion and fusion

Flexion-extension values were used to measure the motion of the lumbar spine. The SiCaP group had a reduced range of motion compared with the other treatment groups; this difference achieved statistical significance (Figure 1). Individual animals in all treatment groups were compared with normal motion was of the lumbar spine, determined by measuring the flexibility.
Assessment of SiCaP-30 in a Rabbit Posterolateral Fusion Model

Table 2. Physiologic range of motion of normal, pseudarthrosis and fused spine

<table>
<thead>
<tr>
<th>Flexion/Extension</th>
<th>ICBG</th>
<th>Vitoss BA</th>
<th>ACTIFUSE ABX</th>
<th>SiCaP-30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>9.906 (± 2.13)</td>
<td>6.939 (± 1.15)</td>
<td>9.391 (± 4.05)</td>
<td>7.58 (± 0.88)</td>
</tr>
<tr>
<td>Pseudarthrosis</td>
<td>4.518 (± 2.12)</td>
<td>n/a</td>
<td>4.122 (± 2.63)</td>
<td>2.805 (± 1.21)</td>
</tr>
<tr>
<td>Flexion/Extension</td>
<td>36 (4/11)</td>
<td>0 (0/11)</td>
<td>25 (3/12)</td>
<td>82 (9/11)</td>
</tr>
</tbody>
</table>

ICBG= iliac crest bone graft; ROM = range of motion; Fusion was defined as less than 5.5° on flexion-extension testing; Superscript letters denote statistical differences between pairs with Fishers exact tests; * = P<0.002

Figure 2. Bone mineral density of the fusion mass. SiCaP-30 demonstrated the greatest change in bone density, followed by iliac crest bone graft, Vitoss BA and Actifuse ABX.

Table 3. Histological assessment’ of new bone formation, fusion, and residual implant

<table>
<thead>
<tr>
<th></th>
<th>Fusion Score</th>
<th>New bone formation/Bone Maturation</th>
<th>Residual Implant</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pseudarthrosis</td>
<td>Fused</td>
<td>Pseudarthrosis</td>
</tr>
<tr>
<td>ICBG</td>
<td>5.00 (n=2)</td>
<td>5.25 (n=2)</td>
<td>2.00 (n=2)</td>
</tr>
<tr>
<td>Vitoss BA</td>
<td>1.00 (n=4)</td>
<td>n/a</td>
<td>1.00 (n=4)</td>
</tr>
<tr>
<td>ACTIFUSE ABX</td>
<td>3.50 (n=2)</td>
<td>4.75 (n=2)</td>
<td>1.00 (n=2)</td>
</tr>
<tr>
<td>SiCaP30</td>
<td>4.50 (n=2)</td>
<td>5.00 (n=2)</td>
<td>1.00 (n=2)</td>
</tr>
</tbody>
</table>

* Fusion was scored using a 1–10 scale where a score of 10 was complete bridging of the TP's with mature bone. NBF was scored on a 0–4 scale. Residual implant was based on a range of 0–4 with a score of 4 having >50% of the implant present.

and mineral density determined. The SiCaP-30 and autograft group had the greatest bone mineral density increase from the day after surgery to time of euthanasia (+29% and +26%) followed by Vitoss BA (+18%) and Actifuse ABX (14%; Figure 2).

Histology

Blinded histological assessments were made on each histological specimen by a boardcertified veterinary pathologist (Table 3, Figure 3). There were no inflammatory reactions at the grafted sites regardless of implant.

DISCUSSION

This study followed on from a previous report that demonstrated similar fusion rates with SiCaP and ICBG in a non chemotherapy rabbit posterolateral fusion model. In the current investigation, fusion rates with the autograft group were diminished compared with historical controls, which is consistent with prior investigations utilizing chemotherapeutic models. Furthermore, SiCaP-30 treated animals had statistically significantly higher fusion rates than the Vitoss BA and Actifuse ABX control, when tested with manual palpation. Histological sectioning showed new bone formation was present in the autograft, Actifuse ABX and SiCaP-30 groups. In contrast, none of the samples from the Vitoss BA group demonstrated new bone within the graft material at the
have been used in bone repair surgery for many years\textsuperscript{29}. Porous HA has similar chemical composition and structural features to bone, and has been designed to promote bone ingrowth after implantation. Attempts have been made to identify the properties that promote the osteostimulatory and osteointegrative capacity of HA-based bone grafting material\textsuperscript{30}. For instance, partial substitution of phosphate with silicate (Si) within the HA lattice results in enhanced protein adsorption\textsuperscript{31}, osteoblastic cell attachment and proliferation\textsuperscript{32} compared with that seen on stoichiometric HA. Furthermore, silicate-based HA (SiCaP) appears to direct the differentiation of mesenchymal stem cells towards an osteogenic lineage\textsuperscript{35}. These properties are believed to be partly responsible for the SiCaP matrix supporting faster repair rates and increased levels of bone ingrowth and apposition than pure phase HA\textsuperscript{34,35}. In a study by Hing et al., SiCaP permitted cell-mediated resorption of the scaffold itself and of new bone, which contributed to the production of a functional repair within the defect site\textsuperscript{36}. Optimal levels of Si substitution appear to be in the region of 0.8 wt% Si (2.6 wt% silicate) for beneficial effects on bone formation\textsuperscript{36}. In this investigation, two silicon-based HA formulations were evaluated; SiCaP-30 and Actifuse ABX which differed in strut porosity (microporosity), but possessed similar macroporosity.

In structural terms, a pivotal characteristic of synthetic bone grafts is their level of strut (micro) porosity (pores <50 µm in size) and macroporosity (pores >50 µm in size). Strut pores are formed from the interconnected spaces existing between particles of calcium phosphate which have been sintered together to form the struts in the scaffold of calcium phosphate biomaterials. The term “strut porosity” refers to the average pore volume fraction within the struts that form the walls around the macropores. These properties relate directly to the subsequent speed and degree of vascularization of the bone graft. Graft vascularization supports the proliferation and differentiation of osteoblasts and new ingrowth into the graft material itself\textsuperscript{27}.

Previous studies using different bone grafting materials have shown that greater levels of strut porosity appeared to promote faster apposition of larger volumes of new bone with a denser morphology\textsuperscript{27,38}. A more recent study, using the ovine critical size defect model, showed that increasing the strut porosity in a SiCaP scaffold from 23% to 32–46%, promotes bone apposition without significantly affecting the stability of the graft\textsuperscript{30}. This study showed that graft materials with higher strut porosities showed more advanced neovascularisation and increased bone contact. It was also demonstrated that SiCaP scaffolds with higher strut porosities (32–46%) had statistically significant increased absolute bone formation of new bone in the Actifuse ABX, SiCaP-30 and ICBG treated groups. No new bone formation was evident in the Vitoss BA group. Both the Actifuse ABX and SiCaP-30 groups had new bone formation in direct apposition to the ceramic granules and connecting individual granules to adjacent granules.

12-week time point. Each of the examined Vitoss BA specimens only had evidence of fibrous tissue within the graft material, indicative of a low healing rate. The histological results correlated with the incidence of fusion reported with manual palpation and flexibility testing. In addition none of the evaluated graft materials in this study showed evidence of inappropriate inflammatory reactions.

Chemotherapeutic agents widely used for the treatment of cancerous lesions are known to delay or decrease the rate of bone healing\textsuperscript{23}. Several studies in both humans and animals have demonstrated that chemotherapeutic drugs can have a significant negative impact in fracture healing and limb-salvage procedures\textsuperscript{24,25}. The anti-proliferative, anti-angiogenic and cytotoxic properties of chemotherapeutic agents negatively impact neovascularization, proper callus formation, and host-bone allograft incorporation resulting in lower rates of bone apposition\textsuperscript{24,25}. Several studies in animal models demonstrated that exposure to chemotherapeutic drugs such as doxorubicin, cyclophosphamide and methotrexate are associated with decreased bone formation and healing\textsuperscript{24,25}. In the rabbit posterolateral fusion model, autograft fusion rates decreased significantly when a single dose of doxorubicin was given intravenously at time of surgery\textsuperscript{20,21}.

Synthetic bone graft substitutes based on hydrated calcium phosphate hydroxyapatite (HA;Ca$_{10}$(PO$_4$)$_6$(OH)$_2$)
volumes compared with SiCaP scaffolds with a strut porosity of 23%, and that sites treated with 32% and 46% strut porosity grafts had achieved a greater equilibrium level of bone formation throughout the defect site. An interesting corollary to our biomechanical findings was the failure to achieve agreement with the radiographic assessments and biomechanical testing. Many synthetic graft materials have a high level of radiodensity on plain films. This investigation showed a trend towards overprediction of fusion based upon plain films alone. This finding is not unique and has been noted in other investigations of HA and HA/β-TCP formulations in our laboratory. Histological sectioning was performed on four specimens in all test groups. While this sampling may not be fully representative of the histological healing of these materials, it did give some insight into the healing process of each group at 12 weeks.

In conclusion, the rabbit chemotherapy model used in this study demonstrated that autograft had a diminished healing rate in comparison with published historical rates. The highest fusion rates were observed with SiCaP-30 which also correlated with the lowest lumbar motion. Actifuse ABX and ICBG had similar healing rates and Vitoss BA had little evidence of healing. The results emphasize the efficacy of the chemotherapy model for investigating the performance characteristics of bone graft substitutes and overall rates of healing. Although, further investigations in higher order animal species are required, modified silicate-substituted graft materials in the form of macro and microporosity may have significant bearing on their healing characteristics in challenging fusion models.

ACKNOWLEDGEMENTS

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REFERENCES


ABSTRACT

Background: Although outcomes following spinal fusion for intervertebral disc disorders have been studied, factors influencing discharge disposition and health care resource utilization have not been determined. This study sought to clarify perioperative risk factors for non-routine discharge and prolonged hospital stay in patients undergoing fusion for intervertebral disc disorders.

Methods: The National Hospital Discharge Survey was queried to identify all patients discharged from U.S. hospitals following spinal fusion for intervertebral disc disorders between 1990 and 2007. A cohort representative of 1,943,707 patients was identified and separated into those who were discharged home and those who were discharged to rehabilitation facilities. Multivariable logistic regression analysis was used to identify independent predictors of non-routine discharge to another inpatient facility and prolonged hospital stay.

Results: The strongest risk factors for non-routine discharge were age>65 years, congestive heart failure, atrial fibrillation, any general in-hospital complication, diabetes mellitus, osteoporosis, hypertension and any surgery-related complication. Patients younger than 50 years and males had the lowest rate of non-routine discharge. The strongest risk factors for prolonged hospital stay were any surgery-related complication, congestive heart failure, any general in-hospital complication, atrial fibrillation, age > 65 years, osteoporosis and diabetes mellitus. Patients 36-50 years of age had the lowest risk of increased length of hospital stay.

Conclusions: Knowledge of these risk factors may aid in better resource allocation and improved strategies for managing patients with spondylosis in order to decrease healthcare costs.

Key words: spinal fusion; intervertebral disc disorder; discharge; length of stay; hospital stay; comorbidities; post-hospitalization care; epidemiology

Level of evidence: 3

INTRODUCTION

Intervertebral disc disorders are a common cause of pain that affects mobility and quality of life and are increasing in prevalence1-3. Spinal fusion is often utilized for treatment of intervertebral disc disorders and studies have demonstrated improved outcomes in bodily pain and physical function compared to conservative therapy among persistently symptomatic patients who have failed nonoperative management4,5. Factors influencing clinical outcomes and operative success among patients undergoing spinal fusion have been studied at length6-8. However, risk factors for nonroutine discharge to other inpatient facilities and variables associated with prolonged hospital stays have not been identified. Early hospital discharge to home has been shown to be an important contributor to better postoperative outcomes, improved quality of life and less health care resource utilization among orthopaedic patients9,10. Knowledge of risk factors associated with nonroutine discharge and prolonged hospital stays may help identify patients at greater risk of prolonged post-hospitalization care, which may aid in proper resource allocation and reduce healthcare costs.

This study sought to identify risk factors associated with nonroutine discharge to inpatient facilities in patients undergoing spinal fusion for intervertebral disc disorders. We also sought to analyze variables associated with prolonged hospital stay and increased post-hospitalization utilization.

METHODS

National Hospital Discharge Survey

The National Hospital Discharge Survey (NHDS), developed by the National Center for Healthcare Statistics division of the Centers for Disease Control and Prevention (CDC)12, was used to estimate incidence and
to evaluate risk factors for nonroutine discharge and prolonged length of hospital stay for patients undergoing spinal fusion for intervertebral disc disorders. The NHDS is a publically available survey providing demographic and medical data for inpatients discharged from non-federal, short stay hospitals in the United States. The NHDS is the principal database for the U.S. government to monitor hospital use and is considered the most comprehensive of all inpatient surgical databases. The survey uses International Classification of Diseases, 9th Revision, Clinical Modification (ICD-9-CM) codes to classify medical diagnoses and procedures. The NHDS uses a stratified, multistage probability design to collect demographic information (age, gender, race), expected source of payment (insurance status), medical information of up to seven discharge diagnoses and up to four procedures, length of care, hospital size, U.S. region, and inpatient outcomes including discharge destination.

To ensure an unbiased national sampling of inpatient records, the NHDS uses a three-stage probability design including: inflation by reciprocals of the probabilities of sample selection, adjustment for no response and population weighting ratio adjustments. This study did not require approval by the institutional review board because the NHDS is a publically available database with no patient identifying information.

**Patient selection**

All patients admitted to hospitals in the U.S. who underwent spinal fusion for intervertebral disc disorders between 1990 and 2007 were identified using ICD-9-CM codes. Discharges with a diagnosis code (ICD-9-CM) of displacement of cervical (722.0), thoracic/lumbar (722.1) or unspecified (722.2) intervertebral disc without myelopathy, degeneration of cervical (722.4), thoracic/lumbar (722.5), or unspecified (722.6) intervertebral disc, intervertebral disc disorder with myelopathy (722.7) or unspecified intervertebral disc disorder (722.9) were identified using previously described techniques. The database was subsequently queried to identify patients treated using spinal fusion (ICD-9 procedure code 81.0x). Patients were split into two groups: (1) patients discharged to home (routine discharge) after spinal fusion and (2) patients transferred to an inpatient facility (nonroutine discharge). Demographic variables were then collected including: age, sex, primary diagnosis, prevalence of comorbidities, length of stay, discharge destination, geographic region, hospital size, and insurance status. The complication screening package was used to determine the incidence of complications. The variable adverse event was created based on the variables: postoperative wound complication (998.3), postoperative bleeding (998.1), acute postoperative infection (998.5), acute postoperative anemia (285.1), acute renal failure (584), acute myocardial infarction (410), pulmonary embolism (415.1), induced mental disorder (293), pneumonia (480-486), pulmonary insufficiency (518.5), deep venous thrombosis (453.4), intubation (96. xx) and transfusion of blood (99.x).

**Statistical analysis**

Because of the large sample size, a normal distribution of the data was assumed. In bivariate analysis, the routine discharge and nonroutine discharge groups were compared using Pearson’s chi-square test for categorical data and independent-samples t test for continuous data. To determine independent predictors of nonroutine discharge to inpatient facilities, all variables present in at least 2% of the population were included in a multivariable binary logistic regression model. For in-hospital adverse events, a 1% cutoff was used due to their lower rates of occurrence, as previously described. A multivariable regression model allows for the control of potential confounders, isolating the effect of individual variables on inpatient outcomes. The dichotomous variables were 1) nonroutine discharge to inpatient facility and 2) prolonged hospital stay. We defined prolonged hospital stay when the average length of stay was greater than the 75th percentile, as previously described. Covariates accounted for in the regression model included: gender, age, region of the country, and pre-existing comorbidities (anemia, obesity, diabetes mellitus, hypertension, congestive heart failure, coronary artery disease, atrial fibrillation, prior myocardial infarction, and osteoporosis). To assess for the association between individual variables and inpatient outcomes, odds ratios and confidence intervals were calculated. A P value of <0.001 was used to define statistical significance, correcting for multiple comparisons, as previously described. United States census data were used to obtain national population estimates for each year of the study 1990-2007. Rates were presented as the number of fusions for every 100,000 standard population. All data were analyzed using the software-statistical package for social sciences [SPSS] version 20 (Chicago, IL, USA).

**Source of funding**

No external funding source was used for the conduct of this study.

