The Iowa Orthopaedic Journal


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

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Matthew J. Teusink, M.D.

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THE IOWA ORTHOPAEDIC JOURNAL

2011 • Volume 31

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William D. Lack, M.D.
Matthew J. Teusink, M.D.

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Joseph A. Buckwalter, M.D.
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The Iowa Orthopaedic Journal
INSTRUCTIONS FOR AUTHORS, 2012

Any original article relevant to orthopaedic surgery, orthopaedic science or the teaching of either will be considered for publication in The Iowa Orthopaedic Journal. Articles will be enthusiastically received from alumni, visitors to the department, members of the Iowa Orthopaedic Society, residents, and friends of The University of Iowa Department of Orthopaedics and Rehabilitation. The journal is published every June. The deadline to receive articles for the June 2012 edition is Monday, February 6, 2012.

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

When submitting an article, send the following:

1. The original manuscript with illustrations and ABSTRACT. The corresponding author must be clearly identified with mailing address, telephone/fax numbers and e-mail address. Manuscripts will not be returned unless requested.

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

3. Legends for all illustrations should be listed in order of appearance and single spaced.

4. Illustrations/Images:
   a. Color illustrations may not be used unless it is the opinion of the journal that they convey information not available in black and white.

b. Each image should be sent to diana-johannes@uiowa.edu as an individual tif or jpg file. All images must have resolution of 600 pixels per inch (ppi). Web page images are to be avoided. Set digital cameras to their highest quality (ppi) setting for photographs.

c. When submitting an illustration that has appeared elsewhere, give full information about previous publication and credit to be given, and state whether or not permission to reproduce it has been obtained.

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

Additional copies of these instructions may be obtained at www.uiortho.com/index.php/education/iowa-orthopaedic-journal.html or by writing to Diana Johannes, University of Iowa Hospitals and Clinics, Department of Orthopaedics and Rehabilitation, 200 Hawkins Drive, 01006 JFP, Iowa City, Iowa, 52242-1088 or by emailing diana-johannes@uiowa.edu.
2011 IOJ EDITORS’ NOTE

It is our great honor and pleasure to present the 31st edition of The Iowa Orthopaedic Journal (IOJ). As in previous years, this edition represents the work and contributions from countless faculty, support staff and residents from the University of Iowa. Submissions were received from within our department and from across the nation and globe. Several articles from previous editions of the IOJ have become “classics” of the University of Iowa Orthopaedic residency program, and have set a high standard for us in editing this year’s edition. The impact of the IOJ continues to increase, as the articles are freely available via Pub Med. A recent analysis demonstrated that more than 1,000 articles from the IOJ are downloaded from Pub Med on an average day. We are hopeful that the Pub Med exposure will continue to increase the IOJ readership and result in continued growth.

As per tradition, we would like to recognize the departing senior residents, Drs. Clark, Henderson, Judd, Vinyard, Volz, and Warne. Their work ethic and “leading by doing” example has been of great value for younger residents to emulate. We wish to thank them for all they have provided for the department and wish them well as they begin their fellowships and the start of what will undoubtedly be remarkable careers.

Speaking of remarkable careers, it is appropriate to introduce the recipient of this year’s Iowa Orthopaedic Journal dedication: Dr. Thomas D. Brown, PhD. Dr. Brown has led the orthopaedic Biomechanics Laboratory at the University of Iowa since 1983, first as co-director from 1983-1998 and then as director of the lab since 1998. His impact on biomechanics is hard to quantify, although a brief look through his extensive curriculum vitae with over 740 abstracts, 260 peer-reviewed publications, and numerous book chapters, may give one some idea. While many orthopaedic residents have completed senior projects with the help of his intellect and drive, all of us become familiar with the classic papers the biomechanics laboratory has produced. It is with great pleasure that we dedicate this year’s Iowa Orthopaedic Journal to Dr. Brown.

This year we continue to remember Dr. Ponseti’s legacy at the University of Iowa. A little more than a year after Dr. Ponseti’s passing, we mourned the passing of his wife, Helena Pernas-Ponseti. She, like Dr. Ponseti, was a fixture of our department for over 40 years. We have again dedicated the first section of the journal to original articles discussing continued progress in the nonoperative treatment of clubfoot via the Ponseti Method. We present five articles regarding worldwide dissemination of his methods.

The IOJ would not be possible without the help of several people. Diana Johannes continues to be a driving force behind the creation of the IOJ. Her countless hours organizing articles for review and proofreading make this publication possible. We would like to thank her for all of her work in making this year’s journal a reality. Second, we would like to recognize the faculty who have overseen various projects, cases, and other efforts that have resulted in works that find themselves in this journal. Finally, we would like to thank our faculty advisers, Dr. Jose Moreuende and Dr. Joseph Buckwalter, whose guidance continues to make the IOJ possible. We are indebted to them for their input, leadership, and service.

We would also like to thank our corporate sponsors for continuing to generously support our publication efforts with integrity in spite of increased industry scrutiny.

We hope you find that this year’s edition of the IOJ continues to fall in line with the same high standards as previous editions. Truly the bar has been set high. It has been an honor to serve as the editors for the IOJ for 2011. We hope that you may learn as much from this journal as we have learned from its production.

William D. Lack, M.D.
Matthew J. Teusink, M.D.
IOWA ORTHOPAEDIC JOURNAL
EDITORS EMERITI

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2010
Christopher E. Henderson
Bryan A. Warme

2011
William D. Lack
Matthew J. Teusink

The Iowa Orthopaedic Journal
The publication of the Iowa Orthopaedic Journal gives us the opportunity to recognize and honor an individual who has made invaluable contributions to Iowa Orthopaedics. No one is more deserving of this recognition and honor than Tom Brown. His critical thinking, commitment to excellence and steadfast determination to advance the understanding of the musculoskeletal system have had profound effects on our department, the field of orthopaedic bioengineering, and the specialty of orthopaedics as a whole.

Thomas D. Brown was born in Dundalk, Maryland in 1947. His father was a tool and die maker and his mother a homemaker. His sister shares his intellectual curiosity and is a microbiologist. He attended Case Western Reserve University after high school where he lettered as a freshman soccer player and studied metallurgy and materials science. It was during his undergraduate studies that he met his wife, Karen, in Zoology 101. They now have three children; Matt, Greg, and Erin.

He left college for the military during the Vietnam War, serving with the 173rd Airborne from 1967 to 1970. He then returned to his studies and graduated with honors in mechanical engineering from the University of Maryland. He subsequently received a masters degree in mechanical engineering as well as a Ph.D. in mechanical engineering – bioengineering from Carnegie Mellon University. He is currently a professor of orthopaedic surgery in the college of medicine (primary appointment) and a professor of biomedical engineering in the college of engineering (secondary appointment) at the University of Iowa. He is the Richard and Janice Johnston Chair of Orthopaedic Biomechanics.

Dr. Brown has been recognized as a leader in the study of orthopaedic biomechanics for more than 35 years. He has earned numerous honors for the excellence of his research. These awards include the Giovanni Borelli Award from the American Society of Biomechanics (1984), the Kappa Delta Award (1984), three Frank Stinchfield Awards from the Hip Society (1993, 1996 and 1997), five Clinical Biomechanics Awards from the American Society of Biomechanics (1994, 1998, 2001, 2002 and 2010), the Mark Coventry Award (2001), the Orthopaedic Research and Education Foundation Clinical Research Award (2003), the Nicolas Andry Award from the Association of Bone and Joint Surgeons (2009), and two Orthopaedic Research Society William H. Harris Awards (1997 and 2011). Most recently, he was honored along with Don Anderson, PhD and Dr. J Lawrence Marsh with the 2011 OREF Clinical Research Award for their paper on the study of post-traumatic osteoarthritis. We were honored to be able to publish this paper in this edition of the Iowa Orthopaedic Journal.

He is justifiably recognized by his peers for his administrative and leadership abilities. He has served as President of the American Society of Biomechanics (1993) and President of the Orthopaedic Research Society (2001), and has built a large and productive team of investigators in the Orthopaedic Biomechanics Laboratory, a laboratory that he has directed since 1983. During his tenure as director the laboratory has received more than ten million dollars in grant funds. He has authored more than 740 abstracts and more than 260 peer reviewed articles in addition to numerous book chapters. Perhaps most impressively, he has supervised the successful completion of at least 46 masters and doctoral theses at the University of Iowa. His students have gone on to have very successful careers of their own. With all these accomplishments he has little time for his other interests, which include history, politics and woodworking.

Dr. Brown’s prolific career as a scientist has benefited countless individuals he has mentored and with whom he has collaborated. The University of Iowa Orthopaedics Department would not be what it is today without the Orthopaedic Biomechanics Laboratory and all it has accomplished under his leadership. Numerous faculty members within the department have collaborated on successful projects with Dr. Brown as exemplified by the OREF Clinical Research Award discussed above. Many
former residents can credit the successful completion of their senior resident projects to Dr. Brown's guidance. In addition to the direct benefit that many have had through working with him on various projects, every member of the department benefits from the productivity of a world-class biomechanics laboratory.

We felt it appropriate to allow his colleagues an opportunity to express their gratitude:

The growth and stature of the University of Iowa Department of Orthopaedics that has occurred over the last three decades would not have been possible without the remarkable talents of Tom Brown. The depth and breadth of his research accomplishments are unparalleled in biomechanical engineering in general and most definitely in the fields of orthopaedic biomechanics and basic science. His skills as a leader, mentor, researcher, teacher, collaborator, and grant writer have not only allowed he and the lab to obtain and maintain excellence, but to continue pursuing answers to the most important questions which will advance the field of orthopaedics in the near and distant future. His work has represented translational research at its finest during these three decades. I feel privileged to have Tom as a mentor, collaborator and friend. Tom has helped many of us advance our own research interests, skills, and careers. I speak for all of us who feel indebted to Tom for his incredible work ethic and abilities that have gained worldwide respect for the University of Iowa Orthopaedic Biomechanics Laboratory and the Department of Orthopaedics.

John Callaghan
Lawrence and Marilyn Dorr Chair
Professor, University of Iowa Department of Orthopaedics and Rehabilitation
Tom Brown is a superb scientist and excellent manager. Tom took over the biomechanics lab in 1982 and has taken it to a whole new level. We now have one of, if not the, best labs in the world for studying basic aspects of clinical problems and suggesting improved understanding and treatments. Jan and I are very proud that he holds the chair that bears our name.

Richard Johnston
Professor, University of Iowa Department of Orthopaedics and Rehabilitation

As a graduate student, Dr. Brown taught me to think critically and realistically about the research I was doing. Along the way I learned to write effectively (and how to avoid the red pen). The main thing Dr. Brown impressed upon me was that he is an advocate for orthopaedic research, that it should be done well, and that you need to stick to sound engineering principles. He is an advocate for his students throughout graduate school and continues to support my professional development today.

Hannah Lundbergh
Postdoctoral Fellow, RUSH Medical Center

I owe a great debt of gratitude to a man who afforded me the opportunity to learn the basic principles of scientific research that I continue to refine. He offered me a position at the Orthopaedic Biomechanics Laboratory as an undergraduate student and my experiences in the lab inspired me to become an orthopaedic surgeon. I remain impressed with his ability to ask the most timely and pertinent questions and his uncompromising pursuit of truth. He has an uncanny ability to cultivate and guide his students. His work ethic is unparalleled. It is through interactions with individuals such as Dr. Brown that young researchers are inspired to strive for the highest standard of scientific study and it is through this process that medical care can be transformed for the benefit of patients.

William Lack
Resident, University of Iowa Department of Orthopaedics and Rehabilitation
I left Germany in 1995 to become a doctoral student under Tom. Today, I still remain his student, since he continues to inspire me on a daily basis by his shining example of scientific rigor, integrity, curiosity, persistence, work ethics, and by his dedication to his staff and students. Training with Tom remains one of the greatest privileges of my professional career. The fact that Tom strongly encouraged and supported me in the risky endeavor of starting a new research laboratory in Portland with other Iowa alumni speaks of his genuine and selfless desire to foster our careers.

Michael Bottlang
Director of the Biomechanics Laboratory at the Legacy Clinical Research and Technology Center

Throughout its long history, Iowa Orthopaedics has been shaped by exceptional faculty who dedicated their energies and talents, throughout long and productive careers, to achieving excellence — people who have made our department a world leader in orthopaedics and musculoskeletal science. Tom Brown is one of those people. The list of his many accomplishments does not adequately document his influence. He never accepts work from himself or others that is not exceptionally well done. The worst colleague you can have is one who always tells you that what you have done, said, or written is great and can't be improved. Tom is not one of those people. Fortunately, he never spares me from his critical analyses and as a result has made me think and work harder, more carefully and more precisely. At the same time he has been endlessly patient in educating me in the most basic of engineering concepts and kind in correcting my most egregious misuse of engineering terms. Working with Tom has been one the greatest pleasures of my career.

Joseph A. Buckwalter
Chairman, University of Iowa Department of Orthopaedics and Rehabilitation

It is difficult to capture the scope of Dr. Brown's accomplishments in a brief article. We are truly honored by his presence in our department. If we can accomplish anything with our writing it would be to express our sincere gratitude to him for his immeasurable contribution to the University of Iowa Department of Orthopaedics and Rehabilitation.
2011
DEPARTMENT OF ORTHOPAEDICS AND REHABILITATION
SCHEDULE OF LECTURESHIPS AND CONFERENCES

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

Carroll B. Larson Shrine Memorial Lecture
May 6-7, 2011
James Sanders, MD, Chief
Division of Pediatric Orthopaedics,
University of Rochester, New York

2011 Senior Residents Day
June 10-11, 2011
VIP VISITING DISCUSSANTS:
Robert A. Arciero, MD
Professor and Chief of the
Sports Medicine Division
Department of Orthopaedic Surgery
New England Musculoskeletal Institute
University of Connecticut Health Center
Farmington, CT

J. Tracy Watson, MD, Professor
Orthopaedics and Traumatology Fellowship
Director and
Chief of the Orthopaedic
Traumatology Division
St. Louis University Medical Center
St. Louis, MO
Contact Gloria Yorek, (319) 356-3523.

Ponseti Clubfoot Treatment Symposium
September 29-30, 2011
Guest Faculty, Lewis E. Zions, MD
Clinical Professor of Orthopaedic Surgery
Geffen School of Medicine
University of California, Los Angeles
Los Angeles, CA

The Ponseti Races will be held on
Saturday, October 1, 2011
Additional speakers to be arranged.
Contact Gloria Yorek, (319) 356-3469.

27th Annual Hawkeye Sports Medicine
Symposium
December 1-2, 2011 (Thurs/Fri)
Marriott Hotel and Conference Center
300 East 9th Street, Coralville

Guest speaker, Patrick A. Smith, MD
Columbia Orthopaedic Group
Columbia, MO
Additional speakers to be announced.
Contact Kris Kriener, (319) 353-7954.

2012 Senior Residents Day
June 8-9, 2012
TBA
Department of Orthopaedics

Matthew Bollier 2010-present
Benjamin Miller 2010-present
Christina Ward 2008-2009
Heather Bingham 2008-present
Phinit Phisikut 2008-present
Nicolas O. Noisieux 2007-present
Robert Yang 2007-2010
Erika Lawler 2006-present
John E. Femino 2005-present
Joseph D. Smucker 2005-present
Jin-woo Suh 2004-2005
Neil A. Segal 2004-present
Brian Wolf 2003-present
Michael O'Rourke 2003-2007
Sergio Mendoca 2003-present
Jose Morcuende 2001-present
Annunziato Amendola 2001-present
Joseph Chen 2000-present
Todd McKinley 1999-present
R. Kumar Kadiyala 1998-2004
Leon Grobler 1996-1999
Brian Adams 1993-present
Charles Saltzman 1991-2005
John Callaghan 1990-present
David Tease 1989-2000
Ernest Found 1987-present
Lawrence Marsh 1987-present
Curtis Steyers 1985-2006
James Nepola 1984-present
Fred Dietz 1984-present
James Weinstein 1983-1996
Arthur Steindler 1913-1949
Theodore Willis 1917-1918
Joseph Milgram 1926-1932
Ernest Freund 1932-1936
Thomas Waring 1932-1939
James Vernon Luck 1936-1939
Ignacio Ponseti 1946-2009
Eberly Thornton 1946-1952
Robert Newman 1948-1956
Michael Bonfiglio 1950-1985
Carroll Larson 1950-1978
Adrian Flatt 1956-1979
Reginald Cooper 1962-present
Howard Hogshead 1964-1965
Maurice Schnell 1964-1965
Donald Kettelkamp 1968-1971
Gerald Laros 1968-1971
Richard Stauffer 1970-1972
John Albright 1971-present
Doug Mains 1972-1973
Bruce Sprague 1972-1979
Richard Brand 1974-2002
Mike Mickelson 1976-1981
Stuart Weinsteine 1976-present
Thomas Lehmann 1978-1987
Joseph Buckwalter 1979-present
Charles Clark 1980-present
Barbara Campbell 1982-1984

The University of Iowa
Roy J. and Lucille A. Carver College of Medicine
2011 GRADUATING ORTHOPAEDIC RESIDENTS

Randy Clark, M.D.
Randy was born in Salt Lake City, Utah, the eldest son of a nurse and IBM computer repairman. He moved to southern Utah in his infancy and spent his early years outdoors riding bikes and building forts. Randy developed an interest in football and went on to gain a scholarship to play for Southern Utah University. During college he spent two years in Peru as a missionary for the Church of Jesus Christ of Latter-day Saints. Upon Randy’s return to college he became a three year starter and All-American.

At college, a cute cheerleader caught Randy’s eye and convinced him to go on a date. That was all it took for Randy to fall in love with his wife, Amy. Ten years later, they are the proud parents of Cooper (four years old) and Caroline (two years old).

After completion of college, Randy was accepted to the University of Utah School of Medicine where he completed his medical school and met his future Iowa Orthopaedics cohort Kyle Judd.

After completion of residency, Randy and his family will move to Los Angeles where he will participate in fellowship training at Southern California Orthopedic Institute (SCOI). After fellowship, Randy and his family hope to make their home in St. George, Utah.

Randy would like to thank all of the wonderful faculty and staff at the University of Iowa for all of their endless effort in mentoring, teaching and guiding his medical career. Most of all he would like to thank his wife and family for all of their support.

Christopher Henderson, M.D.
Chris was born in Lubbock, Texas and was raised in the west Texas town of Amarillo. He grew up with the constant loving support and guidance of his parents and a great role model in his older brother. Chris's brother, during his pursuit of becoming an equine surgeon, introduced Chris to medicine. Chris attended Texas A&M University and then U.T. Southwestern Medical School prior to having the great fortune of moving to Iowa for residency.

Chris counts himself unbelievably lucky to have married Shawn, an exceptional woman. She has provided endless love, support, and sacrifice over the last five years. She is a truly wonderful mother to their three children Julia, Luke, and Jane. Their children continue to be the greatest blessing in their lives.

Chris is grateful to Iowa Orthopaedics for the dedication of all of the faculty mentors who make up the distinguished department. He is also grateful for the opportunity to work with such great residents and friends. Next year he will travel to Auckland, New Zealand where he will complete two fellowships, one focusing on trauma and one in shoulder and elbow surgery. He then plans to return to Texas to begin practice.
Kyle Judd, M.D.

Kyle was born in Delta, Utah, the eldest son of a high school science teacher and dedicated mother. He spent much of his early years laboring on the family farm. He attended and graduated from Delta High School. From there he went on to pursue his degree at Snow College in Ephraim Utah, where the turkeys outnumber the local citizens. From Snow College he went on to Weber State for completion of his undergraduate degree. He subsequently obtained a Master’s Degree from Indiana State University, and then it was back to the University of Utah for medical school.

While he was in college, Kyle met and sweet talked his beautiful wife, Darci into marriage, under the premise of love at first sight. She has been a real trouper, tramping all over the country with him. They have been blessed with three wonderful children Hannah (4), Cody (3) and Ellie (1).

After completion of residency, Kyle and Darci (and the kids) will be moving to Nashville, Tennessee where Kyle will be continuing his training in trauma at Vanderbilt University. From there, the sky is the limit.

Kyle would like to thank all of the wonderful faculty and staff at the University of Iowa for all of their endless effort in mentoring, teaching and guiding his medical career. Most of all, he would like to thank his wife for all of her support.

Timothy Vinyard, M.D.

Tim Vinyard was born and raised with loving parents and two older brothers in the beautiful city of Ottumwa, Iowa where he met his future wife, Erica, in the fifth grade. Erica managed to resist Tim’s early attempts at courtship throughout middle school, but she eventually succumbed to his persistent requests in their sophomore year of high school. Tim was forced to have his mom drop him off at Erica’s house for their first “date” since he wasn’t quite old enough to legally drive.

Tim attended Coe College in Cedar Rapids, Iowa where he was fortunate enough to compete for both the Kohawk football and baseball teams in front of literally dozens of rabid fans. Since Tim’s 40-yard dash was more likely to be timed with a calendar than a stopwatch, he abandoned his farfetched dream of professional athletics and moved to Iowa City for medical school and residency.

Tim has many people that he would like thank as his residency comes to its completion. He would like to thank his parents for their endless love, guidance, and support. They made sure that he understood the value of hard work and gave him every opportunity to succeed. Tim would also like to thank the dedicated and distinguished faculty and support staff at the University of Iowa. He considers himself truly fortunate to have trained at such an exceptional institution. Tim would also like to thank the many outstanding residents he has worked with. He will genuinely miss their friendship and camaraderie. Lastly, and most importantly, Tim would like to thank his beautiful wife, Erica. In addition to being the primary caregiver for their beloved young sons, Jackson (4) and Joseph (2), Erica has served as the proverbial rock for Tim, providing both loving support when he needed it most and the necessary pull to bring him back the ground when his head got too big. Tim is truly grateful for his family’s endless patience and support.

Upon completion of residency, the Vinyard family will live for the first time outside of the fine state of Iowa - they will venture all the way to the Twin Cities, where Tim will continue his education as a sports fellow with TRIA Orthopaedics. Tim then plans to permanently settle closer to family and friends in Des Moines, Iowa and start a busy practice with Iowa Orthopaedics.
Robert Volz, M.D.
Bob Volz, aka Rob Voltz, was born and raised in Arlington Heights, Illinois. He has been blessed with a wonderful family including two older sisters, a loving mother, and an unbelievable provider in his late father. He attended Augustana College in the Quad Cities where he met his beautiful and brilliant wife, Katie. Despite their being friends, a relationship did not start until Bob was nearly done with medical school at Rush in Chicago and Katie was nearing completion of her Ph.D. in mathematics here at the University of Iowa - it turns out the real reason Bob came to Iowa City was for a girl. Bob and Katie were married in 2008 and were recently blessed with their first child Peter John (PJ). Their family also includes two great energetic dogs, Lola and Beau.

Bob’s interests include mushroom hunting (haha), softball, movies, the Chicago Bears, the Chicago Cubs, and, most importantly, his family. He also has a special place in his heart for international aid and did manage to sneak away from residency for a week to assist in the Haiti earthquake relief efforts.

Bob feels truly blessed to have worked with so many wonderful people at Iowa including, faculty, office staff, nurses, aides, therapists, prosthetists, etc. Most of all, he is grateful to have developed lifelong friendships with many members of the orthopaedic residency program. After completion of residency, Bob and Katie are extremely excited about their move to New Zealand, where Bob will complete a year of specialty training in pediatric orthopaedics at Starship Children’s Hospital in Auckland. After returning from Auckland, their family will move to La Crosse, Wisconsin where Bob will start his pediatric/general orthopaedics practice at Gundersen Lutheran.

Bryan Warne, M.D.
Bryan Warne was born in Ames, Iowa, and spent much of his childhood on the family farm in northwest Iowa. After spending his undergraduate years at Yale, he travelled to the west to attend medical school at Stanford. It was there that he met and married his wife, Kara. They then decided to return to Bryan’s roots in Iowa for residency. During Bryan’s residency they were blessed with the birth of their daughter, Emma, and have enjoyed living close to Bryan’s family. For these reasons as well as for the great friends they have made over the past five years, Iowa City will always hold a very special place in their hearts.

Bryan pursues an array of personal interests when he can find the time, including bicycling, SCUBA diving, and hunting. Additionally, the Warne family has thoroughly enjoyed cheering on the Hawks during their time in Iowa City.

Bryan has appreciated the opportunity to train under a distinguished and dedicated faculty and along side a great group of fellow residents. Bryan’s future plans include a sports/shoulder fellowship at the Hospital for Special Surgery and then he plans on returning to his hometown to be a team physician for the Iowa State Cyclones. Bryan would like to thank his family, colleagues and teachers who have supported and will continue to support him in his career.
2011 GRADUATING FELLOWS

Jon Donigan, M.D.

Jon was born and raised in Hawai‘i on the island of Oahu. He then attended Utah State University for a year before serving a two year religious mission in the Philippines. His experiences in the Philippines working with the underserved convinced him to alter his planned career path from the legal field to medicine. Upon returning to the states he transferred to Brigham Young University in Provo, Utah, where he finished his degree in Philosophy while fulfilling the requirements for medical school application. During his junior year he made the best decision of his life and married fellow BYU student Heather Hawkley from Chico, California. He was fortunate to be accepted at Johns Hopkins University School of Medicine the next year, and he and Heather made the cross-country trek to Baltimore, Maryland. Thanks to the guidance of Ed McCarthy and Kevin Jones, Jon was lucky enough to match at The University of Iowa for orthopaedic training. His five years at Iowa were so enjoyable and rewarding that he decided to stay at UIHC to complete a Hand Fellowship upon completion of his residency. Jon wishes to thank his parents, Bob and Marie, his fellow residents, and the distinguished yet approachable faculty at The University of Iowa. Special thanks go to Drs. Adams, Lawler, and Wolf for their patience and support during this extra year of training in hand and upper extremity surgery. Most of all, he is grateful to Heather and their children, Andrew, Luke, and Kate, for their patience and tolerance during the last 10-plus years of education and training.

Mark McConkey, M.D.

Mark grew up in Vancouver, Canada and attended the University of British Columbia (UBC) where he earned a Bachelor of Science in Psychology and played four years of collegiate and semi-professional baseball. He continued at UBC for both medical school and orthopaedic residency, finishing in 2010. Following in his father’s footsteps, he sought fellowship training in knee and shoulder athletic injuries and reconstruction at the University of Iowa. He and his wife, Julia, have since become the biggest Hawkeye fans in Vancouver. After leaving Iowa, Mark will seek further training in hip arthroscopy in New Zealand, after which time he hopes to work in an academic or tertiary care clinical setting.

Andrea Veljkovic, M.D.

Dr. Andrea Veljkovic, M.D. is currently a foot and ankle fellow at the University of Iowa Hospitals and Clinics with specific interest in sports-related foot-and-ankle pathology. She attended medical school at the University of Alberta and completed orthopaedic studies at Dalhousie University and the University of Alberta. Her prior fellowship was in arthroscopy and athletic injuries at the University of British Columbia, where she was a sports physician for Olympic short-track speed skating and an orthopaedic polyclinic on-call surgeon for the Vancouver 2010 Olympic Games. She has served as the team physician for Simon Fraser University Men’s and Women’s soccer, and has enjoyed being involved with the Vancouver Whitecaps Soccer Club, The British Columbia Lions (CFL), the Edmonton Eskimos (CFL), and the Edmonton Oilers (NHL).
NEW ORTHOPAEDIC FACULTY

Matt Bollier, M.D.
Joining the orthopaedic sports medicine team at the University of Iowa is the culmination of a long-held interest in both athletics and medicine for me. After growing up in the Chicago suburbs and attending Loyola Stritch School of Medicine, I completed my orthopaedic surgery residency at Michigan State University. During my sports medicine fellowship at the University of Connecticut, I served as one of their university team physicians. In addition, I was involved in knee and shoulder research with the goal of improving outcomes after athletic injuries.

Benjamin Miller, M.D.
I am an Iowa City native and attended medical school at the University of Iowa. I completed an orthopaedic residency at Rush University in Chicago, followed by an orthopaedic oncology fellowship at the University of Florida. Between my residency and fellowship, I spent a year abroad volunteering and working in several places in Africa and Asia. My clinical and research interests include limb salvage surgery, chondrosarcoma, and orthopaedic outcomes analysis. I am pleased to be returning to the University with my wife Noor, daughter Alia, and dog Stella.
The UI Sports Medicine Center opened on October 19, 2009. The center offers sport injury prevention, treatment and rehabilitation for competitive and recreational athletes of all ages. The staff at the center is responsible for team coverage and taking care of all Hawkeye student athletes. The clinic is conveniently located off-site from the University of Iowa Hospitals and Clinics and offers an array of faculty and staff, including orthopaedic surgeons, family practitioners, pediatricians, internists and physical therapists all specializing in sports medicine. In addition, American Prosthetics and Orthotics provides professional orthotist consultations for custom and off-the-shelf bracing, custom orthotics, athletic shoe modification and post-operative needs.

Since our opening in 2009, the UI Sports Medicine Center has added a number of faculty and services. Dr. Matthew Bollier joined the center in August, 2010 after completing residency training at Michigan State University, and then completed a sports medicine fellowship at the University of Connecticut. Matt’s interests are in knee and shoulder surgery with a special interest in the patellofemoral joint. We are also very excited that Dr. Andrew Peterson joined the UI Sports Medicine Center primary care group in October, 2010. Andy completed his residency training followed by a pediatric sports medicine fellowship at the University of Wisconsin.

We are thrilled that Dr. Carolyn Hettrich will be joining us in August of 2011. She completed her orthopedic training at the Hospital for Special Surgery, and is currently completing an orthopedic sports medicine fellowship at Vanderbilt. Carolyn wants to pursue a career as a surgeon scientist and, obviously, the University of Iowa will provide all the resources necessary for her success. Dr. Mederic Hall will also join the sports medicine group in August, 2011. Mederic is completing his physiatry and sports medicine training at the Mayo Clinic in Rochester. In addition to providing primary care and physiatry expertise, Mederic has an interest in ultrasound imaging of
sports injuries and guided injections. This will enhance the current digital imaging and MRI services we provide, particularly with soft tissue problems.

We have just received approval from the GME office for a Primary Care Sports Medicine Fellowship Program to begin in August of this year. Dr. Kyle Smoot will be the director of the fellowship. This will be a great addition to our existing Orthopedic Sports Medicine Fellowship. In addition, the UI Sports Medicine Center will begin an Athletic Training Physician Extender Residency Program, which will expand the current A.T. educational offerings.

The UI Sports Medicine Center is booming in every aspect. In only one year, the center has seen nearly 40% growth in the number of patients treated - this number will only continue to grow with the addition of new faculty and staff. We are working on expanding further in the near future. The main reason for our success lies in the cohesive team we have assembled at the sports medicine center, including the office staff, research support, reception staff, nurses and medical assistants, technicians, orthotists, physician assistants, rehabilitation specialists, and physicians. It is wonderful to belong to a team that is continuously striving for excellence.
University of Iowa

Work Injury Recovery Center


Timely access to top-flight care

As a human resources director, insurer, case manager, or attorney, you know that orthopaedic work-related injuries and conditions require speedy access to the best possible medical care. And that’s just what you’ll find at the University of Iowa Work Injury Recovery Center (WIRC).

Located within the University’s esteemed Department of Orthopaedics and Rehabilitation—ranked by U.S. News & World Report as one of the top 10 programs in the country—WIRC serves as a prompt, problem-free entry point to services provided by a team of world-renowned orthopaedic surgeons and support staff with decades of experience in handling work-related injuries and conditions.

At WIRC, we understand time is of the essence in providing patients with optimal care and helping them return to work as quickly as possible. We strive to provide same-day service for work-related injuries, including expedited scheduling of necessary imaging and operative procedures, including surgical intervention when warranted. And we pride ourselves on prompt consultation and communication with key members of your team, including case managers, insurers, attorneys, and employers.

WHERE YOU TURN FIRST DOES MATTER.
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<th>Unmatched excellence and experience</th>
<th>Reliable outcomes, proven results</th>
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<td>No other hospital, clinic, or medical practice in the state of Iowa can offer the depth and breadth of expertise available through the UI’s Department of Orthopaedics and Rehabilitation. Currently ranked 8th in the nation—alongside institutions such as Johns Hopkins University, the Cleveland Clinic, and the Mayo Clinic—the UI’s orthopaedic program includes exceptional clinicians and researchers, working together at the leading edge of breakthrough medicine.</td>
<td>Orthopaedic work-related injuries and conditions bring with them a host of complications, ranging from the complexity of the injury, to prior treatment history, to questions about recovery time and the patient’s return to work. The longer those questions linger, the more expensive each case becomes to employers and insurers. What’s needed in every case are medical answers you can depend on—and that’s exactly what WIRC provides.</td>
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<td>Led by James Nepola, MD, a gifted surgeon with more than 25 years experience in orthopaedic workers’ compensation cases, WIRC brings together the UI’s multiple strengths in orthopaedic treatment, research, and rehabilitation to focus on each patient’s unique needs. In complex cases, a multi-disciplinary panel of orthopaedic specialists reviews the case, makes treatment recommendations, and generates a report—all in a timely and coordinated fashion, keeping you fully informed along the way.</td>
<td>Because of the expertise of WIRC surgeons and clinical staff, and their wide-ranging experience in orthopaedic work-related injuries, you can have full confidence in the integrity of WIRC-generated recommendations and outcomes. This means faster and more reliable case resolution, particularly in circumstances where patients have received prior treatment but have failed to improve. Employers and insurers who instruct patients to visit WIRC for their first orthopaedic referral can often eliminate costly delays and uncertainties.</td>
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<td>Excellence is the standard set by our surgeons and shared by every other member of the WIRC staff, whose experience includes many years in medical records, insurance administration, and vocational issues. Our team understands orthopaedic work-related conditions and what it takes to resolve them—just what you’d expect from the best.</td>
<td>Bottom line, we understand your goal is both optimal care and minimal lost time from work. Using the talents and resources of our entire team, WIRC is ready to meet your needs for expert, timely, and reliable care for your employees.</td>
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“As a medical case manager, I find the Work Injury Recovery Center to be ‘user friendly’ and a good fit with worker’s comp cases, which can sometimes be time intensive. Not every clinic is set up to accommodate these special circumstances, which can be very frustrating. WIRC staff members are always very professional, organized, and friendly, and I know that once they’re involved in any of the cases I refer, things will be handled in a timely manner.