**RESULTS**

**Incidence and Demographics:**

A cohort representative of 1,943,707 patients who underwent spinal fusion for intervertebral disc disorders was identified between 1990 and 2007, with the routine discharge group comprising 1,780,071 patients (91.6%) and the nonroutine discharge group comprising 65,966 patients (3.4%) (Table 1). The remaining 5.0% of patients...
Table 1: Characteristics for patients who underwent fusion for intervertebral disc disorders in the United States from 1990 to 2007

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Total 1990-2007 (%)</th>
<th>Discharge to Home (%)</th>
<th>Discharge to Inpatient Facility (%)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>N=</td>
<td>1,943,707</td>
<td>1780071</td>
<td>65966</td>
<td></td>
</tr>
<tr>
<td>% Total</td>
<td>100.0%</td>
<td>91.6%</td>
<td>3.4%</td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>50.8</td>
<td>51.8</td>
<td>33.1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Female</td>
<td>49.2</td>
<td>48.2</td>
<td>66.9</td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤35</td>
<td>14.7</td>
<td>15.3</td>
<td>3.6</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>36-50</td>
<td>48.6</td>
<td>50.6</td>
<td>21.0</td>
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<tr>
<td>51-65</td>
<td>26.7</td>
<td>26.7</td>
<td>27.4</td>
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<tr>
<td>&gt;65</td>
<td>10.0</td>
<td>7.4</td>
<td>48.0</td>
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<tr>
<td>Region</td>
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<td>Northeast</td>
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<td>14.6</td>
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<td>22.2</td>
<td>21.2</td>
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<tr>
<td>South</td>
<td>43.0</td>
<td>43.8</td>
<td>28.5</td>
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<tr>
<td>West</td>
<td>19.8</td>
<td>19.3</td>
<td>32.8</td>
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<tr>
<td>Bedsize</td>
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<td></td>
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<tr>
<td>6-99</td>
<td>4.0</td>
<td>4.1</td>
<td>5.1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>100-199</td>
<td>23.2</td>
<td>23.4</td>
<td>25.9</td>
<td></td>
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<tr>
<td>200-299</td>
<td>27.6</td>
<td>27</td>
<td>32.5</td>
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<tr>
<td>300-499</td>
<td>29.7</td>
<td>29.9</td>
<td>23.4</td>
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<tr>
<td>500 or more</td>
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<td>15.6</td>
<td>13.1</td>
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<td>Insurance</td>
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<tr>
<td>Medicare</td>
<td>13.7</td>
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<tr>
<td>Medicaid</td>
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<td>4.7</td>
<td>6.3</td>
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<tr>
<td>Workmens comp</td>
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<td>16.1</td>
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<tr>
<td>Private</td>
<td>56.4</td>
<td>58.4</td>
<td>30</td>
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</tr>
<tr>
<td>Self pay</td>
<td>1.9</td>
<td>2.1</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>7.6</td>
<td>5.8</td>
<td>4.4</td>
<td></td>
</tr>
<tr>
<td>Not stated</td>
<td>1.9</td>
<td>1.8</td>
<td>0.8</td>
<td></td>
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<tr>
<td>Primary Diagnosis</td>
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<td></td>
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<tr>
<td>722.0x cervical disc displacement</td>
<td>41.1</td>
<td>43.4</td>
<td>7.4</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>722.10 lumbar disc displacement</td>
<td>20.0</td>
<td>19.2</td>
<td>29.8</td>
<td></td>
</tr>
<tr>
<td>722.52 lumbar disc degeneration</td>
<td>18.9</td>
<td>17.8</td>
<td>33.7</td>
<td></td>
</tr>
<tr>
<td>722.71 cervical disc disorder with myelopathy</td>
<td>7.6</td>
<td>7.4</td>
<td>10.7</td>
<td></td>
</tr>
<tr>
<td>722.4x cervical disc degeneration</td>
<td>5.3</td>
<td>5.6</td>
<td>2.8</td>
<td></td>
</tr>
<tr>
<td>Comorbidities</td>
<td>27.6</td>
<td>25.7</td>
<td>58.5</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Adverse Events</td>
<td>8.1</td>
<td>6.9</td>
<td>20.6</td>
<td>&lt;0.001</td>
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<td>Discharge Disposition</td>
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<tr>
<td>Routine/home (1)</td>
<td>91.6</td>
<td>100</td>
<td>-</td>
<td>&lt;0.001</td>
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<tr>
<td>Left AMA (2)</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Short term fac (3)</td>
<td>1.2</td>
<td>-</td>
<td>35.4</td>
<td></td>
</tr>
<tr>
<td>Long term fac (4)</td>
<td>2.2</td>
<td>-</td>
<td>64.6</td>
<td></td>
</tr>
<tr>
<td>Alive, not stated (5)</td>
<td>3.6</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Dead (6)</td>
<td>0.1</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Not reported (9)</td>
<td>1.3</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Age (years), mean (SD)</td>
<td>47.83(12.26)</td>
<td>46.90(11.48)</td>
<td>61.62(14.22)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Days of Care, mean (SD)</td>
<td>3.41(1.25)</td>
<td>3.15(3.50)</td>
<td>7.10(7.73)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

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were excluded from the subgroup analysis because their discharge status was either alive with no discharge status stated (3.6%), dead (0.1%) or not reported (1.3%) (Table 1).

Patients in the nonroutine discharge group were mostly female (66.9% vs 48.2%, P < .001), were significantly older (62 ± 14 years vs 47 ± 11 years, P < .001; 48% >65 years vs 7.4% >65 years, P < .001), living in the West (33% vs 19%, P < .001), and mainly admitted to medium-sized hospitals with 200-299 beds (32.5 vs 277%; P < .001) compared to patients in the routine discharge group.

Length of hospital stay was 7.1 ± 7.7 days in the nonroutine discharge group and 3.2 ± 3.5 days in the home discharge group. The most common primary diagnosis in the nonroutine discharge group was lumbar disc degeneration (33.7% vs 17.8%; P < 0.001) followed by lumbar disc displacement (29.8% vs 19.2%; P < 0.001) compared with the routine discharge group. Among patients in the nonroutine discharge group, Medicare was the most common form of payment (51.6% vs 11.2%; P < 0.001) compared with the routine discharge group (Table 1).

The incidence of patients undergoing spinal fusion for intervertebral disc disorders increased from 23.2 per 100,000 capita in 1990 to 53.3 per 100,000 capita in 2007. From 1990 to 2007 there was in increase in comorbidities (9.9% vs 45.2%; P < 0.001), adverse events (2.7% vs 7.3%; P < 0.001) and blood transfusions (0.6% vs 2.0%; P < 0.001). Nonroutine discharge to inpatient facilities increased from 3.3% in 1990 to 5.5% in 2007 while mean days of in-hospital care decreased from 5.9 ± 4.1 in 1990 to 3.2 ± 3.0 in 2007 for the entire patient cohort (Table 2).

### Table 2: Characteristics in 1990, 1995, 1999, 2003 and 2007 among patients who underwent fusion for intervertebral disc disorders. SD, Standard deviation

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>65510</td>
<td>70669</td>
<td>116904</td>
<td>144368</td>
<td>150448</td>
<td></td>
</tr>
<tr>
<td>Incidence per 100,000 capita</td>
<td>23.2</td>
<td>25.04</td>
<td>41.43</td>
<td>51.16</td>
<td>53.31</td>
<td></td>
</tr>
<tr>
<td>Gender (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>61</td>
<td>61.3</td>
<td>56.2</td>
<td>48.6</td>
<td>49.1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Female</td>
<td>39</td>
<td>38.7</td>
<td>43.8</td>
<td>51.4</td>
<td>50.9</td>
<td></td>
</tr>
<tr>
<td>Comorbidities (%)</td>
<td>9.9</td>
<td>24.0</td>
<td>19.8</td>
<td>29.4</td>
<td>45.2</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Adverse events (%)</td>
<td>2.7</td>
<td>5.9</td>
<td>6.7</td>
<td>10.1</td>
<td>7.3</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Transfusion (%)</td>
<td>0.6</td>
<td>1.4</td>
<td>3.0</td>
<td>3.3</td>
<td>2.0</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Discharge (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Routine</td>
<td>93.9</td>
<td>91</td>
<td>92.2</td>
<td>92.1</td>
<td>91.7</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Non-routine</td>
<td>3.3</td>
<td>3.7</td>
<td>3</td>
<td>3.3</td>
<td>5.5</td>
<td></td>
</tr>
<tr>
<td>Mean Age (yrs) (SD)</td>
<td>43.14(11.8)</td>
<td>45.70(11.55)</td>
<td>46.83(11.69)</td>
<td>48.46(12.1)</td>
<td>50.91(12.78)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Mean DOC (days) (SD)</td>
<td>5.92(4.07)</td>
<td>3.41(3.22)</td>
<td>3.26(8.3)</td>
<td>3.23(4.99)</td>
<td>3.16(3.02)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

### Table 3: Prevalence of comorbidities in patients who underwent fusion for intervertebral disc disorders between 1990 and 2007. (N=1,943,707)

<table>
<thead>
<tr>
<th>Parameter (ICD-9)</th>
<th>Total (%)</th>
<th>Routine Discharge (%) (N=1,780,071)</th>
<th>Nonroutine Discharge (%) (N=65,966)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diabetes mellitus (250)</td>
<td>7.08%</td>
<td>6.29%</td>
<td>21.42%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Obesity (278.00, 278.01)</td>
<td>3.07%</td>
<td>2.98%</td>
<td>4.44%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Hypertensive disease (401-405)</td>
<td>21.16%</td>
<td>20.05%</td>
<td>43.98%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Old myocardial infarction (412)</td>
<td>1.10%</td>
<td>1.04%</td>
<td>1.33%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Coronary artery disease (414.01)</td>
<td>1.90%</td>
<td>1.74%</td>
<td>3.96%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Atrial fibrillation (427.31)</td>
<td>0.90%</td>
<td>0.62%</td>
<td>3.41%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Congestive heart failure (428)</td>
<td>0.60%</td>
<td>0.43%</td>
<td>2.61%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Osteoporosis (733.0)</td>
<td>0.84%</td>
<td>0.74%</td>
<td>2.32%</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>
Risk Factors for Nonroutine Discharge in Patients Undergoing Spinal Fusion

(Table 3). When compared to patients discharged home, those discharged to inpatient facilities had a significantly increased incidence of adverse events including acute postoperative anemia (10% compared to 4%, P < .001), wound complications (0.13% compared to 0.01%, P < .001), acute renal failure (1.4% compared to 0.2%, P < .001), pneumonia (2.4% compared to 0.2%, P < .001), pulmonary insufficiency (1.4% compared to 0.3%, P < .001), and blood transfusion (6.2% compared to 2.3%, P < .001) (Table 4).

Nonroutine Discharge:
Multivariable logistic regression analysis showed the strongest independent predictors of nonroutine discharge following spinal fusion for intervertebral disc disorders were age > 65 years (OR 11.52 range: 11.33-11.71, P < 0.001), congestive heart failure (OR 6.19 range: 5.87-6.52, P < 0.001), atrial fibrillation (OR 5.69 range: 5.43-5.95, P < 0.001), any general in-hospital complication (OR 4.52 range: 4.41-4.64, P < 0.001), diabetes mellitus (OR 4.1 range: 3.98-4.14, P < 0.001), osteoporosis (OR 3.48 range: 3.30-3.66, P < 0.001), hypertension (OR 3.13 range: 3.08-3.18, P < 0.001), and any surgery related complication (OR 2.54 range: 2.48-2.61, P < 0.001). Factors associated with decreased odds of nonroutine discharge include age ≤ 35 years (OR 0.21 range: 0.20-0.22, P < 0.001), age 36-50 years (OR 0.26 range: 0.25-0.26, P < 0.001), and male sex (OR 0.53 range: 0.52-0.54, P < 0.001) (model fit: omnibus test of model coefficients: X² = 18,397, P < 0.001, Nagelkerke R² = 0.177; Table 5).

Prolonged Length of Hospital Stay:
Multivariable logistic regression analysis showed the strongest independent risk factors for prolonged hospital stay following spinal fusion for intervertebral disc disorders were any surgery related complication (OR 7.85 range: 7.74-7.95, P < 0.001), congestive heart failure (OR 6.90 range: 6.63-7.17, P < 0.001), any general in-hospital complication (OR 5.94 range: 5.85-6.03, P < 0.001), atrial fibrillation (OR 3.21 range: 3.12-3.31, P < 0.001), age > 65

**Table 4: Prevalence of adverse events among patients who underwent fusion for intervertebral disc disorders between 1990 and 2007. (N=1,943,707)**

<table>
<thead>
<tr>
<th>Parameter (ICD-9)</th>
<th>Total, (%)</th>
<th>Routine Discharge (%)</th>
<th>Nonroutine Discharge (%)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post Surgery Complications:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Postoperative wound complication (998.3)</td>
<td>0.03%</td>
<td>0.01%</td>
<td>0.13%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Postoperative bleeding (998.1)</td>
<td>0.73%</td>
<td>0.61%</td>
<td>1.85%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Acute postoperative infection (998.5)</td>
<td>0.20%</td>
<td>0.16%</td>
<td>0.69%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Acute postoperative anemia (285.1)</td>
<td>5.01%</td>
<td>4.41%</td>
<td>10.06%</td>
<td>&lt;0.001</td>
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<tr>
<td>General Complications:</td>
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<tr>
<td>Acute renal failure (584)</td>
<td>0.16%</td>
<td>0.04%</td>
<td>1.40%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Acute myocardial infarction (410)</td>
<td>0.90%</td>
<td>0.04%</td>
<td>0.58%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Pulmonary embolism (415.1)</td>
<td>0.05%</td>
<td>0.02%</td>
<td>0.60%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Induced mental disorder (293)</td>
<td>0.10%</td>
<td>0.07%</td>
<td>0.51%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Pneumonia (480-486)</td>
<td>0.36%</td>
<td>0.23%</td>
<td>2.39%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Pulmonary insufficiency (518.5)</td>
<td>0.41%</td>
<td>0.31%</td>
<td>1.40%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Deep venous thrombosis (453.4)</td>
<td>0.04%</td>
<td>0.04%</td>
<td>0.00%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Intubation (96.x)</td>
<td>0.25%</td>
<td>0.19%</td>
<td>1.07%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Transfusion of blood (99.0)</td>
<td>2.69%</td>
<td>2.25%</td>
<td>6.17%</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

**Table 5: Logistic regression for predictors of non-routine discharge among patients who underwent fusion for intervertebral disc disorders (N=1,943,707)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>OR (95% CI)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age &gt;65 years</td>
<td>11.517 (11.331-11.706)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Congestive heart failure</td>
<td>6.187 (5.869-6.523)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Atrial fibrillation</td>
<td>5.685 (5.429-5.953)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Any general complication</td>
<td>4.522 (4.410-4.637)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>4.06 (3.981-4.140)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Osteoporosis</td>
<td>3.478 (3.303-3.662)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Hypertension</td>
<td>3.132 (3.083-3.182)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Any surgery complication</td>
<td>2.544 (2.482-2.607)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Coronary artery disease</td>
<td>2.333 (2.240-2.430)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Obesity</td>
<td>1.508 (1.452-1.567)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Old myocardial infarction</td>
<td>1.283 (1.199-1.374)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Age 51-65 years</td>
<td>1.036 (1.018-1.054)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Region</td>
<td>0.956 (0.803-1.139)</td>
<td>0.614</td>
</tr>
<tr>
<td>Sex (M)</td>
<td>0.532 (0.523-0.542)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Age 36-50 years</td>
<td>0.259 (0.254-0.264)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Age ≤35 years</td>
<td>0.209 (0.201-0.218)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Omnibus X² = 18,397, P < 0.001
Nagelkerke R² = 0.177

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years (OR 2.64 range: 2.61-2.67, P < 0.001), osteoporosis (OR 2.32 range: 2.25-2.39, P < 0.001), and diabetes mellitus (OR 1.64 range: 1.63-1.66, P < 0.001). The strongest independent predictor of normal or decreased length of hospital stay was age 36-50 years (OR 0.55 range: 0.53-0.56, P < 0.001) (model fit: omnibus test of model coefficients: X² = 18,397, P < 0.001, Nagelkerke R² = 0.033; Table 6).

Table 6: Logistic regression for predictors of prolonged hospital stay among patients who underwent fusion for intervertebral disc disorders (N=1,943,707) CI, confidence interval; OR, odds ratio.

<table>
<thead>
<tr>
<th>Variable</th>
<th>OR (95% CI)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Any Surgery complication</td>
<td>7.845 (7.743-7.948)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Congestive heart failure</td>
<td>6.895 (6.633-7.168)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Any General complication</td>
<td>5.938 (5.847-6.031)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Atrial fibrillation</td>
<td>3.21 (3.116-3.307)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Age &gt;65 years</td>
<td>2.639 (2.614-2.665)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Osteoporosis</td>
<td>2.32 (2.248-2.394)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>1.644 (1.625-1.664)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Old Myocardial infarction</td>
<td>1.45 (1.408-1.494)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Coronary artery disease</td>
<td>1.393 (1.362-1.425)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Hypertension</td>
<td>1.244 (1.234-1.254)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Age 51-65 years</td>
<td>1.174 (1.165-1.182)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Age ≤55 years</td>
<td>1.113 (1.103-1.123)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Sex (M)</td>
<td>1.041 (1.033-1.048)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Region</td>
<td>1.009 (0.949-1.074)</td>
<td>0.77</td>
</tr>
<tr>
<td>Obesity</td>
<td>0.971 (0.953-0.990)</td>
<td>0.003</td>
</tr>
<tr>
<td>Age 36-50 years</td>
<td>0.546 (0.532-0.560)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Omnibus X² 18397, P < 0.001  
Nagelkerke R², P=0.0325

years (OR 2.64 range: 2.61-2.67, P < 0.001), osteoporosis (OR 2.32 range: 2.25-2.39, P < 0.001), and diabetes mellitus (OR 1.64 range: 1.63-1.66, P < 0.001). The strongest independent predictor of normal or decreased length of hospital stay was age 36-50 years (OR 0.55 range: 0.53-0.56, P < 0.001) (model fit: omnibus test of model coefficients: X² = 18,397, P < 0.001, Nagelkerke R² = 0.033; Table 6).

DISCUSSION

This study identified perioperative risk factors associated with nonroutine discharge and prolonged hospital stay among patients undergoing spinal fusion for intervertebral disc disorders. Between 1990 and 2007, we identified an increasing incidence (23.2 per 100,000 capita in 1990 to 53.3 per 100,000 capita in 2007) of spinal fusion for intervertebral disc disorders as well as an increasing rate of nonroutine discharge to inpatient facilities (3.3% in 1990 to 5.5% in 2007). Concurrently, this study demonstrated a decreased mean length of hospital stay (5.9 days in 1990 to 3.2 days in 2007). It is possible the decreased length of stay and higher proportion of nonroutine discharges over time is related to earlier transfer to inpatient rehabilitation facilities. The trends found in this study demonstrate a growing use of postoperative care facilities, such as inpatient rehabilitation facilities, which is similar to previous reports.

In this study, patients over the age of 65 had the highest odds of nonroutine discharge and also had higher odds of prolonged length of hospital stay, which is in line with previous studies. Interestingly, this study found females were at greater risk of nonroutine discharge. This finding is similar to the results reported by Katz et al in which women had worse functional outcomes than men following laminectomy for spinal stenosis, as well unilateral hip and knee arthroplasty. Their study found that women had significantly worse preoperative functional status than men, suggesting they may have been treated at more advanced disease stages and allduding to possible gender differences in preferences for symptom relief, attitudes toward surgery, or access to operative procedures. This is supported by several studies that demonstrated women are less likely to undergo cardiac catheterization and revascularization, or renal transplantation then men with similar coronary or renal disease severity. Another finding of this study was that patients in the nonroutine discharge group had higher rates of all comorbid medical conditions compared with those patients in the routine discharge group. Multivariate logistic regression showed that all comorbidities analyzed in this study, except obesity, were independent predictors of both nonroutine discharge and prolonged hospital stays. This is similar to work by Deyo et al, showing that major medical complications, mortality and healthcare utilization were higher in patients with comorbidities such as diabetes, obesity or coronary artery disease who underwent various surgeries for lumbar stenosis. Additionally, Slover et al showed patients with comorbidities had worse scores on bodily pain, physical function and physical component assessments following lumbar spine surgery. Among patients undergoing ankle fusion, Menendez et al showed that diabetes was linked to higher nonroutine discharge and prolonged hospitalization, though obesity was not linked to prolonged hospital stay in this study. One possible explanation for this is coding bias by the NHDS database towards more stable diseases, leading to underestimation of certain conditions. Indeed, of the total patient cohort, only 3.07% had a diagnosis of obesity, which is far below the national prevalence and illustrates its underestimation in this study.

Surgery-related and general in-hospital complications were among the strongest predictors of prolonged hospital stay and nonroutine discharge. The most common surgery related complication was acute postoperative anemia, followed by postoperative bleeding and infection. Blood transfusion was the most common general in-hospital complication followed by pneumonia and pulmonary insufficiency. These complications are similar to those reported by Shamji et al among patients undergoing cervical fusion for cervical spondylosis and are
associated with increased health care utilization among patients with spinal stenosis\textsuperscript{37}.

While large national databases have been recognized as suitable for epidemiological research\textsuperscript{38}, our study has several limitations. Like all large databases, the NHDS is subject to coding error or error in data entry\textsuperscript{39}. Additionally, the database only allows for seven diagnosis codes and four procedure codes per entry. As a result, the prevalence of comorbid conditions and adverse events may be underestimated\textsuperscript{39}. Moreover, the severity of a comorbid disease cannot be appreciated when classified dichotomously\textsuperscript{40}.

Our study is also limited by the inability to distinguish between the types and extent of fusion procedures performed among our patient population. Although the use of instrumentation may lead to higher fusion rates\textsuperscript{41,42}, these procedures have an increased operative time, blood loss, infection rate, as well as risk of nerve root injury or vascular injury from malpositioning\textsuperscript{43}. Patients older than 65 may have more extensive disease with greater rates of instability requiring longer instrumented fusion constructs compared to younger patients. The higher odds of non-routine discharge and prolonged length of hospital stay among patients greater than 65 may be attributable to the more extensive surgical fusion procedures needed to treat this population. Also, the indication for surgery was not recorded, so it is unknown whether these patients had axial pain, radiculopathy or other symptoms. Another limitation of this database is that it only provides inpatient data, so complications that arise after discharge as well as follow up data, are unknown. Furthermore, the database does not provide billing information so cost analysis is unable to be performed. Future work should be conducted to evaluate the cost of length of stay and discharge to another inpatient facility. Lastly, the results of this study are limited to spinal fusion in the United States from 1990 to 2007.

In conclusion, this study provides the largest analysis of perioperative risk factors associated with nonroutine discharge and prolonged hospital stays among patients undergoing spinal fusion for intervertebral disc disorders. Identifying risk factors associated with increased healthcare utilization has the potential to change treatment strategies, improve preoperative optimization and resource allocation for this patient population in an attempt to prevent prolonged hospitalization and postoperative acute care utilization, while decreasing health care costs.

REFERENCES:


ABSTRACT

Introduction: Congenital Talipes Equinovarus (CTEV) or clubfoot is one of the most common congenital abnormalities\textsuperscript{1, 2}. Early diagnosis by means of ultrasonography allows an opportune intervention and improves the deformity’s correction prognosis.

Goal: To describe patients diagnosed with CTEV by means of prenatal sonographies between 2003 and 2012 in Bogotá (Colombia) at both the Instituto de Ortopedia Infantil Roosevelt (IOIR) and one of the authors’ private office.

Methods: A descriptive, retrospective study on the focus population was made. The equality of the data of the quantitative variables in distance measure was analysed by the Kolmogorov–Smirnov test. For the variables “prenatal diagnoses” and “days from the start of the treatment” the Mann–Whitney U test was used. Finally, an analysis was made by means of the SPSS Statistics software package, version 18.0.

Results: 178 patients met the selection criteria. 34.3% of the patients had a prenatal diagnosis by ultrasonography (n=61). Regarding the number of prenatal ultrasounds performed, there were statistically significant differences between the patients with a CTEV prenatal diagnoses and those whose diagnoses came after birth, being higher in the first group (p<0.001). The number of days before the treatment started once the pre or postnatal diagnosis was done was also a subject of study. Significant differences were found in the treatment start between patients with a prenatal diagnosis (mean of 9.9 days) and those diagnosed after birth (mean of 30 days) (p<0.001).

Conclusions: prenatal diagnosis by foetal ultrasonography contributes to an early detection of musculoskeletal abnormalities such as CTEV and promotes an early intervention of the patient.

INTRODUCTION

Congenital Talipes Equinovarus (CTEV) or clubfoot is one of the most common congenital abnormalities\textsuperscript{1}. Although most populations show an incidence of approximately 1-2 cases for every 1000 born alive infants, a study made in three Colombian cities (Bogotá, Ubaté and Manizales) found an incidence of 2.5 cases for every 1000 born alive infants\textsuperscript{2}.

CTEV prenatal diagnosis can be performed whether in early stages of gestation (from the 12\textsuperscript{th} week by a transvaginal ultrasound exam) or in late stages (from the 3\textsuperscript{rd} trimester on by means of an abdominal ultrasound)\textsuperscript{3,4,5,6}. However, most cases are diagnosed between the 18\textsuperscript{th} and the 20\textsuperscript{th} week\textsuperscript{10}. Once a CTEV diagnoses is confirmed, the possibility of a transient deformity (transient CTEV) must always be considered, as described by Bar-Hava et al.\textsuperscript{11}. His study identified CTEV cases in which the deformity was diagnosed at the end of the 1\textsuperscript{st} trimester or the beginning of the second but disappeared in later ultrasound examinations.

On the other hand, there have been described cases diagnosed on a late stage of gestation (week 22\textsuperscript{nd} to 24\textsuperscript{th}) with initially normal ultrasounds, which suggests a late development of the abnormality. It should be noted that such cases almost always correspond to CTEV of a postural origin\textsuperscript{12}.

Incidence of CTEV diagnosed before birth varies significantly in published studies, with a range going from 0.43\%\textsuperscript{7} to 59.8\%\textsuperscript{12}. In Colombia such incidence has been estimated with a presence of 12.54 / 10.000 and a detection rate of 6.67\%\textsuperscript{15}, which is lower than estimates obtained by other studies globally (63\%)\textsuperscript{16} and in Latin America (19.1\%)\textsuperscript{17}.

Additionally, the frequency of false positives also ranges from 0\% to 40\%, especially when it comes to CTEV of the postural type diagnosed by ultrasound on the third trimester of gestation\textsuperscript{12}. It is also known that the rate of
false positives is higher in unilateral cases (29%) than in bilateral ones (7%)\(^7,9,10,12,16,18,19,20,21,22\).

Furthermore, with regard to the prognosis of the deformity treatment, there are publications such as the one produced by Bakalis et al. in 2002 that reported a worse prognosis for the prenatally diagnosed patients, since they were associated with a higher possibility of rigid CTEVs of difficult management\(^7,13,25,27,28,29\).

Even if it is hard to establish before birth the severity of the deformity and the need for surgery of patients with CTEV, it has been proved that patients diagnosed prenatally can be subjected to earlier and less invasive postnatal procedures than those diagnosed after birth\(^13,14,16,23,24\) (Bar-On et al., 2005; Cohen-Overbeek et al., 2006).

**MATERIALS AND METHODS**

A descriptive retrospective study was made having as selection criteria the patients diagnosed with CTEV at the IOIR and at the practice of one of the authors (PR) between 2003 and 2012. Variables associated with prenatal diagnosis were identified such as number of ultrasound examinations performed, gestational age at the time of the ultrasonography, performance of amniocentesis, associated congenital malformations, family background, genetic counselling and beginning of treatment. The study was approved by the Committee of Clinical Practice and Research Ethics at the IOIR.

**Data analysis**

Qualitative variables were represented as percentages. Subsequently, the equality of the data of the quantitative variables in distance measure was analysed by the Kolmogorov–Smirnov test. For the variables “prenatal diagnosis” and “days from the start of the treatment” the Mann–Whitney U test was used. Finally, an analysis was made by means of the SPSS Statistics software package, version 18.0.

**RESULTS**

178 patients diagnosed with CTEV at the IOIR and at the practice of one of the authors between 2003 and 2008 met the selection criteria. 30.9% (n=55) were female whereas 69.1% were male (n=123).

Prenatal ultrasound diagnosis was achieved in 34.3% of the patients (n=61). In 13.1% (n=8) of the cases the diagnosis came in the 1st trimester, in 62.3% (n=38) during the 2nd and in 23% (n=14) during the 3rd one.

Among the patients prenatally diagnosed, 26% showed associated abnormalities, while in contrast the percentage increased to 42% (p<0.10) in the patients without a prenatal diagnosis. The reported abnormalities included hip dysplasia, arthrogryposis, various syndromes and fibular hemimelia.

A relation with the performance of amniocentesis was investigated. It was found that 21% (n=13) of the patients prenatally diagnosed with CTEV had an amniocentesis done, in comparison to only a 4% (n=5) (p<0.001) for the group diagnosed after birth.

31% of the patients had genetic counselling once the CTEV prenatal diagnosis was done, whereas this type of counselling was given to 17% of the patients diagnosed after birth (p<0.031).

Regarding the number of prenatal ultrasounds performed, there were statistically significant differences between the patients with a CTEV prenatal diagnosis (mean of 4.5) and those whose diagnosis came after birth (mean of 3), being higher in the first group (p<0.001).

The number of days before the treatment started once the pre or postnatal diagnosis was done was also a subject of study. Significant differences were found in the treatment start between patients with a prenatal diagnosis (mean of 9.9 days) and those diagnosed after birth (mean of 30 days) (p<0.001).

**DISCUSSION**

Prenatal diagnosis of CTEV has repercussions on the mother and family’s psychological state and in some cases it can modify the pregnancy’s course. Even if the deformity’s progress cannot be modified in utero, most mothers admit as useful the fact of being aware of it before their child’s birth\(^30\). Although it is true that a prenatal diagnosis leaves some questions unresolved (such as rigidity) and that a false positive remains a possibility, it does allow the mother to start the treatment soon after the birth and to seek genetic counselling.

A study made at the IOIR (to be published), aiming to evaluate the results of the Ponseti method on children with clubfoot, found that the main factor leading to good results was not the rigidity level of the deformity, but an early start of the treatment\(^30\). This finding gives great importance to prenatal diagnosis of CTEV.

As far as we are concerned, the major use of a prenatal diagnosis is an early start of the treatment, which is, according to our studies, a decisive factor in the patient’s final results.

The convenience of amniocentesis performance in order to look for additional malformations proposes an interesting discussion. Nevertheless we recommend first seeking genetic counselling; in the absence of further alterations amniocentesis may be discarded.

The greatest limitation of the present study is the data collection. It was collected by asking the patients’ mothers, which represents a recall bias.
ACKNOWLEDGEMENTS

We would like to thank to the IOIR team as well as the Education and Research Area and the residents of the various universities around the country.

REFERENCES


3. Rosselli P, Villanueva J, Eljadue R. Resultados del tratamiento del PEVC con el método de Ponseti entre el 1 de julio de 2002 y 1 de julio de 2009.
ABSTRACT
The Ponseti Method of casting and bracing is the gold-standard treatment for congenital clubfoot in young children. Despite its many advantages, outcomes depend heavily on caregiver adherence to the treatment protocol. Our study explored the experience caregivers had with the Ponseti method using a photography-based participatory research method known as Photovoice. Five adult caregivers were recruited from families pursuing clubfoot treatment at the Children’s Hospital in Lima, Perú, during June, 2013. Each was provided a digital camera and training and agreed to photograph their experiences caring for a child undergoing Ponseti Method clubfoot treatment. Participants held four to five weekly one-on-one meetings with the researcher to discuss their photos. They also attended a group meeting at the end of the study to view and discuss photos of other participants. Using photos collected at this meeting, participants identified themes that summarized their experiences with treatment and discussed ways to improve delivery of care in order to support caregiver adherence to treatment. These results were presented to clinicians in Lima who use the Ponseti Method. The Photovoice method allowed researchers and participants to study the experience caregivers have with the Ponseti Method, and results can be used to inform the design of patient-based care models.

INTRODUCTION
Clubfoot is the most common musculoskeletal birth defect. It affects, on average, one in every 1,000 live births, or 200,000 babies each year, worldwide (80% in developing countries)\(^1\) Additionally, an estimated one million children are currently living with untreated clubfoot, a rigid, unsightly, lifelong disability that often leads to isolation, abuse, limited access to education, and poverty.\(^2\) Traditional treatment has been based on major surgical interventions that are very expensive, require highly trained professionals and facilities, and have poor long-term outcomes. In light of these barriers and due to a lack of awareness and availability regarding a simpler and more cost-effective approach, a high percentage of children are simply left untreated and disabled for life, especially in developing countries.\(^2\)

The Ponseti Method is a simple and inexpensive outpatient treatment that has been proven to be over 95% effective when properly administered\(^3\). Long term follow-up studies spanning on average 34 years have also observed maintenance of clinical and functional results in a majority of patients.\(^4,5\) This treatment method consists of a series of specific gentle manipulations followed by plaster casts, changed weekly. Usually four to six casts are required to correct the deformity. In 85% of cases, patients undergo a simple, percutaneous heel cord tenotomy (usually done as an outpatient procedure) as the final stage of the casting treatment. To prevent relapses, a foot abduction brace is usually worn daily for three months and then nightly until the child is three to four years old.\(^6\) Given then effectiveness of the treatment and the avoidance of surgery, the Ponseti method is now the preferred treatment for clubfoot worldwide.\(^7\) Still, this method is not without its challenges, namely the length of treatment. Although correcting the foot may only take a few weeks, maintaining the correction through the use of the abduction brace requires that caregivers commit their children to wearing the brace for several years. Adherence to the bracing protocol is the main
factor determining the long-term success of treatment, even as it poses a challenge for patients and caregivers. Several studies have explored the reasons for non-adherence using qualitative research methods including semi-structured interviews, focus groups, and observations with parents of patients, health-care providers, and general community members. In this study we continue to explore caregiver adherence using a novel qualitative research method known as Photovoice.

Photovoice has been used since the mid-1990s as a community-based participatory research method that allows participants to use photography as a medium to identify and discuss social issues within their communities. Participants are given cameras and encouraged to photograph images they self-identify as significant to their experience of the world. These images are then used to initiate discussion regarding their community’s strengths and concerns, promote critical dialogue and knowledge about important issues, and to influence policy. Photovoice has been used by researchers in collaboration with different vulnerable populations to address a variety of public health and social justice concerns including infectious disease epidemics, chronic health problems, political violence, and discrimination. This study used Photovoice to gain an inside perspective of the lives of families affected by clubfoot and the Ponseti Method by giving them cameras and engaging them as research partners. By asking them to photograph their experience with clubfoot and its treatment and through joint analysis of the photos, we evaluated opportunities to promote and improve adherence to the Ponseti Method.

**METHODS**

The University of Iowa Institutional Review Board approved this study before implementation. A Spanish-speaking medical student recruited subjects and coordinated meetings and data analysis with study participants. Participants were recruited from the National Children’s Hospital in Lima, Perú. Inclusion criteria were parents (hereon referred to as caregivers) over the age of 18 who have at least one child with clubfoot, for whom they were seeking treatment for the first time. Caregivers agreed to take photographs documenting their experiences with the Ponseti Method and to share them with us and a small group of other caregivers participating in the study. Informed consent was obtained by having caregivers review and discuss a consent form with us. No names were attached to the data and all data was stored in a secure location.

We recruited five adult caregivers pursuing clubfoot treatment for a child during June, 2013. We gave each caregiver a digital camera, trained them how to use it, and instructed them on how to take pictures in a manner that respected the privacy of others, including consent forms to offer photo subjects in the event they needed to do so. Caregivers were also given a 1 hour educational session about clubfoot and the Ponseti method of treatment as well as corresponding printed information.

Caregivers were asked to photograph their experiences caring for a child undergoing the Ponseti Method for clubfoot; instructions on what to photograph was left deliberately broad in scope to allow participants to focus on whatever they identified as important. Caregivers returned in one week and met with the researcher to show and discuss photographs taken over the course of the week. Discussions of the photographs were loosely structured so as to allow caregivers to focus on photographs they felt were the most pertinent to their experience. Conversations were started with the question, “tell me the story of this photo,” and followed up with, “why is this photo important to you?” and, “is there something about this photo that you wish your doctor could understand?” when appropriate. In subsequent weeks, caregivers continued to focus their photographs on themes they self-identified as important. Caregivers participated in four to five of such weekly one-on-one meetings, which were recorded and transcribed. Identifying information was removed from the transcriptions, and transcriptions were attached to the photographs.

After four to five weeks, caregivers attended a group meeting that included all study participants to view and discuss the photos taken and their associated transcriptions. The photo collection, transcriptions, and the discussions revealed that these caregivers had a collective experience associated with clubfoot and the Ponseti Method. Caregivers were asked to identify any repeating themes within their collective experience, and to choose the photos that best represented those themes. Finally, they were asked to identify opportunities to improve delivery of care of the Ponseti Method and support adherence to treatment.

All results were presented at an additional meeting to physicians, nurses, and technicians in Lima who use the Ponseti Method. Meeting participants were encouraged to discuss results and assess whether suggestions made by the caregivers were realistic and implementable.

**RESULTS**

Caregivers identified four major themes that represented their collective experience with the Ponseti Method and their thoughts on adherence: family, education, child development, and judgment. They also chose photos that best represented those themes (Photos 1-14) and brainstormed strategies that healthcare providers could employ to address these observations and encourage adherence (Table 1).
A. Pletch, J. Morcuende, H. Barriga, J. Segura, A. Salas

Table 1. Results of the group meeting involving all caregivers including identified themes, major observations within those themes, and suggested strategies for healthcare providers to address these observations and encourage adherence.

<table>
<thead>
<tr>
<th>Theme</th>
<th>Observation</th>
<th>Suggested strategy</th>
<th>Photographs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Family</td>
<td>Moral and financial support from the family and sharing of caregiver responsibilities were described as critical to supporting caregiver adherence.</td>
<td>Provide printed materials about clubfoot and the Ponseti Method. Use photography to track the progress of the feet.</td>
<td>Figures 1-4</td>
</tr>
<tr>
<td>Education</td>
<td>Caregivers agreed that the more educated they became about clubfoot and the Ponseti Method of treatment, the better they were at caring for their child and eliciting support from others.</td>
<td>Provide printed materials about clubfoot and the Ponseti Method. Raise awareness of the Ponseti Method among other healthcare providers.</td>
<td>Figures 5-8</td>
</tr>
<tr>
<td>Child development</td>
<td>Concerns about the normal development of their children and the inability to track growth while using the Ponseti Method caused some caregivers to question their participation in treatment.</td>
<td>Discuss concerns during regular appointments. Make scales and measuring tables available in the clinic.</td>
<td>Figures 9-11</td>
</tr>
<tr>
<td>Judgment</td>
<td>Caregivers were distressed by what they perceived as others' negative judgments towards them when they appeared in public with a child wearing full leg casts.</td>
<td>Provide printed materials about clubfoot and the Ponseti Method. Suggest alternative terms to discuss clubfoot instead of “deformity” or “sickness”.</td>
<td>Figures 12-14</td>
</tr>
</tbody>
</table>

Description of Photos:
In each case, photo captions are transcriptions of explanations caregivers felt were important to include with the photographs.