Yvonne M. Savoy, RN, BSN, CDMS, CCM
Medical Case Manager
Primacor Rehabilitation, Inc.
Cedar Rapids, Iowa

The Work Injury Recover Clinic opened in January, 2010, and we continue to expand our services considerably. We have added two clerical support staff and most recently, a mid-level provider (ARNP) to work with our surgical faculty sub-specialists. We are also re-organizing the schedules of our surgeon providers with an eye toward continuing to improve patient access as well as services for injured workers as we expand. In addition, we are planning to make our academic mark with clinical research into what factors lead to an early return to work, and the overall function of surgical and non-surgical orthopaedic worker’s compensation patients. We continue to strive to become world leaders in this field while providing the best care for injured workers throughout Iowa and the Midwest.
The 2011 Michael Bonfiglio Award for Student Research in Orthopaedic Surgery

The 2011 Iowa Orthopaedic Society Medical Student Research Award for Musculoskeletal Research

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

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

The Iowa Orthopaedic Society Medical Research Award for Musculoskeletal Research is an award for a student in the Carver College of Medicine who completes a research project involving orthopaedic surgery during one of his or her first three years of medical school. The award consists of a $2000 stipend, $500 of which is designated as a direct award to the student and $1500 of which is designated to help defray continuing costs of the project and publication. The student must provide an abstract and a progress report on the ongoing research. The aim is to stimulate research in the field of orthopaedic surgery and musculoskeletal problems.

This award is also presented at a medical convocation. In addition, the student presents his or her work at the spring meeting of the Iowa Orthopaedic Society and at a conference in the Department of Orthopaedics and Rehabilitation. This award is supported through the generosity of the Iowa Orthopaedic Society.

This year the selection committee consisted of Dr. Matthew Weresh, the president of the Iowa Orthopaedic Society, and Drs. Charles R. Clark, Joseph A. Buckwalter, Jose Morcuende, John Feminio, and Brian Wolf, all members of the Orthopaedics and Rehabilitation Department. They recommended that Austin Ramme, M4, receive the 2011 Michael Bonfiglio Student Research Award. Austin’s award was based on his project, “Improving ACL Reconstruction Outcomes: A Novel 3D Evaluation of Graft Placement”. His advisors were Drs. Brian Wolf, Nicole Grosland and Vincent Magnotta.

The selection committee recommended that The Iowa Orthopaedic Society Medical Student Research Award be given to Curtis Steyers, M2 for his research titled “Glycolysis Inhibitors Sensitize Human Chondrosarcoma Cells to Radiation in Vitro”. His advisor was Dr. Joseph Buckwalter.

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: Charles R. Clark, M.D., Michael Bonfiglio Professor of Orthopaedic Surgery; Joseph A. Buckwalter, M.D., Department Chair, Department of Orthopaedics and Rehabilitation, advisor to Curtis Steyers; Curtis Steyers, M2, winner of the Iowa Orthopaedic Society Medical Student Research Award for Musculoskeletal Research; Austin Ramme, M4, winner of the 2011 Michael Bonfiglio Award for Student Research in Orthopaedic Surgery; Brian Wolf, M.D., advisor to Austin Ramme.
OREF 2011 CLINICAL RESEARCH AWARD PAPER
THE PATHOMECHANICAL ETIOLOGY OF POST-TRAUMATIC
OSTEOARTHRITIS FOLLOWING INTRA-ARTICULAR FRACTURES

Donald D. Anderson, PhD, J Lawrence Marsh, MD, Thomas D. Brown, PhD

FOREWORD
Joseph A. Buckwalter, M.D., Chair, Department of Orthopaedics and Rehabilitation.

The Orthopaedic Research and Education Foundation (OREF) is dedicated to advancing the specialty of orthopaedics through support of research and education. In 1995, recognizing the importance of encouraging clinical research in orthopaedics, the OREF established the OREF Clinical Research Award. The award is given annually in recognition of outstanding clinical research related directly to musculoskeletal disease or injury.

For their efforts to delineate the relationship between trauma and osteoarthritis, Drs. Donald Anderson, J. Lawrence Marsh and Thomas Brown were awarded the 2011 OREF Clinical Research Award. Their paper entitled “The Pathomechanical Etiology of Post-traumatic Osteoarthritis Following Intra-articular Fractures” was presented by Dr. Anderson at the 57th Annual Meeting of the Orthopaedic Research Society in Long Beach, California on January 15, 2011. He described an extensive series of studies in which the authors developed and validated a novel method of measuring the severity of intra-articular fractures; they then applied this method to the study of patients. These measurements are based primarily on the energy released at the time of fracture, and are calculated from digital image analysis of CT scans. The authors also developed and validated a method of measuring cumulative articular surface contact stress elevation following intra-articular fractures, using computational models derived from post-articular fracture reduction CT scans. They then applied these methods to study patients who suffered intra-articular fractures of the distal tibial articular surface. Subsequent work demonstrated that both of these measures predict the development of osteoarthritis: That is, fracture ener-

ABSTRACT
Many intra-articular fracture patients eventually experience significant functional deficits, pain, and stiffness from post-traumatic osteoarthritis (PTOA). Over the last several decades, continued refinement of surgical reconstruction techniques has failed to markedly improve patient outcomes. New treatment paradigms are needed - ideally, bio/pharmaceutical. Progress in that direction has been impeded because the pathomechanical etiology of PTOA development is poorly understood. In particular, the relative roles and pathomechanisms of acute joint injury (from the initial trauma) versus chronic contact stress elevation (from residual incongruity) are unknown, primarily because there have been no objective methods for reliably quantifying either of these insult entities. Over the past decade, novel enabling technologies have been developed that provide objective biomechanical indices of injury severity and of chronic contact stress challenge to fractured joint surfaces. The severity of the initial joint injury is indexed primarily on the basis of the energy released in fracture,
obtained from validated digital image analysis of CT scans. Chronic contact stress elevations are indexed by patient-specific finite element stress analysis, using models derived from post-reduction CT scans. These new measures, conceived in the laboratory, have been taken through the stage of validation, and then have been applied in studies of intra-articular fracture patients, to relate these biomechanical indices of cartilage insult to the incidence and severity of PTOA. This body of work has provided a novel framework for developing and testing new approaches to forestall PTOA following intra-articular fractures.

**INTRODUCTION: THE CLINICAL PROBLEM**

Post-traumatic osteoarthritis occurs following a variety of joint injuries.\(^2\) It ensues most commonly and predictably following injuries that disrupt the articular surface.\(^3\) Data from our institution indicate that roughly 12% of patients presenting with OA of the hip, knee, or ankle have a history of prior joint trauma.\(^4\) Despite the best current efforts at treatment, OA develops in as many as 25% of patients after fractures of the acetabulum,\(^5,6\) between 23% and 44% after intra-articular fractures of the knee,\(^7,8\) and in more than 50% of patients with fractures of the tibial plafond.\(^9,12\) Clinical experience has been that 30% of ankles develop radiographic evidence of significant OA within 2-4 years after a tibial plafond fracture\(^13\) with an associated reduction in general and ankle-specific health status.\(^14\) By 5-11 years after injury, the incidence increases to 74%.\(^15\)

The factors that increase the risk of PTOA after a joint injury have largely eluded meaningful quantification. Most data on the subject have been subjective, anecdotal, and/or based on limited retrospective reviews. PTOA following an intra-articular fracture has been attributed to the initial joint injury\(^16,17\) and to elevated cartilage stresses from residual surface incongruity.\(^18,19\) Neither of these two plausible factors has been amenable to reliable quantification. The severity of the articular injury may well be a primary determinant of outcome, but based on clinical experience, reduction of displaced articular surface fragments has been considered the most important factor leading to a good outcome. Still, case-specific prognoses remain largely speculative.

Tibial plafond fractures are an ideal injury in which to assess the roles of injury severity and chronic contact stress elevation in the pathogenesis of PTOA. OA very frequently develops following ankle trauma, but rarely occurs primarily. Both the amount of articular comminution and the quality of obtained articular reduction exhibit a wide degree of variability,\(^11\) providing ample opportunity to study how these factors influence outcomes. Finally, as stated above, PTOA occurs following a majority of tibial plafond fractures, often within one or two years after injury.

Our research group has combined the complementary expertise and interests of clinical investigators and laboratory bioengineers to address these challenges. Enabling technologies that provide objective mechanical indices of acute cartilage injury and of chronic elevated contact stress have been developed in the laboratory, and applied to prospective clinical series, to provide insight into the mechanical etiology of PTOA following intra-articular fractures.

Both the fracture severity assessment and the chronic contact stress assessment originate from firm physical foundations. Both are implemented using state-of-the-art computer techniques, both have undergone rigorous physical validation, and both have been successfully applied to prospective patient series. The severity of the initial joint injury is indexed on the basis of the mechanical energy released in bony fracture, obtained from digital image analysis of CT scans. Chronic contact stress elevations are indexed by patient-specific finite element (FE) stress analysis, using advanced nonlinear models derived directly from post-reduction CT scans.

**PART I: THE ROLE OF ACUTE FRACTURE SEVERITY**

The difficulty of controlling for the influence of injury severity has been a major confounding factor in clinical studies of intra-articular fracture treatments. It is a broadly accepted viewpoint within the orthopaedic trauma community that “the extent of bone, cartilage, and soft tissue damage is directly related to the energy imparted to these structures”\(^120\) (Figure 1). Yet, the energy involved in producing a given injury has not been measurable, making assessment of the severity of the injury inexact, subjective, and largely empirical.

To scientifically assess the effect of treatment of any condition, an investigator must be able to measure pertinent (patho)physiologic variables. The joint injury in articular trauma is traditionally assessed using categorical fracture classifications.\(^21\) These classifications at best allow only crude assessments of injury severity, and they have been shown to have very poor inter-observer reliability.\(^22\) In the presence of comminution, we\(^23\) (and others) have shown that categorical assessments are virtually useless for clinical research. Thus, the relationship between fracture severity and eventual outcomes remains very poorly understood.

To address this knowledge gap, in 1998 our group introduced the concept of relating the degree of bony comminution to the amount of energy delivered at the time of injury.\(^24\) The basic idea - grounded in principles of
The Pathomechanical Etiology of Post-traumatic Osteoarthritis Following Intra-articular Fractures

Engineering fracture mechanics - was that the mechanical energy absorbed in producing a fracture is converted to de novo surface energy of the fracture fragments. CT scans, acquired routinely for many articular fractures, provide the opportunity to directly measure de novo interfragmentary surface area, from which surface energy can be quantified. For studying PTOA in tibial plafond fracture cases, the primary utility of fracture energy is as a metric of the cartilage-injurious energy pulse that must have crossed the articular surface to create the bony fracture. Over the ensuing decade, we have pursued this fracture energy paradigm as a novel means to quantify injury severity in intra-articular fractures.

Laboratory apparatus for controlled comminution energy delivery

To first resolve several methodological issues arising in this new paradigm, studies were begun to develop and evaluate a brittle polymer foam material which mimics pertinent aspects of natural bone’s impact behavior: propensity to shatter into fragments of sizes and shapes resembling those seen in human comminuted fractures, tendency to produce more fragments which are smaller and sharper as energy absorption is increased, order-of-magnitude similarity of intrinsic material mechanical properties, and similarity to natural bone’s radiographic CT appearance. Working with a specialty vendor, the fracture behavior of various polymer foam compositions and processes were systematically evaluated, under controlled impact conditions. We settled on a high-density, closed cell polyurethane foam. Finely sieved BaSO₄ doping of the resin was used to replicate the radiopacity of bone.

In the course of this work, specialized experimental capabilities were developed to physically quantify the energy of fractures produced under controlled laboratory conditions. An instrumented drop tower impact system was designed and built to study bone (and bone surrogate) fracture comminution. Impact tests with the bone fracture surrogate showed a very close linear proportionality ($R^2 = 0.94$) between de novo fragment surface area and delivered impact energy, very much as would be expected on theoretical grounds.

Digital image analysis for automated measurement of interfragmentary surface area

Next, special purpose image analysis capabilities were developed to automate the task of interfragmentary surface area measurement in CT images. Accurate segmentation to distinguish bone from its surrounding tissues within CT images poses significant technical challenges, due to similar attenuation characteristics between neighboring tissues. This is especially true where metaphyseal articular fracture fragments that are not cleanly bounded by cortex abut one another, producing barely distinguishable fracture lines.

Our original fracture fragment segmentation efforts implemented a seeded region-growing algorithm, which was highly accurate geometrically, although it later proved cumbersomely slow for clinical application. Subsequently, a semi-automated intensity thresholding algorithm was developed which provided comparable accuracy, but with a nearly 100-fold speed gain. This analysis routine runs on a desktop personal computer, and it operates with conventional CT image data encoded in standard DICOM file format.

Bone margins are identified slice-by-slice in CT datasets (Figure 2). Multiplication of the bone perimeters (endosteal, periosteal, and subchondral) in a given CT slice by that slice’s thickness yields the bone surface area over the slice volume. Summing areas across all slices provides the total amount of bone free surface area. Finally, it is necessary to subtract the pre-existing intact bone surface area from the fractured area to determine the de novo interfragmentary surface area. Precisely machined cubes of the polyurethane foam surrogate were used as a gold standard for establishing the accuracy of these measurements.

Interfragmentary surface area measurement in a comminuted fracture

Experiments were next performed using bovine cortical bone. We hypothesized that fragment sets resulting from replicate equal-energy impacts would have similar interfragmentary surface areas, whereas fragment sets from impactions at different energy levels would have correspondingly different interfragmentary areas. After accounting for the through-pass energy, three study groups (n=12 each) were verified to have received distinctly different fracture energies. Intact bone specimens
were CT-scanned prior to impact. After fracturing, the fragments were CT-scanned encased in BaSO$_4$-doped resin (to mimic the CT intensity of soft tissue).

Despite the highly idiosyncratic nature of the individual fragmentation patterns, the de novo surface area generated in the specimens that absorbed greater energy was significantly higher ($p<0.0001$) than that in the lower energy groups (Figure 3), with energy-proportional linearity ($R=0.83$). Further, consistent with fracture mechanics theory, fragment size distributions for the three groups followed the same principles of comminution observed in other brittle materials: greater energy absorption produced a greater number of fragments, of correspondingly smaller size.

**Incorporation of bone density heterogeneity into the fracture energy determination**

The fracture energy assessment technique was then extended for use in human clinical cases. A key difference between the surrogate material and human bone tissue is the latter’s heterogeneity. Since the energy-absorbing capacity of bone is both density- and age-dependent, bone density-based weighting was integrated into the algorithm. Formal fracture energy was calculated by multiplying the interfragmentary surface area times the energy release rate (G, units of Joules/$m^2$), a material property that quantifies the energy required to liberate a given surface area. Theoretical and experimental work with bone from various animal species had shown G to be directly proportional to the first power of apparent density.

![Figure 2: Bone perimeters (matched intact & fractured), plotted along the length of the distal tibia, show how the fracture energy measure is calculated. Inset: CT slice from fracture case, with identified tibia bone fragment edges.](image)

![Figure 3: Controlled fracture experiments performed in bone showed a highly linear relationship between CT-inferred fracture energy and the physically measured energy absorbed in fracture. Inset: The data also showed that fragment sizes correlated with fracture energy, shifting from predominantly larger fragments at lower energies to smaller fragments at higher energies. Adapted with permission from Anderson DD et al. Quantifying tibial plafond fracture severity: absorbed energy and fragment displacement agree with clinical rank ordering. J Orthop Res. 26:1046-52, 2008.](image)

Ideally, bone density would be regressed pixel-by-pixel, based on CT Hounsfield intensities along fragment edges. As a practical matter, however, partial volume effects and high intensity gradients at the edge often preclude reliable scaling using this approach. Therefore, the
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![Diagram showing fracture displacement and articular involvement in comminuted fractures.](image)

Figure 4. Depiction of the fragment displacement/dispersion metric calculation. [Adapted with permission from Anderson DD et al. Quantifying tibial plafond fracture severity: absorbed energy and fragment displacement agree with clinical rank ordering. J Orthop Res. 26:1046-52, 2008.]

Fracture energy algorithm was augmented to partition G according to densities found for the tibial plafond’s three dominant classes of bone: dense diaphyseal cortical, less dense metaphyseal cortical, and cancellous. Apparent densities of these three bone classes are determined on a patient-specific basis, by regression from mixed Gaussian distributions. Finally, energy release rates are then determined by scaling (previously-measured) impact energy/density data to the (patient-specific) bone density values.

**Measuring fracture displacement and articular involvement in comminuted fractures**

Fragment displacement/dispersion is another factor influencing the outcome of intra-articular fractures. As with fracture energy, this is amenable to quantification from CT studies. When fracture fragments are displaced, the bony regions in given cross-sections are generally translated away from their intact positions, the bone structure is disrupted, and fragments are dispersed relative to one another.

The bone surfaces identified in fracture energy analysis were used to quantify fragment displacement. This required alignment of the intact proximal portion of the fractured tibia with a mirrored image of the uninjured contralateral side (Figure 4). Once aligned, fragment displacement was indexed by calculating the volume of tissues through which fracture fragments were collection relative to their pre-fracture position. To determine dispersal volume, for each CT slice, a convex hull (the smallest convex polygon circumscribing a given object) was determined for both the (mirrored) intact bone, and for a composite of the aligned intact and fractured tibias (inset, Figure 4). The difference in these volumes provided a metric of the amount of fragment dispersion, implicitly incorporating limb axial malalignment, as well.

The degree of comminution of the articular surface per se is a key radiographic feature associated with injury severity and with likelihood of PTOA. This was quantified in terms of the amount of interfragmentary surface area located within 1.5 mm of the articular surface, expressed as a percentage of the pre-existing (intact/contralateral) surface area of the distal tibia.

**Validation: Agreement with experienced surgeon assessment of fracture patient datasets**

Despite inter- and intra-observer variability in classifying comminuted intra-articular fractures, the opinion of experienced orthopaedic traumatologists is necessarily the gold standard against which to gage new objective measures of injury severity. Previous work from our group had shown that when experienced clinicians stratify injury severity using simple comparative rank ordering, the agreement between observers is high. A study was undertaken to compare CT-based objective measures of severity versus the gold standard (clinician rank ordering). The study group consisted of twenty tibial plafond fractures (13 in males, patient ages from 20 to 64 years) treated at our institution. Cases were chosen to span the spectrum of injury, from mild partial articular fractures to severely comminuted fractures involving the entire tibial plafond. In independent grading sessions, the fracture cases were ranked for injury severity by three experienced academic orthopaedic traumatologists, based on appearance in plain radiographs. The only instruction given to the raters was to rank the cases in order of least to most severely injured.

Concordance rates were calculated to measure the level of agreement between raters, and between each rater’s assessment of fracture severity versus the CT-based severity metrics. A given pair of injury severity rankings was concordant if the case with the higher ranking for one rater also had the higher ranking for a second rater. (This sample-based statistical measure formally estimates the probability that any two fracture cases would be ranked with the same ordering.)

Each case’s CT dataset took typically eight to ten person-hours to image process (Figure 5), using the above-described image analysis tools then available. The range of different fractures encountered in the study is...
illustrated via plain radiographs in Figure 1. Fracture energies ranged from 11 to 53 J, and fragment displacement volumes ranged from 3.4 to 47.4 cm³, reflecting a wide variation in severity.

The concordance rate between the three raters (Figure 6) ranged from 87 to 91%. The rank ordering of the fracture energy metric also agreed well with the raters' judgment, with concordance rates from 73 to 76%. The concordance rate between raters' assessment of fracture severity and the aggregate fragment displacement metric ranged from 82 to 89%. Summarizing, the (objective) CT-derived measures of comminuted fracture severity agreed with the experienced orthopaedic surgeons' (subjective) rankings. This very important result convincingly supports the image analysis approach for objective measurement of fracture severity. This in turn opens the way to controlling for injury severity in large multi-center studies.

Using the GLCM reduced the time required to obtain an objective fracture severity assessment from roughly 8–10 hours to about 10 minutes, while maintaining excellent agreement (linear regression $R^2 = 0.80$) with the area-based energy metric. Importantly, the expedited technique required absolutely no human analyst intervention or vetting.

A second step toward use of the CT-based methods in orthopaedic practice is to avoid the need for CT scans of the intact contralateral limb. As such scans are not routinely obtained during fracture evaluation, reliance upon them impedes large multi-center and retrospective studies that could provide high statistical power for establishing the relative efficacy of alternative treatment regimes. To bypass the need for contralateral-side CT, a study was designed to establish a normative anthropometric model of the intact distal tibia, from which to derive tare bone surface area data. It was hypothesized that an allometrically scaled tibia model could serve as a surrogate datum capable of accurately measuring interfragmentary surface area. The free bone surface area along the intact distal tibia of 22 subjects was regressed from existing CT data. When the regression data were applied to the above tibial plafond fracture cases, the concordance between fracture energy for the regressed versus true tare bone surface areas was 90%. This result indicated that, when necessary, normative bone surface area can be substituted for measured intact-contralateral surface area.
PART II: THE ROLE OF CHRONIC CONTACT STRESS ELEVATION

Previously lacking a means to reliably measure injury severity, and without any bio/pharmaceutical treatments proven to enhance cartilage survival, orthopaedic management of intra-articular fractures has largely concentrated upon fracture reduction. Attempts have been made to measure residual articular surface incongruity on post-reduction radiographs, as a surrogate for elevated contact stress. Unfortunately, the ability to measure joint incongruity on radiographs has been shown to be poor.\textsuperscript{43,44} Moreover, the measurement of geometric steps or gaps seen on radiographs is a weak surrogate for the actual chronic pathomechanical stimulus of interest at the cellular and molecular level: contact stress abnormality.

In the presence of residual surface incongruity, joint loads that are normally well tolerated generate local areas of elevated contact stress.\textsuperscript{45-47} The degree to which injured articular joints tolerate elevated contact stress is unknown, as is the accuracy of articular reduction required to forestall clinically significant PTOA. Finite element (FE) stress analysis techniques, suitably applied and rigorously validated, provide the basis to address this knowledge gap.

The initial FE analyses by our group to study this issue involved computing the contact stress aberrations engendered for joints with an idealized fracture step-off, subjected to a representative static load.\textsuperscript{48,49} The great majority of FE stress analyses performed to date in the field of orthopaedic biomechanics have involved working with just such models, derived from the anatomy of single individuals. This had been necessary because approaches lending themselves to a high degree of automation in FE model generation are relatively recent. Seminal work in automated meshing (the process whereby a continuous material region is represented by discrete contiguous elements) for orthopaedic stress analysis was reported in 1990 by Keyak et al., who recognized that CT voxels could be converted directly into hexahedral ("brick") continuum elements.\textsuperscript{50} The attraction of voxel-based meshing was immediately evident, and a great many subsequent studies have adopted and refined that essential idea.

To date, however, voxel-based meshing work for orthopaedic stress analysis has involved almost exclusively linear (load-proportionate) analyses. Articular joint contact stress by it nature behaves very nonlinearly. Stresses are non-proportional to load, because (among other things) the engaged contact area changes as load increases. Another consideration is that contact analyses have lent themselves poorly to voxel-based meshing, owing to the "stair-step" jaggedness necessarily present at all external surfaces of voxellated objects.
Yet a third relevant issue relates to the choice of loading conditions for an articular joint model. For the case of the human ankle, level walking gait constitutes the predominant functional activity responsible for aggregate cartilage mechano-stimulus. Articular surface apposition and resultant contact force both vary appreciably throughout functional activities. Therefore, conventional "snapshot" contact stress distributions restricted to a specific instant of the duty cycle provide very limited information regarding the habitual mechano-stimulus at any given site.

Patient-specific FE mesh generation from CT scans

Over the last eight years, we have worked to develop and implement a finite element formulation that automatically generates patient-specific meshes,\(^{51}\) that overcomes the contact surface stair-stepping difficulty, and that implements whole-duty-cycle analysis. To mesh patient-specific articular surfaces (including those with fracture incongruities), layers of continuum hexahedral ("brick") cartilage elements are zoned outwardly from quadrilateral bone surface meshes (subchondral bone plate). Successful treatment of this class of incongruous articular joint contact problems also has required special attention to initial surface apposition, and to contact member constraints during initial contact engagement and subsequent duty cycle simulation.\(^{52}\) Appropriate attention has also been directed to realistic replication of whole-duty-cycle joint surface engagement kinematics.

The procedure for patient-specific contact FE model assembly involves a series of interdependent steps, that begin with image processing/segmentation, surface identification, and mesh generation. The source image dataset is a series of slices obtained from clinical CT scans (in DICOM format). This volumetric image dataset is segmented to isolate structures of interest, yielding a provisional "conventional" voxel-based FE mesh (Figure 7(a)). To eliminate the boundary, or stair-step, artifact from the potential contact surface, a corresponding 'smoothed' surface is generated using isosurface interpolation (Figure 7(b)), which discretizes the initial surface into a very large array of connected triangular facets. The accuracy of this pre-processing approach was verified using precisely known analytic geometries (spherical and cylindrical), with the FE solutions showing close correspondence to gold standard (Hertzian) mathematical contact solutions.\(^{51}\)

Next, upon completion of bone isosurface extraction for both sides of the contact interface, layers of cartilage are superimposed using a purpose-written mesh generation algorithm. A key issue here is that most algorithms for meshing complex 3D objects utilize tetrahedral meshes. Unfortunately, tetrahedral meshes perform notoriously poorly in contact stress analyses, since their contact surface facets (triangles) are mathematically "too stiff." For this reason, we developed specialty algorithms by which external surfaces of epiphyseal regions (subchondral bone surfaces) are meshed into quadrilateral rather than triangular facets, hence allowing superimposition of hexahedral rather than tetrahedral cartilage ele-
ments. This is done by projecting an externally defined rectilinear grid onto the isosurface (triangular-facet) discretization of the subchondral surface, and then meshing layers of continuum hexahedral (“brick”) cartilage elements outwardly from the projected grid intersections with that surface. When data for the thickness variation in the articular cartilage are available (e.g., from MR),\textsuperscript{53} patient-specific cartilage thickness variation is incorporated. Otherwise, normatively-based cartilage thickness is used. These techniques are amenable to both intact and fractured bone surface geometries. Thus, idealized articular surface incongruity (in terms of simplified features such as step-offs or gaps) need no longer be assumed. Rather, the idiosyncratic patient-specific geometry of actual fracture surfaces is directly incorporated.

**FE Validation:** accurate regional reproduction of prevailing contact stress distributions

Next, a validation study was conducted to determine the extent to which thus-computed ankle contact FE results agreed with experimentally measured tibio-talar contact stress.\textsuperscript{54} Two cadaver ankles were loaded axially to 600 N (Figure 8), during which ankle contact stresses were measured with a purpose-designed high-resolution ankle contact stress sensor which our group had developed\textsuperscript{55} (now marketed commercially as Tekscan Model #5033). A CT scan of each ankle was acquired to record the precise loaded joint apposition. Stainless steel marker K-wires were drilled across the joint in order to precisely register sensor orientation relative to the joint surfaces. Bi-planar radiographs were then taken with the K-wires in place, to register the relative locations of the tibia, talus, and the contact stress sensor.

Spatial registration of the contact stress sensor readings with the FE results enabled ideally definitive comparison of the experimentally measured versus computationally predicted contact stress distributions. Since PTOA usually initiates focally, it was especially important that the FE-computed contact stresses be validated locally, in terms of their spatial distribution, rather than just by conventional global measures such as peak or mean contact stress, contact area, etc.

Corresponding contact FE analyses were then performed. The global measures showed very reasonable agreement between FE-computed and experimentally
measured mean (3.2% discrepancy for one specimen, 19.3% for the other) and maximum (1.5% and 6.2%) contact stress, as well as for contact area (1.7% and 14.9%). More importantly, there was good agreement in the measured versus computed distributions of contact areas across the contact stress levels (Figure 9), especially so for the more physiologically challenging higher contact stress range. Formal site-by-site comparisons between the computed and measured contact stress distributions over the articular surface (1472 locations) also showed strong agreement, with correlations of 90% for one specimen, and 86% for the other. This strong level of agreement between physical measurements and the FE—especially including the spatial distributions—convincingly established the computational formulation’s validity.

Physiologic apposition, whole-duty-cycle joint loading, and chronic contact stress exposure

Almost all previous articular contact FE models have been restricted to a single static pose and loading condition. Moreover, as a matter of convenience, the apposition in which the loading has been applied has often been the particular orientation in which the source imaging study (CT or MR) happened to be obtained, despite the fact that this is generally not a position of ankle loading. To perform physiologically meaningful whole-duty-cycle contact stress analysis of articular contact functional loading histories, it is instead necessary to begin from appositions of physical relevance for a specific patient.38

For this reason, whole-duty-cycle level walking gait simulations were based upon a functional neutral weight-bearing apposition of the tibia and talus. This required an experienced foot and ankle surgeon to prescribe the translations and rotations (Figure 7b → 7c) necessary to achieve this neutral weight-bearing apposition. This re-positioning was performed working from biplanar (A-P and lateral) weight-bearing radiographs and from anatomical landmarks, based on normative data from a previous study.39

Apposing cartilage surfaces were defined as deformable contact pairs, with a very low friction (μ=0.01) interface. Whole-duty cycle FE simulations (Figure 10) entailed performing a sequence of thirteen successive
ankle loading contact stress analyses (loads from 0.1 to 3.2 x body weight, and rotations from 5° plantar to 9° dorsiflexion), to simulate the entire stance phase of level walking gait. The tibia was rotated about a provisional ankle flexion/extension axis, with the talus free to rotate as required by the tibio-talar articulation, thus not constraining the ankle’s rotations to occur about a fixed axis.

Having contact stress data from the 13 incremental solutions allowed assessment of cumulative elevated contact stress exposure. Cumulative exposure reflects a joint’s contact stress history over a specified time period. Elevations above a presumably deleterious mechanical insult threshold were postulated to be injurious to the joint. This built upon a paradigm of cartilage degeneration propensity for patients with congenital hip dislocation that we had previously advanced, where a strong positive correlation was found between elevated cumulative contact stress over-exposure and long-term patient outcome (incidence and progression of OA). Cumulative chronic contact stress exposures for the ankle were calculated over the tibial articulating surface on a step-by-step basis using the equation:

\[ \hat{P}_{\text{cumulative}} = \sum_{i=1}^{13} ((\hat{P}_i - P_d) \Delta t_i) \]

where \( \hat{P}_{\text{cumulative}} \) is the spatial distribution of per-gait-cycle cumulative contact stress over-exposure, expressed in MPa-seconds; \( \hat{P}_i \) are the FE-computed nodal contact stress values at given increments in the gait cycle, with \( i \) varying across 13 load increments; \( P_d \) is a scalar contact stress damage threshold (remaining to be established, but provisionally set to 6 MPa, empirically consistent with minimal over-exposure in the intact ankles); and \( \Delta t_i \) is the residence time, in seconds, associated with a given increment in the gait cycle.\(^{50} \)

Contact stress differences in fractured versus intact ankles

Chronic contact stress exposures were then quantified following intra-articular ankle fractures,\(^{50} \) in the same patient series for which fracture energy analyses had been performed. FE models were generated from CT scans of both the fractured (post surgical reduction) and the intact contralateral ankles. FE solutions were obtained for 11 intact/fractured ankle pairs. Figure 11 shows the tibial articular surface geometries of these ankles, and the corresponding FE-computed per-gait-cycle contact stress exposure distributions.

The FE results for the intact contralateral ankles were consistent with the literature. Despite different test setups and applied loads, contact area values reported for the normal ankle joint have been remarkably consistent, with average values of 558 +/- 122 mm\(^2\).\(^{53,62,63} \) The average intact contact area from these 11 patients (in neutral apposition) was 578 +/- 83 mm\(^2\). The peak contact stress value and range for the intact cases (in neutral apposition) agree with values measured by Vrahas et al., who reported a series-average peak stress value of 6.7 MPa (range of 2 to 12 MPa) in cadaveric ankles statically loaded to 1360 N.\(^{64} \) The present FE computed series-average peak contact stress value, at a mean of 1492 N load, was 6.8 MPa (range of 5 to 9 MPa).

In general, the intact ankles had lower peak contact stress exposure values and more uniform and centrally positioned exposure regions, than the (reduced) fractured ankles. The peak contact stress and contact area values occurred at the instant in the gait cycle with maximal joint loading, roughly 61% through the stance phase, in a 7.5° dorsiflexed position. Series-wide, computed peak contact stress values of intact versus fractured cases were 10.1 +/- 1.8 (mean +/- S.D.) versus 13.8 +/- 1.8 MPa, respectively (significant, \( p = 0.0015 \)). Interestingly, the ranges of peak values overlapped substantially: 7.4 to 12.9 MPa for intact cases and 11.0 to 16.5 MPa for fractured cases.

The fracture cases had several-fold higher amounts of area with high contact stress-time exposures, and correspondingly lesser amounts of area with low exposure values, compared to the intact cases (\( \chi^2 \) test statistic =...
### Refinements in the assessment of chronic contact stress elevation, toward clinical use

In the course of this work, it became evident that translating the patient-specific FE analyses methodology to routine clinical use would require substantial increases in the speed and robustness with which contact stress distributions could be calculated. We therefore have since developed more expeditious and substantially more robust elastic contact analysis tools that achieve this objective. 

### PART III: CLINICAL INVESTIGATIONS OF THE PATHOMECHANICAL ETIOLOGY OF PTOA

We have prospectively followed a series of 36 tibial plafond fracture patients, who have been uniformly treated provisionally with a spanning external fixator, and subsequently with definitive fracture reduction and screw fixation at a time when soft tissue injury had sufficiently resolved. A goal has been to assess whether these new biomechanical indices of both the acute mechanical insult (from the initial trauma) and chronic contact stress elevation (from residual incongruity) are predictive of OA. The tibial plafond fractures ranged in severity from minimally to severely comminuted, with idiosyncratic fragmentation morphologies. Two year follow-ups are now complete for these patients. Hypotheses tested have been that functional deficits, symptoms, and the degree of cartilage degeneration in articular fracture patients correlate with metrics of the acute injurious mechanical insult and/or of chronic cartilage contact stress elevations from residual articular incongruity. A corollary hypothesis has been that there is a threshold of acute injury severity and/or of chronic mechanical insult that is predictive of the onset of PTOA.

PTOA severity was assessed by Kellgren-Lawrence (KL) grade at two years post-injury. Functional outcomes were measured using the Ankle Osteoarthritis Scale (AOS), a reliable and validated self-assessment instrument that measures patient symptoms and disabilities related to ankle arthritis. Relationships between fracture severity (using the CT-based metrics described above), PTOA severity, and AOS scores were determined by linear regression.

At two years post-injury, 13% of the patients had developed mild PTOA (KL=2), and 31% had developed moderate to severe PTOA (KL≥3). Linear regression (Figure 12) indicated that fracture energy and articular comminution, when combined, explained 70% of the variation in PTOA severity. Fragment displacement/dispersal correlated much less strongly with joint degeneration ($R^2=0.42$). A combined fracture energy and articular comminution metric was a better predictor of KL scores than was clinician subjective judgment ($R^2$ of 0.70 vs. 0.47, respectively).

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**Figure 11:** FE-computed contact stress exposure distributions for the 11 paired intact and fractured (post-reduction) ankles, for a single gait cycle. [Adapted with permission from Li W et al. Patient-specific finite element analysis of chronic contact stress exposure after intraarticular fracture of the tibial plafond. J Orthop Res. 26:1039-45, 2008.]

26.1, $p = 0.011$). Series-wide, peak per-gait-cycle exposure values for intact versus fractured ankle cases were 2.7+/−0.5 MPa-s versus 3.9+/−0.5 MPa-s, respectively (highly statistically significant, $p=0.003$). For some patients, the difference in stress exposure between intact and fractured ankles was relatively minor, while for others, the difference was dramatic (range from 8% to 91%).
Patients with little or no evidence of PTOA (KL≤2) had an average AOS score of 21.4±20 and an average fracture severity score of 43.5±11. Patients with a KL grade >2 averaged 40.8±18 for AOS and 69.8±20 for fracture severity. When grouped by KL grade, fracture severity and AOS scores were well correlated (R²=0.68). Both the AOS and fracture severity scores were statistically different (p<0.05) between the groups of patients with versus without incident PTOA.

The existence of a threshold of injury severity that predicts whether a joint will develop PTOA has broad implications for the future treatment of intra-articular fractures. In fractured joints identified as being most highly at risk to develop PTOA, the value of accurate surgical reduction should be especially carefully weighed against the backdrop of potential surgical complications. New bio/pharmaceutical interventions aimed at forestalling PTOA would certainly need to stratify patients according to their otherwise-expected risk for joint degeneration. The CT-based methodology suggests that such a threshold indeed exists. Figure 13 shows the cases studied, ordered according to the combined acute fracture severity measure. These data support the existence of a severity threshold (in the vicinity of 40 for this severity range-normalized metric) above which joint degeneration is likely.

Figure 12. A combined severity score including fracture energy and articular commination predicted 70% of the variation in KL arthrosis grade at two-year follow-up. [Adapted with permission from Thomas TP et al. Objective CT-based metrics of articular fracture severity to assess risk for posttraumatic osteoarthritis. J Orthop Trauma. 24:764-9, 2010. 47]

Figure 13. The CT-based severity metric successfully discriminated between cases that developed PTOA and those that did not, in a threshold-like manner.
Figure 14. The % of contact area engaged above selected contact stress levels shows that in the ankles that went on to develop PTOA, a much larger percentage of the post-fracture cartilage surface was subject to high levels of contact stress (dark columns). The inset shows contact stress distributions for a representative pairing of a fractured ankle with its intact contralateral. [Reprinted with permission from Anderson DD et al. Is elevated contact stress predictive of post-traumatic osteoarthritis for imprecisely reduced tibial plafond fractures? J Orthop Res. 29:33-9, 2011.**]

Fragment displacement/dispersal was not a significant predictor of PTOA in this series of intra-articular tibial plafond fractures. Judging by the high concordance between displacement/dispersal and clinician rank ordering, the surgeons' perceptions of injury severity were greatly influenced by the degree of fragment displacement. That focus on displacement may reflect an implicit association with soft tissue damage, and/or with difficulty in obtaining accurate surgical reduction. Both factors certainly are important concerns in acute-term patient management, but they do not appear to be highly predictive of eventual PTOA.

FE-computed contact stress distributions for these patients clearly show that much larger percentages of the post-fracture cartilage experienced high contact stress (areas above 7.5 MPa at the instant of peak joint loading averaged 23.4% of the surface in the fractured vs. only 12.5% in the intact ankles). Furthermore, there was a clear distinction between area engagement histograms from those fractured ankles that developed PTOA within two years, versus those that did not, with the histograms of the latter being much more similar to those of the intact contralateral ankles (Figure 14).

Putative contact stress damage threshold/tolerance parameters were systematically varied to determine the values that provided the best agreement between contact stress exposure metrics and the KL scores for each ankle. A binary OA status was defined as 1 for each ankle with a KL score ≥ 2, and 0 for all other ankles.

The predictive performance of five different contact stress exposure metrics was assessed in the intact versus fractured ankles, with fractured ankles grouped according to whether or not they developed PTOA by two-year follow up. The concordance between the various contact stress exposure metrics and KL score were all excellent, exceeding 88%. The concordance with OA
status was even higher, with all metrics yielding greater than 94% agreement.

The best concordance (KL score of 95%, OA status 100% prediction accuracy) was associated with a local stress-time exposure metric. Figure 15 shows the clear separation between groups with different OA status attained with the local stress-time exposure metric. For some patients, the difference in exposure between intact and fractured ankles was relatively minor (fractured exposure within 40% of intact), while for others, the difference was dramatic (fractured exposure 900% of intact).

To investigate the hypothesis that elevated contact stress exposure results in cartilage thinning, a method was needed to measure cartilage thickness in patients with implanted metallic fixation hardware. MRI of cartilage provides an obvious means for this assessment. Unfortunately, the metallic screws and plates normally placed surgically to maintain fracture reduction introduce susceptibility artifacts, which locally distort conventionally acquired MR images, largely precluding reliable cartilage assessment. In earlier work, we had established that double-contrast CT arthrography was able to measure cartilage thickness in the (cadaveric) ankle with an accuracy superior to MRI. Based on this work, FE measures of contact stress exposure were compared with double-contrast CT images of cartilage thickness in tibial plafond fracture patients, to determine if specific areas of elevated contact stress exposure were associated with corresponding areas of subsequent cartilage thinning.

Double-contrast CTs were obtained at 6 months and 2 years post injury, for 11 patients. Although high-quality images were obtained in these patients, double-contrast MDCT scans were problematic for studying cartilage degeneration in ankles of plafond fracture patients. Efforts to obtain usable scans in an additional 20 patients were unsuccessful, with reasons being related either to the inherent joint pathology (especially arthrofibrosis) and technical difficulties (failed injection, metal artifact).] Successful contrast agent injection into the joints enabled segmentation of the subchondral bone and cartilage surfaces. Registration of the post-op FE simulations to the 2 year cartilage thickness maps was performed, to allow spatial comparison. Cartilage thickness data were then linearly interpolated (spatially) to coincide with the locations of FE-computed chronic contact stress exposure values, and the two quantities were then compared at sites across the articular surface.

Localized areas of cartilage thinning generally corresponded to areas exposed to elevated contact stresses (Figure 16). Contact stress exposures of 2.0 MPa-s or greater were associated with a focal loss of cartilage. The relative reduction in cartilage volumes from the pre-fractured state ranged from 11 to 81%. The most severely comminuted fractures experienced the greatest loss of cartilage, in addition to having the greatest contact stress exposures as predicted by FE. The area of total cartilage loss ranged from 0 to 241 mm², the latter being about 25% of the articular surface.
PATH FORWARD

Olson and Guilak recently described the void in knowledge regarding the etiology, pathogenesis, and mechanisms of PTOA as a "black box," that needs to be opened in order to develop therapies to improve the outcomes of patients with intra-articular fractures. The studies summarized in this paper provide a novel framework for statistically robust multi-center clinical/translational studies of methods to reduce the risk of PTOA following an intra-articular fracture.

Enabling technologies that provide objective mechanical indices of acute cartilage injury and of chronic increased contact stress have been developed in the laboratory, and applied to prospective clinical series, to provide insight into the mechanical etiology of PTOA. The clinical outcomes indicate that acute fracture severity is a primary predictor of the incidence of post-traumatic arthritis and functional outcomes following fractures of the tibial plafond, with chronic contact stress elevation also correlating (secondarily) with outcome. A recent case report of three distinct plafond fractures has served to illustrate the utility of these new objective biomechanical measures to identify clinically significant distinctions among individual patients.

Given the relationship between elevated contact stress and cartilage degeneration identified in this work, continued efforts at improving surgical fracture reduction are warranted. One of these is a new technology utilizing "three-dimensional puzzle solving" methods to facilitate pre-operative fracture reconstruction planning (Figure 17), so that more optimally congruous surgical fracture reductions can be more consistently achieved, to reduce contact stress elevations. This puzzle solving technology informs the surgeon of the original anatomic sites of origin of each of the fragments.

Given the experience of the past several decades, further mechanical refinements of fracture stabilization...
techniques alone seem unlikely to advance the treatment of patients with articular fractures. Future investigation probably needs to focus on bio/pharmaceutical interventions designed to preserve the damaged articular surfaces. Although the basic cellular mechanisms responsible for progressive articular surface degeneration following joint injury are not yet well understood, there is increasing evidence that biologic interventions can decrease chondrocyte damage induced by mechanical stress, suggesting that it may be possible to limit progressive chondrocyte damage after joint injury. To develop such agents, reductionist laboratory studies (e.g., cell/tissue culture) need to work with realistic impact energy and chronic contact stress levels. The development of a large animal model of intra-articular fracture that replicates the important mechanical features of the insult is another area where progress is being made. Moreover, to rationally apply and evaluate these advances, such interventions must eventually be assessed in patient cohorts that are reasonably stratified in terms of the severity of the initial joint injury and that involve large enough numbers of patients to yield statistically robust findings.

Finally, computer-based measures of injury severity, coupled with multi-center electronic pooling of case experiences, offer unprecedented opportunities to accomplish these goals. We are currently conducting a multi-center study of plafond fractures using expedited CT-based fracture severity measurements, with novel capabilities for case-by-case comparisons within a large patient population. This will set the stage for broader clinical use to objectively index injury severity, as an aid to discerning patient prognosis and choosing treatment.

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REFERENCES


A TRIBUTE TO HELENA PERCAS DE PONSETI

Helena Percus-Ponseti was born in Valencia, Spain in January of 1921. She was a graduate of the Institute Maintenon in Paris and of Barnard College in New York. She earned her Ph.D. in Hispanic literature at Columbia University. After teaching at Columbia and at Queens College in New York, she joined the Grinnell faculty in 1948 and became a full professor in 1957. Esteemed by the faculty as both an inspiring teacher and an internationally recognized scholar, Professor Ponseti was named the James Morton Roberts Honor Professor (1961-62) and in 1963, was awarded the Seth Richards Chair of Modern Languages.

Helena met Ignacio Ponseti in Iowa City shortly before Christmas of 1960. The next day he wrote her a four-page letter telling her it was love at first sight and asking her to be his soul mate, friend and wife for life. Six months later they were married.

Helena cherished Dr. Ponseti’s letter, which later became a source of great comfort to her after Dr. Ponseti’s death in October of 2009. She read it every night before going to sleep.

Dr. Ponseti often mentioned that marrying Helena was one of the two best decisions he made in his life. The other was his decision to come to the Department of Orthopaedic Surgery at the University of Iowa in 1941, where he met Helena. He also said that women were like precious art, they needed to be appreciated and cherished, and that to him, Helena embodied a unique and magnificent masterpiece. With a grin, he would add, “I do realize that art appreciation is in the eye of the beholder!”

Dr. Ponseti boasted about Helena’s wonderful and vivacious personality, her athletic ability and love for hiking, the abundance of her wit and intellect, and her culinary skills. Dr. Ponseti admitted that “I had met many women throughout my long life, but none was as great as my wife Helena. She was meant to be my wife, and when I married her, my life and my own persona became complete.” Dr. Ponseti also said that, “Without Helena inspiring me and motivating me, I couldn’t have achieved the accomplishments that we were able to do for our pediatric patients, particularly for babies born with clubfoot.”

By her own right, Professor Helena Percus-Ponseti established herself as a leading Cervantes scholar with publication of several critically acclaimed books. For many years she graced the editorial board of the journal of the Cervantes Society and was a frequent collaborator in its pages through a series of articles of exceptional value.

Helena was admired for the lucidity of her mind and for her kindness and magnanimity. The nobility of Helena’s mind and works will be a perennial example of the best Hispanism has to offer. She will not be forgotten.

Helena Ponseti passed away January 1, 2011, following a stroke. She was preceded in death by her husband of 48 years, Ignacio Vives Ponseti, Professor of Orthopaedic Surgery at the University of Iowa, and creator of the Ponseti Method, the highly successful and innovative non-surgical method for the treatment of clubfoot.

Helena graced our department with her daily visits. She considered every member of the department as a family member. She will be dearly missed.

Paul Etret, Assistant to the Chair
Department of Orthopaedics and Rehabilitation
The University of Iowa
ORTHODONTIC CONSIDERATIONS FOR THE PATIENT WEARING A MILWAUKEE BRACE

A Collaboration of Dr. William Olin¹ and Dr. Ignacio Ponseti²
Preface by Stuart Weinstein, M.D.³

PREFACE

The Milwaukee Brace was developed by Dr Walter Blount of Milwaukee, Wisconsin in the mid 1940’s as a removable postoperative immobilization device for the treatment of neuromuscular scoliosis patients. This was quickly adopted as a nonoperative treatment device for idiopathic scoliosis. The first report of its use for this purpose came in 1958 (JBJS 40A:511-525, 1958). The principle of the brace (cervicothoracic-lumbosacral orthosis, C-TLSO) was to apply longitudinal correction between the pelvic girdle (originally made of leather and later thermoplastics) and the neck ring and lateral corrective forces applied to the curve apex via pads attached to a metal superstructure that connected the pelvic girdle to the neck ring. The brace was constructed to flatten the lumbar lordosis and in theory increase the effectiveness of the appropriately place pads. Correction was thought to occur by passive pad pressure on the apex (in the thoracic spine via pressure on the apical ribs) of the curves and actively by the muscles pulling away from the pads. The orthotic was used 23 hours a day and often combined with an exercise program. The main problem with the brace was adherence to treatment. Gradually the Milwaukee brace gave way to underarm braces (TLSO’s) which were thought to have better patient acceptance. The question of brace efficacy is currently being addressed by the University of Iowa Department of Orthopaedic Surgery led NIH Trial (Brast: http://clinicaltrials.gov/ct2/show/NCT00448448?term=brast&rank=1).

The initial design of the Milwaukee brace used a mandibular occipital ring. In the 1960’s and early 1970’s Dr Ignacio Ponseti (Professor Emeritus of Orthopaedics at the University of Iowa) and Dr William Olin (Professor Emeritus of Orthodontics at the University of Iowa) studied the adverse oral and mandibular consequences of the Milwaukee Brace in scoliosis patients at the University of Iowa. This study was never published but provided critical information regarding the problems created by the initial version of the Milwaukee Brace that eventually resulted in a design change to a neck ring to avoid the negative aspects of the original design.

Dr William Olin was kind enough to share his original manuscript with the Iowa Orthopaedic Journal for publication so that this valuable piece of collaborative University research would be captured for perpetuity. Case 1 has been omitted due to missing data and the figures from cases 3 through 9 have been omitted for space concerns. For those interested in these original images, they have been electronically captured and returned to Dr. Olin.

INTRODUCTION

The purpose of this study is to investigate the effects of the Milwaukee Brace on the maxillofacial complex and to discuss the orthodontic considerations. The Milwaukee Brace is used for the treatment of the young child with progressing spinal curvature (scoliosis) and for some children with paralytic scoliosis (Figure 1A and 1B).

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¹ Professor Emeritus, Orthodontics
The University of Iowa College of Dentistry
801 Newton Road
Iowa City, IA 52242

² Department of Orthopaedic Surgery and Rehabilitation
The University of Iowa
200 Hawkins Drive
Iowa City, IA 52242
(319) 356-1872

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Figure 1A. Patient with progressive spinal curvature (scoliosis) wearing the Milwaukee Brace.

Figure 1B. Patient with paralytic scoliosis wearing the Milwaukee Brace.
The term scoliosis refers to a lateral curvature of the spine with rotation of the vertebral bodies. The deformity develops gradually, usually during the period of fast growth of the trunk and is much more common in girls than in boys. The cause of the deformity may be related to congenital anomalies of the vertebrae or to a paralysis of some of the trunk muscles resulting from poliomyelitis or other neurological diseases. However, the cause of the most common type of scoliosis is unknown, although it is thought to be related to a weakness of the spinal ligaments during the pubertal growth spurt. This type of scoliosis is called idiopathic.

In early medical history, the treatment of structural scoliosis consisted of attempts to straighten the curvature passively with an apparatus. Early braces were made by armors and were very unpleasant and difficult to wear. Until recently, no brace had been successful in obtaining and maintaining correction.

In the 19th century, plaster of Paris was applied as a circular jacket. "Immobilization in plaster was a tedious task for the doctor as well as the patient and the treatment was rarely continued long enough to obtain a permanent improvement. On removal of the cast, there was a substantial or complete loss of correction, for the patient could not be weaned gradually from the support." (personal communication from Dr. Blount).¹

The Milwaukee Brace was first described by Blount and Schmidt at a meeting of the American Academy of Orthopaedic Surgeons in 1946.² Although the principles of the brace remain unchanged, many improvements have been made in the original brace. The brace is constructed with the iliac crests accentuated and the waist constricted so that the pelvic girdle lies on top of the crests and does not press against the side of the pelvis. As you can note from Figure 2, vertical bars are attached from the girdle, one anteriorly and two posteriorly. These extend to the neck region and support the mandible and the occiput. These bars can be changed to exert a greater or lesser amount of pressure upon the mandible and occiput. As the curvature of the spine decreases, the length of the brace increases.

The Milwaukee Brace (Figure 2) is worn full time until curvature reaches its maximum correction and shows no tendency to regress when support is removed briefly. An adolescent must be kept in it constantly until skeletal growth is completed as measured by completion of development of the iliac crest apophysis (grown straight). The permanent correction which the Milwaukee Brace can effect in the growing child is due, in large measure, to the diminished pressure of the vertebral epiphyseal plates resulting in correction of a curve.

Figure 2. The Milwaukee Brace as developed by Blount.

**REVIEW OF THE LITERATURE**

In 1926, Howard wrote in the International Journal of Orthodontics, "In treatment of scoliosis, the orthopedist applies a plaster cast which extends from the hips to the mandible and occiput, and by a gradual increase in the length of the cast, a stretching of the torso is obtained."³ The two points offering the greatest resistance to the pressure applied would be expected to undergo changes in accord with the tangible principle of bone growth. The weight of the head augmented by muscle pull produces an almost constant upward pressure upon the lower border of the mandible. That a depression of the molars
and premolars, with a consistent derangement of the anterior teeth would occur, should not be a surprise to the orthodontist.”

Only three weeks of pressure from the cast produced marked infra-occlusion of the posterior teeth. Howard mentioned that his choice of treatment was a removable splint. The purpose was to maintain the relative position of the opposing teeth; however, it would not prevent a depression of the teeth nor a shortening of the lower third of the face.

In 1930, Stallard observed in the American journal of Orthodontics that extra oral pressure habits had profound effects upon the occlusion. Stallard demonstrated dental anomalies and malocclusion caused by pressure habits, such as arm, hand, forearm and shoulder pillowing, thumb sucking, chin propping and cheek resting, after careful observation for a period of over five years.

Kjellgren experimented with the influence of external pressure on occlusion. A ball of rubber seven centimeters in diameter, with walls thin enough not to offer any noteworthy resistance in themselves against the outside pressure, was used. It was connected to an open-end air mercury manometer to measure pressure. His results showed that various extra-oral pressures can result in deformation of the bony facial structures. Kjellgren showed lateral deformities of the maxilla with continuous application of pressures by the seven-centimeter rubber ball.

More recently, Bunch described orthodontic positioner treatment during orthopedic treatment of scoliosis (Figure 3). Bunch concluded that the rubber dental positioner appeared to play a valuable correlative role in orthopedic treatment of spinal scoliosis by maintaining or improving dental and craniofacial relationships and by preventing dental malocclusion during such orthopedic treatment. Others have commented on the effect of the Milwaukee brace on dentition and the use of a non-elastic occluso-palatal splint.

**CASE NUMBER 2, M.R.**

This patient was first seen on October 16, 1962, in the Department of Orthopaedics at which time a diagnosis of scoliosis was made. It was recommended that the patient be fitted with a Milwaukee Brace to be worn full time until completion of growth and then only at night from one to two more years.

The Milwaukee Brace was placed in December of 1962, at which time the patient was referred to our clinic for dental evaluation. A Hawley Retainer with a bite plate was inserted in March of 1963.

The Milwaukee Brace was worn full time for one year and then part time. In 1964, the brace was worn at night only; and, in 1965, the brace was again worn part time during the day. In November of 1966, the brace was stopped completely. During the period of our treatment, the interdigitations of the teeth remained quite good; however, there was a shifting of the midline, one-half tooth to the right. The facial esthetics remained excellent and the X-ray examination revealed the Tweed analysis to be basically unchanged with very little change in the Steiner analysis.

![Figure 8A. Frontal view of patient wearing Milwaukee Brace in February, 1963](image-url)

![Figure 8B. Lateral view, 1963](image-url)

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Orthodontic Considerations for The Patient Wearing a Milwaukee Brace

Figure 8C. Occlusion in February, 1963

Figure 8D. Frontal view in November, 1967, following removal of Milwaukee Brace and intraoral appliance

Figure 8F. Occlusion in November, 1967

Figure 8G. X-ray tracing, February, 1963

Figure 8E. Lateral view, 1967

Figure 8H. X-ray tracing, November, 1967
### Cephalometric Tracking Analysis

**Patient’s Name:** M. H.  Number 2

#### Steiner Analysis

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*Figure 81. Cephalometric tracing analysis*
CASE NUMBER 3, C.F.

This patient was first seen by the Department of Orthopaedics on the 23rd of October, 1964, at 12 years of age. The mother had noted curvature of the spine while fitting a dress for the child during the spring. When she was brought to Orthopedics, the diagnosis of scoliosis was made.

The Milwaukee Brace was recommended to be worn until completion of skeletal maturation and then at night for one to two years longer.

The Milwaukee Brace was fitted on the first of November, 1962. The patient was then referred to our office approximately seven to eight months later, and on the 31st of July, 1963, a Hawley Retainer with a bite plate was inserted. The patient had been wearing the Milwaukee Brace approximately eight months before the retainer was placed, and it appeared she might have some changes in her occlusion while wearing the Milwaukee Brace.

In the fall of 1964, the patient was instructed to wear the brace after school and at night only. In March of 1965, she was instructed to wear the brace only at night, and the brace was discontinued in October, 1965. She was at that time discharged with no return. The scoliosis was very mild.

The Hawley Retainer with a bite plate was removed when the patient stopped wearing the Milwaukee Brace. The occlusion remained within normal limits and was somewhat improved at the conclusion of treatment. This patient appeared to have some facial changes; however, we do not have photos at the start of her treatment with the Milwaukee Brace. X-ray examination revealed a slight change in the Tweed analysis, which means that there might have been a slight loss of vertical dimension. There were very minimal changes in the Steiner analysis. The improvement noted might have been due to improvement in the relationship of the upper to the lower incisors.

Figure 9, A through I – Omitted for Space Concerns

CASE NUMBER 4, S.K.

The mother first noted that this patient had problems at seven days of age. She could not rotate her neck at that time, and the problems increased as she began to walk. At age five, the patient had a spinal curvature of 18 degrees, this was in 1959. In June of 1960, when the patient was examined again, she had an increase of her spinal curvature of 36 degrees.

The patient was then put in a full-body cast and kept in one for about 14 months. The curve regressed with casting to 15 degrees and progressed again to 20 degrees when the cast was removed.

In September 1961, the patient was fitted with a Milwaukee Brace. She wore the Milwaukee Brace for 18 months prior to March of 1963, when she moved from Denver to Iowa City.

On the 8th of July, 1963, a maxillary Hawley Retainer with a bite plate was inserted. On the 30th of November, 1964, a tooth positioner was made and inserted.

As we can note from the photographs and X-rays of this patient, the body cast and the Milwaukee Brace had a considerable influence upon the growth and development of vertical dimension. The patient was either in a brace or a body cast for approximately three years without any treatment to maintain her vertical facial dimensions.

The mother stated that in watching this young patient most of the damage was done while she was wearing the body cast. She is now wearing a bite plate with a Hawley Retainer and will continue to wear this appliance as long as she wears the Milwaukee Brace. At present, she is also wearing a plastic positioner similar to the athletic mouth protector, part time.

We have been able to make some corrections for this patient; however, most of the facial damage occurred prior to the beginning of intra-oral treatment, and I do not feel we can overcome growth problems which develop at six or seven years of age.

On examining the X-rays, we do find that there have been some continued undesirable changes in the Tweed analysis; however, in observing the Steiner analysis, we find that there were basically no undesirable changes between 1963 and 1967. There was some slight uprighting of the maxillary anterior segment and some tripping of the mandibular anterior segment.

Figures 10A through L - Omitted for Space Concerns

CASE NUMBER 5, J.C.

It was first discovered that this patient had scoliosis when he was three years of age. He was seen by the Department of orthopedics and fitted with a Milwaukee Brace at six-and-one-half years of age, which was in January of 1959. In November of 1967, when he was 15, the patient had been wearing the Milwaukee Brace for approximately eight years.

We inserted a Hawley Retainer with a bite plate on February 12, 1962, which was approximately three years after the Milwaukee Brace treatment was started. New bite plates were inserted in July 1963 and in April 1964. There was some damage to the vertical growth prior to the insertion of the Hawley Retainer; however, since that time, photographs and X-rays do not reeal undesirable changes. The occlusion in this boy presented some problems at the start of treatment; and, because of lack of space in the maxillary arch, the first premolars were extracted on the 10th of January, 1962. The reason for the extraction was that the space of the maxillary canines was occupied by the first premolars. Today, the molar
relationship is Class II; however, there has been some improvement in the occlusion as well as facial esthetics. Some minor orthodontic adjustments may be necessary when he patient discontinues wearing the Milwaukee Brace. The examination of the X-rays revealed no undesirable changes in the Tweed Analysis and basically no change in the Steiner analysis from 1961 to 1967. The maxillary and mandibular anterior segments were retracted and uprighted, associated with an opening of the bite.

Figures 11A through I - Omitted for Space Concerns

CASE NUMBER 6, L.W.

This patient was seen for the first time in the Department of Orthopaedics at 10 years of age for curvature of the spine. The diagnosis at that time was idiopathic scoliosis. On the 23rd of January, 1963, a Milwaukee Brace was fitted and a maxillary Hawley Retainer with a bite plate was inserted on the same date.

The patient wore the Milwaukee Brace full time. She was seen periodically for examination of the maxillofacial development and on the 6th of April, 1967, a new Hawley Retainer with a bite plate was inserted.

On June 8, 1967, approximately four years after the Milwaukee Brace was fitted, cephalometric X-rays and photographs showed the occlusion to be quite good, as well as facial esthetics.

During the summer of 1967, the patient was instructed to do a lot of swimming and to be out of the Milwaukee Brace for four hours a day. We will continue to observe this patient and she will wear the Hawley Retainer with a bite plate until the Milwaukee Brace is discontinued. X-ray examination showed some changes in her Tweed analysis, indicating a slight loss of vertical dimension; however, the Steiner analysis does not reflect any serious changes. A slight change in the occlusal plane was noted. This was associated with the uprighting of the mandibular segment and some tipping of the maxillary anterior segment.

Figure 12A through I - Omitted for Space Concerns

CASE NUMBER 7, B.R.

On September 9, 1964, this patient was fitted with a Milwaukee Brace after a diagnosis of Marfan's syndrome with progressive scoliosis. A tooth positioner was inserted on the 3rd of December, 1974, or approximately three months after the Milwaukee Brace was fitted. The patient wore the brace full time until November, 1965, at which time she started to wear it at night only. In July, 1966, it was recommended that she wear the brace three more months, and then discontinue it for three months. Since that time, September, 1966, she has not worn the brace.

The maxillary left lateral incisor was extracted in February of 1966, because of lack of space and severe malposition. As can be seen by her photographs, the occlusion is good and there is no apparent change in the vertical dimension of her face. With the tooth positioner, we were able to reduce the space in the area of the maxillary left lateral which was removed. The canine is now in contact with the central incisor. Examination of the X-rays revealed very little basic change in the Tweed analysis and no undesirable change in the Steiner analysis.

Figure 13A through I - Omitted for Space Concerns

CASE NUMBER 8, M.K.

This patient was first seen in the Department of Orthopedics at the University Hospitals in June of 1964, at the age of 14. At that time, a diagnosis of scoliosis was made. A Milwaukee Brace was placed in October of 1964.

The patient was referred to our office and on the first of February, 1965, a tooth positioner was inserted to maintain vertical dimension and to accomplish some minor tooth movements. The minor tooth movements were accomplished and the tooth positioner was discontinued.

A Hawley Retainer with a bite plate was then inserted. The patient started wearing the Milwaukee Brace at night only in June of 1966. The Milwaukee Brace was discontinued completely in February of 1967, after two-and-one-half years.

Cephalometric X-ray readings revealed a slight amount of bite opening with no undesirable facial changes in either the Steiner or Tweed analysis. As we can see from the photographs, the facial esthetics were excellent and the occlusion was within normal limits in November of 1967.

Figure 14 A through I - Omitted for Space Concerns

CASE NUMBER 9, K.S.

On the 27th of April, 1965, this patient was first seen in the Department of Orthopedics, at which time a diagnosis of idiopathic thoracic scoliosis was made.

On June 1, 1965, a Milwaukee Brace was fitted. This was to be worn full time. In June of 1966, the Hawley Retainer with a bite plate was inserted.

There have been no undesirable changes in Kathy's occlusion or facial dimension; however, some improvements of the occlusion were observed since the insertion of the retainer. The patient will continue to wear the appliance until the Milwaukee Brace is discontinued. She will start wearing the brace at night only in January of 1968. Examination of the X-rays reveals no undesirable changes in either the Tweed or Steiner analysis. The lower anterior teeth appeared to have come forward, which improved the occlusion.

Figures 15 A through H - Omitted for Space Concerns
DISCUSSION

After treating patients wearing the Milwaukee Brace for approximately eight years, and after closely examining the dental casts, photographs and cephalometric X-rays, we have concluded that the Milwaukee Brace will have severe detrimental effect on the growth and development of the facial structures.