Photos 1-4. Family. These photos were selected to represent the important role that family plays when a child is undergoing the Ponseti Method.

Photos 5-8. Education. These photos were selected to represent the importance of properly educating both caregivers and other healthcare providers about clubfoot and the Ponseti Method.

Photos 9-11. Child development. These photos were selected to represent concerns caregivers have regarding the normal development of their children while undergoing the Ponseti Method.

Photos 12-14. Judgment. These photos were chosen to represent how caregivers feel judged when others see their child’s legs in casts.

DISCUSSION

Family
Caregivers identified “Family” as a major theme in their experience with clubfoot and the Ponseti Method. Family provides the financial support necessary for weekly trips to the National Children’s Hospital in Lima. Family also shares in caregiver responsibilities, making caring for a child with two full-leg casts more manageable. Caregivers also found that securing these forms support from family was not always easy. One caregiver, originally from a rural province, was living her brother in Lima while her son received treatment. She was keenly aware of being a financial drain and worried that she would overstay her welcome before her son’s feet were corrected (photo 1). Another caregiver had to argue with her husband for money to take her son to the hospital for his weekly cast change. Her husband wasn’t convinced that the treatment was working, because he only ever saw his son in casts and never saw the progress of the treatment (photo 2). Other caregivers experienced difficulty explaining to family members what was wrong with their child’s feet and securing more help in caring for the child (photos 3 and 4).

When asked what healthcare providers could do to help caregivers address these challenges, caregivers felt that if they understood better what clubfoot was and how the entire treatment process worked, they could better advocate for resources and support from their family. They felt that printed materials provided to them by the study would help them teach their family about clubfoot...
and the Ponseti Method and add legitimacy to their requests for support. One caregiver began taking photos of her child's feet after the old cast was removed and before the new cast was applied so that she could show her husband the progress the child's feet were making (photo 2). After she began doing this, she no longer had difficulty obtaining money from her husband for weekly appointments. This caregiver felt that healthcare providers should encourage other caregivers to photograph the treatment progress using cellphones, as even the most basic models usually have a camera function.

**Education**

“Education” was another major theme identified by caregivers in their experience with clubfoot and the Ponseti Method. One caregiver found herself needing to explain what clubfoot was to a sister-in-law who was in her third-trimester and worried that her unborn child could have clubfoot too. That caregiver struggled to explain both clubfoot and its treatment until she found the printed information given to her during the educational sessions when she first joined the study, at which point she could explain what clubfoot was and how the Ponseti method worked (photo 5). Another caregiver
regularly struggled with adhering to treatment given the major doubts she had regarding the Ponseti method’s effectiveness. Her son began the treatment at three years old (as opposed to within the first few months of life), and consequently was not progressing as quickly or noticeably at the other children who started within the first 6 months after birth. She did not share her questions with the physician, however, and remained unsure whether the expense of getting the treatment was worthwhile (photo 6).

Another caregiver was frustrated with a general lack of knowledge among healthcare professionals about clubfoot and the Ponseti Method. Prior to seeking treatment at the National Children’s Hospital, this caregiver spent a lot of money on diagnostic tests and imaging studies requested by different physicians who were not familiar with clubfoot (photo 7). These physicians recommended surgery as the only option to correct her daughter’s bilateral clubfeet. Fearing disfiguring scars that would result from the surgery, this caregiver sought out alternative therapies and chose the Ponseti Method of treatment because it sounded less risky, not because it had better outcomes. Due to the lack cohesive medical opinions regarding clubfoot and its proper treatment, she admitted to feeling initially distrustful of even the Ponseti Method and it took her several weeks before she felt confident that the treatment would work. Another caregiver felt that she was not instructed properly by her physician how to care for her child while the child was wearing casts. Her daughter experienced reoccurring urinary tract infections while wearing the casts and she wasn’t sure if it was related. She did not bring her question to the physician, but rather chose to ask other mothers in the waiting room if they had experienced

Photo 6. This is my son with animals from my family’s farm. I get upset when I see this because I worry that he’ll never be able to take over the family business. I am discouraged when I look at this, I don’t see progress.

Photo 7. These are all of the tests and x-rays we got for our daughter when she was born. They were very expensive, but the doctors we saw still didn’t know her diagnosis. We looked for a long time for an alternative to surgery. It seems that other doctors don’t know about the Ponseti Method.

Photo 8. My daughter got a UTI because I didn’t change her diaper carefully enough. I wish I knew that could happen! Now I use plastic bags on her casts when I change her.
anything similar. They suggested she protect the casts while changing her daughter's diapers by tucking plastic bags around the rim of the cast to prevent trace fecal contamination (photo 8). After adopting this suggestion and with treatment, her daughter's infections stopped and did not reoccur.

When asked what healthcare providers could do to help caregivers address these challenges, caregivers again suggested that hospitals provide printed materials explaining club foot and the Ponseti Method. They also wanted advice on how to care for a child with full leg casts such as how to bath, change, and dress a child wearing casts, how to determine if a cast is too tight, and acceptable activities for a child wearing casts. They also suggested that while applying the new casts the healthcare provider should use that opportunity to check in with the caregiver’s understanding of clubfoot and the Ponseti method and ask if there were any new concerns or questions. Finally, caregivers emphasized the need for their healthcare providers to raise awareness of clubfoot and the availability of the Ponseti Method among other healthcare professionals, including midwives, nurses, obstetricians, pediatricians, and orthopedic surgeons.

Child Development
Caregivers identified “Child Development” as a major theme in their experience with clubfoot and the Ponseti Method. Caregivers of children only a few months old at the start of treatment were concerned that the casts would not allow the proper development of their children since the casts prohibited them from normal activities like crawling, standing, and walking (photo 9). One caregiver was also mislead by other mothers to believe that while the treatment would help to straighten her daughter’s feet, she would still be unable to walk properly due to being prevented by the casts from learning how at an early age. Another caregiver was worried by the inability to accurately monitor the length and weight of her baby at Well Child appointments as she had with her previous children due to the casts (photos 10 and 11). She was also worried about the difficulty accessing the thigh for childhood immunizations with the casts on. These concerns related to child development caused caregivers to wonder whether delaying the Ponseti Method would be a better choice so as to allow the child a chance to comply with Well Child appointments and develop better motor skills.

When asked what healthcare providers could do to help caregivers address these concerns, caregivers...
again suggested that healthcare providers establish a time for caregivers to ask questions or voice concerns about the treatment, and suggested that that time be while the caregiver assisted the healthcare provider in reapplying the new cast. Caregivers also suggested that a measuring table and scale be available in the same room as where the casts are removed and reapplied so that accurate measurements of length and weight may be made in between casts. Finally, caregivers suggested that healthcare providers make nurses who give vaccinations aware of alternative places to administer vaccinations other than the upper thigh if that region is unavailable due to the casts.

Judgment

Caregivers identified “Judgment” as a major theme in their experience with clubfoot and the Ponseti Method. The casts, being conspicuous, often lead to questions from both strangers and family members about clubfoot at the Ponseti Method of treatment. Caregivers felt ill-prepared initially to answer these questions and were distressed by what they perceived as judgment from others, such as the belief that they did or didn’t do something during pregnancy, thus causing their child’s clubfoot. One caregiver’s husband refused to introduce their child to other family members while the child was wearing casts because he felt his family would either blame his diabetes or the great difference in age between him and his wife as the cause for the clubfeet (photo 12). Another caregiver was so bothered by questions from strangers regarding the casts that she practiced role-playing responses with her cousin before using public transportation (photo 13). Another caregiver, whose son also had Mobius Syndrome, was more concerned by how the casts prevented her son from playing with other children and caused him to be teased for crawling than by how Mobius Syndrome interfered with his ability to socialize (photo 14).

When asked what healthcare providers could do to help caregivers address these concerns, caregivers again suggested that the hospital provide them with printed materials by the hospital explaining clubfoot and the Ponseti Method could help facilitate conversations with family and friends about these topics. After brainstorming among themselves, caregivers felt that the term “condition” instead of “illness” or “deformity” helped explain clubfoot and the Ponseti Method in a way
that mitigated judgment from others and suggested that healthcare providers encourage other caregivers to use this term when explaining clubfoot to others. Caregivers also felt that describing the bones in the feet as “being crooked”, similar to crooked teeth, might help create a visual of the problem and support the rational for using casts as a means of straightening the feet.

After caregivers finished organizing their experiences into themes, they were asked to rank their suggested strategies for promoting treatment adherence. Caregivers believed that receiving more education about clubfoot and the Ponseti method in the form of printed materials would be the most effective intervention. Following this was tracking the progress of their children’s feet using cell phone photography, regularly discussing their concerns with their doctors, and receiving counseling from their doctors on how to teach others about clubfoot and the Ponseti Method. Finally, they felt that making scales and measuring tables available in the office to track height and weight would also support adherence.

At a final meeting in Lima, we presented the results to physicians, nurses, and technicians who use the Ponseti Method. Certain findings were expected and understood by health professionals, for example, how a lack of education about clubfoot and the Ponseti Method contributes to caregiver non-adherence. The group agreed that printed informational material would be a valuable resource for caregivers and could help address common misconceptions and promote adherence. While many providers felt they did not have the resources (paper and printing costs) to offer such material, they believed that institutions like Ponseti International Association could provide such material for their clinics.

Findings that the group did not anticipate included how the Ponseti Method can interfere with Well Child appointments and how that could impact a parent’s decision to adhere to treatment. The group agreed that they could and should equip examination rooms with scales and measuring tables in order to accurately track developmental milestones for Well Child documentation. They also agreed that those who administered childhood vaccinations in the hospital should be educated about alternative appropriate injection sites for a child with leg casts so that these patients did not miss any scheduled immunizations. Overall, the group of healthcare providers found the results of the study to be insightful, and the proposed suggestions for improving treatment adherence to be sensible and implementable.

CONCLUSION

Treatment adherence is critical to successful immediate and long-term outcomes of the Ponseti Method. Caregiver adherence can be influenced by multiple factors ranging from financial constraints to logistic and cultural barriers. In this study, Photovoice was used as a novel qualitative participatory research method to explore issues affecting adherence to the Ponseti Method in Lima, Perú. Participant caregivers used digital photography to collect data and explore their experiences with clubfoot and the Ponseti Method, asking themselves why adherence to the Ponseti Method is difficult and what can be done about it. The results of this inquiry were well-received by other stake-holders in the treatment of clubfoot, namely healthcare professional who use the Ponseti Method. They felt this study clarified the degree to which certain barriers may impede caregivers’ adherence to the Ponseti method, and illuminated new barriers to treatment adherence. Finally, both caregivers and healthcare professionals discussed and agreed upon practical strategies that could help improve adherence to treatment.

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THE HEEL PAD IN CONGENITAL IDIOPATHIC CLUBFOOT: IMPLICATIONS OF EMPTY HEEL FOR CLINICAL SEVERITY ASSESSMENT

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ABSTRACT

Background: Clubfoot has been evaluated in many ways, including the most common classifications of clubfoot, described by Caterrall and Pirani based on six clinical signs. The purpose of this study was to gain better understanding of the heel pad in relation to the term “empty heel”, and to propose modification of clubfoot severity scoring system based on “empty heel”.

Methods: A combination of prospective study of 79 clubfoot patients treated with Ponseti method and literature review of heel pad anatomy and biomechanics. The setting was a university teaching hospital. The ethical research committee approved study protocol and informed consent of patients’ parent obtained. The selection criteria included: patients’ diagnosed congenital idiopathic clubfoot, age < 2 years, no history of previous treatment and tenotomy indicated. An evaluation of patient was assessed by orthopaedic surgeons trained on Ponseti method and has above 5 years experience.

Data analysis performed on the age, sex, Pirani scores at onset of treatment, tenotomy, and 6 month after initial full correction.

Results: One hundred and thirty-two clubfeet in 79 patients (56 males, 23 females) completed Ponseti protocol. The median age at presentation was 5.2 months (range: 0.1 - 23.7 months). The mean right foot abduction after correction 57.30 (S.D. 9.20), and for the left foot, was 56.30 (S.D. 9.40). The mean right foot dorsiflexion was -13.70 (S.D. 18.40) before correction while after correction, it was 20.00 (S.D. 4.50) and for the left, the mean was -8.50 (S.D. 9.60) before correction and 21.00 (S.D. 4.30) after correction. Eighteen (22.8%) patients (10 bilateral, 9 unilateral) had clubfeet with empty heel score above zero point at initial full correction (p<0.001). Clinic anatomy shows the heel pad is a solid complex structure existing in normal, moderate and severe atrophied form. Heel pad is attached tightly to calcaneus without a cavity for the calcaneus to drop.

Conclusions: Heel pad probably could replace “empty heel” in modify Pirani scoring system. Clinical indication for repeat tenotomy should be based on equinus, not on the feeling of an empty heel, and families can be advised that the heel pad has a tendency to remodel over time to a normal shape.

Level of Evidence: Level II

Clinical Relevance: Empty heel feeling at initial full correction of congenital idiopathic clubfoot based on Ponseti protocol is not indication for repeat tenotomy.

Key words: Clubfoot, Heel Pad, Pirani Scoring System, Ponseti Protocol.

INTRODUCTION

Tenotomy of the Achilles tendon is an integral part of Ponseti method for treatment of club foot. Achilles tenotomy is crucial in 80-95% of congenital idiopathic clubfoot (CIC) to correct the equinus and reduce calcaneum from its plantar flexed position. Clubfoot has been evaluated in many ways, including the most common classifications of clubfoot described by Caterrall and Pirani based on six clinical signs. (Table 1) This scoring system predicts the number of cast required for correction and the likely chance of requiring Achilles tenotomy.

The morphological abnormalities of the hindfoot play a major role in the pathoanatomy of the clubfoot. Malpositioned and deformed talus and calcaneus along with soft tissue contractures account for the ankle equinus and hindfoot varus. Interestingly, the concept of empty heel was described by Catterall and Pirani in their scoring system to reflect the degree of equinus and presence of high riding calcaneus. The emptiness of the heel is one of the signs reflecting the severity of the equinus contracture and its persistence has been considered a sign of not full correction in congenital idiopathic clubfoot (CIC).
However, the description ‘empty heel’ might be misunderstood as a ‘true cavity’ within the heel where the calcaneus should drop with correction. The presence of the feeling of an empty heel after achieving initial full correction of the deformity could be depressive for the parents. This misunderstanding can be a source of worry for the orthopedist, and it is uncustomary to observe indications for a repeated Achilles tenotomy to bring the calcaneus down based on the persistence of the feeling of an empty heel.

The purpose of this review was to gain better understanding of the heel pad in relation to the term “empty heel”, and to emphasize the clinical importance of identifying and treating the equinus element of the deformity to avoid complications associated with manipulating the foot against tight posterior structures. We are not aware of published literature on combine review of basic sciences of heel pad and clinical severity assessment of clubfoot managed with the Ponseti method. The hypothesis was that the empty heel feeling at initial full correction of congenital idiopathic clubfoot based on Ponseti protocol is not indication for repeat tenotomy. The study aims to propose a modification of clubfoot severity scoring system based on empty heel sign.

METHODS

We performed a literature review as step I about the applied anatomy and biomechanics of the heel pad to gain a better understanding of the term “empty heel”. The step II involved prospective study of 132 idiopathic clubfeet in seventy-nine patients treated with Ponseti method. The setting was a university teaching hospital. The ethical research committee approved study protocol and informed consent of patients’ parent was obtained. The selection criteria include patients’ diagnosed congenital idiopathic clubfoot, age ≤ 2 years, no history of previous treatment and prior tenotomy indicated. The standard Ponseti method protocol administered to all patients. In this study, true contracture of the gastrocnemius-soleus muscle complex is indicated by the equinus assessed with the knee extended. The difference between the equinus recorded with the knee flexed and that measured with it extended indicates the amount of stiffness in the ankle joint and is not ascribed to empty heel. The posterior wall of the calcaneus was palpated carefully when the equinus is assessed because the bone could be pulled proximally away from the heel pad and clinically portrayed the empty heel perception. An evaluation of patient was assessed by orthopaedic surgeons trained on Ponseti method and had more than 5 years experience in the method.

DATA ANALYSIS

All analyses performed based on the intention-to-treat cohort, defined as all clubfoot patients who had tenotomy and maintain full correction within the study period. Data collected included the age, sex, Pirani scores at onset of treatment, tenotomy, and 6month after initial full correction. Data analysis was performed using the statistical package for social sciences (SPSS; Chicago, Illinois) software for Windows version 17. A change in the mean Pirani points was evaluated using Chi-Square test and ANOVA for parametric data. A confidence interval (CI) of 95% with p<0.05 was taken to be significant.

RESULTS

Clinical Assessment

Over two years period between October 2012 and September 2014, seventy nine patients (53 males, 26 females) with 132 clubfeet were treated using the Ponseti method. The median age at presentation was 5.2 months (range: 0.2 -23 months). The distribution of age, sex, foot affected and empty heel score are shown (Table 2). Eighteen (22.8%, 10 bilateral, 9 unilateral) patients had clubfoot with empty heel score above zero point after initial full correction. The mean right foot dorsiflexion was -13.7° (S.D. 2.9°) with values ranging from -1° to 11° before correction and after correction 53.3°(S.D. 9.2°) with values ranging from 50° to 72°. For the left foot, the mean value was -7.8° (S.D.7.5°) with values ranging from -1° to 13° before correction while after correction, it was 56.3° (S.D. 9.4°) with values ranging from 50° to 70°.

The mean right foot abduction was -5.3° (S.D. 2.9°) with values ranging from -1° to 11° before correction and after correction 53.3°(S.D. 9.2°) with values ranging from 50° to 72°. For the left foot, the mean value was -7.8° (S.D.7.5°) with values ranging from -1° to 13° before correction while after correction, it was 56.3° (S.D. 9.4°) with values ranging from 50° to 70°.

The mean right foot dorsiflexion was -13.7° (S.D. 18.4°) with ranges from -33° to -7° before correction while after correction, it was 19.0° (S.D. 4.5°) with ranges from 16° to 27°. The mean dorsiflexion for the left foot was -8.5° (S.D. 9.7°) with values ranging from -20° to -5° before correction and 20.0° (S.D. 4.3°) with values ranging from 15° to 31° after correction.
The Pirani scores of affected feet at onset of treatment, tenotomy and six month after full correction is shown in Table 3. The mean Pirani score was above zero points after full correction (p <0.001) reflecting residual empty heel score.