The following undesirable effects have been observed in patients wearing a Milwaukee Brace with no intra-oral treatment: 1. protrusion of the anterior teeth, especially in the maxillary arch; 2. intrusion of the posterior teeth; 3. A loss of facial height associated with inhibition of maxillary and mandibular growth.

Our study, along with the others mentioned, has shown that intra-oral appliances will aid in preventing these severe facial deformities. We have shown that some patients, especially older ones, had little or no significant changes in their facial development and that the occlusion was normal at the conclusion of our intra-oral treatment.

An important factor to be mentioned is that orthodontic treatment can be accomplished while the patient is wearing a Milwaukee Brace if necessary. It is our opinion that any of the mentioned intra-oral appliances will aid in maintaining facial height and in the prevention of progression of the anterior teeth. However, we feel that the maxillary Hawley Retainer with a bite plate is the simplest appliance that can be worn and be successful in treatment. It may be desirable in some instances to use a combination of the Hawley Retainer and one of the positioner types of appliances.

As one can observe from the nine cases we have presented, the results were mostly very favorable.

BIBLIOGRAPHY

THE PONSETI METHOD IN LATIN AMERICA: INITIAL IMPACT AND BARRIERS TO ITS DIFFUSION AND IMPLEMENTATION

Allison Boardman, BA; Asitha Jayawardena, BS; Florin Oprescu, MD; Thomas Cook, MD; and Jose A. Morcuende, MD, PhD

ABSTRACT

The Ponseti method for correcting clubfoot is a safe, effective, and minimally invasive treatment that has recently been implemented in Latin America. This study evaluates the initial impact and unique barriers to the diffusion of the Ponseti method throughout this region. Structured interviews were conducted with 30 physicians practicing the Ponseti method in three socioeconomically diverse countries: Chile, Peru and Guatemala. Since learning the Ponseti method, these physicians have treated approximately 1,740 clubfoot patients, with an estimated 1,705 (98%) patients treated using the Ponseti method, and 35 (2%) patients treated using surgical techniques. The barriers were classified into the following themes: physician education, health care system of the country, culture and beliefs of patients, physical distance and transport, financial barriers for patients, and parental compliance with the method. The results yielded several common barriers throughout Latin America including lack of physician education, physical distance to the treatment centers, and financial barriers for patients. Information from this study can be used to inform, and to implement and evaluate specific strategies to improve the diffusion of the Ponseti method for treating clubfoot throughout Latin America.

INTRODUCTION

Clubfoot, the most common musculoskeletal birth defect, is a deformity that results in complete inward-turning of the foot. Clubfoot can be idiopathic or occur in conjunction with other disorders, such as myelomeningocele or arthrogryposis. It is estimated that the incidence for congenital clubfoot worldwide is about 1.6-1.8/1000 live births.1

The traditional treatment for clubfoot has been casting shortly after birth, followed by surgical intervention, usually a posteromedial soft-tissue release. Surgical procedures are expensive, and in developing countries the cost of surgery can be prohibitive. Untreated clubfoot is both a physical and social deformity, as babies with this defect are often abandoned, and older individuals are often ostracized from their communities.

The Ponseti method for correcting clubfoot was created in the 1940’s by Dr. Ignacio Ponseti, and has started to become the gold standard around the world for treating this deformity.2 The Ponseti method uses a combination of manipulations and casting to correct the deformity, requiring a minimal, office-based procedure – an Achilles tenotomy. After the casting period, the child wears a foot abduction brace until the age of four to prevent relapse.3 The Ponseti method has been shown to achieve complete correction in as little as 16 days in >95% of patients. Additional surgical release is required in as few as 1% of patients.4,5

Within the last 10 years, the Ponseti method has been diffused throughout Latin America and has begun to be implemented there. Latin America contains a diverse group of countries and has a population estimated at 577 million people. This study looked at three socioeconomically diverse countries in the region: Chile (population 16.6 million; GDP per capita of $16,600); Peru (population of 29.5 million; GDP per capita of $8,500) and Guatemala (population of 13.3 million; GDP per capita of $5,100) to identify the challenges faced in the diffusion and implementation of the Ponseti method.6 By identifying those barriers, specific strategies can be employed to improve the diffusion of the method throughout these and other countries in this region. Furthermore, awareness of countries’ knowledge about and attitudes toward the Ponseti method will allow evidence-based and culturally appropriate strategies to be developed, evaluated and implemented.

MATERIALS AND METHODS

Face-to-face semi-structured interviews were conducted in Spanish with physicians practicing the Ponseti
method in Chile, Peru and Guatemala. These providers were chosen both from lists of those attending Ponseti training workshops and from referrals made to Ponseti providers in each country. Thirty physicians were interviewed, 22 of whom had attended Ponseti training workshops and six of whom trained on their own. Two of the physicians interviewed were practicing a modified version of the Ponseti method, and were not included in this study. These 28 interviewed physicians were the final group for this study. In addition, observations of health care practices in both hospital and clinical settings were recorded, providing an in-depth look at the health care system of each country and the initial impact of and barriers to diffusion of the Ponseti method.

Interviews were conducted by a medical student fluent in both Spanish and English. Responses were collected in Spanish over a period of ten weeks, and the results were translated into English and sorted into themes. Participant's names were removed from the data and the data was stored in a secure location. Informed consent was obtained by having participants review a consent letter. The study methodology was approved by the University of Iowa Institutional Review Board.

RESULTS

Ponseti workshops were first held in Santiago, Chile in 2005; in Lima, Peru in 2007; and in Guatemala City, Guatemala in 2009. Courses consisted of a two-day workshop with lectures and hands-on practice on models and patients, and case presentations with discussion. Today, it is estimated that Ponseti training has educated 23 physicians in Chile, 75 physicians in Peru, and 25 physicians in Guatemala. The majority of participants in Chile work in Santiago, but one physician has been trained per region (totaling 10 regions). In Guatemala, participants came from several regions, but in Peru all were concentrated in Lima.

Twenty-eight physicians from the three countries were interviewed, including nine in Chile, 11 in Peru and eight in Guatemala. In Chile, all nine physicians interviewed were practicing in Santiago. In Peru, all 11 physicians interviewed were practicing in Lima. In Guatemala, six physicians were interviewed in Guatemala City and two in Quetzaltenango. Since implementation of the Ponseti method in these countries, the majority of physicians responded that after their training they treated patients with the Ponseti method, whereas prior to that they performed surgery. There were, however, a few physicians who still did some surgery for complicated cases. They had treated approximately 1,740 clubfoot patients since learning the Ponseti method. More importantly, of these patients, an estimated 1,705 (98%) were treated using the Ponseti method, and 35 (2%) were treated using surgical techniques, most often a posteromedial soft-tissue release.

Physicians were asked to identify which of the following themes were barriers to the diffusion and implementation of the Ponseti method in their country: Physician education, the health care system of the country, the culture and beliefs of patients, physical distance and transport, patient financial barriers and/or parental compliance with the method.

Physician education
Nine of nine physicians in Chile, nine of 11 physicians in Peru and five of eight physicians in Guatemala identified physician education as a barrier to the diffusion and implementation of the Ponseti method. In Chile and Peru, for example, the Ponseti method is not currently being taught as a method of treating clubfoot in medical schools and residency programs. In order to attend a Ponseti training session, physicians must take time off of work and pay a nominal fee (approximately $100 US) to attend; therefore, there is little financial incentive for physicians to learn the Ponseti method. Additionally, some physicians that have attended training sessions may see only a few clubfoot patients each year. They may have enough training, but lack an adequate volume of patients to sustain their experience and successfully treat patients using the Ponseti method. Six of the physicians interviewed had not attended formal training sessions, but had learned the method from other physicians or over the Internet. Several physicians interviewed expressed distrust in those who had not been formally trained in the Ponseti method because they have seen unsatisfactory results mostly due to modification of the techniques and protocols.

Implementation of the Ponseti method is relatively new in Guatemala, as the first training course took place in 2009. Some of the physicians there cited a widespread lack of knowledge about and trust in the Ponseti method, as well as a lack of incentives for continuing education, as their primary reasons for physicians not receiving Ponseti training in Guatemala.

Health care system of the country
Eight of nine physicians in Chile, nine of 11 physicians in Peru and six of eight physicians in Guatemala cited their nation’s health care system as a barrier to the Ponseti method. In each country, the Ministry of Health has not yet accepted the Ponseti method as a treatment for clubfoot. In Chile, this means that there has been little publicity about the benefits of the method. In Peru, several physicians explained that though many people have some form of insurance, some insurance companies will
not pay for treatments related to congenital problems. Private hospitals may cover all treatment costs, while in public hospitals the patient assumes the entire cost of treatment. Several physicians also described a deficit of knowledge or providers of the Ponseti method outside of Lima. In Guatemala, there is little knowledge of the benefits of the method, though CURE International, a non-governmental organization, is currently leading a widespread publicity campaign. In the public sector of the health care system in Guatemala, several physicians identified the poor quality of available casting materials as a barrier. The poor quality of materials makes the casts more uncomfortable for the children and also means the treatment is more difficult for physicians to perform. Many Guatemalans are uninsured, therefore all treatment costs would be paid out of pocket.

Culture and beliefs of patients

Zero of nine physicians in Chile, three of 11 physicians in Peru and seven of eight physicians in Guatemala described the culture and beliefs of patients as being a barrier to the Ponseti method. In Chile, some parents initially reject using the abduction brace because of the social stigma they associate with children in orthotics braces. However, this does not appear to be a long-term issue with compliance with or acceptance of the method. Several physicians in Chile have structured appointments so that all their clubfoot patients are treated on the same days of the week. This provides an opportunity for parents and children undergoing the different stages of the Ponseti method to interact with one another, and has made a positive difference in compliance and the attitudes of the parents. Parents not only hold one another accountable for consistent use of the brace, but parents of children in the casting phase of treatment can see the corrected feet of children in the later bracing phase, giving them hope that that the Ponseti method will fix their child's feet.

In Peru as in Chile, some parents initially rejected the use of the abduction brace because of the social stigma. However, most parents tended to comply after the physician explained that the brace was required to prevent regression of the clubfoot.

In Guatemala, one of the largest cultural barriers that the Ponseti method faces is the language barrier. Besides Spanish, there are many different dialects and languages spoken throughout Guatemala, especially in the indigenous populations. With few translators available, it is difficult for physicians and patients to communicate effectively with one another. Several of the physicians interviewed stated that it was especially difficult to explain the bracing schedule to parents, and that this is one of the major barriers they face when using the Ponseti method. Another social issue in Guatemala is that of child abandonment. Many children in rural Guatemala are born in family homes with midwives or other relatives present, and children born with birth defects are often abandoned shortly after birth. This may be due to a number of factors, including lack of midwife education about clubfoot treatments and the social stigma surrounding people with disabilities. If parents have no knowledge of available clubfoot treatment methods, they may not want to raise a child with a disability who may be ostracized from their community and unable to work later in life.

Physical distance and transport

Four of nine physicians in Chile, nine of 11 physicians in Peru, and eight of eight physicians in Guatemala identified physical distance and transport as a barrier to the Ponseti method. In all three countries, the frequency of appointments the patient is required to attend (during the casting portion of Ponseti treatment) pose a significant barrier for implementation. In all three countries, the majority of Ponseti physicians are located in the capital cities. For families living outside of the capital city, this means they must travel a great distance each week for their child to receive treatment. This creates many issues for parents; many of them have to request time off work in order to make the journey into the city, or find alternate childcare for their other children remaining at home. Many families are reliant on public transportation, which may not be reliable. In Peru, for example, the Andes Mountains, which traverse the majority of the country, make it very difficult and time consuming for people to reach Lima, where the only Ponseti physicians are located. Some families elect to stay in the capital city for the entirety of the casting portion of the Ponseti treatment. However, this option, while convenient, is not financially feasible for many patients. Physicians in all three countries identified physical distance and transport as a major reason for patients abandoning the treatment regimen, or choosing surgical procedures, which require only one physician visit.

Financial barriers for patients

Nine of nine physicians in Chile, seven of 11 physicians in Peru and seven of eight physicians in Guatemala described finances as being a barrier to the Ponseti method. In all three countries, cost of the treatment can have a large impact on initiation of treatment and compliance. The most expensive portion of the treatment, universally, is the bracing portion. As a child grows, they will need approximately four abduction braces to complete the treatment course. Physicians in all three
countries stressed that the cost of the braces is the biggest factor in patient non-compliance to the treatment, as many families cannot afford to keep buying braces through the duration of the treatment.

In Chile, the costs of treatment depend on the patient’s insurance and whether or not they are receiving care in the public or private system. One physician estimated the total cost of treatment, including transportation and several abduction braces, to be approximately $1,000 US. Another physician has started a program of collecting and reusing shoes to defray treatment costs. Parents donate the shoes used on the abduction brace when their child has outgrown them, and the shoes are attached to a new bar to be used by another child. This program allows patients to complete their treatment using the Ponseti method without their parents assuming the entire cost of several new braces, each estimated to cost about $120 US.

In Peru, there is currently only one orthotics company producing the abduction braces, and each costs around $200 US. As previously discussed, some insurance companies will pay for treatment costs, while others will not because clubfoot is a congenital birth problem. No insurance company will pay for the cost of the braces, so families must assume those costs on their own.

In Guatemala, there is no cost for the casting portion of the treatment, but families must pay out of pocket for the abduction braces, each of which costs about $90 US. Families must also pay out of pocket for the transportation costs of getting to the treatment facility.

Parental compliance to the Ponseti method

Three of nine physicians in Chile, six of 11 physicians in Peru, and three of eight physicians in Guatemala identified parental compliance as a barrier to the Ponseti method. In all three countries, many of the physicians stated that once a child is in the bracing portion of the treatment, and parents see a corrected foot, they think the child is “cured,” and discontinue bracing before the child has completed treatment. Parents may also stop coming to the treatment center because they cannot afford the braces or the transportation costs. Both of these lead to regression of the clubfoot in the majority of cases. In Peru, two physicians estimated that 10% of parents abandon the treatment program after they see the corrected foot.

DISCUSSION

Latin America, with a population of 577 million people and an estimated 15,400 children born each year with clubfoot, represents a world region in which the development of effective clubfoot treatment programs has the potential for a vast impact on the lives of many children and families. Each of the 20 countries that make up Latin America is unique; however, they share a common cultural heritage and values. Therefore, evaluation of the three countries chosen in this study was considered to be representative for the region and could provide information on the impact of and barriers to the diffusion and implementation of the Ponseti method.

Interestingly, when one considers the Ponseti method as an innovation in health care, the framework for how innovation disseminates could be applied and lessons learned in other fields could be used to improve it. In “Diffusion of Innovations,” EM Rogers discusses three basic clusters of influence that correlate with the rapid spread of a change: Perceptions of the innovation, characteristics of the people who adopt the innovation or fail to do so, and contextual factors. When considering successful diffusion and implementation of the Ponseti method, these concepts can be applied to the data collected in this study as well as others done previously in China, Uganda, Malawi, and rural areas of the United States.

The first influence on the rapid spread of change by an innovation is the perception of the innovation itself. Rogers discusses the perceived benefit of the change—people are more likely to adopt an innovation if they think it will help them. In Latin America as a whole, there is a widespread lack of knowledge about the Ponseti method. As the first training sessions took place just a few years ago, many physicians and patients have not heard of the benefits of the Ponseti method. In rural areas, many families may not even know that there is a treatment for clubfoot. These results are comparable to those initially found in both Uganda and Malawi, however, national clubfoot treatment programs have been initiated in each of these countries. In Uganda and Malawi, hundreds of healthcare workers, including orthopaedic officers, and midwife and immunization teams have been trained in the early detection and referral of patients. This has resulted in increased access to care for hundreds of children born with clubfoot in these countries, but the treatment is concentrated in specialized clinics where clinical experience and materials are more available.

The second influence on the rapid spread of change of an innovation is the characteristics of the individuals who adopt the innovation or fail to do so. Rogers classifies several groups of people based on how they adopt an innovation: the “innovators,” first to adopt a new innovation, followed by “early adopters,” “early majority,” “late majority,” and last, the “laggards.” Typically, “innovators” and “early adopters” are often leaders within their hospitals or communities—in Latin America, these are the physicians who heard about the Ponseti method over
the Internet or at a conference and sought out a training session. The “early majority” of the physicians are those who have heard about or learned the method from the “innovators” and “early adopters.” These three groups of people represent the physicians interviewed for this study. These are the physicians who took the incentive to learn about the Ponseti method on their own. The other two groups of physicians, the “late majority” and “laggards,” will likely not adopt the Ponseti method until it is being taught at a national level in medical schools and residency programs. Because there are many physicians who have not yet heard of the Ponseti method, and because there are still countries where no training sessions have even been held, it is necessary to increase the number of Ponseti training sessions available in Latin America. But most importantly, these courses should be targeted first to those individuals that are very interested and willing to practice the method rather than as a mass teaching program. Unless the courses build capacity for successful treatment, there is a high risk for deterioration of the results over time. A potential mechanism to help resolve this issue is the use of virtual videoconferencing for continual medical education. This mechanism would enable a Ponseti physician to discuss and present cases to any other physician in Latin America, even those using a low-bandwidth (dial-up) internet connection. Potentially, physicians in cities and rural areas could be trained in the Ponseti method, decreasing the transportation barriers that many patients and families face. The feasibility and impact of training physicians using Elminate Live! is currently being studied.

The third influence on the rapid spread of change of an innovation is represented by the contextual factors surrounding the innovation. Things such as poverty and communication within the social system of these countries may improve or impede the spread of the innovation. In the countries where the Ponseti method has been evaluated, many patients face financial hardship, and the frequency of required physician visits during the casting phase of the treatment, combined with the out-of-pocket costs of the braces, can result in discontinuation or decreased use of the method. Though China and Latin America have different health care systems and insurance standards, the cost of transport and the abduction braces seems to be the most financially constraining factors for parents.

Communication between physicians and parents of children undergoing Ponseti treatment has also been shown to be a barrier to the diffusion of the method. In countries in Latin America and even in the rural United States (where different languages and dialects are spoken) it can be difficult for parents to understand the bracing schedule for their child. Lack of understanding of the bracing protocol can lead to early termination of bracing and regression of the corrected feet.

The Ponseti program in Latin America can benefit greatly from the findings of the programs in China, Uganda, Malawi, and the rural United States. In order to increase the diffusion of the Ponseti method throughout this region, the Ponseti method must achieve national recognition in each country, as has been done in Uganda and Malawi. This would involve gaining approval from the Ministry of Health, training large numbers of healthcare providers throughout the countries, and integrating the Ponseti method into the medical school and residency program curricula. Increasing the number of Ponseti providers by implementing more training opportunities would also ensure that rural providers would have the chance to be trained, possibly decreasing the transportation barriers for patients living in rural areas. As previously discussed, these programs should first be targeted toward individuals who are very interested in and willing to practice the method. Additionally, nationwide publicity campaigns to educate the public that clubfoot is treatable without surgery, mirroring current campaigns by the Sustainable Clubfoot Program in Uganda and CURE International in Guatemala, would be of great assistance.

Finally, studies in Uganda have shown that an effective, low cost brace can be produced for as little as $10 US. By streamlining a brace production program in Latin America (in each country or centrally), effective and low-cost braces could be produced, eliminating the financial burden that the current bracing system places on families. Also, to facilitate increased communication between physicians and parents, informational pamphlets with photos and directions - translated into as many native dialects as possible - could be distributed. This would give families something tangible to take home when questions arise about treatment protocol. Increasing parental understanding of the method could go a long way toward reducing the rates of regression of corrected clubfoot.

**CONCLUSION**

This study identified several potential barriers to the diffusion and implementation of the Ponseti method in Latin America. Three diverse countries were studied, but many of the barriers faced by the Ponseti method were common regardless of socioeconomic differences. Overcoming these educational, social, and financial barriers will allow the continued diffusion of the Ponseti method throughout Latin America, resulting in better access and patient care.
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DIFFUSION OF INNOVATION: ENHANCING THE DISSEMINATION OF THE PONSETI METHOD IN LATIN AMERICA THROUGH VIRTUAL FORUMS

Asitha Jayawardena, BA, Allison Boardman, BA, Thomas Cook, PhD, Florin Oprescu, PhD, and Jose A. Morcuende, MD, PhD

ABSTRACT

This ethnographic study evaluated the use of low-bandwidth web-conferencing to enhance diffusion of a specific best practice, the Ponseti method to treat clubfoot, in three economically diverse countries in Latin America. A “Ponseti Virtual Forum” (PVF) was organized in Guatemala, Peru and Chile to examine the influences of economic level and telecommunication infrastructure on the effectiveness of this approach.

Across the three countries, a total of 14 different sites participated in the PVFs. Thirty-three Ponseti-trained practitioners were interviewed before and after each PVF, which included interactions with a Spanish-speaking Ponseti method expert. Semi-structured interviews, observations, and IP address data were triangulated and analyzed. The results demonstrated that 100% of the practitioners rated the sessions as very useful and that they would use this approach again. The largest obstacles to using PVFs were financial (7 out of 9 practitioners) in Guatemala; a lack of equipment and network access (6 out of 11) in Peru; and the organization and implementation of the conferences themselves (7 out of 9) in Chile. This study illustrates the usefulness of Ponseti Virtual Forums in Latin America. Health officials in Peru are currently developing a large-scale information session for traumatologists about the Ponseti method, while practitioners in Guatemala and Chile are organizing monthly scholarly meetings for physicians in remote areas. This initial feedback suggests that low-bandwidth web-conferencing can be an important vehicle for the dissemination of best practices, such as the Ponseti method, in developing countries.

INTRODUCTION

Congenital idiopathic clubfoot occurs worldwide in up to 1.8 per 1000 children, making it the most common congenital musculoskeletal birth defect. Clubfoot is characterized by plantar flexion of the foot at the ankle joint (equinus), inversion deformity of the heel (varus), and medial deviation of the forefoot (adductus) with increased foot arch (cavus).1,2 It can occur in an otherwise normal child (idiopathic) or as a part of a syndrome.3 It occurs twice as often in males than females and up to 50% of all cases are bilateral4.

Traditionally, clubfoot has been treated with surgical interventions that are very expensive and highly technically demanding. In addition, this type of operation has many disadvantages including up to a 50% complication rate and, when complications do occur they are very difficult to treat.5 In developing countries, where resources and health care professionals are very limited, surgery is not always a feasible option. This is one of the factors leading to many children not receiving treatment. Globally, neglected clubfoot is the most common cause of physical disability among musculoskeletal birth defects.5

Importantly, a method of clubfoot treatment developed by Dr. Ignacio Ponseti at the University of Iowa in 1963 has demonstrated tremendous success in correcting this deformity in many countries.6 This simple, effective, quick, and economical method is based on very specific manipulation and casting techniques, and requires a minor procedure, a percutaneous Achilles tenotomy, which can be performed under local anesthesia in the office.5,7 A foot abduction brace is worn at night for a few years to prevent relapses.8 The Ponseti method allows complete clubfoot correction in over 95% of patients in as few as 16 days.6,8,9

To date, education programs have been successfully implemented in more than 50 nations.5,7 However, despite these efforts, there are still barriers to the dissemination of this innovation in developing countries.10 When
the current diffusion of the Ponseti method is analyzed using Everett Rogers’ “Diffusion of Innovation” model, it can be concluded that the progress made so far is due to “early adopters” and some “early majority” that have accepted the method. This progress mirrors growth in the United States prior to the development of Internet-based support groups of parents sharing their children’s successes being treated with the Ponseti method. This Internet-based sharing led to information exchange and worldwide growth of interest in the Ponseti method. However, as the demand from parents to treat their children with the Ponseti method increased, the need for well-trained Ponseti practitioners also increased. While many practitioners have been formally trained by the Ponseti International Association, many are practicing the method with limited training. The use of the Ponseti method by those who are untrained, or have limited training, may result in sub-optimal results that counteract the positive patient interest generated by the Internet-based support groups. Poor treatment from untrained practitioners can disseminate through the same Internet based support groups and reduce patient confidence and demand for the method. Maintaining well-trained, high profile early adopters/practitioners of the Ponseti method is a key step in maintaining successful diffusion of this important “best practice.”

The success of the Internet in spreading the Ponseti method to parents of children with idiopathic clubfoot suggests that it may also be a means to enhance practitioner knowledge of the Ponseti method, helping maintain optimal results, and therefore fueling patient demand for the method. Collaboration between the Global Health Campus of the University of Iowa College of Public Health and the Ponseti International Association has led to the creation of Ponseti Virtual Forums (PVFs): a web-conference-based electronic collaborative workshop for Ponseti practitioners to exchange information about difficult cases, patient follow-up, public health measures, and any other pertinent information.

_Elluminate Live!_ is a low-bandwidth videoconferencing software program which is relatively easy to use, allows text chat, can display multimedia, and supports live video streaming on a low-bandwidth Internet connection. It can serve as the ideal catalyst for high-yield information diffusion. The Global Health Campus network through the University of Iowa College of Public Health utilizes this software to deliver health information to more than 600 Internet sites in over 60 countries. PVFs between the Ponseti International Association Providers and practitioners in developing countries—both novice and intermediate—should foster a teaching environment to include different levels of practitioner experience. Eventually, PVFs have the potential to create a self-sustainable regional network for collaborative reinforcement of the Ponseti method. The development of this network of well-trained Ponseti practitioners is imperative for the advancement of the Ponseti method in developing countries.

This study analyzes the introduction of Ponseti Virtual Forums in Latin America to support the diffusion of the Ponseti method. Three specific countries were chosen to understand the effect of gross domestic product (GDP) and telecommunication infrastructure. A GDP analysis from the CIA World Factbook suggested that Guatemala ($5,300 per capita), Peru ($8,500 per capita) and Chile ($14,900 per capita) would provide a reasonable spectrum of economic development in Latin America. The telecommunications infrastructure, measured through percentage of the population with access to the Internet reflects GDP: Guatemala with 14.76%, Peru 24.12% and Chile 32.86%.

**MATERIALS AND METHODS**

Semi-structured interviews, observation, and IP address data were compared in an ethnographic study in Guatemala, Peru and Chile. Ponseti-trained practitioners were contacted through email prior to observation and interview. Interviews were conducted at each practitioner’s respective clinical facility. This study was previously approved by the University of Iowa Institutional Review Board. Informed consent was obtained by having interviewees review a consent sheet prior to the interview. No names were attached to the data and the data was kept in a secure location.

Each practitioner was first briefly introduced to the web-conferencing program (Elluminate Live!) and asked to complete an interview regarding the potential of the program. A virtual conference with a Spanish-speaking expert in the Ponseti method was then scheduled in each country using the web-conferencing system. After this web-conference, practitioners were asked to complete a questionnaire about the effectiveness of their experience.

The interviews were conducted in Spanish by one of the authors (AJ). The interview data was then coded manually and sorted into themes. The validity of the data was confirmed via triangulation using a combination of on-site observations and IP address data, which was compiled on the University of Iowa Global Health Campus network. A team approach was used to draw conclusions about the collected data.

Observation of the telecommunication infrastructure of each facility, interactions with families of clubfoot patients, and observation of individual physicians treatment of clubfoot took place in the following hospitals in Guatemala: IGGS (semi-private, Guatemala City); San Juan de Dios (public, Guatemala City); Clinica Privada
RESULTS

Thirty-three total practitioners were interviewed. This number included 9 from Guatemala, 11 from Peru, and 9 from Chile who responded to the pre-PVF survey. Four practitioners from Guatemala, 1 from Peru, and 8 from Chile responded to the post-PVF questionnaire. Some practitioners responded to both the pre- and post-surveys while some only responded to the pre-surveys. One hundred percent of those interviewed (33 of 33) stated that they would like to continue use of the web-conferencing approach and that training sessions with a Spanish-speaking expert in the Ponseti method would be very useful for their practice. The most common reasons cited for the continued use of PVFs in the future were: to share successes and failures with other Ponseti-practicing physicians; to discuss complicated cases; and to improve personal technique by communicating directly with Ponseti experts.

GUATEMALA

Success

In Guatemala, practitioners gave PVFs an average satisfaction rate of 4.75 out of a possible 5, the highest of any country introduced to PVFs (Figure 2). One intra-country session was conducted between Guatemala City, the capital and Quetzaltenango, a city in the highlands. Another session was successfully completed between the University of Iowa Orthopaedics Department and Guatemala City. Remarkably, these sessions were completed using a borrowed computer and a 56k mobile-broadband card paid for by a Guatemalan practitioner. Practitioners were very impressed with the amount of media exchange they were able to achieve using a simple portable cell-phone modem.

Barriers

Predictably, the largest barrier cited in Guatemala was financial (7 of 9 practitioners). This was despite the fact that each practitioner knew they would not have to pay for the web-conferencing service. The majority of doctors don’t own personal computers and the computer services at hospitals are limited and outdated. Six of 9 practitioners cited computer access as a barrier to using PVFs. Six of 9 also stated that the actual implementation of the forums was a barrier. Convincing hospitals to allocate time and space for events such as this may be a challenge and was addressed by at least one physician. Finally, in addition to the financial barriers faced by Guatemalan doctors, 4 of 9 cited network access as a barrier to using PVFs. In Guatemala, the percentage of average monthly GDP per capita spent on the Internet is 21.4% (Figure 1). This statistic is particularly alarming when compared to the typical United States average monthly GDP per capita spent on the Internet of 0.5%. The majority of practitioners cannot afford regular Internet service, and most access it through Internet cafes.

Future Use

Practitioners were asked how they would consider using the web-conferencing system in the future. Nine of 9 indicated they would use a PVF to consult on cases with their fellow colleagues in other parts of the country. Seven of 9 wished to use PVFs to learn and master the technique of the Ponseti method. Seven of 9 thought PVFs would be useful to share experiences, including successes and failures, so others practicing the method would not make similar mistakes. Five of 9 thought that the use of PVFs would specifically increase the acceptance of the Ponseti method in Guatemala. Three of 9 mentioned that they would like to use PVFs to help document the use of the technique in the country of Guatemala.
Success

One successful PVF was held between Peru and the University of Iowa Department of Orthopaedics. Due to a miscommunication at the University of Iowa, the first PVF was cancelled. Only one practitioner was able to attend the second PVF due to it being rescheduled. However, this practitioner gave it a 4.25 satisfaction rating out of 5 (Figure 2).

Barriers

The largest obstacle encountered in Peru was equipment and network access (6 of 11). Similarly to Guatemala, computer access is limited within hospitals and wireless connections are only available in private hospitals. Five of 11 practitioners cited finances as an obstacle. The percentage of average monthly GDP per capita spent on the Internet is 19.2%, not much less than Guatemala (Figure 1). Doctors mentioned that they face a dilemma: they need to be seeing the overwhelming amount of patients that are at their offices and don’t have the time to attend a training session for the Ponseti method, despite understanding that some training could occur through a PVF. The infrastructure of Peru is much more developed than in Guatemala; however the number of Ponseti practitioners is limited. Not a single practitioner knew of other Ponseti-trained practitioners outside of the capital city of Lima.

Future Use

Eleven of 11 Peruvian physicians wished to use PVFs to perfect their technique in the Ponseti method. Nine of 11 wished to use the method to learn more about the method. Seven of 11 wished to use it to consult with other physicians about specific cases. Seven of 11 also wished to use PVFs to share experiences regarding patients. Finally, 5 of 11 specifically stated that the use of PVFs will be important in spreading the Ponseti method throughout the country.

Chile

Success

The first intra-country conference between Santiago, Chile and Antofogasta, Chile, a city in the north, failed because of an unexpected surge of orthopaedics patients in Antofogasta during the scheduled PVF. However, the most successful PVF took place soon after between Chile and the University of Iowa Orthopaedics Department. This PVF included 18 different computer connections among 7 different hospitals in 5 different cities within Chile. The participants included both orthopaedic surgeons and their residents. The satisfaction of this PVF was 3.52 out of 5 (Figure 3).

Barriers

The largest obstacles to using PVFs in Chile were the implementation of the PVFs themselves (7 of 9 practitioners). Chile is now considered a developed country and many doctors admit reluctance to take advice from
the United States. They do not want to be treated like a country that needs help to be dug out of poverty. The infrastructure in Chile is vastly improved compared to the infrastructure in both Guatemala and Peru. Only 2 of 9 practitioners cited equipment access as being a problem and only 1 of 9 believed network access may hinder the success of PVFs. The percentage of average monthly GDP per capita spent on Internet was only 6.1%, far lower than both Guatemala and Peru, although still remarkably higher than the United States (Figure 1).

**Future Use**
Seven of 9 practitioners interviewed stated that they would use PVFs to share their experiences with other practitioners. Five of 9 believed they could use the web-conferencing system to consult regarding specific cases with other physicians. Five of 9 wished to use it to perfect their technique of the Ponseti method. Three specifically stated they would like to use web-conferencing to help document their work with the Ponseti method. Two of 9 specifically mentioned the use of PVFs in diffusing the Ponseti method around the country. One of 9 wanted to receive updates about the method using PVFs.

**Public Awareness**
Past success of the dissemination of the Ponseti method has been based on an increase in patient demand through Internet-based support groups. While PVFs have shown to enhance diffusion of the Ponseti method among physician practitioners, this same Internet-driven web conferencing can be applied to the education of the general public of the Ponseti method.