**Applied Heel Pad Anatomy**

*Location:* The heel pad lies between the calcaneus and the skin and consists of neuronal, vascular, fibrous and elastic components intertwined with fat cells\(^1\) (Figure 1). It is securely anchored to skin and to bone, providing stability desirable in gait. The thickness ranges between 14.4 and 24.5mm with an average value of 18mm. The distribution of thickness varies with loading by impacts\(^1\). The heel pad is a complex structure consisting of a fat pad with micro- and macro-chambers divided by an intricate fibroelastic septation (Figure 2).

*Relation:* Skeletal support to the heel pad is a function of the calcaneal tuberosity, which exhibits two prominent plantar processes off which the plantar fascia originates\(^18,19\). Figure 3 depicted the schematic view of the whorled turbine-shaped fatty-fascial compartments of the human heel pad. Anterior and deep (dorsal) to those processes lie the origins of the two layers of intrinsic plantar muscles: abductors hallucis brevis and digitii quinque flanking flexor digitorum brevis in the first layer, quadratus plantae more deeply together with the long plantar ligament\(^21\). The proximal plantar surface of the plantar fascia serves for the partial attachment of the fibrofatty heel pad\(^17\).

*Neurovascular supply:* The innervation and arterial supply of heel pad tissues seem primarily dependent upon the posterior tibial artery and nerve\(^20\). Also it contained many Vater-Pacini corpuscles, generally felt to be pressure and vibration transducing nerve terminals and characterized as sources of pain\(^21,22\).

**Differential Diagnosis:**

The fat pads are to be differentiated from the “walking pads” which are most pronounced in the fetus but whose residual can still be seen as small, puffy mounds between the metatarsal heads\(^16\).

**Disposition:**

Heel pads also atrophy with old age (loss of collagen, fat atrophy)\(^12\). Owing to the loss of the heel pad, the rubbery, thick, rounded feel of the pad is no longer palpable; instead, one feels the underlying hard os calcis directly under the skin\(^35\). Figure 4 shows the heel fat pad cells and septa. Atrophy of heel pads occurs secondary to severe trauma, slough, and infection. Hypertrophy of fat pads is noted in association with obesity and gout.
pads and subcutaneous fat is seen most frequently in acromegaly, neurofibromatosis and congenital vascular tumors versus congenital arteriovenous aneurysms which causes more diffuse limb hypertrophy\textsuperscript{15,20}.

**Function:**
The main role is shock absorption, peak force reduction, and protection against excessive local stresses\textsuperscript{23-26}.

**Heel Pad Biomechanics**
Morphologically, the thickness of the heel pad can be measured by different methods including ultrasound\textsuperscript{12,17}. Histologically, the heel pad is a honeycomb pattern of fibroelastic septa that completely enclosed packed fat globules\textsuperscript{16} (Figure 2). The tissue septae are U-shaped around the tuberosity and anchored to the calcaneus and the skin. The tight adherence of the heel pad to the calcaneus was described by Tietze\textsuperscript{21} in 1921. The remodeling tendency of the heel pad was first described by Kuhn in 1949\textsuperscript{15}. MRI studies of the heel showed the heel pad septae to be vertical in the midline and arch shaped adjacent to the calcaneus. Medially and laterally are crescentic with their convex surfaces facing peripherally. On simulated weight bearing, the central fat globules appear flattened and the crescentic globules bend exaggerating their convexity\textsuperscript{25,27} (Figure 5). In the heel pad, there is no true cavity\textsuperscript{28}.

Clinical examination and biomechanical investigation indicate that heel pads may be divided into three major classifications\textsuperscript{16}. The first type, normal heel pad, is thick, resilient, and terse, with most of the weight-bearing forces being absorbed by the relatively high peak pressures within a small area. The second type of heel pad is moderately atrophied, soft, pliable, and "floppy", as seen in peripheral neuropathy, where the compression forces are distributed over a greater area of heel pad with the weight bearing more evenly distributed among areas of high, medium, and low pressure. The third type, the

### Table 2: Demographic characteristics of 79 clubfoot patients.

<table>
<thead>
<tr>
<th>Patient Characteristics</th>
<th>Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age</strong></td>
<td></td>
</tr>
<tr>
<td>Birth -12months</td>
<td>67 (84.8)</td>
</tr>
<tr>
<td>13-24months</td>
<td>12 (15.2)</td>
</tr>
<tr>
<td><strong>Sex</strong></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>52 (65.8)</td>
</tr>
<tr>
<td>Female</td>
<td>27 (34.2)</td>
</tr>
<tr>
<td><strong>Foot affected</strong></td>
<td></td>
</tr>
<tr>
<td>Bilateral</td>
<td>53 (67.1)</td>
</tr>
<tr>
<td>Unilateral</td>
<td>26 (32.9)</td>
</tr>
<tr>
<td>Left sided</td>
<td>11 (13.9)</td>
</tr>
<tr>
<td>Right sided</td>
<td>15 (19.0)</td>
</tr>
<tr>
<td><strong>Empty heel</strong></td>
<td></td>
</tr>
<tr>
<td>Before Ponseti casting</td>
<td>0.0 52 (39.4)</td>
</tr>
<tr>
<td>0.5</td>
<td>69 (52.3)</td>
</tr>
<tr>
<td>1.0</td>
<td>11 (8.3)</td>
</tr>
<tr>
<td>After full correction</td>
<td>0.0 103 (78.0)</td>
</tr>
<tr>
<td>0.5</td>
<td>26 (19.7)</td>
</tr>
<tr>
<td>1.0</td>
<td>3 (2.5)</td>
</tr>
</tbody>
</table>

### Table 3: Average Pirani score at pre casting, at full correction and at 6month follow up

<table>
<thead>
<tr>
<th>Pirani score</th>
<th>Mean Pirani Score</th>
<th>F</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Pirani score before Ponseti casting</td>
<td>5.141± 1.018</td>
<td>818.032</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Pirani score at full correction</td>
<td>0.203±0.342</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pirani score at 6month</td>
<td>0.313±0.070</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Repeated ANOVA measures p<0.001

senescent, severely thin, atrophied heel pad shows a concentrated areas of very high peak pressure within a very small area of contact\textsuperscript{16}.

**DISCUSSION**
In this study, the heel pad showed a great amount of remodeling in the empty heel score during the course of treatment (Table 2). Lehman et al\textsuperscript{10} data and present results revealed some persistence of an empty heel even in those children who underwent tenotomy and achieved full initial correction with the median Pirani score for empty heel at the end of treatment was 0.5. The emptiness of the heel is not more than softness in the consistency of the heel pad tissue. In addition the size of the tarsal bone in clubfoot is smaller compared to the unaffected foot\textsuperscript{11}. The malposition and the smaller size of the tarsal bone probably is compensated by the packing effect of the elastic adipose tissue of the heel fat pad, which makes the heel feels softer and more mobile as if it is empty\textsuperscript{15}.
Weight bearing may have contributed to the normal size look of heel pad among walking babies. The normalization of heel pad of “empty heel” babies noted before walking age was in keeping with natural remodeling as development occurred. This was a puzzle against solitary weight bearing theory sited for embarking on multiple tenotomy. It is essential for truly Ponseti method practitioner to reevaluate idiopathic clubfoot adequately after achieving initial full correction. It would prevent the error of multiple tenotomies in attempt to correct completely all deformities for self or parent’s reassurance when “empty heel” persist.

More than 20% of clubfoot patients in this study at initial full correction have mean Pirani score point above zero (Table 3). Our findings was supported by earlier report by Ponseti and Ippolito in 1980 who presented theory of retraction fibrosis of the distal muscles of the calf and the supporting connective tissues. These occurrences were attributed to be the cause of clubfoot deformity and for the common recurrence of the deformity after surgery and not the heel pad. It was noted in severe rigid or complex clubfoot deformity with poor muscle development, relapse or incomplete correction may occur. The Ponseti practitioner may not be able to influence the rigidity of the connective tissue but can change the muscle imbalance by anterior tibia tendon transfer to obtain correction.

Both clinical examination and biomechanical investigation indicate that heel pads exist in three major forms. The “empty heel” in Pirani scoring could be modify in Table 4 to include, normal heel pad, moderately atrophied, and severely atrophied heel pad. The zero point score on the Pirani’s rating probably related to the degree of softness of the heel pad. Families can be advised that the heel pad in clubfoot remolds over time and becomes of normal shape after few years. Idiopathic clubfoot babies would always have some amount of heel fat pad and do not appeared to influence absolute indication for repeat tenotomy.

Based on the previous anatomical details and from our documentation on fully corrected clubfoot patients, we can conclude that the heel pad is a complex, solid structure that is firmly attached to the periosteum of calcaneal bone with no evidence of a cavity where the calcaneus could drop. The role of Achilles tenotomy in correcting the equinus and reducing the plantar flexed calcaneus is very important; however, repeating the tenotomy based on persistence of empty heel alone is not recommended. Heel pad (normal heel pad, moderately atrophied, and severely atrophied heel pad) probably could replace “empty heel” in a modified Pirani scoring system.

### SOURCE OF FUNDING
USAID Grant (2012-2014) to Nigeria for “Clubfoot Disability: Model of Sustainable Health System” enhance patients volume and strengthen Ponseti method adoption during this study.

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6. Dyer PJ, Davis N. The role of the Pirani scoring system in the management of clubfoot by the Ponseti method. JB JS [Br] 2006;88-B:1082-4

### Table 4. Modification of Catterall/ Pirani Scoring (Normal: 0 points; most abnormal 1.0 points)

<table>
<thead>
<tr>
<th>Hindfoot contracture (HFCS)</th>
<th>Points</th>
<th>Midfoot contracture (MFCS)</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Posterior crease: 0, 0.5, or 1.0 points</td>
<td></td>
<td>a. Curvature of lateral border: 0, 0.5, or 1.0 points</td>
<td></td>
</tr>
<tr>
<td>b. Heel pad: 0, 0.5, or 1.0 points</td>
<td></td>
<td>b. Medial crease: 0, 0.5, or 1.0 points</td>
<td></td>
</tr>
<tr>
<td>c. Rigid equinus: 0, 0.5, or 1.0 points</td>
<td></td>
<td>c. Lateral head of talus: 0, 0.5, or 1.0 points</td>
<td></td>
</tr>
<tr>
<td>Total Score (HFCS and MFCS)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

N.B: Heel pad severity scoring
Normal Heel pad: 0; Moderately atrophied heel pad: 0.5; Severely atrophied heel pad: 1.0
17. Tietze A. Concerning the architectural structure of the connective tissue in the human sole. Foot Ankle 1982; 2:252-259
22. Natali AN, Fontanella CG, Carniel EL. Constitutive formulation and analysis of heel pad tissues mechanics. Medical Engineering & Physics 2012; 35:516-522
ABSTRACT

Background: Chronic Regional Pain Syndrome type I (CRPSI) in children is a disorder of unknown etiology. No standard diagnostic criteria or treatment exists. Published treatment protocols are often time and resource intensive. Nonetheless, CRPSI is not rare and can be disabling. This reports the results of a simple and inexpensive treatment protocol involving no medicines, nerve blockades, physical therapy resources or referrals to pain specialists. The patient is instructed in a self-administered massage and mobilization program. The diagnosis required allodynia (pain on light touch of the skin) and signs or the history of signs of autonomic dysfunction.

Methods: A chart review of patient coded for “reflex sympathetic dystrophy” or “autonomic dysfunction” was performed yielding a cohort of eighty-three patients treated by a common protocol. Most patients were identified in the last 15 years. Most patients with this CRPSI were doubtless coded simply as “foot pain” or “knee pain”, etc and were not identified in this search. Charts were reviewed for patient demographics and outcomes. A subset of patients filled out the Pediatric Outcomes Data Collection Instrument (PODCI) giving a validated pre-treatment disability measure.

Results: The cohort characteristics were similar to prior reports with respect to age, gender, location, and history of trauma. Of the 26 patients who completed the PODCI before treatment the Pain/Comfort Core Scale score mean was 20.81(0-63). The Global Functioning Scale score mean was 52.11(27-83.5). Eighty-nine percent of 51 patients who attended clinic until their outcome was definite had no or minimal residual pain. Treatment averaged 2.2 visits per patient, typically over a six-week period.

Conclusions: A simple, inexpensive protocol can be effective in treating CRPSI in children. The protocol is risk free, inexpensive to families and conservative of physician and physical therapy resources.

Level of Evidence: Therapeutic Level IV.

INTRODUCTION

Chronic Regional Pain Syndrome (CRPS) in children, like that in adults, is presently divided in Types I and II. CRPS I (previously called reflex sympathetic dystrophy) has no direct injury to peripheral nerves. CRPS II (commonly called causalgia) has clear evidence of peripheral nerve injury.

Little progress has been made in understanding and treating Chronic Regional Pain Syndrome Type I (CRPSI) in children over the last 30 years, since the first reports of this disorder appeared in the orthopaedic literature. The etiology remains unknown and the optimal treatment is unclear. Average length of time from symptom onset to diagnosis continues to be measured in months. Many unnecessary diagnostic investigations are performed prior to diagnosis. This limited progress has occurred in spite of significant attempts by the International Association for the Study of Pain (IASP) to define diagnostic criteria for use in research and clinical diagnosis. The most recent consensus definition for clinical diagnosis in 2004 from the IASP is summarized as follows:

1) Continued pain that is out of proportion to the inciting event.
2) A history of three of the four of the following symptoms or signs:
   Sensory: Hyperesthesia or allodynia.
   Vasomotor: Temperature asymmetry or skin color changes or skin color asymmetry.
   Sudomotor/edema: edema or sweating changes or sweating asymmetry.
   Motor/Trophic: decreased range of motion or motor dysfunction or trophic changes.
3) Presence of at least one of the following signs in two or more of the following categories:
   Sensory: hyperalgesia or allodynia.
   Vasomotor: Temperature asymmetry or skin color changes or skin color asymmetry.
   Sudomotor/edema: edema or sweating changes or sweating asymmetry.
   Motor/ Trophic: decreased range of motion or motor dysfunction or trophic changes.

The diagnosis is excluded by the existence of conditions that would otherwise account for the degree of pain and dysfunction.

The criteria used in this study for the diagnosis of CRPS I predated the various consensus recommendations but have similar elements. The criteria used by the senior author are 1) presence of allodynia or dysesthesia; 2) signs of autonomic dysfunction or a history of signs of autonomic dysfunction; and, 3) an absence of pathological process to explain the pain.

The natural history of CRPS I in children is generally reported to be more benign than the adult version in that most patients are eventually relieved of their symptoms without suffering permanent atrophy or joint contracture\(^2,4,5,7,11,12,13\). However, a 2009 study investigating the quality of life of forty-two adults who had childhood CRPS I found that 52% of the patients had pain in the affected limb at a mean 12 year follow up\(^6\).

A consensus is developing that the primary effective treatment is intensive physical therapy, although “intensive therapy” has been poorly defined and its efficacy has not established in a rigorous fashion\(^2,5,6,7,11,13,14,15,16\). Most authors feel that behavioral counseling of the patient and/or family of some sort is critical to the expedient and effective resolution of symptoms\(^3,6,7,11,13,14,15,16,17\). Most treatment programs are quite intensive in terms of family and medical practitioner commitments of time and resources.

This is a case series report of patients with CRPSI evaluated and treated by a program developed in 1987 by the senior author. A series of 5 cases treated by this method was reported in 1989\(^6\). This report is a much larger series of patients treated in the same manner over the last 25 years. We attempted to assess the pre-intervention disability in these children and the effectiveness of treatment using the Pediatric Outcomes Data Collection Instrument (PODCI), which is a validated pediatric orthopaedic outcomes instrument.

The treatment program consists of a patient directed program of mobilization and massage after a detailed description of the problem and validation of the patient’s pain is accomplished during the initial clinic visit. There is no external physical therapy involved. The parents are not involved. It usually requires 1-2 visits at three-week intervals until sufficient symptom resolution has occurred so that no further visits are necessary. The underlying philosophy of the treatment program is that RSD in children is a “mind (brain)-body” problem. It is, therefore, best addressed by having the patient take responsibility for his/her own body. Any external interventions are seen by the body as invasions that tend to entrench rather than relieve the symptoms and signs of CRPSI. The written instruction sent home with the patients are in Table I.

**Table I.**

<table>
<thead>
<tr>
<th>Treatment Plan for Reflex Sympathetic Dystrophy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Massage 3-5 times/day</td>
</tr>
<tr>
<td>2 minutes firmly</td>
</tr>
<tr>
<td>1 minute lightly</td>
</tr>
<tr>
<td>2 minutes firmly</td>
</tr>
<tr>
<td>2) Focus on the body part that is causing you pain and talk to it while massaging.</td>
</tr>
<tr>
<td>3) Always keep it moving, never let it be still.</td>
</tr>
<tr>
<td>4) Use it! Walk, run, jump and play as soon as possible.</td>
</tr>
<tr>
<td><strong>Remember, it will hurt worse at first but it will get better!</strong></td>
</tr>
</tbody>
</table>

**METHODS**

To identify patients, the patient billing database was searched for patients treated by the senior author and given the diagnosis of CRPSI in the time from 1987-April 2010. ICD9 codes for Autonomic Nerve Disorder NEC(337.9) and Reflex sympathetic dystrophy (upper and lower limb, 337.21, 337.22) were used to search the patient database. The search identified 83 patients who met the inclusion criteria. All patients were 18 years old or less and they met the senior author’s criteria for the diagnosis of CRPS I. These criteria were: 1. Presence of allodynia or dysesthesia; 2. Signs of autonomic dysfunction or a history of signs of autonomic dysfunction; and, 3. An absence of pathological process to explain the pain. The records of these 83 patients were then reviewed further to evaluate demographic data, presenting symptoms and outcomes. PODCI scores were assessed when available.

**RESULTS**

Eighty-three patients with the diagnosis of CRPSI were identified. The age at the time of diagnosis ranged from 6-17 years (mean 12.5). Sixty-eight were female and 15 male. The mean time of presentation from onset of symptoms was 7.0 months (range 3 days to 4 years). An onset associated with a minor traumatic injury was identified in 46 patients (55%). Thirty-one patients (37%) had no precipitating injury. Five patients had recent surgery, and one patient gave a history of a prior stress fracture. The
lower extremity alone was involved in 80 patients, upper extremity alone in 2 patients, and both upper and lower extremities involved in 1 patient. Of patients with lower extremity symptoms, the foot or ankle was involved in 61 patients and the knee was affected in 17 patients. One upper extremity case involved the forearm with the other 2 cases involved the hand and wrist.

All patients were noted to have allodynia or dysesthesia on examination in the clinic as this was required for diagnosis Tache cérébrale was only positive if seen in clinic. Physical exam findings of other sings of “autonomic” dysfunction were positive if noted to be present on examination or positive by history. Tache cérébrale was positive in 40 patients, negative in 3, and not mentioned in 40. Swelling was positive in 50, negative in 19, and not mentioned in 14. Temperature change was positive in 42, negative in 17, and not mentioned in 24. Color change was positive in 58, negative in 10, and not mentioned in 15. Range of motion was normal in 45, decreased in 17, and not mentioned in 21. Of the 81 patients with lower extremity involvement, 49 were walking without assistance at the time of clinic evaluation, 27 were unable to walk without crutches, and in 5 walking status was not mentioned.

Prior to presenting for evaluation 15 (18% of the patients) patients had bone scans. Five showed increased uptake, one showed decreased uptake, and nine were normal scans. Thirty-eight patients (46% of study group) had an MRI prior to diagnosis. Five MRI’s had abnormalities including one osteochondral defect; one non-specific edema in the calcaneus, medial cuneiform, and tibialis anterior insertion; two possible stress fractures; and one enhancement within the cuboid. Six patients had a CT scan, with all being negative. Eighty-one of 83 patients initially diagnosed with RSD, 62 (75%) attended their scheduled return appointment in three to four weeks after the initial visit. Improvement was noted in 55 of 62 (89%) of returning patients with 18 patients (29%) reporting complete resolution of pain. Seven patients (11%) reported no relief. Three of the unimproved patients admitted to not following the suggested protocol.

Ultimately, only 51 of 83 patients were followed until symptoms had resolved or the treatment failed. Of the entire cohort 51 patients (62%) had complete resolution of symptoms (47 patients) or minimal pain with no limitations (four patients). Six patients (7%) had continued, limiting pain. Twenty-six patients (31%) have uncertain outcomes because they failed follow-up after one or two clinic visits. Of the patients followed-up with certainty, 89% had good outcomes with no limitation and no or minimal pain and 11% failed treatment. Of the failures, one patients showed initial improvement followed by multiple recurrences and was referred to rheumatology with resolution of symptoms 6 months later; one patient showed no improvement and was referred to anesthesia pain clinic and was treated with regional IV sympathetic blockade, TENS unit, tricyclic antidepressants, and calcium channel blockade without relief and last documentation noted 6 years later to have continued intermittent problems; four patients continued to have symptoms at their last visit and were subsequently lost to follow-up.

Four successfully treated patients (10%) suffered a recurrence of symptoms that was treated in the same
manner either at a clinic visit or recommended by phone. In one patient the recurrence was successfully treated with the same method followed by another recurrence in the opposite extremity to be treated in the same manner without further follow-up. The remaining three cases were instructed to treat as before without any follow-up on their outcomes.

For the entire cohort, there was an average of only 2.2 follow-up visits per patient (range 0-6 visits) and the average duration of treatment was 6.25 weeks (range 0-40 weeks)

**DISCUSSION**

Patients presented in this report displayed similar demographic characteristics to other studies of children and adolescents with CRPS I.11,13,14,15,18 The patients were predominantly female (female: male, 4.5:1) and the lower extremity was most frequently involved (98%). This extremely high percentage of lower extremity patients may be due to the fact that children’s upper extremity problems are seen by hand surgeons at our institution. Prior to the onset of symptoms, patients suffered minor trauma (55%) or no trauma (37%).

The typically recommended treatment for CRPS I in children is intensive physical therapy coupled with individual and/or family psychological therapy. In 1992 Wilder reported on seventy patients treated with multiple modalities. Over one-half of the patients received combined treatment with physical therapy (91%), NSAIDS (71%), transcutaneous electrical nerve stimulation (87%), psychological therapy (63%), tricyclic anti-depressants (59%), and sympathetic block (53%). With a median 3 year follow up period, 46% of these patients had persistent symptoms and less than half had returned to sports.2 In 1999, Sherry, et al. reported outcomes of 103 children, one-half of whom were followed for more than 2 years, who were treated by a daily program of 4 hours of aerobic exercises, 1-2 hours of hydrotherapy, and desensitization11. Seventy-seven percent were referred for psychological counseling. Ninety-two percent became pain free with this program and 88% remained symptom free at more than 2 years. Lee et al. in 2002 randomized 28 children to weekly physical therapy versus triple weekly physical therapy, each program lasting 6 weeks.14 The specific therapy sessions were not standardized and were very variable. Both groups underwent cognitive-behaviors therapy in addition. Ten of the 28 patients were reclassified as CRPS II but were continued in the study. Outcomes were not different between patients with one versus three physical therapy sessions per week. Ten of the 28 patients failed to obtain relief, either initially or on recurrence and required lumbar sympathetic and continuous lumbar epidural infusions. In 2007, Low et al. described 20 children treated with intensive physical therapy, psychological assessment and intervention (mostly cognitive behavior therapy), with most receiving amitriptyline or gabapentin.7 All but 2 had resolution of symptoms with a mean time of 15 weeks.

The value of both physical therapy and psychological therapy has been questioned in recent years. A 2012 systematic review concluded that the evidence for the effectiveness of physiotherapy children with CRPS I is based on a small volume of poor-to-fair quality evidence.18 Rarely is the physical therapy prescribed standardized or even described in most reports. The authors further noted that all studies combined other treatment interventions such as medications and psychological treatment, as well as the physiotherapy. The authors concluded that it was not possible to determine whether physiotherapy alone was effective in treating this population. A 2013 study assessed whether children and adolescents with CRPS I had more underlying psychological problems than children with other types of chronic pain.30 They compared 101 children and adolescents with CRPS I with 103 children with chronic abdominal pain, 291 children with chronic headaches, and 119 with chronic backache. The overall psychological functioning of CRPS I patients was not different from children suffering these other types of chronic pain. This argues against a primary underlying psychological cause for CRPS I, but does not suggest that addressing psychological stress might not be important in treating the disorder.

While treatment of CRPS I with intensive physical therapy, psychological therapies and ad hoc adjunctive medicines have been shown to be effective, they can be costly and disruptive to families due to the time commitment and expense involved. Our protocol was effective in 89% of the patients who attended follow-up clinic in 6 weeks or less. The program is designed and required to be performed by the patient without involvement of any other services or resources.

The report is the first of our knowledge to present PODCI scores in patients diagnosed with CRPS I. The
poor scores for transfer and mobility (65), sports and physical functioning (26), pain (21), happiness (66) and global function (52) documents the debilitated condition the patients are in at time of presentation. Although our PODCI data is limited, it shows that patients with this disorder are severely physically disabled and provides a standard for comparison for future studies. The PODCI forms were completed by less than half of the patients in the study. There were no PODCI scores available from the return visits to clinic.

There are several limitations to this current report. The retrospective nature of data collection depends upon the accuracy of data in the patient’s record. Many signs or symptoms of CRPS I were not mentioned as either being present or absent. This cohort is certainly only a fraction of the CRPS I patients seen at our institution. Most CRPS I patients would be coded as “foot pain” or “knee pain” as this is a simpler diagnosis to find than “autonomic nerve dysfunction” and “reflex sympathetic dystrophy” which were used to identify this cohort. The number of patients coded with the nonspecific “pain” in a region of the body is so great as to be prohibitive in the amount of time required to find CRPS I patients coded as such. From January through June of 2013, the senior author personally coded all CRPS I patients. Eleven patients presented with CRPS I during that 6-month period. This suggest that we identified somewhat less than 1/3 of CRPS I patients from 2000 to 2013. There is no reason to suspect that the patients identified were different from those not identified except that is seems likely that more difficult patients who returned more frequently were more likely to be coded as “reflex sympathetic dystrophy” than those who were seen once or twice with a chief complaint of “foot pain”. A significant further limitation is that thirty-one percent of the patients failed to return for follow up after the initial or second clinic visit and their symptom status is not known. It is possible that some did well and chose not to return. It is also possible that if the protocol did not work, the patients chose not to return and/or found other treatment.

Strengths of the paper are a well-defined protocol for treatment. A fairly large cohort for this disorder was reviewed. The senior author's practice location is very limited in other option for pediatric orthopaedic care, suggesting that many or most of the patients lost to followup did not seek care elsewhere.

The data presented in this report shows that a patient-directed program for treatment of CRPS I can be effective. If so, the reason that this approach works is unclear. It is possible that CRPS I is, in fact, a “mind-body” problem that the protocol addresses. It is also possible that this is just a “poor man’s” physical therapy program. Furthermore, it is possible that the senior author’s strong confidence in the effectiveness of the protocol is communicated to the patient and is of itself, therapeutic. Finally, if the protocol itself is therapeutic, it is unclear which elements of the protocol are critical, e.g. mobilization vs massage vs talking to the painful limb during massage vs constant motion. Nonetheless, we have found this to be an effective and resource conservative treatment.

**REFERENCES**


THE VARIABILITY IN SURGICAL MARGIN REPORTING IN LIMB SALVAGE SURGERY FOR SARCOMA

Kevin Hoang, BS1, Yubo Gao, PhD2, Benjamin J. Miller, MD, MS2

ABSTRACT

Background: Surgical margins are a standard reported measurement in tumor surgery that has implications for functional outcome, local control, and overall survival. There is no single accepted classification, and it is unclear what form or margin reporting predominates in the sarcoma literature.

Methods: We performed a PubMed literature search to identify articles that reported surgical margins and oncologic outcomes in limb salvage surgery for sarcoma from 1980 to 2013. We recorded the margin classification, specialty of the journal, specialty of the author, and location of the authors’ institution.

Results: We found that 159/448 (35%) of articles included in the study did not report surgical margins. Of the 289 papers that did include data on margins, 160 (55%) of articles used Enneking’s classification. There has been an increase over time in the proportion of articles reporting surgical margins by the residual tumor (R) classification and the proportion of articles reporting margins dichotomously as “positive” or “negative.”

Conclusions: We did not find a common method for reporting margins in the limb salvage sarcoma literature. Of most concern was over 1/3 of clinical reports of oncologic outcomes did not include margin status, which substantially compromises any conclusions that readers may infer about treatment success, local recurrence, or survival. We believe there should be renewed efforts to encourage use of a common surgical margin reporting system that is simple, reproducible, and prognostic.

INTRODUCTION

Soft-tissue and bone sarcomas classically arise from the mesodermal embryonic cell layer and account for less than 1% of all cancer-related deaths. In 2014, 15,000 new patients in the United States were estimated to be diagnosed with a sarcoma. Historically, the primary treatment for sarcoma was amputation of the affected limb to achieve acceptable rates of local control. Advances in chemotherapy in the 1980s dramatically increased the survival of adolescent bone sarcoma and coincided with a movement to minimize the number of amputations required for adequate management of sarcoma. In addition, increasing use of computed tomography scans, magnetic resonance imaging, and peri-operative radiation therapy allowed limb salvage surgery to become the preferred intervention to amputation.

Limb salvage surgery challenges practitioners to find a balance between removing tissue sufficient to prevent recurrence or metastatic spread while retaining structures integral to maintain acceptable functional outcomes. The quantification of this measure of “closeness” to the tumor is reflected in the reported margin, the significance of which remains a consistent source of controversy and may be dependent on the specific type of sarcoma in question. The final surgical margin is a standard measurement for all operatively treated sarcomas and has been shown to be a key prognostic factor for local recurrence, metastatic spread, and overall survival for a variety of sarcomas.

Therefore, it is imperative that the oncologic team (surgeons, medical oncologists, radiation oncologists, radiologists, and pathologists) utilize a common classification for margin reporting. The ideal classification allows the treating team to understand the risk of recurrent disease, and assists with treatment decisions, surveillance protocols, patient counseling, and comparative research.

All systems of margin reporting account for tumor at the edge of the resection (a “positive” margin), but may differ on whether it is further categorized as “grossly” or “microscopically” positive. In addition, some systems will equate all “negative” margins, while others will account for the extent of a negative margin by differentiating between a resection through the reactive zone of peri-tumorous tissue or reporting a distance from the closest margin. This results in surgical margin criteria.
that are not always interchangeable, making comparison of outcomes and risk factors for recurrence following limb salvage surgery across multiple investigations difficult or impossible. These inconsistencies suggest a clear need for a universal system of margin reporting, however, the scope of the issue and magnitude of the problem has not been previously defined. Therefore, we seek to identify 1) the common classification systems for reporting surgical margins utilized within the current literature, 2) the trends in the use of these classifications over time, and 3) characteristics of the article (journal, specialty of author, location of authors’ institution) that may demonstrate a preference for a specific classification system.

**MATERIALS AND METHODS**

A PubMed database search was conducted on July 4, 2014 using the keyword combination “sarcoma limb salvage.” PubMed filters for human species, English language, and publication dates between January 1, 1980 and December 31, 2013 were applied to the search. The starting year of 1980 was selected because it was the year the Enneking surgical margin classification system was first reported. Article titles, MeSH terms, abstracts, methods, and results were examined to exclude: 1) articles that did not report new surgical margin data, 2) case reports, 3) articles unrelated to sarcomas, 4) animal studies, 5) articles that could not be retrieved, and 6) articles that did not report any oncologic treatment outcomes (overall survival, disease-free survival, event-free survival or local recurrence). Articles that did not report new surgical margin data included review articles, meta-analyses, editorials, comments, letters, practice guidelines, and technical reports.

For articles included in the study, the first author’s departmental affiliation, the first author’s institutional location, and the journal’s specialty focus were recorded. The first author’s departmental affiliation was categorized as orthopaedic surgery, general surgery, medical oncology, radiation oncology, or other. The “other” category included articles where the first authors were from epidemiology, pathology, pediatrics, radiology, or where the department was not listed in the article. The first author’s institutional location was categorized as: Africa, Asia, Europe, Oceania, or Americas. There were only six articles from South America; therefore these articles were grouped with articles from North America to form the “Americas” category. The journal’s subject was categorized using the Science Citation Index (SCI) as: “oncology,” “orthopaedic surgery,” “surgery, not listed,” or “radiology, nuclear medicine, & medical imaging.”

Articles were placed into one of six unique categories based on the surgical margins criteria used to report data (Table 1). Articles that reported surgical margins using Enneking’s criteria (radical, wide, marginal, or intralesional) were categorized as “Enneking.” Articles that used a classification system based upon Enneking’s criteria to report adequate (radical or wide) or inadequate (marginal or intralesional) margins were categorized as “Dichotomous.” Articles that described surgical margins simply as positive or negative without further description were categorized as “Dichotomous.” Articles that reported surgical margins using three categories of margins without further description, typically as negative, close, or positive, were categorized as “Trichotomous.” Articles that reported surgical margins as the distance from the resection edge to the closest site of tumor were categorized as “Measurments.” Articles that reported surgical margins using the criteria proposed by Kawaguchi were categorized as “Japanese Orthopaedic Association (JOA).” Articles that did not report surgical margins were categorized as “Margins Not Reported.” Additionally, if an article was found to use multiple surgical margin criteria to report data, then each criteria type was included and recorded separately.

**STATISTICAL ANALYSIS**

Data analysis was performed with XLSTAT (version 2014.4.08, Addinsoft USA, New York, NY, USA). The articles were ordered by year of publication and separated by the surgical margin criteria used to report data. The trends over time in the number of articles and proportion of articles using a specific surgical margin criterion were analyzed. The Mann-Kendall statistics (S)
The Variability in Surgical Margin Reporting in Limb Salvage Surgery for Sarcoma

A positive S indicates an increasing trend, while a negative S indicates a decreasing trend. The null hypothesis (H₀) for the Mann-Kendall trend test is that no monotonic trend exists. The alternative hypothesis (H₁) is that a monotonic trend exists. Additionally, t-test p-values were recorded in order to determine if a relationship exists between the surgical margin criteria used and first author’s departmental affiliation, first author’s institutional location, or SCI subject matter of the article. Articles classified as JOA or trichotomous were analyzed from their year of first appearance in the literature, 2004 and 1993, respectively. Statistical significance was defined as p<0.05.

and Mann-Kendall trend test p-values were recorded. A positive S indicates an increasing trend, while a negative S indicates a decreasing trend. The null hypothesis (H₀) for the Mann-Kendall trend test is that no monotonic trend exists. The alternative hypothesis (H₁) is that a monotonic trend exists. Additionally, t-test p-values were recorded in order to determine if a relationship exists between the surgical margin criteria used and first author’s departmental affiliation, first author’s institutional location, or SCI subject matter of the article. Articles classified as JOA or trichotomous were analyzed from their year of first appearance in the literature, 2004 and 1993, respectively. Statistical significance was defined as p<0.05.

Table 2: Statistical tests for monotonic correlation and trend for the number of articles reporting surgical margins from 1980 to 2013 (unless otherwise noted).

<table>
<thead>
<tr>
<th>Surgical margin criteria used to report</th>
<th>Mann Kendall statistic (S)</th>
<th>Mann-Kendall trend test p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enneking</td>
<td>S = 402</td>
<td>P &lt; 0.01 **</td>
</tr>
<tr>
<td>R Classification</td>
<td>S = 272</td>
<td>P &lt; 0.01 **</td>
</tr>
<tr>
<td>Dichotomous (From 1993)</td>
<td>S = 238</td>
<td>P &lt; 0.01 **</td>
</tr>
<tr>
<td>Trichotomous (From 1993)</td>
<td>S = 50</td>
<td>P = 0.20</td>
</tr>
<tr>
<td>Measurements</td>
<td>S = 41</td>
<td>P = 0.51</td>
</tr>
<tr>
<td>JOA (From 2004)</td>
<td>S = -9</td>
<td>P = 0.41</td>
</tr>
<tr>
<td>Margins not reported</td>
<td>S = 324</td>
<td>P &lt; 0.01 **</td>
</tr>
</tbody>
</table>

**Denotes statistical significance.

RESULTS

Between 1980 and 2013, 1,207 articles were identified through PubMed with the keyword combination: sarcoma limb salvage. After applying PubMed filters, 969 articles remained for review. 521 articles were subsequently excluded leaving a collection of 448 scientific reports available for analysis (Fig. 1).

Margin vs. Year

Of the articles between 1980 and 2013 that examined at least one oncologic outcome, 160 used the Enneking criteria, 38 used the R classification criteria, 38 used dichotomous criteria, 26 used trichotomous criteria, 23 used measurements, and 5 used the JOA criteria. One article reported margins using two different criteria (Enneking and R Classification). 159 articles (35%) did not report surgical margins.

From 1980 to 2013, there was an increasing trend in the number of articles using Enneking’s criteria (S = 402, p < 0.01), articles using R classification criteria (S = 272, p < 0.01), articles using dichotomous criteria (S = 238, p < 0.01), and articles that did not report surgical margins (S = 324, p < 0.01). There was no statistically significant trend in articles that reported surgical margins using the JOA criteria, measurements, or trichotomous criteria. (Table 2) (Figure 2)

From 1980 to 2013, there was an increasing trend in the proportion of articles using R classification criteria (S = 231, p < 0.01) and dichotomous criteria (S = 144, p = 0.025) to report surgical margins (Table 3). There were no other statistically significant trends in the proportion of articles using specific criteria to report surgical margins.
Table 3: Statistical tests for monotonic correlation and trend for the proportion of articles reporting surgical margins from 1980 to 2013 (unless otherwise noted).