Centro Ann Sullivan de Peru (CASP) is a non-profit organization in Peru that works with children of different abilities including autism and Down syndrome. The Center has been utilizing web-conferencing to provide distance education for parents, teachers, and children since 2008. They have educated over 10,000 people in over 12 different countries using their network of auditoriums and facilitators. In collaboration with the University of Iowa Department of Orthopaedics, CASP assisted in organizing a PVF administered to the general public. This lecture appealed to general health practitioners, students of healthcare, as well as parents and friends of children with clubfoot. The initial session was broadcast to the cities of Lima (12 attendees) and Mancora (20 attendees). The 12 who attended in Lima completed a similar questionnaire assessing the Ponseti Virtual Forums.

Nine of the 12 who responded were fully satisfied with the PVF, 1 was not fully satisfied and two did not respond to the question. The overall satisfaction with the event was rated 3.92 out of a possible 5. Those who attended were very satisfied with the amount of information they gained from the lecture and suggested that further advertising and expansion of these forums would be beneficial. Examples of specific information gained included parents understanding how to use their brace, physical therapists learning how to advise their clubfoot patients, and physicians understanding specific details about the method. Participants particularly enjoyed the presentation format, which included a PowerPoint presentation with video, photos, and an interactive question and answer session.

**DISCUSSION**
Each of the three countries visited presented remarkably different challenges. While each country was economically, geographically, and culturally diverse, the PVFs have the potential to succeed in each individual country. The self-sustainable and locally-driven nature of PVFs allows for country-specific uses. For example, in Guatemala where practitioners have only been recently introduced to the Ponseti method, they wished to organize a monthly scientific meeting between all practitioners in which they could discuss experiences with the method, challenging cases they have had, and any other pertinent issues. In Chile, where practitioners have a well-established Ponseti network, practitioners similarly wished to organize a PVF on a regular basis. However, in Chile the Sociedad Chilena de Orthopedia y Traumatologia (SCHOT) wished to use PVFs at their annual meetings to discuss their experiences with the Ponseti method as well as other orthopaedic advances. Finally, in Peru, where the largest obstacle is a lack of trained practitioners, practitioners suggested utilizing PVFs to contribute to larger scale Ponseti training conferences using a similar framework to what CASP used to create their public awareness PVF.

The Ponseti method to treat clubfoot was invented over 50 years ago; however, despite the best efforts of orthopaedic surgeons around the world and the obvious benefit of the Ponseti method, this best-practice has not yet cemented a place in the treatment for clubfoot in developing countries. While many orthopaedic surgeons are at the forefront of this change, there are still many who are not using the Ponseti method for a variety of different reasons. Much of this is simply due to both a lack of knowledge about the method that includes both practitioners and the general public. Ponseti Virtual Forums have the ability to address these issues in both areas.

The orthopaedic surgeons who have already adopted this change are known, through Rodgers' Diffusion of Innovation theorem, as “early adopters” 19. They are
typically innovative, constantly the leaders of their respective fields and seek out change independently and unprompted. After witnessing the success of the “early adopters,” those who adopt the method are called the “early majority.” Finally, the “late majority” and “laggards” eventually accept the innovation but only after much prompting and often only after it is a required change. According to Rogers, a potential means to expedite the diffusion of innovation is through increasing communication between the different groups of adopters. Although it is known in the academic world that the Ponseti method to treat clubfoot is the “gold standard” best-practice clubfoot treatment, many orthopaedic surgeons in developing countries still have doubts. These doubts are often due to a lack of knowledge about the method, poor personal outcomes with the method due to improper technique, or a surgeon’s preference for highly-skilled technical procedures versus the simple, non-surgical Ponseti method. Direct communication among practitioners, enhanced with video, photos, and audio, may provide an easy feasible way to dispel falsehoods about the Ponseti method.

PVFs allow a level of communication between orthopaedic surgeons that simple email or phone conversation cannot provide. The communication between Ponseti practitioners can facilitate individual mastery of the method by allowing communication of doubts among different levels of “adopters”. The Internet should transcend the various geographic barriers that have previously made this form of instant communication impossible. As a matter of fact, in the developed world, web-based conferencing is already being utilized. The Elluminate Live! program simply allowed The University of Iowa to use this technology to reach medical professionals in the low-bandwidth arena of developing countries.

The potential of PVFs in Latin America is supported by the opening of and interest in information technology. Guatemala experienced the highest satisfaction rate of any country introduced to the Ponseti Virtual Forums which may be due to the lack of Internet resources in the country. The PVF allowed instant communication with Ponseti practitioners on a different continent to take place on a single 56k cellphone modem. The high satisfaction rate may correlate to the novelty of the virtual forum in a place where the Internet is yet to become ubiquitous. However, despite the currently inadequate telecommunications infrastructure in Guatemala, the country has experienced unprecedented growth in Internet connectivity over the past decade (3408%) when compared to Peru (223%), Chile (376%) and the United States (152%).

This remarkable Internet growth rate is not limited to Guatemala. Numerous developing countries around the world have experienced dramatic increases in Internet use in the past decade. The entire continent of Africa has averaged 2357% growth while Asia (621%) and Europe (352%) are also experiencing growth. As the Internet continues to grow, specific high-yield education tools such as the PVF should mirror that growth as well.

CONCLUSION

Although there are many specific challenges to the widespread implementation of Ponseti Virtual Forums in Latin America, the initial success of PVFs suggests that low-bandwidth web-conferencing may be used to enhance the worldwide diffusion of best-practice medical knowledge. The ease of use, low-bandwidth requirements, and the ability to have multiple simultaneous connections may make web-based conferencing an important player in the spread of medical knowledge around the world.

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PONSETI BRASIL: A NATIONAL PROGRAM TO ERADICATE NEGLECTED CLUBFOOT – PRELIMINARY RESULTS

Monica Paschoal Nogueira, Julio Cesar Rodrigues Pereira, Paulo Schiavom Duarte, Alexandre Lourenço, Ana Paula Tedesco, Laura Alves Ferreira, Edilson Forlin, Reinaldo Volpi, Francisco Violante, Gilberto Brandão, Eduardo Novaes, José Luís Amin Zabeu, Jung Ho Kim, Carlos Aguilar, Maria Henriqueta Renno Merlotti

ABSTRACT

Background
After hearing about the reproducible and excellent results of the Ponseti method for clubfoot treatment, a group of Brazilian orthopaedic surgeons organized and participated in a standardized national program to teach the Ponseti technique in 21 different cities across Brazil.

Methods
A total of 21 Ponseti symposiums were organized in a standard fashion from January, 2007 to December, 2008. They consisted of a two-day program with lectures, hands-on cast application, and discussion of local clinical cases presented by orthopaedic surgeons. Thirteen Brazilian orthopaedic surgeons, who had been trained by the University of Iowa or centers recognized by them, taught the method. Financial support for travel was provided by an English charity: La Vida (Vital Investment for Developing Aid in Latin America). The physicians who attended the symposiums answered questionnaires before and after the training.

Results
About 7% of the 8000 orthopaedic surgeons in Brazil (556 orthopaedic surgeons) were trained. These orthopaedic surgeons stated that they had treated about 4905 babies in the previous year via other methods, including extensive surgery. Seventeen percent of the surgeons did not know about the Ponseti technique at the start of the symposium. Eighty-eight percent reported they felt able to treat children with the Ponseti technique after the symposium. Ninety-four percent of respondents reported that the symposium changed their way of treating clubfoot.

Conclusions
These Ponseti symposiums brought about an exchange of medical information and empowered the participants. This program is a good educational tool which can be used in eradicating neglected clubfoot in Brazil.

INTRODUCTION
Congenital clubfoot is an orthopaedic deformity affecting the foot and leg that consists of a combination of equinus of the ankle, hindfoot varus, and cavus and adduction of the forefoot. Worldwide, it occurs in 0.39 of 1000 newborns, with differences related to race and ethnic group. It is the seventh most common congenital and the first most common congenital anomaly involving the musculoskeletal system. In Brazil, clubfoot occurs in approximately two of 1000 newborns; it is estimated that about 7000 children are born in Brazil with one or two clubfeet every year (www.ibge.gov.br).

The severity of clubfoot deformity varies. About 130,000 children worldwide are born every year with clubfoot, many in developing countries where they do not get proper treatment, resulting in a neglected deformity. The neglected clubfoot is a social, psychological, and physical burden for the patient, his/her family, and society. It is the most important cause of physical disability among all congenital musculoskeletal defects. In the next ten years, there will be about 2 million adults living with this deformity who could easily have been treated in their first months of life.
Children with neglected clubfoot can become locked in a cycle of deformity, incapacity, dependence, demoralization, depression and segregation. These children are intellectually able to participate in school activities, but many do not have the opportunity. Less than 2% of children with deformities are in school in developing countries. The more difficulty these children have walking, the less likely they are to attend school. In rural societies, physical incapacity is the most important cause of disease and poverty. People with deformities have economic and social disadvantages with few opportunities for education or a professional life.

Ten years ago, standard treatment for congenital clubfoot in Brazil consisted of the Kite technique, as first published in 1939. This technique consists of corrective manipulations followed by applications of short-leg casts for three to 12 months, followed by posteromedial releases in 60 to 80% of cases. The results of this technique have proven unsuccessful. Aronson et al. described deformity, disability and complications from this technique. Dobbs et al. described long-term results after posteromedial release which confirmed the clinical impression that feet treated with this technique were more rigid and painful, and often required multiple surgeries. Additionally, extensive surgery is expensive and requires the expertise of tertiary medical centers with well-trained specialists and general anesthetics.

The Ponseti method is a well-described treatment consisting of five to seven serial casts applied after manipulations followed by a tenotomy. To prevent recurrence, continuous use of an abduction brace is recommended for three months and then during night time (14 hours) until the child is four years of age.

Feet treated with this technique are flexible, mobile, functional, and are clinically very close to normal. This is corroborated by published long-term follow-up studies. These results have been reproduced in clinics all around the world. The correction rate with the Ponseti technique (over 90%) can be accomplished in about two to three months. Extensive surgery is rarely indicated.

Furthermore, the Ponseti technique has been used in Brazil to treat neglected clubfeet, even after a child achieves walking age, with good results. It has also been demonstrated that the Ponseti method can be successful in clubfoot that recurs after extensive surgery. This makes the Ponseti method a very powerful tool in public health, a much more “democratic” treatment that is cost effective and can be made accessible. This method is very useful for developing countries. The technique is easy to teach, but requires great attention to detail. It is very important for health care practitioners to counsel parents regarding the bracing protocol after correction, to avoid recurrences. Treatment is not expensive, and is painless for babies. When the Ponseti method proves successful in Brazil, it should reduce the number of disabled people with clubfeet.

Medical education projects employing the Ponseti method are the most effective way to reduce neglected clubfoot deformities. As reported by the World Health Organization in 2002, the best approach to pediatric problems in developing countries includes strengthening educational projects. Good examples are the Uganda Clubfoot Project, the project developed in Nepal, and most recently, clubfoot projects in Mali, Kenya, and Malawi. Similar projects have been developed since 2007 in Ethiopia and Cambodia and are expanding into the Dominican Republic, Honduras and Nigeria. Those programs are producing good results under adverse conditions including political instability and a shortage of practitioners. Happily, these conditions do not exist in Brazil.

A group of Brazilian orthopaedic surgeons heard of the reproducible and excellent results of the Ponseti method of clubfoot treatment around the world and organized a standardized national program to teach the Ponseti method in 21 different cities in Brazil. This study describes the Ponseti method training program titled “Ponseti Brasil”, and evaluates the preliminary results of the training program.

METHODS

Program characteristics

“Ponseti Brasil” consisted of training groups of 15 to 30 Brazilian orthopaedic surgeons in 21 different cities in Brazil. The cities included in the program were: Manaus, Belém, Goiânia, Campo Grande, Brasília, São Luís, Teresina, Fortaleza, Natal, Recife, Maceió, Aracaju, Salvador, Belo Horizonte, Rio de Janeiro, Vitória, Londrina, Uberlândia, Florianópolis, Campina Grande and Porto Alegre. The orthopaedic surgeons were contacted by letter or electronic message and were asked to participate in two days of training, free of cost. Regional centers were chosen to maximize the number orthopaedic surgeons who could be trained. Some cities were not included because it was known that they already had a number of surgeons trained in the Ponseti method.

Symposiums were held in 2007 and 2008 and were given by three instructors in each city, chosen from a group of 13 orthopaedic surgeons who were trained in the technique (all professionals with Ponseti training recognized by the University of Iowa – Ponseti International Association). Planning of the symposiums was based on regions of the Brazilian Orthopaedic Society in each state. Invitations were sent to the orthopaedic
surgeons listed in the state and in some cases, states nearby. Local leaders arranged for facilities and casting materials. Local doctors were encouraged to bring patients who agreed to participate (treated and untreated) for discussion. Thus, symposiums had characteristics specific to their own regions. Discussions included the treatment itself, but also the related issues of healthcare access, difficulty in obtaining the abduction brace, and specific issues unique to each region.

The “Ponseti Brasil” program consisted of a two-day course; Friday consisted of theoretical lectures in the morning followed by casting workshops with clubfoot models, and Saturday morning included clinical case discussions and abduction brace manufacturing. A manual printed in Portuguese was distributed with content adapted to Brazilian realities. The lectures were standard with specific content given to each of the faculty participants. The financial support for all faculty members for traveling and hotel stays was donated by La Vida, an English charity. (www.lavida.org.uk).

**EVALUATIONS**

Participants filled out a questionnaire before lectures on the first day of each symposium requesting identification data and contact information. The questions were:
- Do you treat clubfoot?
- Do you perform posteromedial releases?
- How many children did you treat last year?
- Have you ever heard of the Ponseti technique?
- What are your expectations from this symposium?

At the end of the symposiums, participants again filled out questionnaires. After completion of all the symposiums, results were compiled which are reproduced below with Likert scales (Table 1). After one year, another questionnaire was sent electronically to every participant asking them to provide additional information about how the Ponseti Method had been integrated into their practice.

Questions at one year were:
- How many patients have you treated with clubfoot?
- For how many of them did you apply the Ponseti technique?
- In how many patients was a successful correction obtained after casting and tenotomy?
- How many casts were used in each treatment?
- What were the main problems in using the Ponseti method?

**RESULTS**

Five-hundred and fifty-six orthopaedic surgeons (about 7% of the 8000 orthopaedic surgeons in Brazil) were trained in the Ponseti method by “Ponseti Brasil”.

### TABLE 1. Evaluation of Ponseti Symposium

<table>
<thead>
<tr>
<th>Did the symposium correspond to your expectations?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4 5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Was the Ponseti technique well presented?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4 5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>With information from this course, do you consider yourself able to treat patients with Ponseti technique?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4 5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>After your participation in the symposium are you convinced that Ponseti Technique is the most indicated way of treating clubfoot?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4 5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Do you believe this symposium could have changed the way you treat clubfoot?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4 5</td>
</tr>
</tbody>
</table>

**Suggestions and comments:**

The trainees answered a questionnaire before and after their symposium. All participants completed the initial form prior to the symposiums, but not all of them filled out the forms after the 2nd day, since some did not stay to the end of the second day. Fifty-two percent answered the final evaluation forms.

Orthopaedic surgeons who had participated in the Ponseti training answered the initial questionnaire, and stated they had treated about 4905 babies altogether in the year prior to the training using the Kite technique and posteromedial release. Seventeen percent did not know of the Ponseti method before their training. Eighty-eight percent reported that after training they felt able to treat children with the Ponseti method. Ninety-four percent of those reported the symposium changed their way of treating clubfoot.

After one year, an inquiry was sent electronically to symposium participants asking them to provide more
information about how the Ponseti technique was integrating into their practice. Only 4% of the 556 participants responded to this survey, a very small sample size. They were from 10 of the 21 cities where the symposiums took place. They had treated 160 patients altogether since their training. Sixty percent of them reported they treated all clubfoot patients with the Ponseti method. Seventy-eight percent reported successfully treating clubfeet in more than 90% of the patients they treated. On average, respondents reported applying a total of eight casts for correction of clubfoot.

When asked to cite problems or complications, these surgeons reported problems related to application of the casts (six), issues with the brace protocol such as getting the correct braces and fitting them (three), and issues related to cast removal (two). One surgeon commented on difficulties related to the evaluation of recurrence.

**DISCUSSION**

This program was very important in increasing awareness of the Ponseti method among orthopaedic surgeons in Brazil, but it is not yet known how many orthopaedic surgeons effectively mastered the technique. A hypothesis for this could be that the course was open and free of charge and some of the participants were curious and interested in knowing about the technique, but some of them may not have ever treated children with clubfeet.

Brazil has a population of 183 million people and about 8000 orthopaedic surgeons (SBOT, Brazilian Orthopaedic and Traumatology Society), one for every 22,800 inhabitants. The distribution of orthopaedic surgeons in Brazil is described in Table 2. With more than 8000 orthopaedic surgeons in Brazil, training in different states could potentially increase the number of orthopaedic surgeons treating children with clubfoot, reduce the occurrence of neglected clubfoot, reduce cost of treatment, and result in patients with better clinical results.

Unfortunately, only 52% of the evaluation forms were filled in by participants at the end of the symposiums: one reason for this was that many orthopaedic surgeons could not come for both days of the symposium and the forms were only presented at the end of the practical session on the second day. Other possible reasons were that the evaluation forms were printed and handed out by instructors, who may have been more concerned about course content. On the second day, the instructors would have been occupied with discussion and treatment of children brought by the local doctors. There were no clerical workers to distribute the forms, and many orthopaedic surgeons left before completing them.

Some consequences of the training could not be measured by the forms, but were noted by the instructors. One important consequence was the empowerment the symposiums gave each participant. Participants were provided with a treatment “tool” they could use, essentially the same treatment performed in well-equipped medical centers around the world, with expectations of getting the same excellent results. In a heterogenous nation such as Brazil, this was very important. The symposiums also fostered cooperation among the orthopaedic surgeons from each center, as well as between trainees and instructors. Many experiences were shared in a very academic but informal way, which contributed to a very positive result at the end of the training as reported by both participants and instructors.

The sample size was small for the one-year follow-up questionnaires, but the data may be very important. The majority of those who responded reported good

<table>
<thead>
<tr>
<th>States</th>
<th>Number of orthopaedic surgeons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minas Gerais</td>
<td>809</td>
</tr>
<tr>
<td>Paraíba</td>
<td>74</td>
</tr>
<tr>
<td>Bahia</td>
<td>292</td>
</tr>
<tr>
<td>Rio de Janeiro</td>
<td>978</td>
</tr>
<tr>
<td>Ceará</td>
<td>160</td>
</tr>
<tr>
<td>Pernambuco</td>
<td>168</td>
</tr>
<tr>
<td>Amazonas</td>
<td>71</td>
</tr>
<tr>
<td>Pará</td>
<td>81</td>
</tr>
<tr>
<td>Mato Grosso do Sul</td>
<td>107</td>
</tr>
<tr>
<td>Sergipe</td>
<td>43</td>
</tr>
<tr>
<td>Rio Grande do Norte</td>
<td>70</td>
</tr>
<tr>
<td>Acre</td>
<td>11</td>
</tr>
<tr>
<td>Alagoas</td>
<td>48</td>
</tr>
<tr>
<td>DF</td>
<td>150</td>
</tr>
<tr>
<td>Espírito Santo</td>
<td>157</td>
</tr>
<tr>
<td>Goiás</td>
<td>238</td>
</tr>
<tr>
<td>Maranhão</td>
<td>40</td>
</tr>
<tr>
<td>Mato Grosso</td>
<td>74</td>
</tr>
<tr>
<td>Paraná</td>
<td>548</td>
</tr>
<tr>
<td>Piauí</td>
<td>41</td>
</tr>
<tr>
<td>Rio Grande do Sul</td>
<td>530</td>
</tr>
<tr>
<td>Rondônia</td>
<td>37</td>
</tr>
<tr>
<td>Roraima</td>
<td>6</td>
</tr>
<tr>
<td>Santa Catarina</td>
<td>268</td>
</tr>
<tr>
<td>São Paulo</td>
<td>2897</td>
</tr>
<tr>
<td>Tocantins</td>
<td>32</td>
</tr>
</tbody>
</table>

**Total** 7930

Source: [www.sbot.org.br](http://www.sbot.org.br), December, 2007
results with a good average number of casts. However, even with this small sample, it was realized that many of those trained were still having problems with the basics. One of the most crucial aspects of the technique is how to apply a good cast. It may be necessary for “Ponseti Brasil” to offer “advanced” or “refresher” courses.

It is very important that Ponseti-trained orthopaedic surgeons follow the guidelines for treatment, without modification, so optimum results are obtained. Incorrect use of the Ponseti method could result in the technique being viewed as less effective.

Clinics around the world are experiencing excellent results from the Ponseti method, and Brazil can also achieve that. The Ponseti method is very reproducible, as evidenced in many publications (Table 3).

The Brazilian Ponseti Study Group will try to measure continued results from this program, inviting trained surgeons to present both their treated patients and data from their treatment. This will also be an opportunity for “advanced training” for surgeons who are actively treating children with clubfoot.

In conclusion, Brazilian orthopaedic surgeons are working to get the best results with the Ponseti method. This is important for empowering Brazilian surgeons, improving the practice of orthopaedics in Brazil, and for providing better treatment for our children. Further efforts toward achieving these goals are under way.

### ACKNOWLEDGEMENTS

We would like to thank all the Brazilian orthopaedic surgeons involved in the organization of the symposiums in all 21 cities of the project.

**Conflict of interest:** None declared

This study discusses a Brazilian Project of Medical Education in the Treatment of Congenital Clubfoot in 21 cities in Brazil. This pioneering public health approach in orthopaedics is following the same steps as used for the eradication of poliomyelitis.

### REFERENCES


COMPARISON OF HOSPITAL COSTS AND DURATION OF TREATMENT WITH TWO DIFFERENT CLUBFOOT PROTOCOLS

Laura Fernanda Alves Ferreira,¹ Monica Paschoal Nogueira,²
Julio Cesar Rodrigues Pereira,³ Paulo Schiavom Duarte⁴

INTRODUCTION

In Brazil, clubfoot has traditionally been treated by serial manipulation and casting over a period of several months with the Kite technique. In most cases, complete correction was not achieved and posterosomedical release was required. In 2003, the University Hospital at the University of São Paulo (Campus University City) changed their clubfoot treatment protocol to the Ponseti technique. This was due to the dissemination of this technique in the medical literature. In 2004, the Ponseti technique was recognized by the Brazilian Orthopaedic Society Guidelines Book as a recommended way to treat clubfoot.

The authors retrospectively compared the hospital costs in the treatment of five consecutive patients with the previous protocol (Kite technique and posterosomedical release) with the hospital costs for treatment of five consecutive patients with the new protocol (the Ponseti technique).

The objective of this study was to compare direct hospital costs and duration of treatment from these two different protocols.

METHODS

This is a retrospective study of ten children under one year of age with bilateral clubfoot, treated in Hospital Universitário at the University of São Paulo, Brazil. The first five children (age range from two weeks to eight months; average, three months) were treated by the Kite method followed by posterosomedical release, as was commonly done until 2005.

As described in the original Kite report, the Kite method consists of nine to 14 casts (11 on average) intending to sequentially correct the adduction, cavus, varus and equinus alterations of clubfoot. Because correction of the deformity was usually not complete, a posterosomedical release was then indicated (age range from four to 14 months; average, six months). In this group, posterosomedical release was performed using a Cincinnati circular incision, release of medial, posterior and lateral structures and pinning with two Kirschner wires. (Posteromedical releases were performed for only one foot at a time, with the second procedure occurring one to two months after the first.)

Two months after the posterosomedical release, each patient was taken to the operating room for removal of the two Kirschner wires and application of a long-leg cast under anesthesia. About four weeks after that, the plaster cast was removed and orthopaedic shoes were recommended.

Five other children were treated consecutively by the Ponseti method. This treatment consisted of four to six casts (average 4.8 casts) followed by a percutaneous tenotomy of the Achilles tendon under local anesthesia, with a new cast to be worn for three more weeks. After this treatment, the feet were considered corrected and an abduction brace was then recommended to maintain the correction.

Direct hospital costs for the first protocol, the Kite technique followed by posterosomedical release, included preoperative casts, preoperative examinations (including blood tests and radiographic films), anesthesia medical charges, surgical clubfoot treatment (related to the posterosomedical release), postoperative medications in the hospital, the cost of three days in the hospital, cast removal, removal of sutures and Kirschner wires, anesthesia for this procedure, and day-hospital taxes for this procedure. These costs also included two postoperative casts and orthopaedic shoes.

Direct hospital costs for the second protocol, the Ponseti technique, included casts, a percutaneous tenotomy and abduction braces. All costs are reported in the monetary unit of Brazil, the real (R$).

The duration of treatment was recorded, from the first cast to the day the correction was considered complete in both feet. Complete correction for the Kite protocol was considered achieved after removal of the postoperative cast following surgery on the second foot. Complete correction for the Ponseti protocol was considered achieved after removal of the post-tenotomy cast.

¹Hospital Universitário – USP
²Faculdade de Saúde Pública da USP
Contact Author
Monica Paschoal Nogueira, M.D.
Faculdade de Saúde Pública da USP
São Paulo, Brazil

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TABLE 1.
Patients from first protocol (Kite and posteromedial release)

<table>
<thead>
<tr>
<th>Patient</th>
<th>DIAG</th>
<th>Age at 1st visit</th>
<th>Nº CASTS</th>
<th>Age at 1st surgery</th>
<th>Age at 2nd surgery</th>
<th>Total Treatment Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bilateral clubfoot</td>
<td>259 days</td>
<td>14</td>
<td>435 days</td>
<td>491 days</td>
<td>267 days</td>
</tr>
<tr>
<td>2</td>
<td>Bilateral clubfoot</td>
<td>43 days</td>
<td>12</td>
<td>139 days</td>
<td>160 days</td>
<td>160 days</td>
</tr>
<tr>
<td>3</td>
<td>Bilateral clubfoot</td>
<td>90 days</td>
<td>9</td>
<td>201 days</td>
<td>285 days</td>
<td>242 days</td>
</tr>
<tr>
<td>4</td>
<td>Bilateral clubfoot</td>
<td>15 days</td>
<td>10</td>
<td>126 days</td>
<td>147 days</td>
<td>182 days</td>
</tr>
<tr>
<td>5</td>
<td>Bilateral clubfoot</td>
<td>51 days</td>
<td>11</td>
<td>166 days</td>
<td>279 days</td>
<td>278 days</td>
</tr>
<tr>
<td>AVERAGE</td>
<td></td>
<td>91.6 days</td>
<td>11.2</td>
<td>213.4 days</td>
<td>272.4 days</td>
<td>225.8 days</td>
</tr>
</tbody>
</table>

Table 2.
Patients from Ponseti protocol

<table>
<thead>
<tr>
<th>NAME</th>
<th>DIAG</th>
<th>Age at 1st visit</th>
<th>Nº CASTS</th>
<th>Age at Tenotomy</th>
<th>Total Treatment Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bilateral clubfoot</td>
<td>28 days</td>
<td>6</td>
<td>71 days</td>
<td>65 days</td>
</tr>
<tr>
<td>2</td>
<td>Bilateral clubfoot</td>
<td>35 days</td>
<td>5</td>
<td>71 days</td>
<td>56 days</td>
</tr>
<tr>
<td>3</td>
<td>Bilateral clubfoot</td>
<td>9 days</td>
<td>4</td>
<td>37 days</td>
<td>49 days</td>
</tr>
<tr>
<td>4</td>
<td>Bilateral clubfoot</td>
<td>40 days</td>
<td>5</td>
<td>78 days</td>
<td>59 days</td>
</tr>
<tr>
<td>5</td>
<td>Bilateral clubfoot</td>
<td>109 days</td>
<td>4</td>
<td>136 days</td>
<td>49 days</td>
</tr>
<tr>
<td>AVERAGE</td>
<td></td>
<td>44.2 days</td>
<td>4.8</td>
<td>78.6 days</td>
<td>55.6 days</td>
</tr>
</tbody>
</table>

Table 3. Ponseti Method Costs

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Casts (5x28, 24)</td>
<td>R$ 142.10</td>
</tr>
<tr>
<td>Percutaneous tenotomy under local anesthesia</td>
<td>R$ 28.24</td>
</tr>
<tr>
<td>Orthosis</td>
<td>R$ 170.000</td>
</tr>
</tbody>
</table>

Table 4. Kite Method Costs

<table>
<thead>
<tr>
<th>Section</th>
<th>Unit Cost</th>
<th>Total Cost</th>
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<tr>
<td>Pre-op casts (11)</td>
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<td>312.62</td>
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<tr>
<td>Pre-op exams (blood and TX)</td>
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<td>12.57</td>
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<tr>
<td>Anesthesia</td>
<td></td>
<td>284.06</td>
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<tr>
<td>Surgical treatment of clubfeet with fixation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pos-op medication</td>
<td></td>
<td></td>
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<tr>
<td>3 days of stay in Hospital</td>
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<tr>
<td>Removal of cast sutures and Kirschner wires</td>
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<td>151.67</td>
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<tr>
<td>Anesthesia</td>
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<tr>
<td>Day Hospital</td>
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<tr>
<td>Pos-op casts (2)</td>
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<tr>
<td>Orthopedics shoes</td>
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<td>R$</td>
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<tr>
<td><strong>TOTAL (1 foot)</strong></td>
<td></td>
<td>R$ 947.76</td>
</tr>
<tr>
<td><strong>TOTAL (2 feet)</strong></td>
<td></td>
<td>R$ 1,895.52</td>
</tr>
</tbody>
</table>

50 *The Iowa Orthopaedic Journal*
RESULTS

The average number of casts was 11.2 (nine to 14) in the first protocol (Kite and posteromedial release) and 4.8 (four to six) in the second protocol (Ponseti). The age at the beginning of treatment was a little higher in the first protocol group, but the difference was not statistically significant (Mann-Whitney test, p-value =0.465; significance level 0.05, confidence interval 95%).

Treatment costs using the Kite protocol totaled R$947.56 for one clubfoot and R$1895.52 for bilateral clubfeet. Treatment costs using the Ponseti protocol totaled R$340.34 for the treatment of one foot, and R$510.68 for treatment of bilateral clubfeet. Costs were about 2.5 times lower in the Ponseti protocol than with the Kite protocol. The duration of treatment to complete correction was, on average, 225.8 days with the Kite protocol and an average of 55.6 days with the Ponseti protocol.

The reported costs were taken from the table of coded procedures of Brazilian Health System and applied to the Hospital Universitario in 2004, when this research was performed.

DISCUSSION

Indirect costs such as patient transportation and out-of-work days for caretakers were not included in the cost estimates. The Kite group had more casts and more hospital visits, which would further increase the costs for this group if these variables had been taken into consideration. It is also important to consider that for each foot procedure in the Kite group, at least three hours of hospital operative time were required; thus, there were six fewer available operative-hour hours for treatment of other orthopaedic or surgical problems in this secondary medical center.

Another important consideration is that the Kite group had only 11 casts on average. This is not commonly seen in orthopaedic centers which have adopted this method of treatment. The more typical situation would be for a patient to undergo six months to a year of casting (every one to two weeks), for an expected total of 24 to 48 casts. This would increase costs even further for the Kite group. The unusually low number of casts applied in this hospital is thought to be secondary to the indication for surgery (posteromedial release) at a younger age.

This limited study should not be considered a complete analysis of costs from these two protocols; the number of patients is small and many indirect costs were not included. Also, this study does not take into consideration the clinical results for these patients, but data in the literature suggest the Ponseti protocol has better long-term clinical and functional results. However, this limited study highlights the striking differences in costs and duration of treatment for patients treated with these two different protocols. Our hope is that this may help raise awareness in public health professionals, aid in decision-making, and lead to health policy changes regarding the treatment of clubfoot.

REFERENCES

RELIABILITY OF VARIOUS OBSERVERS IN DETERMINING
COMMON RADIOGRAPHIC PARAMETERS OF ADULT HIP
STRUCTURAL ANATOMY

John C. Carlisle, MD, Lukas P. Zebala, MD, Derek S. Shia, MD, Devyani Hunt, MD, Patrick M. Morgan, MD, Heidi Prather, DO, Rick W. Wright, MD, Karen Steger-May, MA, John C. Clohisy, MD

ABSTRACT

Background
Radiographic evaluation of the hip is extremely important in the diagnosis and treatment decision-making process for pre-arthritis hip disease. Many different radiographic measurements have been described as indicators of underlying structural hip deformity. The purpose of this study was to determine the interobserver and intraobserver reliability of various musculoskeletal physicians in performing selected measurements of adult structural hip anatomy.

Methods
A blinded review of 45 sets of radiographs from patients with developmental dysplasia, femoroacetabular impingement, and normal anatomy was performed. Data points included the lateral center-edge angle (LCEA), vertical-center-anterior angle (VCA), head-neck offset ratio (HNO), alpha angle, Tönnis angle, Tönnis osteoarthritis grade and a radiographic diagnosis. One orthopaedic fellow, two orthopaedic residents, and two attending musculoskeletal physiatrists analyzed radiographs on two separate occasions. One sports medicine orthopaedic attending physician completed a single analysis of the image sets. Intraobserver and interobserver reliability was established using intra-class correlation coefficients (ICC) for continuous variables. Agreement regarding categorical variables was performed using the kappa coefficient.

Results
Excellent intraobserver reliability was found for the following: LCEA (ICC = 0.88), VCA (0.88), Tönnis angle (0.83), HNO on the frog lateral (0.78), alpha angle on the frog lateral (0.76), HNO on the cross-table lateral (0.75), and angle alpha on the cross-table lateral (0.76). Intraobserver reliability for osteoarthritis grade was poor (weighted kappa = 0.57). For all data points, interobserver reliability was considerably worse, with 95% confidence intervals spanning below 0.55.

Conclusions
While the described measurements of adult structural hip anatomy provide excellent reliability for a single reader, these measurements are less reliable across readers. Taken in isolation, these measurements, as performed by observers with varied clinical experience and clinical backgrounds, are limited in determining a consistent radiographic diagnosis.

INTRODUCTION

The majority of chronic, non-inflammatory hip disorders in the young adult population are mechanically-based and are associated with structural instability of the hip and/or femoroacetabular impingement (FAI). While structural instability of the hip and FAI are well-described, many patients with symptomatic disease experience major delays in diagnosis, inaccurate diagnoses, and ineffective or inappropriate treatments. Consultation with healthcare providers in various disciplines (primary care, orthopaedics, physiatry, physical therapy, rheumatology and chiropractic) is commonly necessary.
for these patients to obtain an accurate diagnosis and appropriate treatment. Thus, there exists a major need to improve the diagnostic skills of healthcare providers involved in the evaluation and treatment of patients with groin, lateral hip, and posterior pelvic pain.

Proper diagnosis of pre-arthritic hip disease in the skeletally mature patient is dependent on the patient history, physical examination, and imaging studies. The radiographic examination is critical in screening patients for underlying structural abnormalities, establishing an accurate diagnosis, and in developing an appropriate treatment strategy. Many different radiographic measurements have been described as indicators of structural hip disease. In particular, measurements such as the lateral center-edge angle of Wiberg, the anterior center-edge angle of Lequesne, and the Tonnis angle have been consistently used as primary markers for acetabular dysplasia. Similarly, measurements of the head-neck offset (initially described by Eijer) and the alpha angle have recently been used to identify potential cases of femoroacetabular impingement. A complete review of any hip series in an adult patient also requires an overall assessment of the degree of osteoarthritis, such as that outlined in the classification system described by Tonnis.

While the reliability of some of these measurements has been evaluated in the pediatric patient population, less has been published in the orthopaedic literature regarding their reliability in the skeletally mature hip. Much of the information available on the reliability of specific measurement tools for the adult hip is buried within larger studies or is relevant to hip specialists only. In order to have a standardized set of radiographic parameters to help reliably define structural hip disorders, it is imperative that the radiographic measurements be reproducible. Ideally, the reliability of these measurements should be established for various healthcare providers and not limited to experienced hip specialists, since many of these patients present to a variety of physicians involved in musculoskeletal care. Therefore, the purpose of this study is to evaluate the reliability of healthcare providers with varied clinical experience and medical backgrounds in performing selected measurements of adult structural hip anatomy.

**METHODS**

The computerized patient database of the senior author (housing lists all patients having undergone surgical intervention) was utilized to select preoperative images for 15 patients with acetabular dysplasia and 15 patients with impingement (cam, pincer, or combined). A control group of 15 patients was selected independently, consisting of a previously reported patient cohort that was evaluated clinically and radiographically by the senior author and found to have no clinical evidence of hip disease. Specifically, none of the patients had groin pain, a positive impingement test, or hip irritability on examination. All of the patients had alternative findings suggestive of a disorder not involving the hip (i.e., degenerative disc disease of the lumbar spine). The image sets for patients in the dysplasia and impingement groups were randomly selected from an alphabetized list of consecutive operative cases from 2001-2005. Patients were included in these groups if they had surgical treatment for symptomatic disease, intraoperative findings consistent with the preoperative diagnosis, and a positive response to surgery. All patients in the dysplasia group underwent periacetabular osteotomy, and all patients in the impingement group underwent either surgical dislocation with osteochondroplasty or hip arthroscopy with limited open osteochondroplasty.

Image sets were excluded from the study if the radiographs demonstrated any evidence of previous surgery, or if the radiographs were taken before 2001, as images prior to this date did not meet the Digital Imaging and Communications in Medicine (DICOM) standard. Prior Institutional Review Board approval existed for the protocol.

All study patients had a series of four radiographs: an anteroposterior (AP) pelvis, cross-table lateral, frog-lateral, and a false profile view of the hip. Though multiple radiology technicians obtained the image sets, all radiographs were taken in the same imaging center using a standardized imaging protocol. This protocol has been previously published and is available for reference.

All identifying data was removed from the radiographs, and each patient was assigned a study number. Additionally, all observers in the study were blinded with regard to the patient’s clinical history, physical
examination, and underlying diagnosis. The observers had various clinical backgrounds and experience levels in order to simulate the evaluation of radiographs by healthcare providers who are not hip specialists. The radiographs were retrospectively reviewed by one adult reconstruction fellow, two third year orthopaedic surgery residents, an attending sports medicine orthopaedic surgeon with specific interest in knee and shoulder, and two attending physiatrists who treat all musculoskeletal disorders. All six observers had some exposure to treating hip disorders, yet none had an established practice focus in this area.

The radiographic parameters measured included: (Figure 1) the lateral center-edge angle (LCEA) of Wiberg,5 (Figure 2) vertical-center-anterior (VCA) angle of Lequesne,6 (Figure 3) Tönnis angle,7 (Figure 4) head-neck offset ratio8,9,11 (on frog-lateral and cross-table lateral radiographs), and (Figure 5) alpha angle8 (on frog-lateral and cross-table lateral radiographs). Observers were also asked to estimate the degree of joint degeneration based on the Tönnis classification of osteoarthritis.11 The specific techniques for making these measurements have been previously reviewed8 and are succinctly summarized below.

Before the initial radiographic review, the study participants underwent a training session to review the study protocol and to review the originally described techniques for making the measurements in question. These techniques were summarized in written form.
Reliability of Various Observers in Determining Common Radiographic Parameters of Adult Hip Structural Anatomy

and were available to the readers as a reference. Case examples were utilized to demonstrate the measurement techniques. Each observer performed the radiograph review independently and was blinded to the other participants’ measurements and diagnoses. To assess intraobserver reliability, a second review of the image sets took place at least 6 weeks after the first. One reader (blinded) provided a single read only for purposes of interobserver reliability. For all other readers, image sets remained the same for the second read, however, the sequence of images was randomly altered and each image set was labeled with a new identification number. Observers were asked to remain blinded to their initial reads, were not allowed access to the images between sessions, and were asked not to discuss their data with other study participants between readings.

Source of funding: Washington University Institute of Clinical and Translational Sciences Research Grant. These resources were utilized for research personnel support.

STATISTICS

Before initiating the study, a biostatistician was employed to determine the appropriate number of cases needed. A minimum sample size of 15 per group was determined to provide adequate spread across the rating categories and thus provide adequately precise confidence intervals for the reliability estimates. As the reliability coefficients in this study were not assessed for statistical significance, no formal sample size calculation was performed.

Intraclass correlation coefficients (ICCs) and corresponding 95% confidence intervals (CIs) were calculated to quantify interrater and intrarater reliability for continuous variables. For intraobserver reliability, agreement was calculated for each reader separately as well as for raters combined. Because of the potential for bias and practice effects, we did not calculate interobserver reliability using second readings. Kappa values were utilized to determine interobserver and intraobserver reliability for categorical variables (diagnosis and Tönnis OA grade). The simple kappa was reported for the unordered variable of diagnosis. The weighted kappa is a refinement of the kappa coefficient that takes into account the magnitude of the disagreement between ratings and was used for Tönnis OA grade as a result of the ordering of the variable. Kappa values and ICCs of 1.0 are indicative of perfect agreement, whereas values less than 1.0 suggest progressively less agreement between readers (in the case of interobserver reliability) or between reads (in the case of intraobserver reliability). The classification scheme of Landis and Koch was utilized to provide an additional, more generalized tool for understanding the kappa results. In this system, kappa values of 0.81-1.0 are indicative of excellent agreement; 0.61-0.80, substantial agreement; 0.41-0.60, moderate agreement; 0.21-0.40, fair agreement; 0.0-0.20, slight agreement; and values less than 0, poor agreement.

RESULTS

In general, readers were substantially more consistent with individual measurements from read to read than they were comparing those same measurements across readers. Interrater reliability was substantial to excellent, with kappa values greater than 0.7, for all of the continuous variables studied, with the lowest combined intrarater reliability of ICC = 0.75 existing for measurements of head-neck offset on the cross-table lateral (Table 1). Combined intrarater agreement for the single categorical variable (Tönnis OA grade) was also limited, having a kappa value of 0.57 (moderate agreement). The majority of the lowest individual intrarater reliability scores for the continuous variables came from measurements of the alpha angle, with ICC ranging from 0.33-0.47 (fair to moderate agreement). All readers achieved excellent intrarater agreement for LCEA (ICCs ≥ 0.8); whereas agreement across readers for VCA ranged from 0.67 to 0.97. As indicated by the non-overlapping CIs, measures of the femoral head-neck morphology (HNO and alpha angle) were less reliably identified between reads than measures of acetabular morphology (CEA, VCA, and Tönnis angle). For measurements of head-neck offset ratio, combined intrarater reliability minimally improved on the frog-lateral radiograph compared to the cross-table lateral, unlike the alpha angle, which had the same combined reliability for the two different views. Combined intrarater reliability in making a radiographic diagnosis was substantial, as demonstrated by a kappa value of 0.66.

Interrater values were substantially lower than those noted for combined intrarater reliability. The LCEA was the most reproducible between readers, having an ICC = 0.64 (Table 2). Measures of acetabular morphology were collectively more reproducible than those for femoral morphology, though the interrater value for head-neck offset ratio on the frog-lateral had the second highest kappa value (0.55). Interrater values were significantly lower on the cross-table lateral radiograph than they were for the frog-lateral radiograph. For measures of femoral morphology, readers had more difficulty reproducing the alpha angle than the HNOR (0.55 vs. 0.21 on the frog-lateral and 0.08 vs. -0.08 on the cross-table lateral). Readers had only slight agreement in making a determination of the degree of osteoarthritis (kappa = 0.17).
TABLE 1

<table>
<thead>
<tr>
<th>Variable</th>
<th>RATER</th>
<th></th>
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<tr>
<td></td>
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<td>3</td>
<td>4</td>
<td>5</td>
<td>All raters combined</td>
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<tr>
<td>CEA</td>
<td>0.82 (0.70, 0.90)</td>
<td>0.88 (0.79, 0.93)</td>
<td>0.92 (0.86, 0.95)</td>
<td>0.86 (0.76, 0.92)</td>
<td>0.87 (0.78, 0.93)</td>
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<tr>
<td>VCA</td>
<td>0.67 (0.47, 0.80)</td>
<td>0.75 (0.59, 0.86)</td>
<td>0.96 (0.94, 0.98)</td>
<td>0.97 (0.95, 0.98)</td>
<td>0.88 (0.79, 0.93)</td>
<td>0.88 (0.85, 0.91)</td>
</tr>
<tr>
<td>Tönnis Angle</td>
<td>0.90 (0.83, 0.94)</td>
<td>0.72 (0.55, 0.84)</td>
<td>0.87 (0.77, 0.92)</td>
<td>0.72 (0.55, 0.84)</td>
<td>0.93 (0.87, 0.96)</td>
<td>0.83 (0.79, 0.87)</td>
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<tr>
<td>HNO (Frog)</td>
<td>0.77 (0.62, 0.87)</td>
<td>0.63 (0.41, 0.77)</td>
<td>0.90 (0.83, 0.94)</td>
<td>0.84 (0.72, 0.91)</td>
<td>0.78 (0.64, 0.88)</td>
<td>0.78 (0.72, 0.83)</td>
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<tr>
<td>α (Frog)</td>
<td>0.70 (0.51, 0.82)</td>
<td>0.68 (0.49, 0.81)</td>
<td>0.84 (0.73, 0.91)</td>
<td>0.33 (0.05, 0.57)</td>
<td>0.58 (0.35, 0.74)</td>
<td>0.76 (0.70, 0.81)</td>
</tr>
<tr>
<td>HNO (XTL)</td>
<td>0.53 (0.29, 0.71)</td>
<td>0.45 (0.18, 0.65)</td>
<td>0.36 (0.08, 0.59)</td>
<td>0.82 (0.69, 0.89)</td>
<td>0.50 (0.24, 0.69)</td>
<td>0.75 (0.69, 0.80)</td>
</tr>
<tr>
<td>α (XTL)</td>
<td>0.47 (0.21, 0.67)</td>
<td>0.29 (0.01, 0.54)</td>
<td>0.74 (0.57, 0.85)</td>
<td>0.93 (0.88, 0.96)</td>
<td>0.64 (0.43, 0.78)</td>
<td>0.76 (0.70, 0.81)</td>
</tr>
<tr>
<td>Tönnis OA grade</td>
<td>0.31 (0.09, 0.53)</td>
<td>0.57 (0.35, 0.78)</td>
<td>0.93 (0.83, 1.00)</td>
<td>0.53 (0.23, 0.82)</td>
<td>0.49 (0.31, 0.67)</td>
<td>0.57 (0.47, 0.66)</td>
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</tbody>
</table>

Table 1. Intrarater reliability for 1st and 2nd reading per rater for continuous (CEA, VCA, Tönnis angle, Head-neck offset ratio (HNO) and alpha angle) and categorical variables (Tönnis osteoarthritis grade and diagnosis). Data are ICC (95% CI for ICC) for continuous variables and kappa values for categorical variables. Abbreviations: CEA = lateral center-edge angle; VCA = anterior center-edge angle; α = alpha angle; Frog = frog leg lateral; XTL = cross table lateral; OA = osteoarthritis.

TABLE 2

<table>
<thead>
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<th>Variable</th>
<th>κ or ICC (95% CI)</th>
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<td>CEA</td>
<td>0.64 (0.52, 0.75)</td>
</tr>
<tr>
<td>VCA</td>
<td>0.38 (0.26, 0.53)</td>
</tr>
<tr>
<td>Tönnis Angle</td>
<td>0.42 (0.29, 0.56)</td>
</tr>
<tr>
<td>HNO (Frog)</td>
<td>0.55 (0.42, 0.68)</td>
</tr>
<tr>
<td>α (Frog)</td>
<td>0.21 (0.11, 0.36)</td>
</tr>
<tr>
<td>HNO (XTL)</td>
<td>0.08 (-0.01, 0.20)</td>
</tr>
<tr>
<td>α (XTL)</td>
<td>-0.08 (-0.12, -0.01)</td>
</tr>
<tr>
<td>OA grade</td>
<td>κ=0.17</td>
</tr>
</tbody>
</table>

Table 2. Interrater reliability for agreement across multiple raters (using 1st readings only).

Data are multiple kappas (κ) for categorical variables (OA grade, film quality, diagnosis) and ICCs for continuous variables (95% CI for ICC).

Abbreviations: CEA = lateral center-edge angle; VCA = anterior center-edge angle; α = alpha angle; Frog = frog leg lateral; XTL = cross table lateral; OA = osteoarthritis.

DISCUSSION

The purpose of this study was to assess the ability of a collection of readers (with differing specialties and varied levels of clinical experience in treatment of hip disorders) to reliably calculate multiple commonly used radiographic parameters of structural hip anatomy. None of the observers had an established practice focus on the treatment of this patient population. This specific collection of observers was utilized to simulate the variety of healthcare providers that evaluate these patients. In general, we found that readers were able to reproduce their individual measurement techniques from read to read, but that readers as a whole were unable to reliably agree on precise measures of acetabular and femoral morphology.

There are certain limitations to the study. First, despite a standardized imaging protocol, inconsistencies in radiographic technique were inevitable as multiple technicians were involved in the creation of the radiographs. This was particularly reflected in the quality of cross-table lateral films which lacked uniformity in both limb positioning (degree of femoral rotation) and beam penetration. This likely contributed to the markedly lower kappa values and inter-rater reliability noted on these views compared to the frog-leg lateral.

Secondly, an argument could be made that the limited number of readers with specific training in joint reconstructive surgery negatively impacted the results. This may be true, yet our goal was to assess a variety of health care providers to mimic clinical practice.

Other investigators have recently reported on hip radiographic reading reliability. Using two experienced readers and 100 hips, Tannast et al. evaluated the lateral center-edge angle (LCEA), anterior center edge angle (VCA), and acetabular inclination in their study on validation of the Hip2Norm software. They found intraobserver reliability for acetabular inclination to range from a kappa value of 0.74-0.89 (compared to a range of 0.72-0.93 in our study), and for interobserver reliability, an interclass correlation coefficient of 0.61 (compared to 0.42 in our study). They noted intraobserver kappa values of 0.97 to 0.98 for the lateral center-edge angle (compared to 0.82 – 0.92), and an interobserver ICC = 0.92 (compared to 0.64). For the anterior center edge angle, they noted intraobserver kappa values of 0.54 to 0.69 (compared to 0.67-0.97), and an interobserver ICC = 0.63 (compared to 0.38). While our interobserver numbers remain comparatively lower, in the case of acetabular inclination this might be partially explained by the use of the lateral edge of the acetabulum as the lateral marker for inclination (as opposed to the most laterally projected point of the acetabulum, as done in the Tannast study). Though the inclination of the weight-bearing dome of the acetabulum is comparatively more representative of structural instability, finding the
true lateral aspect of the sourcil can be difficult, and is somewhat dependent on radiographic technique. For purposes of creating a more reproducible marker of dysplasia, use of the technique as performed by Tannast et al. might prove more reliable, even in the hands of a larger number of readers. Additionally, this study highlights impaired reliability with experienced readers and with a computerized software system.

Steppacher et al.12 evaluated the reliability of the Tönnis classification of osteoarthritis utilizing two readers and 50 image sets. They found intraobserver reliability of \( \kappa = 0.73-0.76 \) and interobserver reliability of \( \kappa = 0.74 \). Both values are higher than the mean combined intraobserver kappa value of 0.57 and the interobserver kappa value of 0.17 noted in our study. Likewise, in our previous study with expert readers,24 kappa values were also lower than those noted by Steppacher et al with combined intraobserver values of 0.60 and interobserver values of 0.59. As we noted previously, the difference in values might be secondary to the introduction of a “normal” cohort of patients in both of our studies (versus a dysplastic only cohort in their study), as the distinction between grade 0 osteoarthritis (seen in the normal cohort) and grade 1 osteoarthritis (seen in some of the less severe cases of impingement and dysplasia) can sometimes be difficult and dependent on radiographic quality.

In summary, this study highlights the limited ability of various readers to reproduce radiographic measurements for structural hip anatomy. Nevertheless, individual readers are able to reliably recreate such measurements. These data are important and suggest that there is a need to standardize and educate providers regarding the radiographic evaluation of the hip. Doing so may enhance the ability of healthcare providers to more effectively screen and treat patients with prearthritic hip disease. Future efforts should be targeted at improving the reliability of hip radiographic analysis by both primary musculoskeletal caregivers and hip specialists. This may be facilitated by refining or clarifying the definitions for specific radiographic measurements, establishing detailed methodology for making these measurements, and incorporating imaging software programs to improve the reliability between observers.

REFERENCES


CONCOMITANT INFECTION AND LOCAL METAL REACTION IN PATIENTS UNDERGOING REVISION OF METAL ON METAL TOTAL HIP ARTHROPLASTY

Kyle T. Judd, M.D., Nicolas Noisieux, M.D.

ABSTRACT

Total hip arthroplasty (THA) with conventional polyethylene bearings is traditionally the standard operative treatment for endstage arthritis of the hip. This design has excellent survivorship in most populations, with a low occurrence of infection and other associated complications. Due to concern over increased wear in younger, more active populations, other bearing surfaces have been evaluated, particularly metal-on-metal with wear rates theorized to be lower than conventional THA. Unique to metal-on-metal THA, however, is the possibility of local soft tissue reactions that can mimic infection, making proper diagnosis and treatment difficult. We present a case series of nine hips in eight patients undergoing revision of metal-on-metal THA for local soft tissue reactions, three of which were also found to be concomitantly infected. The laboratory and hip aspirate data described show significant overlap between the infected and non-infected cases. Care must be taken when evaluating patients with failed metal-on-metal THA as there may be an increased incidence of co-infection in this group of patients.

INTRODUCTION

Total hip arthroplasty is a well established treatment for hip pain and dysfunction due to advanced osteoarthritis. The traditional bearing in hip arthroplasty is metal-on-polyethylene, formerly standard, and more recently highly cross-linked. Wear rates with this bearing surface have been studied extensively and found to be acceptable over long periods for most. With metal-on-polyethylene bearing surfaces, there is typically no significant local soft tissue reaction to wear. Infection rates are usually seen as a distinct complication for primary total hip arthroplasty, and have been shown to be approximately 1%. Patients with a total hip arthroplasty presenting with complaints of pain, systemic symptoms, wound issues and/or local swelling, redness or warmth are evaluated with tests that make detection of an infection relatively straightforward, if they can all be done. These include serum ESR and CRP, and a hip aspiration sent for a cell count and differential as well as a culture and sensitivity profile. These patients often have typical signs and symptoms, and abnormal results of one or more of these laboratory values that are independent of and unrelated to any bearing wear. In those patients who are found to have an infected THA, the most common pathogen is Staphylococcus Aureus, followed by other strains of Staphylococcus, mainly coagulase-negative species. For total hips undergoing revision for presumed aseptic loosening, between 4% and 13% are found to be concomitantly infected at the time of revision surgery. Based on evidence of higher revision rates in younger, more active patients with THA, interest in alternative hard bearings including metal-on-metal has increased. The theoretical advantage of lower wear rates with this bearing surface has made it attractive for higher demand patients. Recently, however, the particles or ions generated by metal-on-metal bearings have been implicated in significant local reactions. These reactions, alternatively termed Aseptic Lymphocytic Vasculitis Associated Lesion (ALVAL), Adverse Reaction to Metal Debris (ARMD), Adverse Local Tissue Reaction (ALTR), metallosis or pseudotumor, can cause considerable dysfunction and local tissue destruction. Proper diagnosis of these local complications can be challenging as the clinical picture of one of these local reactions can be hard to distinguish from an infected metal-on-metal total hip arthroplasty. Laboratory values, radiographic imaging and aspiration cell count results can be similar in the aseptic (reaction to metal debris) and septic conditions. Infection rates for metal-on-metal arthroplasty (without concomitant local reactions) have also been shown to be approximately 1%, with typical pathogens being Staphylococcus species. Infection rates for patients with adverse local tissue reactions are currently not well defined.
TABLE 1
Serum Cobalt and Chromium, Total nucleated cells from hip aspirate, ESR and CRP for each patient.

<table>
<thead>
<tr>
<th>Patient</th>
<th>Preoperative Serum Co/Cr Ion Levels (ug/L)</th>
<th>Total Nucleated/MM3</th>
<th>ESR (mm/hr)</th>
<th>CRP (mg/dl)</th>
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<tr>
<td>1</td>
<td>n/a</td>
<td>1599*</td>
<td>75*</td>
<td>33.2*</td>
</tr>
<tr>
<td>2a</td>
<td>n/a</td>
<td>57715*</td>
<td>81*</td>
<td>7.7*</td>
</tr>
<tr>
<td>2b</td>
<td>33.7 / 2.4</td>
<td>11147</td>
<td>29</td>
<td>3.6</td>
</tr>
<tr>
<td>3</td>
<td>n/a</td>
<td>lost sample</td>
<td>42</td>
<td>8.9</td>
</tr>
<tr>
<td>4</td>
<td>9.1 / 3.9</td>
<td>41344</td>
<td>43</td>
<td>2.5</td>
</tr>
<tr>
<td>5</td>
<td>127.5 / 1.0</td>
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<td>3</td>
<td>0.5</td>
</tr>
<tr>
<td>6</td>
<td>n/a</td>
<td>183530</td>
<td>14</td>
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</tr>
<tr>
<td>7</td>
<td>n/a</td>
<td>112432</td>
<td>3</td>
<td>0.5</td>
</tr>
<tr>
<td>8</td>
<td>n/a</td>
<td>480195*</td>
<td>58*</td>
<td>30.8*</td>
</tr>
</tbody>
</table>

* denotes infected cases.
For patient #2 both the right (a) and left (b) metal-on-metal total hips were revised.

Treatment of an infected total hip arthroplasty is typically by irrigation and debridement or two stage revision. Our hypothesis is that the concomitant infection rate in patients with a local tissue reaction around a metal-on-metal THA may be higher than in patients with either conventional bearing (metal-on-polyethylene) THA or those with a metal-on-metal THA without evidence of a local tissue reaction. Secondly, we predict that the causative pathogens in patients with local tissue reactions and concomitant infection are atypical compared to what is commonly seen with infected THA. We present a consecutive case series of patients undergoing revision THA for adverse reaction to metal debris and the subgroup that was found to have concomitant infection.

METHODS

Nine metal-on-metal total hip arthroplasties in eight consecutive patients undergoing revision for persistent pain and dysfunction, and with pre-operative and/or intra-operative findings of ALVAL, pseudotumor or metal debris reaction were followed post operatively via chart review. IRB approval was obtained from the institution’s internal review board prior to the initiation of the study. The patients were followed between 3 months and 1 year after revision. Pathological, microbiology and laboratory markers for infection were assessed. Post operative treatment courses were also reviewed.

RESULTS

Demographics: The current series consisted of five men and three women ages 50 to 73 years. For one patient (#2) both the right and left hips were involved at separate incidences. Time from index procedure to revision ranged from 12 months to five years. Revisions were undertaken due to: Pain (3/8), acetabular loosening (2/8), dislocation/instability (1/8), and infection (2/8).

Laboratory Evaluation: Pre-operative ESR/CRP levels, hip joint aspirate cell counts, and serum cobalt/chromium levels (Table 1) when available.

Microbiology: Thirty-three percent (3/9) of the cases were culture positive via pre-operative aspirate (Patient 1 and Patient 8), or with post-operative growth of intra-operative cultures (Patient 2a). Of the culture positive patients all three grew streptococcus; two with -Hemolytic streptococcus (Patients 1 and 8) and one with nutritionally variant streptococcus-Granulicatella Abiotrophia (Patient 2a).

Intraoperative Findings: Thirty-Three percent (3/9 cases) with necrotic appearing tissues (Figure 1). Other common findings were large joint effusions 33% (Patients 2a/b, 6) and metallosis 33% (Patients 4, 5, 7).

Pathology: (Table 2).

Operative Treatment: Irrigation and debridement alone (Patient 8, acute hematogenous infection, monoblock cup). Irrigation and debridement with bearing exchange (Patient 1, 3). Acetabular Revision w/polyethylene liner (Patients 2a/b, 4-7).
Infection and Local Metal Reaction in Patients Undergoing Revision of Metal on Metal Total Hip Arthroplasty

TABLE 2
Final pathology tissue diagnosis from specimens obtained at the time of operation.

<table>
<thead>
<tr>
<th>Patient</th>
<th>Final Tissue Diagnosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1*</td>
<td>Coagulative Necrosis</td>
</tr>
<tr>
<td>2a*</td>
<td>Acute inflammation with areas of histiocytic and fibrotic appearance.</td>
</tr>
<tr>
<td>2b</td>
<td>Coagulative Necrosis. No acute/chronic inflammation</td>
</tr>
<tr>
<td>3</td>
<td>Necrosis, acute and chronic inflammation and fibrinopurulent exudate</td>
</tr>
<tr>
<td>4</td>
<td>Dense fibrous tissue with chronic inflammation, focal granulomatous inflammation and foreign body giant cell reaction and necrosis.</td>
</tr>
<tr>
<td>5</td>
<td>Aseptic lymphocytic vasculitis associated lesion</td>
</tr>
<tr>
<td>6</td>
<td>Necrotic tissue without significant associated inflammation</td>
</tr>
<tr>
<td>7</td>
<td>Necrotic tissue. No viable synovium oracute inflammation identified.</td>
</tr>
<tr>
<td>8*</td>
<td>Fibrovascular tissue w/mixed acute and chronic inflammatory infiltrate. Focal areas of dense perivascular lymphocytic aggregates</td>
</tr>
</tbody>
</table>

* denotes infected cases.

Figure 1. Representative intra operative photo showing soft tissue necrosis and “purulence” which is typically seen. GT: Greater Trochanter, SER: Residual short external rotators.

DISCUSSION

This case series presents eight patients with nine metal-on-metal total hips undergoing revision arthroplasty for pain, dysfunction or arthroplasty failure. All patients had evidence of an adverse local tissue reaction to metal debris, pseudotumor or ALVAL, by direct intra-operative observation of significant tissue destruction or a cystic mass, or by pathological tissue diagnosis. Thirty-three percent of the cases were found to be concomitantly infected.

The concern over adverse metal reactions and soft tissue pseudotumors in patients undergoing metal bearing hip arthroplasty continues to grow. Reports to date have been mostly single cases or case series, but Glyn-Jones et al. presented a large series of patients undergoing revision of metal-on-metal hips, and found a 1.8 % revision rate for pseudotumor alone. In their series, Kaplan Meier curves showing cumulative revision rates for pseudotumor increased with time, to as high as 4% at eight years.

It has also been found that infection in the face of adverse local tissue reaction after metal-on-metal total hip arthroplasty may be challenging to properly diagnose and treat given the overlap of symptoms, signs and laboratory values in both processes. Despite the similarities in clinical presentation, the treatment strategies for these two problems is usually quite different, making accuracy of the diagnosis important in optimizing patient outcome after revision.

In general, the infection rate for traditional (polyethylene) bearing THA is around 1%. (NIH Concensus Development Panel). The overall infection rate for metal-on-metal THA has also been shown to have an incidence of 1% or less. The presenting symptoms and signs of infection should be similar for both traditional (polyethylene) bearings and metal bearings particularly in the absence of any adverse local soft tissue reaction. Patients presenting with an adverse soft tissue reaction and/or pseudotumor typically present with more vague complaints of pain and hip dysfunction along with radiographic findings of a cystic mass. This presentation may be difficult to differentiate from infection.
The standard evaluation to diagnose an infected arthroplasty includes serum ESR and CRP values, and if these are elevated or suspicion is high, a hip joint aspiration sent for white (total nucleated) cell count and differential (PMN percentage in particular) and bacterial culture with sensitivity testing. Although nonspecific, the ESR and CRP are good indicators of systemic inflammation when elevated. The joint aspiration is a more accurate test for the diagnosis, but false positives and negatives do occur, as well as an inability to obtain fluid on occasion. Hip aspirates with a total nucleated cell count greater than 4200 cells/ml and greater than 80% PMN if taken in isolation or with a total nucleated cell count >3000, if both ESR and CRP are elevated above 30 mm/hr and 10 mg/DL respectively, have a high probability of being infected. A positive culture from the hip aspirate is the gold standard for pre-operative diagnosis of an infected THA, but it can take as long as 5-10 days to grow. Gross purulence and positive intra-operative tissue culture then becomes the final test used to confirm or refute infection.

It is now being recognized, however, that many of these pre-operative laboratory values may also be abnormal in metal-on-metal hips with local tissue reactions but without infection. In the current series, ESR and CRP were elevated in 3 of 6 hips without infection, and the total nucleated cell count was highly elevated in all uninfected hips (4/6) that had a successful aspirate. Furthermore, patient 3 did have an aspirate with this report: “Approximately 13 ml of pus were aspirated (from the hip). The fluid was delivered to pathology for cell count and to microbiology for culture . . . per the clinical request.” Unfortunately, the cell count tube was lost during transportation. The culture was negative. Thus, it appears that aspirates of affected metal-on-metal hips without infection can even have purulent appearing fluid.

This considerable overlap can make obtaining an accurate diagnosis and choosing the optimal treatment quite challenging. Differentiating the two processes as being separate or concomitant is critical since isolated local soft tissue reactions can often be treated with revision of the bearing surface only to a non-metal alternative; but for infection, irrigation and debridement with extended IV antibiotics or more commonly two stage revision of the entire prosthesis may be necessary.

In the current series, 38% (3/9 hips) were found to be infected as well as have signs of local reaction to metal debris. Two patients had known infections at the time of operation with a pathological diagnosis of ALVAL or intraoperative pseudotumor. The third, with a large pseudotumor and presumed ALVAL only, proved to be culture positive on post operative day 4. This ratio is much higher than that reported for either traditional bearings or metal-on-metal bearings without evidence of a local soft tissue reaction. Prior to this series concomitant infection and local soft tissue reaction had only been described in a single case report by Watters et al. In this case, the presentation and treatment of a patient with concomitant local soft tissue reaction and local infection is described. This rate of coinfection is also presumably higher than those patients found to be infected at the time of revision for polyethylene wear.