<table>
<thead>
<tr>
<th>Surgical margin criteria used to report</th>
<th>Mann Kendall statistic (S)</th>
<th>Mann-Kendall trend test p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enneking</td>
<td>S = 47</td>
<td>P = 0.49</td>
</tr>
<tr>
<td>R Classification</td>
<td>S = 231</td>
<td>P &lt; 0.01 **</td>
</tr>
<tr>
<td>Dichotomous (From 1993)</td>
<td>S = 144</td>
<td>P = 0.025 **</td>
</tr>
<tr>
<td>Trichotomous (From 1993)</td>
<td>S = -7</td>
<td>P = 0.88</td>
</tr>
<tr>
<td>Measurements</td>
<td>S = -87</td>
<td>P = 0.18</td>
</tr>
<tr>
<td>JOA (From 2004)</td>
<td>S = -14</td>
<td>P = 0.19</td>
</tr>
<tr>
<td>Margins not reported</td>
<td>S = -79</td>
<td>P = 0.25</td>
</tr>
</tbody>
</table>

**Denotes statistical significance.

Margin vs. Department

Examination of the first authors’ departmental affiliation revealed that 198 were from orthopaedic surgery, 89 were from general surgery, 40 were from medical oncology, 17 were from radiation oncology, and 105 were from “other” departments. Articles that included surgical margin data were further analyzed. First authors from orthopaedic surgery (P = 0.035) and medical oncology (P < 0.01) were more likely to use Enneking’s system than other criteria to report surgical margins. First authors from general surgery (P = 0.025) and radiation oncology (P < 0.01) were less likely to use Enneking’s criteria than other criteria to report surgical margins. There was no statistically significant difference (P = 0.99) in the use of the Enneking criteria by first authors from “other” departments.

Margin vs. Continent

Upon examination of the physical location of the first author, we found that 172 were from Europe, 153 were from the Americas, 111 were from Asia, 7 were from Oceania, and 6 were from Africa. Articles that included surgical margin data were further analyzed. First authors from Europe were more likely (P < 0.01) to use Enneking’s criteria than other criteria to report surgical margins. First authors from the Americas were less likely (P < 0.01) to use Enneking’s criteria than other criteria to report surgical margins. There was no statistically significant difference in the use of Enneking’s criteria by authors from Africa (P = 0.31), Asia (P = 0.52), and Oceania (P = 0.31).

Margin vs. SCI

Examination of the SCI subject category revealed: 156 articles were published in orthopaedic surgery journals, 109 articles were published in surgery journals, 92 articles were published in oncology journals, 22 articles were published in radiology, nuclear medicine, and medical imaging journals, and 70 were published in journals not listed in the SCI. Articles that included surgical margin data were further analyzed. Articles published in journals that were classified as “radiology, nuclear medicine, and medical imaging” by the SCI subject category were less likely (P = 0.012) to report margins using Enneking criteria. There was no statistically significant difference in the use of Enneking’s criteria to report surgical margins in articles published in orthopaedic surgery journals (p = 0.083), surgery journals (p = 0.21), oncology journals (p = 0.096), and journals not listed in the SCI (p = 0.21).

DISCUSSION

There have been multiple authors who have recognized that the methods to report sarcoma surgical margins are disjointed. In our study, we found that there exists six unique surgical margin criteria commonly used in the scientific literature: Enneking, R classification, dichotomous, trichotomous, measurements, and the JOA. While the number of articles reporting surgical margins has increased since 1980, there remain a notable proportion of articles not reporting surgical margins. When surgical margins are reported, Enneking’s criteria are the most commonly used among authors, especially orthopaedic surgeons. To our knowledge, this is the first study to quantitatively analyze surgical margin reporting in the sarcoma and limb salvage literature.

Our data demonstrate that there are several distinct surgical margin classification systems, none of which were represented in the majority of publications. In our opinion, it was surprising that 35% of articles did not report surgical margins, as this limits the information that may be gleaned, specifically for any conclusions regarding local control of the tumor. If we examine the remaining reports (when authors chose to report surgical margins), the majority (55%) used Enneking’s criteria to report their data. The next most common surgical margin reporting systems were R classification and dichotomous (both 13%). Trichotomous criteria, measurements, and the JOA criteria were the least used surgical margin criteria (9%, 8%, and 2% respectively). This variability is also a concerning finding, as the investigations that do report margins utilize several different systems that may not be easily compared to one another.

Our trend analysis shows that there has been a positive linear trend in the number of articles that use Enneking’s criteria, articles that use dichotomous criteria, and articles that do not report margins. This finding is likely due to the overall increase in the number of articles reporting oncologic outcomes after limb salvage surgery over time. The number of articles reporting
surgical margins using trichotomous criteria, measurements, and the JOA criteria did not show any definable changes over the study period. When examining trends in the proportion of margins reported in each system over time to account for the overall increase in publications, we found that there has only been an increase in the proportion of articles using R classification and dichotomous criteria. One possible explanation for the growing popularity of these systems is that physicians are becoming convinced that additional detail apart from the presence of tumor at the surgical margin is not important. Another possibility is that this reflects an increase in articles written by those outside orthopaedic surgery. As the Enneking classification was motivated by surgical decision-making and developed and presented primarily in the arena of orthopaedic oncology, it is plausible that those outside this specialty are unlikely to find it as commonplace or useful as an orthopaedic surgeon. Finally, it may be explained by the simplicity of dichotomous criteria as the easiest and most reproducible method to report margins. In reality, this trend is likely due to a combination of factors.

We also examined criteria usage preferences of first authors in other departments, by continent, and journal subject category. We found that first authors from orthopaedic surgery, hematology and oncology, or Europe were more likely to use Enneking’s criteria than other systems to report surgical margins. Alternatively, first authors from surgery, radiation oncology, the Americas, or journals in medical imaging were more likely to use a system other than the Enneking classification. The lack of preference for the Enneking classification system in the Americas may be explained by the presence of more authors from radiation oncology (who use non-Enneking criteria to report surgical margins 92% of the time) within the Americas. The preference for the Enneking classification system in Europe may be explained by the presence of more first authors from hematology and oncology, which use Enneking criteria to report surgical margins 86% of the time within Europe.

This report has two major findings that warrant further study. The first is that the substantial number of papers not reporting any detailed margin status, but still commenting on the oncologic outcome after surgical treatment, is problematic. Submitting authors and accepting journals should be expected to include some mention of margins if commenting on local or systemic control. The second is that there is a substantial need for a universal system of margin reporting. The lack of such a system inhibits interdisciplinary communication and comparative literature reviews. Some reporting can be extrapolated to other systems, such as “positive” in the dichotomous classification and “intralesional” in Enneking’s. However, some labels cannot. For instance, a “R0” margin could be either a “marginal” or “wide” margin in Enneking’s system. This is critical as margins are the language of limb salvage surgery and local control of sarcoma, and a mechanism of documentation that is simple, meaningful, reproducible, and prognostic is an important and attainable goal.

This study had a number of limitations. We only identified articles for inclusion using a PubMed search. Although the PubMed database contains numerous articles, it does not contain the entire scientific literature. Our purpose was not to determine the most appropriate margin classification system, and more work must be performed prior to any definitive recommendations on which classification is best. Clearly this is an important and complex issue that is outside the scope of this report. Therefore, our findings are generally observational, and any conclusions drawn from these data are necessarily limited.

To conclude, it is essential that sarcoma specialists have an understanding of the effects of surgical margins on the prognosis of their patients. Disjointed surgical margin reporting in the scientific literature creates difficulty in comparing treatment outcomes between articles that use different margin criteria. A single universal surgical margin reporting system to facilitate communication between physicians would enhance the understanding of all the subspecialties involved in sarcoma treatment.

**SOURCE OF FUNDING**

No funding was required for this investigation.

**REFERENCES**


HEALTH LITERACY IN PATIENTS SEEKING ORTHOPAEDIC CARE:
RESULTS OF THE LITERACY IN MUSCULOSKELETAL PROBLEMS
(LIMP) PROJECT

Andrew J. Rosenbaum, MD, Denis Pauze, MD, Daniel Pauze, MD,
Nancy Robak, RN, MPH, Ralph Zade, MD, Michael Mulligan, MD, Richard L. Uhl

ABSTRACT
Background: Health literacy is the most important predictor of an individual’s health status, with more frequent hospitalizations, worse control of chronic conditions, and suboptimal treatment outcomes associated with limited literacy. Despite this, little is known about musculoskeletal health literacy. As such, this study utilized a musculoskeletal specific literacy survey (the LIMP questionnaire) to evaluate the level of comprehension in patients presenting to the emergency department with musculoskeletal complaints, with an emphasis on their understanding of anatomy, terminology, diagnosis and treatment of musculoskeletal conditions. The relationship between musculoskeletal specific and general health literacy was also assessed, in addition to the risk factors for limited musculoskeletal comprehension.

Methods: In this cross-sectional study, each of the 248 participants completed a demographic survey, the LIMP questionnaire, and the Newest Vital Sign (NVS), a general health literacy assessment tool. A $x^2$ analysis was used to compare results from the LIMP questionnaire and NVS, and to evaluate the relationship between musculoskeletal health literacy and demographic parameters.

Results: The mean LIMP score was 4.68 ± 1.78 out of a possible nine points. Questions regarding musculoskeletal conditions were answered correctly by 47.4% of respondents. Questions regarding diagnosis and treatment were answered correctly by 31.2% of respondents. Questions regarding anatomy and terminology were answered correctly by 65.3% of respondents.

Limited musculoskeletal literacy, defined as LIMP questionnaire scores of <6, was observed in 69% of subjects. Inadequate general health literacy, defined as NVS scores <4, was observed in 48% of subjects. This difference was statistically significant ($p<0.001$).

Those who identified themselves as Caucasian and having an education level of ≥ college were significantly more likely to have adequate musculoskeletal literacy ($p=0.001$, $p<0.001$, respectively).

Conclusions: The prevalence of limited musculoskeletal literacy is greater than that of limited general health literacy, with minorities and those with lower education levels most at risk. These findings are consistent with other disease and specialty specific literacy studies. Although such insight will assist providers in accurately targeting education and outreach campaigns, it remains imperative that additional research be performed to determine if limited literacy correlates with increased complications and worse outcomes in those with musculoskeletal conditions.

Level of Evidence: Level IV

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INTRODUCTION
Recent reports by the Institute of Medicine, American Medical Association Foundation, and Agency for Healthcare Research and Quality suggest that nearly half of all English-speaking adults have inadequate health literacy$^{1,2,3}$. This is concerning, as health literacy is the ability of individuals to perform the basic reading and numerical tasks needed to function in the modern health care environment, and is considered the single best predictor of an individual’s health status$^{4,5,6}$. Those with limited literacy have decreased medical knowledge, poorer health related outcomes, more hospitalizations, and poorer communication with physicians$^{7,8}$. Further, an additional $\$73 billion of healthcare spending is attributed to limited health literacy annually; the healthcare cost of Medicaid patients with limited literacy are about four times that of patients with adequate health literacy$^{6,9,10}$.

Despite the high prevalence of inadequate health literacy, clinicians often struggle to identify these patients$^{7,11,12}$. As such, researchers have developed several instruments to evaluate health literacy based on reading and numeracy skills; the Test of Functional
Health Literacy in Adults (TOFHLA), Rapid Estimate of Adult Literacy in Medicine (REALM) and the Newest Vital Sign (NVS) are some of the most commonly used. However, these tools have been designed to assess general health literacy and are not applicable to all clinical situations, with few disease and specialty specific health literacy assessments available. Additionally, there is ongoing debate regarding which factors are associated with inadequate patient comprehension and limited literacy. This study aims to examine patients’ comprehension regarding anatomy, terminology, diagnosis and treatment of common musculoskeletal conditions, and to correlate this comprehension with demographic characteristics and their levels of general health literacy.

**METHODS**

**Setting and Study Sample**

Following Institutional Review Board approval, a convenience sample was obtained of 248 English-speaking adults (≥18 years of age) presenting with a single musculoskeletal complaint to the emergency department (ED) of an academic medical center.

Written consent was obtained from all willing participants. Patients were excluded if they did not meet the aforementioned inclusion criteria, as well as if they were cognitively impaired, unable to sign their own consent for participation, unable to read English, presenting with a primary complaint of a non-musculoskeletal condition, and if presenting with an open fracture or dislocation.

**Data Collection and Literacy Assessments**

While in the emergency department, patients first completed a five-minute demographic questionnaire in which they identified their musculoskeletal complaint, age, gender, race, level of education, whether or not they had ever worked in a healthcare field before and whether or not they had been seen in the past by a physician for a musculoskeletal complaint.

Next, patients’ general health literacy skills were assessed using the Newest Vital Sign (NVS). The NVS is a validated health literacy assessment in which patients answer six questions pertaining to an ice-cream label. Adequate health literacy was present when ≥4 questions were answered correctly. To administer the NVS, the standardized label was given to each participant, followed by a research assistant verbally asking the participant each question. The NVS took participants less than five minutes to complete. Permission to use the NVS was obtained from Pfizer, Inc.

After NVS completion, participants completed the LiMP survey (Figure 1). This was self-administered,
Health Literacy in Patients Seeking Orthopaedic Care

Consisting of nine multiple-choice questions and took patients five to seven minutes to complete. The survey’s questions were based on the most commonly emphasized themes (anatomy, terminology, diagnosis, treatment) found in the patient education section of the American Academy of Orthopaedic Surgeons (AAOS) website (Table 1). It was written at a Flesch-Kincaid grade level of 4.2, as many health organizations recommend the readability of patient education materials to be no higher than sixth-grade level. Scores ≥6 were indicative of adequate musculoskeletal health literacy, a cutoff determined in an earlier study and based on methods described by Pendlimari et al.

Table 1: A listing of each question, corresponding theme and percentage of respondents who answered it correctly.

<table>
<thead>
<tr>
<th>Question</th>
<th>Theme</th>
<th>Correct Answer Chosen (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>MSK Conditions</td>
<td>47.5</td>
</tr>
<tr>
<td>2</td>
<td>Diagnosis &amp; Treatment</td>
<td>8.4</td>
</tr>
<tr>
<td>3</td>
<td>Anatomy &amp; Terminology</td>
<td>53.2</td>
</tr>
<tr>
<td>4</td>
<td>Anatomy &amp; Terminology</td>
<td>76.2</td>
</tr>
<tr>
<td>5</td>
<td>MSK Conditions</td>
<td>56.8</td>
</tr>
<tr>
<td>6</td>
<td>Anatomy &amp; Terminology</td>
<td>66.5</td>
</tr>
<tr>
<td>7</td>
<td>MSK Conditions</td>
<td>53.2</td>
</tr>
<tr>
<td>8</td>
<td>MSK Conditions</td>
<td>32.2</td>
</tr>
<tr>
<td>9</td>
<td>Diagnosis &amp; Treatment</td>
<td>54.0</td>
</tr>
</tbody>
</table>

Statistics

Data analysis was performed with the Statistical Package for the Social Sciences (IBM, Armonk, NY). Theme-based and overall performance on the LiMP questionnaire was calculated. The percentage of participants with adequate literacy, as based on LiMP and NVS performance, was also determined. Contingency table analysis was used with χ² analysis to identify trends and determine the significance of these results. χ² analyses were also used to evaluate for associations between literacy and demographic characteristics of study participants. Values of p < 0.05 were considered significant.

RESULTS

A total of 248 subjects completed the LiMP, NVS, and demographic surveys. Table 2 summarizes subject demographic and baseline characteristics. The average age was 42.8 ± 17.6 years, with almost an equal number of males and females (50.4% and 49.6%, respectively). Most subjects were Caucasian (62%) and had at least some college education (52%). Approximately one-third of the patients identified themselves as being either a current or previous employee in a healthcare field. More than half of the participants had seen a physician in the past for a musculoskeletal complaint. As illustrated in Figure 2, presenting complaints were classified as involving the lower extremity (including pelvis, 37%), upper extremity (29%), or neck and/or back (34%).

The mean LiMP score was 4.68 ± 1.78. Table 1 lists the theme of each LiMP question and the percentage of participants that answered each question correctly. Questions evaluating knowledge of musculoskeletal conditions were correctly answered by 47.4% of respondents (117 out of 248, 95% CI 41.1%-53.51%), while anatomy and terminology questions were correctly answered by 65.3% (162 out of 248, 95% CI 59.3%-71.22%), and those pertaining to diagnosis and treatment by 31.2% (77 out of 248, 95% CI 25.4%-36.97%).

Table 2: Participants’ demographics and baseline characteristics.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean (± SD) or Frequency (Proportion)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>42.8 ± 17.6</td>
</tr>
<tr>
<td>≥30</td>
<td>72 (29%)</td>
</tr>
<tr>
<td>31-50</td>
<td>100 (40%)</td>
</tr>
<tr>
<td>&gt;50</td>
<td>76 (31%)</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>125 (50.4%)</td>
</tr>
<tr>
<td>Female</td>
<td>123 (49.6%)</td>
</tr>
<tr>
<td>Race</td>
<td></td>
</tr>
<tr>
<td>Caucasian</td>
<td>153 (62%)</td>
</tr>
<tr>
<td>African American</td>
<td>63 (25%)</td>
</tr>
<tr>
<td>Other</td>
<td>32 (13%)</td>
</tr>
<tr>
<td>Education</td>
<td></td>
</tr>
<tr>
<td>College or more</td>
<td>130 (52%)</td>
</tr>
<tr>
<td>High School or less</td>
<td>118 (48%)</td>
</tr>
<tr>
<td>Healthcare employee/professional (currently or previously)</td>
<td>83 (33%)</td>
</tr>
</tbody>
</table>
Adequate Literacy & Limited Literacy & Limited Literacy & Adequate Literacy & Adequate Literacy & Limited Literacy & Limited Literacy & Adequate Literacy & Adequate Literacy

Limited musculoskeletal literacy, as defined by a score of <6 on the LiMP questionnaire, was seen in 69% (95% CI 63.2%-74.7%) of participants. Limited general health literacy, as defined by a score of <4 on the NVS, was present in 48% (95% CI 41.7%-54.2%) of subjects. This difference was statistically significant (p<0.001). The sensitivity, specificity, positive predictive value and negative predictive value of the LiMP questionnaire in predicting inadequate general health literacy were 82.5%, 43.7%, 57.9%, and 72.9%, respectively (Table 3).