Intraoperative observational evaluation also has the potential to be unreliable in distinguishing infection from isolated local soft tissue reactions. Common to both, in this series (whether or not infection was present) and those previously published, are the findings of metal staining of the soft tissues, cystic masses, large exudates and tissue necrosis. In the current series pathological evaluation is consistent with previous descriptions of pseudotumor and local metal reactions. In our infected patients, a pathology reading of the intraoperative frozen section of ‘acute inflammation’ (>5 WBC per hpf in multiple fields) seemed to be the most predictive descriptor of infection as two of the three patients had this present.

Finally, the prevalence of uncommon infective agents in our series was also felt to be unusual. Streptococcus has occasionally been implicated in concomitant infection and local metal reaction, but it is not among the more common bacteria isolated from infected total hip arthroplasties, particularly Granulicatella Abiotrophia. This finding may certainly be a function of the small number of patients, but predilection for infection with atypical agents in the face of soft tissue metal reaction cannot be excluded.

CONCLUSION

The prevalence of concomitant infection and adverse local tissue reaction in patients with a metal-on-metal total hip arthroplasty may be higher than in patients with traditional polyethylene bearings or in patients with metal-on-metal bearings without signs of ALVAL, ALTR, or pseudotumor. Distinguishing between isolated adverse soft tissue reactions, deep infection and the co-existence of both can be challenging in a metal bearing total hip arthroplasty. Vigilance should be maintained in the evaluation of patients with painful metal-on-metal total hips with a suspicion of infection or ALTR, as the treatment algorithm and outcome for each problem can vary significantly. Atypical pathogens may be found more frequently in hips with ALTR and concomitant infection.
REFERENCES


DEMOGRAFIC AND COMORBID DISPARITIES BASED ON PAYER TYPE IN A TOTAL JOINT ARTHROPLASTY COHORT: IMPLICATIONS IN A CHANGING HEALTH CARE AREA

Lucian C. Warth, MD,John J. Callaghan, MD,Christopher W. Wells, BA,Steve S. Liu, MD,Alison Klaassen,MA,Yubo Gao, PhD,Richard C. Johnston, MD

ABSTRACT

Introduction

The purpose of this study was to compare differences in demographic, functional, access to care, and comorbidity data between a Medicaid and Iowa Care (state Medicaid) insured patient cohort and Medicare and a Commercial Payer patient cohort undergoing lower extremity total joint arthroplasty (TJA).

Material & Methods

A retrospective review of 874 primary TKAs and THAs by a single surgeon at an academic institution between January, 2004 and June, 2008 was performed. Data on the primary insurance payer was used to stratify the cohort into two groups; Medicaid and Iowa Care (state Medicaid) insured and Medicare and commercial payer. Demographic, functional, access to care, and comorbidity data obtained from a standard preoperative survey were compared.

Results

Of 874 primary TKAs and THAs, 18.3% of patients were Medicaid and Iowa Care insured, while 81.7% were insured by Medicare and commercial payer. Average age was 53.7 and 62.3 respectively, while average BMI was 35.2 and 32.9 respectively. The Medicaid and Iowa Care group was found to be 3 times more likely to smoke tobacco (25.2% v. 8.3%). Preoperative WOMAC Function scores were 33.9 and 46.8, respectively. Self reported diabetes was used as a general surrogate for health comorbidities and occurred in 12.3% and 11.5% respectively. Distance traveled was used as a general surrogate for access to care with averages of 92.5 miles and 62.8 miles, respectively.

Conclusion

The Medicaid and Iowa Care (state Medicaid) group had significantly higher rates of smoking, were significantly younger, and had significantly lower WOMAC scores (p<0.05) preoperatively. BMI comparison showed a trend to greater obesity in the Medicaid and Iowa Care cohort (p=0.056). Diabetes rates were comparable between the two cohorts. Medicaid and Iowa Care patients traveled 29.7 miles farther, suggesting they had less access to local orthopaedic care. There are major differences in comorbidities and patient demographics between payer types.

INTRODUCTION

Few investigations have been performed evaluating the differences in comorbidities between insurance payer groups of patients undergoing total joint arthroplasty (TJA). The purpose of this study was to determine whether Medicaid and Iowa Care insured patients undergoing primary TJA differed from Medicare and commercial payer patients in terms of demographic, functional, access to care, and comorbidity data. The authors examined patients undergoing total knee arthroplasty (TKA) and total hip arthroplasty (THA) in a single surgeon’s practice at an academic institution to evaluate disparities in comorbidities and demographics based on payer mix.

In light of evolving health care legislation it is foreseeable that socioeconomic, demographic and comorbid characteristics of orthopaedic patient populations will shift as access to health care continues to develop. The changing health care arena will affect the practice of both the academic and the private orthopaedic surgeon. The United States Centers for Medicare and Medicaid Services have advocated for pay-for-performance programs as a way to improve health-care quality and decrease medical costs. It has been suggested that high volume TJA teaching hospitals such as the one examined in this study will tend to succeed should pay-for-performance
programs be enacted on a broader spectrum. If pay-for-performance tenets are to become increasingly adopted into orthopaedic practice, a more concrete understanding of how complex social, functional, and demographic factors affect outcomes will become more important. We will need to ensure that outcome and performance measure are appropriate and that they account for these variables.

Hospital economics with respect to TJA will necessarily continue to evolve, and the trend towards decreasing reimbursement and increasing cost has yet to reach a steady balance. A more definitive understanding of complex patient factors and how patient groups can be stratified will help ensure appropriate measures of success. An improved grasp of patient characteristics will become increasingly important to facilitate optimal preoperative planning and postoperative management to maximize clinical outcomes and ensure continued financial viability across institutions as well as across various insurance providers.

Economic barriers in access to health care are becoming increasingly difficult to overcome for low income and Medicaid insured patients. The recent economic downturn is also forcing many total joint surgeons to accept fewer Medicare and Medicaid payer patients. The university setting examined in this study is one of only two facilities accepting the state aid (Iowa Care) patients who are representative of this disadvantaged cohort. A more nationwide trend towards increasingly limited access to care of Medicaid beneficiaries has also been observed. Recent studies have implicated socioeconomic factors and preoperative status in predicting postoperative outcomes. The authors hypothesized that disparities in demographics and payer mix would exist between patients of various payer types.

**MATERIALS AND METHODS**

A retrospective cohort study design was used to mine and review data on all patients who underwent total joint arthroplasty by a single surgeon (JJC) at the University of Iowa Hospitals and Clinics from January, 2004 to June, 2008. CPT codes for primary total hip arthroplasty and primary total knee arthroplasty were used to define our initial patient group. Prior to new patient clinic visits in the total joint arthroplasty clinic, all patients routinely complete a standard questionnaire which included information on baseline demographic, social, and functional data (age, race, zip code, self-reported smoking status, self-reported diabetes status, Harris Hip Score, and WOMAC score). This was cross-referenced with the hospital billing system to determine primary insurance payer status.

Subjects were stratified into two cohorts based on primary insurance carrier. The Medicaid and Iowa Care group included a subgroup of patients with Medicaid as their primary insurer, in addition to a subgroup with Iowa Care (state Medicaid) insurance as their primary payer. Iowa Care is a limited health care program provided by the State of Iowa that covers adults (ages 19-64) who would not normally be covered by Medicaid. A second cohort included Medicare and commercially insured patients.

Self-reported smoking rates were considered as a general surrogate for social comorbidities. Body mass index (BMI) and self-reported diabetes rates were considered a general surrogate for medical comorbidities. Distance traveled was considered a general surrogate for access to care, and was calculated using an on-line map service and the home address zip codes from billing and demographic data.

The authors hypothesized that the Medicaid and Iowa Care group would have traveled significantly farther for care, would have a significantly greater BMI, significantly higher rate of smoking, and higher rate of self-reported diabetes when compared to the Medicare and commercial payer group.

This study was conducted in compliance with IRB approval.

**STATISTICAL ANALYSIS**

All categorical variables were analyzed using standard t-test, and Chi-square analysis to determine p-values with significance set at p<0.05.

**RESULTS**

Of the 874 primary TKAs and THAs, 155 (18.3%) patients were Medicaid and Iowa Care insured, and 719 (81.7%) were covered by Medicare and Commercial Payer. With respect to patient demographics, we found the average age was 53.7 in the Medicaid and Iowa Care group, and 62.3 in the Medicare and commercial payer group, while average BMI was 35.2 and 32.9, respectively (p=0.056) (Table 3). While the difference in age was significant (p<0.05), this data is inherently skewed as utilization of services varies with insurance status, and Medicare becomes the primary payer of elective TJA after the age of 65. The average BMI of both groups was obese. There was a trend toward greater obesity in the Medicaid and Iowa Care group which did not reach statistical significance.

Self-reported smoking information which was obtained on our preoperative survey included the following 6 groups: currently smoking, never smoked, quit more than 6 months ago, quit less than 6 months ago, and no
TABLE 1. Medicaid and Iowa Care Smoking Data

<table>
<thead>
<tr>
<th>Smoking Subgroup</th>
<th>Medicaid and Iowa Care</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
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<td>100</td>
</tr>
<tr>
<td>Q&lt;6mo</td>
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<td>3.8</td>
</tr>
<tr>
<td>Never</td>
<td>48</td>
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</tr>
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</table>

Preoperative WOMAC scores were significantly less for the Medicaid and Iowa Care group when compared with the Medicare and commercial payer group (33.9 v. 46.8, p<0.05). Self reported diabetes rates showed no statistical significance (12.3 % v. 11.5%).

Distance traveled was considered a general surrogate for access to care with averages of 92.5 miles for the Medicaid and Iowa Care group and 62.8 miles Medicare and commercial payer group (Table 3).

DISCUSSION AND CONCLUSIONS

The rate of smoking was found to be significantly higher in the Medicaid and Iowa Care group (p<0.05). While body mass index between the two groups examined showed a trend towards greater obesity in the Medicaid and Iowa Care group (p=0.056) without statistical significance, a population which was less obese overall or a larger cohort may exhibit a significant difference.

TABLE 2. Medicare and Commercial Payer Smoking Data

<table>
<thead>
<tr>
<th>Smoking Subgroup</th>
<th>Medicare and Commercial Payer</th>
<th>%</th>
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<tr>
<td>Total</td>
<td>719</td>
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<tr>
<td>Q&lt;6mo</td>
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<td>Never</td>
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<td>124</td>
<td>17.2</td>
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</table>

These trends are concerning. If continued research shows these differences to be real they may need to be incorporated for payment equity and to minimize incentives for selection bias among hospitals that perform TJA procedures.

In a Medicare cohort of patients undergoing TKA, comorbidities increased infection risk, and patients re-
ceiving public assistance for Medicare premiums were at higher risk for total joint infection. In a Medicare cohort of patients undergoing THA, comorbidities and socioeconomic status were found to be significant risk factors for total joint infection. Webb et al found an increased risk of infection in total joint arthroplasty based on socioeconomic background. In contrast, better preoperative pain scores and fewer comorbidities have been associated with better outcomes after revision total hip arthroplasty.

The goal of Medicare payment policy is to set payment rates proportional to relative resource use. Bozic et al concluded that both severity of illness and surgical complexity should be incorporated for payment equity and to minimize incentives for selection bias among hospitals that perform TJA procedures. Based on our findings, preoperative smoking status, socioeconomic and payer status may also merit consideration.

Hinman et al showed that Medicaid patients traveled twice as far to receive orthopaedic treatment. We found that Medicaid and Iowa Care patients traveled 29.7 miles farther (almost a 50% increase), also suggesting they had less access to local orthopaedic care. Decreased access to care and increased time to presentation could logically correlate with the decreased functional scores and poorer clinical outcomes they observed in their Medicaid population when compared to a commercially insured cohort.

Socioeconomic factors were found by Butler et al to have more impact on the clinical outcome of cementless total hip arthroplasty than implant-related factors. Ethnicity, educational level, poverty level, income, and low preoperative WOMAC score have been found predictive of inferior clinical results postoperatively. In the Medicaid and Iowa Care cohort examined in this study we found a significantly lower preoperative WOMAC score.

It seems clear that socioeconomic factors and preoperative status play a key role predicting postoperative outcomes. Further research to define our understanding of complex social, functional, and demographic factors will be necessary. Moving forward this knowledge will be crucial to ensure improved outcomes and to guide appropriate compensation if pay-for-performance tenets are to become increasingly adopted into orthopaedic practice.

There were several limitations to this study. Our initial preoperative survey was optional, and consequently there were a significant amount of non-responders (for smoking data, 24.5% of Medicaid and Iowa Care, 17.2% of Medicare and commercial payer). While there were a large percentage of non-responders in both groups, it is possible that this may have significantly altered our results. Additionally, rates of smoking and diabetes were self-reported. Self-reporting likely introduces under-reporting of smoking rates secondary to patient unease with respect to associated stigma. Diabetes rates may have been under-reported secondary to a poor understanding of the disease process or inadequate diagnostic evaluation at the time of the survey. Lastly, this was a single surgeon cohort at a Midwestern academic center and may not hold external validity when compared with other cohorts. Although we recognize the limitations of the study, this work corroborates the findings of others that there are major difference in comorbidities and patient demographics between total joint replacement patients of varying payer types. These differences must be accounted for when determining the significance of any differences in outcomes or performance in populations with different distributions of payer types.

ACKNOWLEDGEMENTS
We would like to acknowledge the Bierbaum Research Fund.

BIBLIOGRAPHY


HINGED CAST BRACE FOR PERSISTENT FLEXION CONTRACTURE FOLLOWING TOTAL KNEE REPLACEMENT

Matthew D. Karam, MD1 Andrew Pugely MD,2 John J. Callaghan, MD,1 Donald Shurr, CPO, PT2

ABSTRACT

The reported incidence of persistent knee flexion contracture following total knee arthroplasty (TKA) has varied from 1-15 percent. Various treatment modalities have been described in attempts to manage this often difficult problem. This paper describes a novel method of treatment by using a hinged cast brace (previously reported for treatment of femur fractures and knee contractures secondary to hemophilia and cerebral palsy) for use in patients with symptomatic knee flexion contractures. Application of this cast brace with frequent adjustment (every three to four days, initially) toward full extension can often improve knee extension, after physical therapy and other modalities such as extension-assist braces have failed. Care must be taken in the application and use of this device which utilizes frequent manipulations to reduce and maintain the knee flexion angle. We report two clinical cases in which this protocol was effectively used in decreasing symptomatic knee flexion contractures.

INTRODUCTION

The history of fracture care is filled with testimonials by bone-setters and physicians alike, professing the value of both immobilization and early motion. Dr. H. H. Smith wrote a short clinical report about femoral fractures using a brace/orthosis (which he labeled a prosthesis) for treatment of femoral fracture nonunion. This stabilized the bone, allowed the patient to ambulate and avoided amputation. He reported on a group of patients whose fractures healed following use of this brace with weight bearing.3

Sarmiento and Sinclair reported initial results using Smith’s concepts.2 Although they referred to the device as a brace or orthosis, Mr. Sinclair (who did the technical work of using the femoral fracture brace) was a Certified Prosthetist. The concept of using the ischial loading principal and the quadrilateral socket is a technique borrowed from prosthetics to treat an orthotic problem. The concept includes a quadrilateral socket with polycentric knee joints, allowing free motion of the hip, knee and ankle while the patient ambulates weight-bearing on the brace, allowing the fracture to heal.

Development of internal fixation for fracture care minimized the number of occasions where cast braces were used. However, it is not uncommon to now use a fracture brace to treat femoral fractures where the patient is not a surgical candidate due to medical comorbidities. The hinged cast-brace fracture orthosis is therefore in the orthotists’ “quiver”. It is not unusual for an orthotist/prosthetist associated with a large total joint practice to provide care for patients whose knee extension is not complete. This paper is dedicated to that group of patients.

It is well known that flexion contracture of the knee can lead to symptomatic gait abnormalities. Knee flexion contracture has also been shown to increase the energy expenditure of walking.3 The reported incidence of flexion contracture following total knee arthroplasty is between 1 and 15%.4 Various treatment options have been described for the management of persistent symptomatic knee flexion contractures, including targeted strengthening exercises, manipulation under anesthesia and surgical debridement. The reported effectiveness of these management strategies has varied. Aside from technical considerations, the pathogenesis of flexion contracture

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1 Orthopaedic Trauma Fellow
Hennepin County Medical Center
701 Park Ave
Minneapolis, MN 55415

2 Orthopaedic Surgery Resident
Department of Orthopaedics and Rehabilitation
The University of Iowa
200 Hawkins Drive
Iowa City, Iowa 52242

3 The Lawrence and Marilyn Dorr Chair
Department of Orthopaedics and Rehabilitation
The University of Iowa
200 Hawkins Drive
Iowa City, IA 52242

4 Manager, American Prosthetics and Orthotics
200 Hawkins Drive
Iowa City, Iowa 52242

Contact:
Don Shurr, Manager
American Prosthetics and Orthotics
200 Hawkins Drive – 01400 JPP
Iowa City, IA 52242
(319) 356-2420

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of the knee following TKA is thought to be the result of tightening of the posterior capsule, the biceps femoris, the gastrocnemius muscles and tendons, as well as the collateral ligaments.\(^5\)

Fernandez-Palazzi et al. utilized a serial casting/wedging technique in the management of 58 patients with flexion contractures resulting from hemophilia. It was determined that, on average, it was possible to achieve 5 degrees of extension in four weeks, with little improvement thereafter.\(^6\) In another study, Westberry et al. performed a retrospective review of all cerebral palsy (CP) patients with resistant or recurrent knee flexion contracture treated with serial stretch-casting. Their protocol, which also included serial wedging (five degrees/week), was performed on 46 subjects (75 extremities), with a mean duration of 30 days casting. They noted correction to within 10 degrees of full extension in 76% of patients.\(^7\)

Our institution has used hinged cast-braces for treatment of symptomatic knee flexion contractures for several years. We have developed a formal protocol in conjunction with an orthotics team for treating this challenging entity. This protocol consists of an initial application of a cast brace, followed by serial manipulations and rocking of the articulated hinge. The goal is to achieve gradual and controlled extension as quickly as allowed, and then to maintain full extension for one to two weeks before removing the brace. This report describes our novel use of hinged cast braces to treat knee flexion contractures. In addition, we present two cases of patients who developed knee flexion contractures following TKA and were successfully managed according to this unique protocol.

**DESCRIPTION OF TECHNIQUE/PROTOCOL**

Following inspection of the entire limb, a wool and Lycra Spandex-knitted, full-length, closed-toe sock is applied. This sock acts as an interface with the skin and offers gentle compression due to its design. Once the sock is wrinkle-free, polyester soft roll is applied over the head of the fibula, the malleoli, the heel, and any other bony prominence. Elastic plaster is then rolled on, starting just below the fibular head distally to the mid-metatarsal heads of the first and fifth rays. Care is taken to overlap approximately one third of each wrap, using care to not place any undue circular compression at any level.

Next, the thigh is wrapped, again using elastic plaster. The key to this procedure is using enough compression to allow medial and lateral flattening of the cylinder to later accept the knee-joint uprights. The proximal trim line is just distal to the trochanter laterally, angling medially and distally to maintain medial wall height while not impinging on the perineum. The thenar eminences of both hands compress the cast from the medial and lateral sides, forming a flat surface on the lateral wall and an indentation medially to allow the plaster to follow the contour of the medial femur and condyle. Once the plaster is set it is allowed to cool, so application of the joints allows for their suspension just proximal to the knee center.

Polycentric aluminum or stainless steel knee-joint uprights are used for the cast brace depending on the weight and size of the patient. As seen in figure 2 below, the joint heads have a back plate with set screws around them limiting both flexion and extension. These set screws are adjusted throughout the duration of treatment. With dorsal compression above and below the knee, additional extension may be attained following limitation of flexion during the use of the orthosis. Adjustments are performed every four-to-seven days in an attempt to increase each patient’s knee extension; after that point, extension is maintained for another one-to-two weeks with full weight bearing. The patient may need to take a small amount of narcotic medication for the initial adjustment period, but rarely thereafter. Maintenance of the cast brace after achieving full extension, and having the patient walk as much as possible, allow continued stretching of the tight capsular, ligamentous and muscular structures behind the knee.

Care must be taken during application of the orthosis to use extra soft roll or foam over the posterior heel, the anterior tibia at the proximal cast trim line near the tibial tubercle, and at the anterior distal trim line of the thigh shell just above the patella. Extension measurements are taken and recorded prior to and following each application and adjustment. These numbers are always shared with patients in an effort to maintain their cooperation in this sometimes uncomfortable process.

This study was approved by the Institutional Review Board of The University of Iowa.
CASE REPORTS
A 53-year-old female presented in 2006 with significant knee pain and radiographic evidence of tricompartmental osteoarthritis. Her past medical history was positive for hypothyroidism. In June of 2006, after failed conservative management, she underwent an uncomplicated left total knee arthroplasty. Soon after discharge, the patient noted stiffness for which physical therapy was prescribed. At six weeks post-operatively, without improved range of motion (ROM), she underwent manipulation under anesthesia. Still, at seven months after surgery, her maximal left knee ROM was 15 to 90 degrees. At that time, the patient agreed to the placement of a hinged cast brace per the aforementioned protocol. The cast brace was removed after two weeks and knee ROM was 0 to 85 degrees. No complications of the brace were noted. Two months after brace removal, the patient maintained a ROM of 3 to 110 degrees.

A 61-year-old male construction worker presented in 2006 with severe medial-sided left knee pain. He had a history of a left knee meniscal tear with arthroscopic repair 15 years prior. After failed conservative management with non-steroidal anti-inflammatory drugs, physical therapy and steroid injections, the patient saw a joint replacement specialist in 2009. Tricompartmental osteoarthritis was diagnosed and in early 2010 a left total knee arthroplasty was performed without complication. Initially, the patient had excellent ROM without flexion contracture. Several months after surgery, however, the patient noted increasing pain, effusion, and reduced ROM. Workup for infection was negative. Both systemic and joint-injected steroids did not provide adequate improvement in ROM, which was 15 to 110 degrees. At six months, a hinged cast-brace system was applied and then removed after two weeks without complication. Immediate post-bracing ROM was 0 to 90 degrees. Two-and-a-half months after brace removal the patient reported doing well, with minimal effusion and a ROM of 3 to 115 degrees.

CONCLUSION
Flexion contracture of the knee leads to increased energy expenditure of walking and can lead to alteration in gait and increasing knee pain. Knee flexion contracture has been reported in patients with hemophilia and cerebral palsy, and following total knee arthroplasty. When flexion contracture is symptomatic, it can prove difficult to manage non-operatively. We present a protocol and technique for use of a hinged femoral cast-brace orthosis in the treatment of symptomatic knee flexion contracture. Two clinical cases with short-term follow-up demonstrate acceptable results.

Table 1
Patient Case Data

<table>
<thead>
<tr>
<th>Patient</th>
<th>Gender</th>
<th>BMI</th>
<th>Age</th>
<th>Diagnosis</th>
<th>Surgery</th>
<th>Post-op time</th>
<th>Time n cast brace</th>
<th>ROM before brace</th>
<th>ROM after brace</th>
<th>ROM two months after brace</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient 1</td>
<td>F</td>
<td>24</td>
<td>53</td>
<td>Osteoarthritis</td>
<td>LTKA</td>
<td>7 months</td>
<td>14 days</td>
<td>15 to 90</td>
<td>0 to 85</td>
<td>3 to 110</td>
</tr>
<tr>
<td>Patient 2</td>
<td>M</td>
<td>32</td>
<td>61</td>
<td>Osteoarthritis</td>
<td>LTKA</td>
<td>6 months</td>
<td>12 days</td>
<td>15 to 110</td>
<td>0 to 90</td>
<td>3 to 115</td>
</tr>
</tbody>
</table>

LTKA = Left total knee arthroplasty (primary)
ROM = Range of motion, measured in degrees
REFERENCES


RANGE OF MOTION AND PATIENT SATISFACTION WITH TRADITIONAL AND HIGH-FLEXION ROTATING-PLATFORM KNEES

Clifford Kent Boese, MD, ’ ’ Theresa J Gallo, M-PAS, PA-C, ’ Carla J Plantikow, MSc

ABSTRACT

Although a high degree of flexion is necessary for some activities of daily living, most total knee arthroplasty implants are designed to provide only up to 120° of flexion. Some new designs claim to provide greater flexion. In this retrospective study, we evaluated the Sigma rotating-platform high-flex knee against the traditional Sigma rotating-platform knee (DePuy, Warsaw, IN). There were 153 knees evaluated. We matched the subjects primarily on preoperative flexion and had 64 matched pairs. We also evaluated the knees based on their preoperative flexion, either <120° or ≥120°. In comparing the two implants, there were no significant differences in the patients’ overall satisfaction, flexion gained or lost, or the need for further surgery. This study was approved by an institutional review board.

INTRODUCTION

Traditional knee replacements have been designed to provide painless range of motion from 0° to about 120° of flexion. More recently, designs have been introduced to allow up to 155° of flexion, which is necessary and/or helpful for kneeling, squatting, and sitting cross-legged. The PFC Sigma Rotating Platform High Flex (RP-F) is a high-performance posterior-stabilized knee based on the successful PFC Sigma posterior-stabilized design (DePuy, Warsaw, IN). There are a number of differences between the Sigma Rotating Platform (RP) and the RP-F. The RP-F has a reduced sagittal radius of the posterior condyles; a third articulating surface has been added behind the post-cam mechanism that is supposed to reduce the high-contact stresses seen in the posterior condyles during deep flexion; the design requires resection of an additional two-to-four millimeters of bone from the posterior femoral condyles; on the tibial side, a pin device has been added to reinforce the post during deep flexion (Figure 1); and the tibial post-and-strap insert has beveled surfaces to reduce the risk of soft-tissue impingement and allow greater rotation of the implant, respectively. The RP-F knee does cost more than the RP knee; for the patients in this study, the difference in cost was $1,100.

There have been two previous studies evaluating this knee system. In both studies, knees implanted with the RP-F device had significantly greater postoperative flexion than those with the RP knee. However, there were no significant differences in knee society scores, and one of the studies showed only a 1° difference in flexion between the two knee types. In studies evaluating other brands of high-flex implants, conclusions regarding flexion were varied. Some studies found significant differences in flexion between the traditional and high-flex knees while others did not show a significant difference. Most of these studies also used standard follow-up forms to assess the performance of the knee designs. In all but one of these studies, there were no significant differences between the high-flex and standard knee systems. Nutton et al. found that patients with high-flex implants had a slight advantage when squatting and getting into a bathtub. However, they concluded that this difference was too small to be clinically relevant. No study has specifically evaluated the effect of high-flexion knee designs on the patients' overall satisfaction with their knee replacement.

In the short term, the RP-F implant has been shown to be as safe as the RP knee, and it is supposed to provide lower levels of wear in deep flexion as compared to the traditional device. However, this claim has not been clinically evaluated.

The purpose of this study was to evaluate the performance of the Sigma RP knee versus the Sigma RP-F knee. As the high-flex knee is more expensive than the traditional implant, it is important to critically assess if its increased cost is justified by better performance. Our main research questions were:
1. Does knee-device type (high-flex vs regular) influence either the flexion measurements from pre-operative to post-operative, or overall patient satisfaction?

2. Does either the RP or RP-F knee have increased rates of complication leading to further surgery?

3. Based on the results of this study, is the higher cost of the RP-F implant justified?

MATERIALS AND METHODS

This was a retrospective, match-controlled study, with some of the data being collected prospectively. We conducted chart reviews on 163 total knee arthroplasties (TKAs) performed between December of 2006 and January of 2008. Inclusion criteria were a TKA performed by the senior author using Sigma rotating platform components. Patients were excluded if they did not have a recorded preoperative range of motion or if they received anything other than Sigma rotating platform components. During this period, 79 RP-F knees were implanted consecutively. The RP surgeries were performed immediately before and after the RP-F knees (43 before and 41 after). Seven subjects were lost to follow-up and three died from causes unrelated to their joint replacement, resulting in an analysis group of 153 subjects. The surgical procedure was similar in all cases, with a medial parapatellar arthroscopy, a tourniquet used intraoperatively, and DePuy Endurance MV cement for all components. There were 90 females (59%) and 63 males (41%). Mean age at surgery was 64.0 years, mean weight was 99.9 kg, and mean preoperative flexion was 111.9°. All patients were diagnosed with osteoarthritis.

Subjects' postoperative active extension and flexion measurements were taken with a goniometer by clinic workers blinded to the type of implant received. These measurements were then compared to preoperative records to determine net gain or loss in flexion. Follow-ups were at least nine months postoperatively (mean 16.7, range 9-33). Patients also answered a simple survey asking “How happy are you with your implanted knee?” with 1 equaling “completely dissatisfied” and 5 equaling “completely satisfied.” We monitored the patients' charts through 2010 (mean 42.8 months postoperatively, range 35.3-48.8), and any further surgery on the same knee was noted.

In order to minimize sample bias, RP-F knees were matched to RP controls. Sixty-four pairs of subjects were matched primarily on preoperative flexion, and secondarily on duration of follow-up, sex, age, and weight (see Table 1). In addition to this analysis, subjects were also divided into two groups based on preoperative flexion. Both previous studies of the RP-F knee found that it performed best in patients with <120° of preoperative
Range of Motion and Patient Satisfaction with Traditional and High-Flexion Rotating-Platform Knees

<table>
<thead>
<tr>
<th>TABLE 1. Demographic data for matched pairs</th>
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<tbody>
<tr>
<td>Pre-op flexion</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>RP</td>
</tr>
<tr>
<td>RP-F</td>
</tr>
<tr>
<td>P value*</td>
</tr>
</tbody>
</table>

RP= Sigma Rotating Platform   RP-F= Sigma Rotating Platform High Flex
* Two-tailed Student’s t-test and chi square test (for sex)

flexion\textsuperscript{13}. Therefore, analysis was performed separately on all patients with preoperative flexion of <120° and those with \( \geq 120° \).

We used independent Student’s t-tests for continuous variables and chi square analysis for categorical data. Statistical significance was set at \( p<0.05 \).

We performed a power analysis to ensure adequate sample size. At a power of 0.95 with an alpha of 0.05, at least 53 subjects were needed in each group to see a difference of 10° in flexion gained or lost from preoperative to final measurements. This estimate was based on previous data from the same surgeon, hospital(s), and type of implant.

RESULTS

In the matched-pair analysis, there were no significant differences in gained flexion between the two study groups (\( p=0.47 \)). Of all subjects whose preoperative flexion was <120°, there were 56 RP knees and 50 RP-F knees. There were no significant preoperative differences between the groups. However, the RP knees showed significantly more flexion gained than the RP-F knees (\( p=0.004 \)). Of the subjects whose preoperative flexion was \( \geq 120° \), there were 22 RP knees and 25 RP-F knees. For these subjects, there were significantly more women in the RP-F group (60%) than in the RP group (40%; \( p=0.01 \)). There were no other significant differences between the groups. The majority (77%) of patients in this group lost flexion, but there was no significant difference in the mean flexion lost (\( p=0.50 \), see Table 2 and Figure 2).

There were no significant differences in satisfaction scores between any of the analysis groups (see Table 2).

Of the 64 matched pairs, four of the RP-F patients later had additional surgery on the same knee. Three of these were arthroscopies for painful patellar clunk syndrome, and one was a revision because of a loose cement fragment. In the RP group, one patient had further surgery on the knee, an arthroscopy for painful patellar clunk. Although there were more surgeries in the RP-F group, this was not statistically significant (\( p=0.17 \)).

![Figure 2. Gain in flexion from pre-operative measurement to follow-up (9-33 months postoperatively)](image)

There were three patients who had non-simultaneous bilateral TKAs with one implant of each type. When asked if they felt a difference between their two implanted knees, they all said that they did not notice any difference.

DISCUSSION

Postoperative range of motion is an important outcome measure after TKA, as patients generally need a high degree of flexion if they want to engage in activities which include kneeling and squatting. Although there are many brands of high-flex knee implants which claim to improve flexion after TKA, past studies have shown mixed results as to whether or not the new designs actually increase flexion\textsuperscript{1,3-10}. With this study, we aimed to evaluate one of these high-flex designs by conducting a matched-pair study. The matched-pair study design is helpful in eliminating some of the extraneous variables that can cause bias. We matched subjects primarily on preoperative flexion, as this has been shown to be the primary factor affecting postoperative flexion.\textsuperscript{11}

From their preoperative examination to the time of last follow-up, the matched RP and RP-F subjects both gained a small amount of flexion, 3.1° and 1.6° on average, respectively. It is interesting that the RP-F knee did not even provide a small increase in flexion over the RP knee, as was the case in a previous study.\textsuperscript{1}
In one of the other studies comparing Sigma RP and RP-F knees, there were 50 matched pairs; results showed that the RP-F knee increased flexion by an average of 12°. The other Sigma Flex knee study was a simultaneous, bilateral, randomized controlled trial of 93 subjects. They still found that the RP-F knee increased flexion, although this increase only averaged 1°.1

In both of the previous studies conducted on the Sigma knees, results showed that the RP-F provided better results in patients whose preoperative flexion was less than 120°. However, we found the opposite to be true. For all patients whose preoperative flexion was less than 120°, the RP knee patients actually averaged 6.6° more flexion gained than the RP-F patients (p=0.004). For subjects whose preoperative flexion was greater than or equal to 120°, the majority of subjects (77%) lost flexion. The RP-F patients, on average, lost 1.7° less flexion than the RP knee patients; however, this result was not significant (p= 0.50).