The relationship between participants’ demographic characteristics and the prevalence of adequate musculoskeletal literacy, which was defined as a LiMP score of ≥6, was evaluated with χ² tests. There was no significant difference in prevalence as a function of age, gender, employment type, or a prior visit to physician for a musculoskeletal complaint (p>0.05). However, the prevalence of adequate musculoskeletal literacy was significantly influenced by race (Caucasian, p=0.001) and education (≥ college, p<0.001) (Table 4). Orthopaedic patients have demonstrated limited comprehension in clinical settings²⁵,²⁶. A prospective investigation evaluating the level of patient comprehension during the process of obtaining informed consent for elective orthopaedic surgery, Crepeau et al. found comprehension to be unexpectedly low, emphasizing the need for new ways of educating patients about the risks and benefits of a surgical procedure²⁵. Kadakia et al. presented similar findings in their study of orthopaedic trauma patients, as their cohort demonstrated a limited understanding of their injuries, surgeries, and postoperative instructions²⁶.

The mean LiMP score of study participants (4.68 ± 1.78) was suggestive of limited musculoskeletal literacy. Less than half of the subjects correctly answered questions regarding musculoskeletal conditions and diagnosis and treatment (47.4% and 31.2%, respectively), while approximately two-thirds of the participants correctly answered anatomy and terminology questions (65.3%). This is consistent with other orthopaedic patient comprehension studies²⁵,²⁶.

In our study, 48% of our subjects were found to have inadequate general health literacy based on NVS scores, a proportion in line with national estimates. A higher proportion of patients were found to have inadequate musculoskeletal literacy (69%), a finding consistent with prior work on disease and specialty specific literacy⁷,¹⁹,²⁰,²¹.

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Table 3: Contingency table. The sensitivity, specificity, PPV and NPV of the LiMP survey in predicting inadequate general health literacy was 82.5%, 43.7%, 57.9%, and 72.9%, respectively.

Table 4: The prevalence of adequate musculoskeletal health literacy amongst study participants as a function of demographic characteristics. Those values highlighted in green represent statistically significant (p<0.05) differences in literacy.
Most of the limited literacy patients identified by the LiMP were also found to have limited general health literacy (99 out of 120), making the LiMP a sensitive test (82.5%) with a low false negative rate (17.5%) for detecting inadequate health literacy. These are important attributes of a screening test, as they suggest that LiMP scores of ≥6 can effectively rule out both limited musculoskeletal literacy and general health literacy. Conversely, the NVS was not as sensitive at predicting limited musculoskeletal literacy (57.8%). These findings support the need for a musculoskeletal specific assessment tool and elucidate the complexity of musculoskeletal health literacy. Additionally, our results suggest that musculoskeletal health literacy requires an enhanced set of skills that includes, but also exceeds, those needed for general health literacy. It is only with this more sophisticated skill set that that individuals can effectively manage and make informed decisions regarding their musculoskeletal care.

Those who identified as Caucasian and having an education level ≥ college were significantly more likely to have adequate musculoskeletal health literacy ($p=0.001$, $p<0.001$, respectively). This is consistent with other works. Although we expected subjects who identified themselves as currently or formerly working in a healthcare field to outperform those who did not, no significant difference was observed. This is indicative of the extreme diversity of individuals possessing inadequate musculoskeletal health literacy, and should serve as a gentle reminder to physicians that one should not assume adequate literacy in patients with a healthcare background.

Our study has several limitations. Patients were not randomly selected, as this was a cross-sectional study utilizing a convenience sample. The generalizability of our results may also be limited, as all participants were from the ED of a single academic medical center. Despite being informed of confidentiality, some patients may have been reluctant to truthfully answer questions regarding educational background, leading to response bias. Volunteer bias could have also occurred, particularly if only those patients who were confident in their baseline musculoskeletal knowledge agreed to participate.

Our study has demonstrated the application of a musculoskeletal specific health literacy assessment tool in an ED setting and identified a greater prevalence of limited musculoskeletal health literacy as compared to general health literacy. This is concerning, and suggests that many of our patients lack the necessary comprehension required for informed and shared decision making. Although we have begun to delineate the demographics most at risk, future studies must further define this and determine if inadequate musculoskeletal literacy adversely affects patient outcomes.

There is also a need for continued investigation into the optimal means of educating patients. The benefits of more readable patient education materials must be explored, as many of the current materials are considered too difficult for patients to comprehend. Additionally, newer methods of educating patients should be developed and promoted, such as pictorial-enhanced discharge instructions, which is one example of an intervention that has shown promise. Finally, based on the results of our study, increased time and education should be provided for patients identifying as non-Caucasian and with secondary or lesser levels of formal education. It is with this emphasis on musculoskeletal literacy and comprehension that patients will be empowered with the skills pivotal to making informed decisions regarding their musculoskeletal health, an approach that will ultimately enhance physician-patient interactions and may improve clinical outcomes.

REFERENCES


EVALUATION OF DIFFERENT EXPERIENCE LEVELS OF ORTHOPAEDIC RESIDENTS EFFECT ON POLYMETHYL METHACRYLATE (PMMA) BONE CEMENT MECHANICAL PROPERTIES

Jonathon M. Struemph, MD1, Alexander CM. Chong, MSAE, MSME1,2, Paul H. Wooley, PhD1,2

ABSTRACT

Background: PMMA bone cement is a brittle material and the creation of defects that increase porosity during mixing or injecting is a significant factor in reducing its mechanical properties. The goal during residency training is to learn how to avoid creating increased porosity during mixing and injecting the material. The aim of this study was to evaluate and compare tensile and compression strength for PMMA cement mixed by intern orthopaedic residents (PGY-1) and senior orthopaedic residents (PGY-5). The hypothesis was that the mechanical properties of PMMA cement mixed by PGY-5 would be significantly better than PMMA cement mixed by PGY-1 residents.

Methods: Four PGY-1 and four PGY-5 orthopaedic residents each prepared eight tensile specimens. The bone cement used was Simplex™P bone cement (Stryker Howmedica Osteonics, Mahwah, NJ) under vacuum mixing in a cement-delivery system. Tensile testing of the specimens was performed in an MTS Bionix servohydraulic materials testing system with loading rate of 2.54 mm/min at room temperature. The mean and standard deviation of the ultimate tensile strength (UTS) for each orthopaedic resident group was calculated. The compression specimens were cylinders formed with a central core to mimic a prosthetic implant. Ten samples from each orthopaedic resident were tested using the same MTS system under identical conditions at room temperature. The specimens were loaded from -50N to complete structural failure at the rate of 20 mm/min. The ultimate compressive strength (UCS) was then determined and the mean and standard deviation calculated for each group.

Results: The average UTS of the bone cement for the PGY-1 and PGY-5 residents was 37.5 ± 4.5 MPa and 39.2 ± 5.0 MPa, respectively, and there was no statistically significant difference between the two groups. For the tensile elastic modulus of the bone cement, the results for the PGY-1 and PGY-5 residents were 2.40 ± 0.09 GPa and 2.44 ± 0.08 GPa, respectively, and again there was no statistically significant difference. For the compression elastic modulus of the bone cement, the results for the PGY-1 and PGY-5 residents were 1.19 ± 0.13 GPa and 1.21 ± 0.18 GPa, respectively, with no statistically significant difference. However, the UCS of the bone cement for the PGY-1 and PGY-5 residents was 87.4 ± 5.8 MPa and 91.1 ± 4.5 MPa, respectively, and there was a statistically significant difference between the groups.

Discussion: The PMMA specimens prepared by both the PGY-1 and PGY-5 resident groups had similar characteristics during tensile and compression testing, and were similar to known standards. Although mixing and applying bone cement is an important skill for joint replacement surgery, our results indicate that no special training appears to be necessary for orthopaedic residents. Rather, a basic training video demonstrating manufacturer standard procedure is all that is necessary.

Clinical Relevance: The results of this study indicate the importance of experience in bone cement mixing and injecting on cement mechanical properties, but indicate that no special training appears to be necessary for orthopaedic residents.

Keywords: Polymethylmethacrylate (PMMA); Bone cement; Mechanical behavior; Experiences; Orthopaedic Resident Education

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INTRODUCTION

Each orthopaedic resident should become familiar with the basic technique for mixing polymethylmethacrylate (PMMA) bone cement and to understand the impact of PMMA preparation. Although orthopaedic surgeons frequently delegate the mixing of PMMA bone cement to physician assistants, nurse practitioners, or scrub nurses, the surgeon is responsible for ensuring it is performed correctly. PMMA bone cement is a brittle material and the creation of defects that increase porosity during mixing or injecting is a significant factor in reducing its mechanical properties. Porosity has been shown to negatively affect the fatigue life of bone cements. However, vacuum mixing (widely used to reduce porosity and pore size in the clinical setting) has had mixed results that suggest the effects of porosity are not completely understood. Thus, the technique used or the practitioner’s experience in mixing PMMA bone cement could potentially influence the clinical outcome of cemented prostheses.

Orthopaedic resident education relies on directed reading, didactic sessions, skills labs, and surgical experience to train capable orthopaedic surgeons. Best practice in resident training is an understudied topic with increasing relevance in a culture demanding standardization. This is compounded by the growing need to test resident skills as work hour restrictions change the way residents are trained and evaluated. PMMA bone cement mixing at our institution is taught primarily through intraoperative experience. It is possible that more instruction may be needed in areas such as cement mixing and cement injecting, which are incorporated differently in different institutions. Comparing experienced and inexperienced residents’ skills could identify potential shortcomings in the educational process.

Our study was conducted to evaluate and compare the level of training needed for mixing and injecting bone cement by comparing more experienced senior residents with less experienced interns. The aim was to detect any differences in mechanical properties (tensile and compression strength) of the bone cement and correlate this with experience level.

MATERIALS AND METHODS

Four intern orthopaedic residents (PGY-1) and four senior orthopaedic residents (PGY-5) were involved in this study. The PGY-1 residents have no prior training or experience for mixing PMMA bone cement, while the PGY-5 residents have previously trained in skills labs and mixed at least 50 times during the 5 years residency education. The PMMA bone cement used in this study was Simplex P bone cement (Stryker Howmedica Osteonics, Mahwah, NJ) under vacuum mixing in a cement-delivery system (Advanced Cement Mixing (ACM), Stryker Instruments, Kalamazoo, MI). Universal precautions were followed in accordance with Occupational Safety and Health Administration standards. Both groups of residents viewed a 3-minute training video (Stryker Howmedica Osteonics, Mahwah, NJ) for using the Stryker® ACM cement-delivery system and were provided a 5-minute reading period for the modified manufacturer standard procedure printout. Two types of mechanical properties of the bone cement were investigated for this study: 1) tensile strength and 2) compression strength.

Part I: Tensile Strength Testing

A custom-designed tensile specimen mold from the Orthopaedic Research Institute (ORI) lab, which created four standard tensile specimens, was used. Figure 1 shows the dimensions of each tensile testing specimen, and the thickness of the samples was 3 mm (0.12 inches). Eight samples from each orthopaedic resident were tested for a total of 64 samples. The PMMA bone cement specimens were prepared by following the modified manufacturer standard procedure, which includes vacuum mixing for 90 seconds in a Stryker® ACM cement-delivery system under a vacuum of 508 - 559 mmHg at standard operating room temperature (18 to 19°C). The cement was then transferred into the polyethylene tensile specimen molds using the cement injection gun. Care was taken not to trap air in the cement during the injection process by avoiding the layering of cement. These specimens were allowed to cure in the mold for 24 hours, and then were removed.

The tested regions of all the specimens (cross-sectional area) were measured using a digital caliper, and radiographs of all the specimens were taken. Tensile testing was performed using a MTS Bionix servohydraulic materials testing system (MTS Model 858, Eden Prairie, MN). The specimens were loaded from 0 N to complete structural failure at the stroke rate of 2.54 mm/min. Load and deflection data were recorded continuously at 10 Hz. The ultimate tensile strength (UTS) and the tensile elastic modulus (E) were then determined. The mean and standard deviation of the groups were calculated for each orthopaedic resident. This mechanical test was performed in air at room temperature (21°C).
Part II: Compression Strength Testing

A custom designed compression testing specimen mold from the ORI lab was used (Figure 2), and Figure 3 shows the dimensions of the specimens. The specimens were made of PMMA cement surrounding a central core cylinder made from a professionally machined stainless steel rod intended to mimic a prosthetic implant. This rod was left in place for all of the samples during testing but only the cement was compressed during the testing (Figure 4). The cement was prepared by following the manufacturer’s standard procedure, and then injected into the appropriate polyethylene molds. These specimens were allowed to cure in the mold for 24 hours, and then were removed.

All compression testing was performed with strict adherence to the American Society for Testing and Materials (ASTM) F451-99a standards - Standard Specification for Acrylic Bone Cement. The dimensions for each cylindrical-shaped specimen was measured using a digital caliper and was recorded prior to testing. Ten samples from each orthopaedic resident were tested, for a total of 80 samples. All the specimens were tested in compression using the MTS Bionix servohydraulic materials testing system. The specimens were loaded from -50N to complete structural failure at the rate of 20 mm/min. Load and deflection data were recorded continuously at 10 Hz. The ultimate compressive strength (UCS) and the compression elastic modulus were then determined. The mean and standard deviation were calculated for each orthopaedic resident’s group. All mechanical tests were performed in air at room temperature (21°C).

Statistical analysis

Data retrieved for UTS and UCS of PGY-1 and PGY-5 residents were analyzed using one-way analysis of variance (ANOVA) of SPSS software (Version 16.0; SPSS, Chicago, IL) with the Least Significant Difference (LSD) multiple comparisons post hoc analysis. The level of significance was defined as p<0.05. Means and standard deviations were also calculated for each orthopaedic resident group. These analyses were used to determine if there were any statistical differences in mechanical properties of the bone cement between the two experience levels.

RESULTS

Part I: Tensile Strength Testing

Figures 5 and 6 show UTS and tensile elastic modulus of the PMMA bone cement for the two groups of residents. The average UTS of the bone cement for the PGY-1 and PGY-5 residents was 38 ± 5 MPa and
39 ± 5 MPa, respectively, and there was no statistically significant difference between the two groups. When compared to data in the literature reported by Davies et al., in which the UTS of the bone cement was reported to be 36 ± 10 MPa, there was no significant difference.

For the tensile elastic modulus of the bone cement, the results for the PGY-1 and PGY-5 residents were 2.40 ± 0.09 GPa and 2.44 ± 0.08 GPa, respectively, and there was no statistically significant difference between these two groups. When compared to the data from Davies study, in which the elastic modulus of the bone cement was 2.53 ± 0.33 GPa, no significant difference was detected.

**Part II: Compression Strength Testing**

Figures 7 and 8 show the UCS and compression elastic modulus of the PMMA bone cement for the two groups of residents. The UCS of the bone cement for the PGY-1 and PGY-5 residents was 87 ± 6 MPa and 91 ± 5 MPa, respectively. Even though statistically there was a statistically significant difference detected between these two groups, but the difference was so small and would suggest there will be no difference in clinically. For the compression elastic modulus of the bone cement, the results for the PGY-1 and PGY-5 residents were 1.19 ± 0.13 GPa and 1.21 ± 0.18 GPa, respectively, and there was no statistically significant difference between these two groups.

**DISCUSSION**

Our results suggest that no specific training during residency is needed for mixing and injecting bone cement when using Simplex™ P bone cements with the ACM cement-delivery system. This was in contradic-
tion to our hypothesis that training during the course of residency teaches surgeons the skill of appropriately mixing and applying cement. Rather, after a brief movie and handout demonstrating the manufacturer's standard technique, interns having recently completed medical school performed as well as senior residents with experience mixing cement. For tensile strength tests, both groups of residents met the standard established by Kurtz et al., who used ASTM F2118-01a with 65 mm long tensile specimens and found that the tensile elastic modulus and UTS to be $2.44 \pm 0.19$ GPa and $32 \pm 1$ MPa for Simplex™ P bone cement. There was no significant difference between the residents' tensile strength specimens or between the resident's specimens and data from Davies study. For compression strength testing, there was a small but significant difference with senior residents having a higher average UCS, but the compression elastic modulus showed no difference. The resident UCS (PGY-1: $87 \pm 6$ MPa, and PGY-5: $91 \pm 5$ MPa) approached the standard from Kurtz study, which used ASTM F451-99a with cylindrical compression specimens and found the UCS to be $97 \pm 4$ MPa for Simplex™ P bone cement. Kurtz's study used solid cylindrical compression specimens with 6 mm in diameter and 12 mm in height, whereas our study used hollow cylindrical specimens in order to mimic cement used with a prosthetic implant. From our results, we concluded that not only are both groups essentially equally skilled in cement mixing and injecting, but they are also competent, approaching or meeting Simplex™ P bone cement standards. Knowing this, cement mixing should not require additional skills lab or skills testing in the orthopaedic residency curriculum. This is in contrast to other skills that require practice and instruction for competence, such as arthroscopic technique.

Our experimental design had certain limitations. First, we were limited by class size to a small number of residents and specimens tested. This could have introduced sampling bias and thus decreases the study's generalizability. Second, we limited specimen testing to compression and tensile testing. Many studies focus on fatigue failure of cement with cyclic loading as a better marker of longevity. This might be more clinically relevant to the way total knee or hip prosthesis fail when failure is related directly to the performance of the cement. Next, the metal central cores used in this study are a smooth and perfect round surface and do not represent many of the current prosthesis designs. Finally, it was assumed that senior residents had more experience with mixing and injecting cement than interns. This may not be true for the mixing cement experience as physician assistants or other operating room staffs typically mix the bone cement in our community, and therefore seniors may not have had as much more bone cement mixing experience as we initially thought. However, the senior residents do have more experience with injecting cement than interns as they have had intraoperative experience during their residency training.

To our knowledge the technical ability of residents to mix cement has not be published in the literature. Skills like these may become more important to residency programs that are trying to train competent surgeons in an environment full of restriction and standardization. Studies related to how to train and evaluate residents, are likely to follow. Additional research into cement mixing could investigate physician assistant and scrub technician competence in mixing cement as a way to ensure high quality mixing from a group with difference educational backgrounds. Studies could also see if there is a difference in more clinically relevant scenarios, such as cadaveric bone or fatigue testing.

CONFLICT OF INTEREST STATEMENT:
This study did not receive any funding support for this research. However, Stryker (Kalamazoo, MI) provided the Simplex™ P bone cements and ACM cement-delivery systems used in this study, but had no role in the collection, analysis or interpretation of data, in the writing of the manuscript, or in the decision to submit the manuscript for publication. The participants and authors of this study did not receive any payments or other personal benefit, or commitments or agreements that were related in any way to the subject of the research that was conducted.

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