Overall patient satisfaction did not seem to be affected by knee design, as the RP-F knee did not significantly increase or decrease satisfaction in any of the analysis groups.

It is also interesting to note that in the matched-pairs group, four RP-F subjects had further surgeries on their affected knee, while there was only one in the RP group; however, this result was also not statistically significant (p=0.17). Greater subject numbers and a study of longer term would be needed to investigate the relationship between the RP-F implant and its effect on the need for subsequent surgery on the knee.

The strengths of this study include data from a single surgeon and similar surgical practices, for each patient. However, this data may be difficult to generalize to other surgical or hospital practices. Consecutive surgeries and matched-pair analysis served to minimize selection bias, although the study would have been stronger if a prospective, randomized selection process had been used.

It is recommended that the efficacy of high-flex knee devices be systematically evaluated prior to their routine use in TKA. In this study, we did not see any improvement in functional or qualitative outcomes for patients with the RP-F knee versus the RP knee. Therefore, in this population, the increased cost of the RP-F implant was not justified.

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EFFICACY AND COST-EFFECTIVENESS OF A BLOOD SALVAGE SYSTEM IN PRIMARY TOTAL KNEE ARTHROPLASTY—A RETROSPECTIVE MATCH-CONTROLLED CHART REVIEW

Clifford Kent Boese, MD, Theresa J. Gallo, PA-C, MPAS, Marcia Weis, BSN, RN, ONC, Rebecca Baker, BSN, RN, ONC, Carla J. Plantikow, MS, Brian Cooley, MSN, RN, ONC

ABSTRACT
We retrospectively reviewed the clinical and cost effectiveness of the OrthoPAT blood salvage system (Haemonetics Corp., Braintree, MA) following total knee arthroplasty (TKA). Two-hundred-and-two patients who received the OrthoPAT system were matched to 202 controls. A second match was performed for subjects weighing <75 kg. For all matched subjects, no significant difference in allogeneic blood transfusion (ABT) rate was found between the control and study groups (p = 0.55). In the subjects <75 kg, use of the OrthoPAT system almost halved the incidence of ABT; however, in this small population the result was not statistically significant (p = 0.10). Blood management costs for study patients were significantly higher than those of the control group in both the total matched pairs and those <75 kg (p < 0.0001 and p = 0.05, respectively).

INTRODUCTION
One risk associated with total joint replacement surgeries is the potential for significant loss of blood during or following the procedure. Several factors predispose patients to allogeneic blood transfusions (ABT) including the type of surgery (with bilateral and revision procedures requiring more ABT than primary unilateral surgeries), low preoperative hemoglobin (Hgb) and/or hematocrit levels, female sex, low body weight, and advanced age. Providing allogeneic blood transfusions to these patients adds the risk of immunosuppression, transfusion reaction, disease transmission, fluid overload, and increased length of stay. There have been many techniques used to minimize ABT after surgery, including preoperative blood donation, preoperative erythropoietin supplements, and perioperative blood salvage systems (BSSs). In the 1990s, preoperative donation of blood was very common; however, the high costs, inconvenience to the patient, and amount of waste have led to a decrease in the use of this method of blood management. Perioperative BSSs use a standard suction drain to collect shed blood during and/or after surgery. This blood is then either re-infused as is, or it goes through a washing system and is then re-infused. The true impact of blood salvage on the subsequent need for ABTs, and blood management costs have been evaluated before, and the literature varies in its conclusions. Although BSSs have been in use for over 30 years, OrthoPAT is a relatively new system specifically designed for use in orthopaedic procedures. The single-use processor is connected to a main device that can be used during and after surgery to collect shed blood. The blood is then centrifuged to separate the red blood cells from the rest of the collected product. After the cells are washed with fresh saline, they are re-deposited into a bag that is ready for reinfusion to the patient. This system has been promoted as providing a safe, cost-effective way to reduce the need for ABTs.

With the rising costs of healthcare, therapeutic decisions should be based on both best practices and cost effectiveness. The purpose of this retrospective chart audit was to evaluate the effectiveness of using the OrthoPAT BSS to decrease ABT following a primary total knee arthroplasty and to determine how the utilization of blood salvage affected direct blood management costs.

MATERIALS AND METHODS
Retrospective chart audits were conducted on 848 patients who underwent consecutive, primary, unilateral TKA performed by the primary author at a Midwestern hospital. These surgeries occurred between January of 2003 and February of 2009. Excluded from this sample were the charts of patients who had donated blood preoperatively (N=15). The surgical procedure for all patients was consistent—each patient receiving a cemented TKA. A tourniquet was used intraoperatively, a suction drain was inserted, and warfarin anticoagulant...
therapy was initiated postoperatively per protocol. There were no set criteria for using the OrthoPAT system, but in general it was used when patients presented with a preoperative hemoglobin level less than 13 g/dL and/or age greater than 72 years. As all TKA surgeries made use of an intraoperative tourniquet to minimize bleeding, the OrthoPAT system was used only postoperatively. Standard Hemovac drains were used on all control-group patients. The study patients had the OrthoPAT system in place from the time of wound closure to 6:00 a.m. the next morning. This resulted in a total time of 14-to-20 hours with the OrthoPAT in place, with the collection bags being changed every six hours. If the machine had collected at least 50 cc of washed and packed red blood cells in any six-hour period, this was re-infused to the patient. All patients were given ABT if their hemoglobin (Hgb) level dropped below eight g/dL, or less than 10 g/dL if they had significant cardiac risk. They were also transfused if they showed clinical symptoms of anemia, such as tachycardia or hypotension not responsive to volume replacement. (It should be noted that the hospital has since altered their protocol for using ABT.)

Chart reviewers collected data on OrthoPAT use, sex, length of stay, ABT, age, pre-operative Hgb, weight, estimated blood loss (EBL), and American Society of Anesthesiologists (ASA) score. The direct blood-management costs for each procedure were determined through normal chargemaster processes. OrthoPAT therapy cost $207.80 per use and allogeneic blood transfusion was $354 per unit. These cost calculations include the blood product and the cost of lab procedures. Not included were nursing productivity, tubing, and saline fees. For analysis, the total cost for each patient was calculated, and the group means were compared.

285 OrthoPAT patient charts and 548 control charts were reviewed by study-team members employed by the medical facilities, whose primary job responsibilities included reviewing patient data and routine access to patient charts. Therefore, an Institutional Review Board found this study to be exempt.

For statistical analysis, the chi square test was used for categorical data and Student’s t test was used for the analysis of continuous data. Statistical significance was set at \( p < 0.05 \). The demographics of the full sample of 833 patients found statistically significant differences between the study and control subjects in age, pre-operative Hgb, weight, and ASA scores. Gender differences approached significance at \( p = 0.056 \). To control for these confounding variables—age, sex, weight, pre-operative Hgb, and ASA score—the OrthoPAT patients were matched to similar controls. Matching the subjects resulted in a final number of 404, with 202 patients in each group (Figure 1).

In order to assess the effects of the OrthoPAT system on a high-risk group, all subjects less than 75 kg were included in a second matching process. As these patients weighed less, their total blood volume was less and they were more likely to need ABT after surgery. This resulted in a match with 48 subjects per group (Figure 1). All pre-operative data can be found in Table 1.

RESULTS

There were 848 patient charts reviewed in this study, and 404 were chosen for a matched-pair analysis. Of the 202 subjects that used the OrthoPAT, 41 were re-infused, and 23 subjects needed ABT (five of whom were also re-infused with autologous blood). The remaining 141 OrthoPAT subjects did not need any type of transfusion after surgery. In the control group, 27 subjects needed ABT. For the patients who received ABT, the average number of units transfused was 1.92 for the control group and 1.95 for the OrthoPAT group \( (p = 0.81) \). This result was not significant \( (p = 0.55) \). Please see Figure 2 for the complete analysis.

In subjects <75 kg, 16 out of 48 control subjects required ABT (33.3%), whereas only 9 of the 48 OrthoPAT subjects required ABT (18.8%). These results came close to significance \( (p = 0.10) \). Of the patients who needed ABT, average units used were 1.93 for the controls and 1.89 for the study group \( (p = 0.72) \). Of the 48 OrthoPAT subjects <75 kg, 12 subjects had enough blood collected to use for reinfusion (25%), and one of these subjects went on to need ABT in addition to the salvaged blood (2.1% of 48).
In this population, the majority of cases in the blood salvage group did not get a re-infusion of products with the OrthoPAT system. Therefore, we looked to see if there was a difference in ABT rate or amount between the OrthoPAT patients who were re-infused and those who were not. Of the total number of 285 OrthoPAT subjects, 58 were re-infused (20.4%). Of these 58 subjects, 5 still required ABT (8.6%). Of the 227 patients who had OrthoPAT but the system did not create enough packed red blood cells for reinfusion, 31 patients required ABT (13.7%). This result was not statistically significant (p = 0.30). Of all OrthoPAT patients who needed ABT, the average number of units transfused was 1.80 in patients who were re-infused and 1.90 in patients who were not (p = 0.72).

Regarding cost, the OrthoPAT system significantly added to the cost of TKA surgery for the total matched pairs group. Surgeries using blood salvage had an average blood management cost of $283.16, as opposed to $87.62 for the surgeries without OrthoPAT (p < 0.0001). In the matched subjects <75 kg, the OrthoPAT patients again had significantly higher blood-management costs than the control group ($333.18 and $213.88, respectively, p = 0.05); however, the discrepancy in cost was much lower than in the full sample.

**DISCUSSION**

With the increasing concern over the risks of ABT, perioperative BSSs have become a common alternative method of blood management. The OrthoPAT system is specifically designed for use in orthopaedic procedures, and it has been promoted to decrease ABT rates. There have been only a handful of previous studies assessing the OrthoPAT system in TKA. Clark and Spratt reported that TKA patients with no preoperative autologous blood donation were 2.3 times less likely to need ABT when using blood salvage. While they did not perform an official cost analysis, they suggested that the OrthoPAT system could save money by decreasing the need for pre-operative blood donation. Carrero and Del Monte
Trujillo also saw a decrease in ABT rates when using OrthoPAT versus a standard drain (19% and 50%, respectively)\(^5\). Both sets of authors agreed that the OrthoPAT can be a cost-effective means for reducing ABT rates, but only if used in a select group of patients.\(^3\) The literature varies in its conclusions about using other perioperative BSSs or in using BSSs in procedures other than TKA.\(^6\), \(^12\)\(^15\)

Although this was not a randomized study, the matched-pair design allowed for confounding variables to be equalized across the groups. This study design has not been used in previous evaluations of BSSs. This is also the largest sample size seen in this type of study. Our results suggest that the OrthoPAT system does not significantly reduce ABT rates and is not cost effective when used in the general TKA population. When using a sample of only high-risk patients, results came close to significantly reducing ABT rates. However, the OrthoPAT still significantly increased blood management costs, even in this high-risk population.

Interestingly, the OrthoPAT system only collected enough packed red blood cell product to re-infuse about 20% of patients using it. In many cases where there was not enough washed blood to re-infuse, the patients went on to need ABT later in their hospital stay. It is unclear why this would be the case in this patient population, especially as the system was connected for a total of 14-20 hours postoperatively.

The strengths of this study are its large sample size and the tight control of variables, including cases from a single surgeon, a matched-study design, and consistent surgical and hospital procedures for each patient. While the consistency of a single surgeon and facility present advantages for scientific rigor, they also limit generalizing these findings to other facilities and surgical practices. These findings also cannot be generalized to other available blood salvage systems, or to procedures other than TKA. The study could have been strengthened through a prospective, randomized study approach.

While the OrthoPAT system appears to slightly lower ABT rates, our results suggest that its use should be confined to a certain subset of patients, specifically those at high risk for ABT. In this study, we focused on patients under a certain body weight, and thus a lower total blood volume. Low body weight has been shown to be a risk factor for ABT. Other risk factors include the type of surgery (with bilateral and revision procedures requiring more ABT than primary unilateral surgeries).
low preoperative hemoglobin and/or hematocrit levels, female sex, and advanced age. More research needs to be carried out in order to determine which patients would benefit from blood salvage.

In both sets of matched-pair analyses performed, use of the OrthoPAT system significantly increased blood management costs. Therefore, the OrthoPAT did not save on costs, as it has been promoted to do. However, more research needs to be carried out to evaluate the cost of ABT in terms of increased infections and longer hospital stays. Studies on the relationship between ABT and infections have shown that blood transfusions can more than double the risk of post-operative infections. It is possible that in the long term, the OrthoPAT system can be cost-effective in high-risk patients.

It is recommended that the efficacy and cost of blood salvage systems be systematically evaluated prior to their routine use in orthopedic surgical patient populations. The results of this study suggest that the use of blood salvage systems should be considered only in patient populations most at risk for blood transfusion.

REFERENCES
ASSESSMENT OF WALKING PATTERN
PRE AND POST PERI-ACETABULAR OSTEOTOMY

Matthew D. Karam MD,¹ Yubo Gao Ph.D.,² Todd McKinley MD³

ABSTRACT

Background
Adult hip dysplasia (AHD) is a common etiology of hip pain in the young adult. Patients with adult hip dysplasia may present with hip pain and early degenerative changes resulting from elevated cumulative hip-contact stress. While there are numerous studies using radiographic parameters coupled with general and disease-specific health status measures to demonstrate that periacetabular osteotomy improves the orientation of the acetabulum, decreases pain and improves function, to our knowledge there is only one study that utilized gait analysis to demonstrate an objective functional alteration. The purpose of the present study was to prospectively evaluate the walking pattern and assess the activity level of patients undergoing periacetabular osteotomy for symptomatic adult hip dysplasia.

Methods
Institutional review board approval was obtained for collection and review of data on 55 patients who underwent periacetabular osteotomy at one institution by the senior author (TM) between the years 2007-2009. Walking pattern characteristics were assessed including velocity, cadence, stride length of the affected side, and percent of single-limb support on the affected limb using GaitRite® walking pattern analysis. Activity was assessed as average steps/day over a consecutive seven-day period. As a secondary analysis, the disease-specific and generalized health status outcome measures of all patients who underwent periacetabular osteotomy were reviewed.

Results
At an average of 11.5 months post periacetabular osteotomy the walking patterns of 27 patients were available for review. Several trends were observed, including an approximate 5% increase in walking velocity (118 cm/sec to 125 cm/sec), and a 4.5% increase in stride length (132 cm to 138 cm, p=0.01). At a mean 9.5 months following surgery, 26 patients reported an 8.75% decrease in average steps taken daily (4598 steps/day to 4196 steps/day). A significant improvement in SF-36 PC scores (p<0.01), the WOMAC hip pain and function scores (p<0.01) and the HHS (p<0.01) was noted during the same period.

Conclusion
At an average of 11.5 months following periacetabular osteotomy for the treatment of symptomatic hip dysplasia, a trend toward increased walking velocity and a significant increase in stride length was noted. A significant improvement in pain relief as well as improved physical function was observed in the short term. Subgroup analysis of patients without pre-existing osteoarthritis (as compared to those with pre-existing osteoarthritis) revealed increased walking velocity, stride length of the affected limb, and percent of gait cycle in single support on the affected limb following periacetabular osteotomy. Further prospective studies are needed to fully clarify the long-term impact of the periacetabular osteotomy on patients with symptomatic hip dysplasia.

¹Orthopaedic Trauma Fellow
Hennepin County Medical Center
701 Park Ave
Minneapolis, MN 55415

²University of Iowa
Department of Orthopaedics and Rehabilitation
200 Hawkins Drive
Iowa City, IA 52242

³Professor, Department of Orthopaedics and Rehabilitation
The University of Iowa
200 Hawkins Drive
Iowa City, IA 52242

Contact Author
Matt Karam, M.D.
Hennepin County Medical Center
701 Park Avenue
Minneapolis, MN 55415
INTRODUCTION
Adult hip dysplasia is a common etiology of hip pain in the young adult.\(^1\) Patients with AHD may present with hip pain and early degenerative changes resulting from elevated cumulative hip-contact stress\(^2\). As a result of this adverse mechanical environment, dysplasia of the hip is a frequent cause of pain and secondary osteoarthritis.\(^3,4\) First described in 1988, Ganz et al developed a periacetabular osteotomy (PAO) to reorient the acetabulum;\(^5\) the goal was to increase femoral head coverage, improve radiographic parameters of AHD, decrease aberrant cumulative contact stress and prevent osteoarthritis.\(^6\) There are numerous studies using radiographic parameters coupled with general and disease-specific health-status measures to demonstrate that the procedure improves the orientation of the acetabulum, decreases pain and improves function.\(^7,8\) However, to our knowledge, there is only one study that utilized gait analysis to demonstrate an objective functional alteration.\(^9\)

A previous study by Romanò et al. reported that in subjects with symptomatic unilateral hip dysplasia there was a tendency to walk with a reduced velocity, shorter steps, and an increased stance on the unaffected side.\(^10\) The relevance of these gait alterations remains unknown. The purpose of the present study is to prospectively evaluate the walking patterns and objectively assess the activity levels of patients who undergo periacetabular osteotomy for symptomatic adult hip dysplasia. To accomplish this, a series of patients was assessed prior to surgery and then after recovery from the surgery, to allow comparison to their baseline status. Secondary goals were to assess changes in their health status and hip pain and function after the procedure.

METHODS
Institutional review board approval was obtained for all patients who underwent periacetabular osteotomy for symptomatic hip dysplasia by one of the authors (TM) from 2007-2009. Patients who were consented and enrolled into the study group underwent prospective walking pattern analyses using the GaitRite\(^{\text{®}}\) and StepWatch\(^{\text{®}}\) pedometer systems.

Demographic as well as radiographic parameters of all patients who underwent periacetabular osteotomy were reviewed by one author (MK). These included patient age at the time of surgery, operative side, body mass index (BMI) and radiographic parameters as measured from pre- and postoperative standing anterior posterior (AP) pelvis radiographs. The severity of subjects’ deformity was classified by the lateral center-edge angle (CEA), which quantifies the supero-lateral coverage of the femoral head. The acetabular index of the weight-bearing zone or HTE angle ("horizontal toit externe") was used to measure the horizontal tilt of the sourcil and further characterize femoral head coverage. The presence or absence of hip subluxation was determined by the integrity of Shenton’s line. The presence or degree of osteoarthritis of the hip joint was determined prior to surgical intervention by the Tonnis classification.

General and disease-specific outcome measures including the SF-36, WOMAC, and Harris Hip Score were prospectively collected and retrospectively reviewed on all patients.

The walking pattern of patients enrolled into the study group was assessed using the GaitRite\(^{\text{®}}\) system. This system, which has been shown to be a valid and reliable instrument for the measurement of temporal-spatial parameters of gait in young people, was used for all described measurements.\(^22-24\) The GaitRite\(^{\text{®}}\) system includes a fourteen-foot portable mat with 16,128 imbedded sensors; this captures electronic footprints, and allows for quantification and assessment of velocity, cadence, step length and other tempo-spatial gait parameters. Subjects were asked to walk on the GaitRite\(^{\text{®}}\) mat at a self-selected pace, once during their preoperative visit and at subsequent postoperative visits. Data for two patients who underwent bilateral PAOs during the study period were excluded.

The StepWatch\(^{\text{®}}\) pedometer system was utilized in an attempt to characterize a change in activity level following PAO. Total step taken were assessed using the StepWatch\(^{\text{®}}\) pedometer system for seven consecutive days prior to surgery, and following subsequent postoperative visits. Subjects were provided with a prepaid mailer to return the pedometer after each of the seven-day periods.

Statistical analyses were conducted using SAS, version 9.1.3. Descriptive statistics including means, and standard deviations were used to characterize the study group. The level of significance for all statistical tests was set at \(P<.05\), and corrections based on Bon Feroni adjustments for multiple comparisons were considered.

RESULTS
A total of 55 patients underwent periacetabular osteotomy between the years 2007-2009. Thirty-three of these patients were consented and enrolled into the study group. A minimum of six months postoperative data collection was requisite in subsequent analysis. Patients consisted of six males and 27 females. The average age at the time of the procedure was 28.5 years (range 16-50 years), average BMI was 26.5 (range 19.1-38.3) and 20 were right sided (60%) and 13 were left sided (40%).

Twenty-two additional patients who were not enrolled into the study during this time period were identified. This group consisted of 20 females and two male patients with an average age of 30.1 (range 17-55) which
is similar to the study cohort. For the majority of these patients a clear justification for lack of enrollment was not identified.

Radiographic measurements were performed by one author (MK). The average preoperative lateral CEA as was 21.5 (+/- 7.5), and this increased to 34.3 (+/- 6.7) postoperatively. Preoperatively, the HTE angle was 17.8 (+/-11.6); this decreased to 7.4 (+/- 6.5) postoperatively (Table 1). Preoperatively, the Tonnis Classification of Osteoarthritis averaged 0.62 (+/- 0.68), and Shenton’s line was disrupted in 8/33 subjects.

GaitRite® data was available and reviewed on 27 patients preoperatively and at an average of 11.5 months (+/-3.9) postoperatively (Table 2). Preoperative self-selected walking velocity of 117.7 cm/s (+/-17.2) improved postoperatively to 124.6 (+/-14.5) representing an approximate 5% increase in walking velocity. A small change in the preoperative [106.9 (+/-7.4)] to postoperative [108.7 (+/-7.8)] cadence (steps/minute) was identified. Stride length (cm) of the affected side was analyzed pre- and post-operatively and demonstrated an improvement from 131.7 cm (+/-13.5), to 137.6 (+/-11.2), representing an increase of approximately 4.5% per stride (p<0.01). The percentage of the gait cycle spent in single support on the affected limb did not change [(37.2 vs. 37.8); (p=0.2)].

Average total daily steps taken was recorded preoperatively [4597.7 (+/-1771.3)] and at a mean 9.5 months (range 6 -18) postoperatively [4196.3 (+/- 1977.5)] (p= 0.1). This decline, although not statistically significant, represented a nearly 8.75% decrease in physical activity level.

The mean SF-36 physical component scores (PCS) of 28 patients (Table 3), at an average of 11.5 months (+/-3.8) following surgery, improved from 38.7 (+/-9.1) to 47.2 (+/-9.4) (p<0.01). The pre- and postoperative SF-36 mental component scores (MCS) were unchanged (p=0.6).

Significant improvements in mean WOMAC hip pain, function and Harris Hip Scores were observed in 24 patients at an average of 11.5 months following periacetabular osteotomy (Table 4). A similar trend was not identified for mean WOMAC stiffness scores during this same time period.
Previous reports have identified factors predicting poor clinical outcome in patients following periacetabular osteotomy. One of these factors includes the presence of osteoarthritis prior to surgical intervention. In an attempt to further characterize our population, we stratified two cohorts based on the presence or absence of preoperative osteoarthritis according to the Tonnis classification. Bon Fferoni adjustments were made for the multiple comparisons. These groups demonstrated no difference preoperatively.

The absence (Tonnis 0) of osteoarthritis was associated with an improvement in postoperative walking velocity, stride length of the affected side, and percentage of the gait cycle spent on the affected limb (Table 5).

The first number represents the mean for patients without pre-existing OA (Tonnis 0), the second number represents the mean for patients with pre-existing OA (Tonnis 1,2). In addition, the absence of osteoarthritis was associated with a higher overall post-operative mean SF-36 PCS (Table 6).

**DISCUSSION**

In the present study, we prospectively evaluated the walking pattern of 27 patients who underwent periacetabular osteotomy for symptomatic adult hip dysplasia. Given the limited numbers available, and relatively short duration of follow-up, we were unable to demonstrate obvious improvements in observed gait parameters or physical activity level following periacetabular osteotomy. However, subjective short-term improvement [as assessed by common-general (SF-36 PCS) and disease-specific (WOMAC Hip Pain, Function, HHS) health status measures] was demonstrated in this follow-up study.

It has previously been shown that in subjects with hip dysplasia, there is a tendency toward a reduced walking
velocity, shorter stride length, and having an increased proportion of the gait cycle spent on the unaffected side. Despite our failing to demonstrate a statistically significant difference, we did note a trend toward increased walking velocity, and a significantly longer stride length of the affected limb after PAO. Subgroup analysis revealed a statistically significant increase in the walking velocity, stride length, and percent of gait cycle spent on the affected limb, in the group of patients without pre-existing osteoarthritis (Table 5). This finding, although unique, is in accord with other studies that have demonstrated improved outcomes following periacetabular osteotomy in patients without baseline osteoarthritis.

It is conceivable that the improvements in walking velocity and stride length may result from improved joint mechanics from decreased contact stresses and associated soft-tissue related discomfort. These differences may be more noticeable in those patients without baseline degenerative hip disease. Longer-term follow-up would likely help clarify the effect of periacetabular osteotomy on the walking pattern of patients with symptomatic hip dysplasia.

In an attempt to further characterize activity level following periacetabular osteotomy the StepWatch® pedometer system was utilized. Walking-energy expenditure has been accurately estimated with the use of pedometers. Previous studies have not used this instrument to assess the relationship of physical activity level following acetabular reorientation procedures. Although we noted a decrease in physical activity level at an average of 9.5 months following PAO (range 6-18 months), this difference was not found to be significant. This finding is not surprising given the magnitude of an acetabular reorientation procedure. Further, it has been shown that activity levels in patients can be extremely variable. In a previous study, Schmalzlried et al. used a digital pedometer to monitor activity level following joint arthroplasty. This particular population consisted of 111 non-random volunteers at least six months following either total knee or hip arthroplasty. These 111 patients averaged 4988 steps/day; but there was remarkable variability in activity levels among subjects (up to 40 times). In our present study the average daily steps taken post-operatively was 4200 steps/day, which is less than that demonstrated by patients following total joint arthroplasty. The decline in post-operative activity level following surgery may indicate ongoing disability, or might be indicative of a prolonged recovery period. Further study with longer follow-up is necessary to fully understand the effect of periacetabular osteotomy on activity level.

At an average of 11.5 months following periacetabular osteotomy there was a significant improvement in SF-36 PC scores (p<0.01), WOMAC hip pain and function scores (p<0.01) and the HHS (p<0.01). A systematic review by Clohisy et al. demonstrated pain relief and improved hip function in the majority of patients at short- and mid-term follow-up. The HHS was the most commonly used outcome measure, and in eight studies the mean improvement ranged from 14.5 to 33 points. Although this was statistically significant (p<0.01), we noted a mean improvement of only 7.5 points. This may indicate lower baseline morbidity in our particular population. Van Bergayk et al. reported the outcomes of 25 patients who underwent periacetabular osteotomies for symptomatic hip dysplasia. Reported primary outcomes included WOMAC pain and function scores as well as SF-36 physical component scores. SF-36 PCS improved from 33.9 points preoperatively to 49.2 at a minimum two-year follow-up. Our cohort of patients demonstrated similar improvement in the SF-36 PCS, albeit in the shorter term, from 38.7 points preoperatively to 47.2 (p<0.01).

A recent report by Steppacher et. al reports the longest-term follow-up of patients who have undergone periacetabular osteotomy. Sixty-three patients were evaluated retrospectively. At a mean 20-year follow-up they reported a 60.5% survivorship with 38% conversion to total hip arthroplasty. Patients who had no pre-existing osteoarthritis had a 75% survivorship. They noted that in all remaining patients the Merle d’Aubign score decreased to preoperative levels. They identified several factors that predicted a poor outcome including the degree of pre-existing osteoarthritis. In the present study, patients without osteoarthritis prior to surgery had improved postoperative mean SF-36 physical component scores as compared to those with pre-existing osteoarthritis (Table1). Furthermore, patients without pre-existing osteoarthritis demonstrated increased walking velocity, stride length, and percent of single support on the affected limb as compared to those with pre-existing osteoarthritis, a difference that was not observed preoperatively. As with any major elective operation, careful consideration of the risk/benefit profile is warranted, particularly in patients with underlying osteoarthritis.

The current study has several limitations. Despite our obtaining informed consent on 33 patients and enrolling them prospectively, we failed to enroll 22 patients who underwent PAO during this same time period. Several patients had implicit reasons for not wanting to participate. One factor that likely led to decreased enrollment was poor communication between investigators and clinical personnel involved in the process.

In an attempt to eliminate selection bias, demographic and health-status outcome measures of those not prospectively enrolled in the study were reviewed retrospectively. There were no significant differences
among groups in any of the described variables. Another limitation of the present study is the relatively short-term follow-up. This, in part, is a limitation of the finite study period and the prospective nature of the investigation.

One of the strengths of this study includes its prospective design, coupled with a novel and objective measurement of a patients’ functional status prior to and after a major reconstructive procedure. As mentioned, there have been numerous studies using radiographic parameters and health-status measures to characterize clinical outcome. To our knowledge, only one other study has utilized gait analysis to demonstrate a functional alteration. Our study represents the first utilization of temporospatial parameters of gait to assess walking pattern pre and post periacetabular osteotomy. We further attempted to characterize activity level with the use of a pedometer. In addition to these innovative techniques, we further described our patients’ clinical experience with commonly used general and disease-specific health status measures.

In conclusion, at an average of 11.5 months following periacetabular osteotomy for the treatment of symptomatic hip dysplasia, a trend was noted toward increased walking velocity and a significant increase in stride length. A significant improvement in pain relief as well as improved physical function was observed in the short term. Subgroup analysis of patients without pre-existing osteoarthritis, as compared to those with pre-existing osteoarthritis, revealed increased walking velocity and stride length of the affected limb, as well as increased percent of gait cycle in single support on the affected limb following periacetabular osteotomy. Longer follow-up and further prospective studies are needed to fully clarify the long-term impact of the periacetabular osteotomy on patients with symptomatic hip dysplasia.

REFERENCES


QUANTIFYING THE EFFECTS OF EXTENSOR MECHANISM MEDIALIZATION PROCEDURES USING MRI:
A CADAVER-BASED STUDY

Kyle Dychman, BA, †Chloe Mellecker, BS, †Daniel R. Thedens, Ph.D., †John P. Albright, MD

ABSTRACT

Background:
Patellofemoral joint kinematics are dependent on a variety of anatomical features. One of the most common causes of patellar instability is malignment of the quadriceps extensor mechanism. The Southwick-Fulkerson osteotomy focuses on correcting malalignment of the quadriceps extensor mechanism through medialization of the tibial tubercle. MRI, in conjunction with established patellofemoral indices, allows quantitative evaluation of the patellofemoral joint during active quadriceps extension both pre- and postoperatively.

Purpose:
This study aims to quantitatively evaluate the effects of extensor mechanism medialization procedures using established patellofemoral indices in order to establish a relationship between tibial tubercle transfer distance and patellar tracking. It is believed that a 15mm medial transfer of the tibial tubercle will produce statistically significant changes in patellar tracking when evaluated during active quadriceps contraction.

Methods:
Four fresh-frozen cadavers underwent a modified Fulkerson osteotomy. The central quadriceps tendon was identified and traction was applied with a vector parallel to the femoral diaphysis using sutures, to simulate active quadriceps contraction. MRI images were obtained following 0mm (control) and 15mm tibial tubercle medialization. Each knee was evaluated at 30, 20, 10, and 0 degrees of flexion.

Results:
Quantitative evaluation of patellar tracking during active quadriceps contraction detected significant changes in patellar translation following 15mm medial transfer of the tibial tubercle as compared to the control. The significantly reduced indices suggest reduced patellar lateralization and improved patellar tracking during the critical range of motion from 30 to 0 degrees of flexion.

Conclusions:
The results of this study indicate that significant quantitative changes in patellar tracking occur following 15mm tibial tubercle medialization when evaluated during active quadriceps contraction using MRI in conjunction with established patellofemoral indices. These findings suggest that quantitative evaluation of patellar tracking may be a valuable pre- and postoperative tool when coupled with qualitative clinical findings.

INTRODUCTION
Patellofemoral joint kinematics and patellar tracking describe the relationship between the patella and femur during flexion and extension of the knee. Patellofemoral joint kinematics are dependent on a variety of anatomical features including bony geometry, soft tissues, and the action of the quadriceps.1 While the healthy knee is unlikely to dislocate or undergo severe subluxation,2 any number of anatomical or physiological abnormalities could produce patellar instability. This is especially common in near-full knee extension as the patella moves proximally relative to the increasingly shallow trochlear groove while the tibia externally rotates, resulting in lateral patellar movement even in healthy subjects.3,4,5 It is at these lower degrees of flexion (0-30°) where soft
tissue restraints and quadriceps muscle action exert the most important patellar stabilizing forces.\textsuperscript{6,7,8} Misalignment of the extensor mechanism does not allow the patella to properly track in the trochlear groove, producing lateral patellar instability.\textsuperscript{9,10}

One of the most common causes of patellar instability is malalignment of the quadriceps extensor mechanism.\textsuperscript{9,10} Malalignment of the extensor mechanism has a wide spectrum of clinical presentations including an increased Q-angle, patellar subluxation as seen on the

Merchant view, or more subtle presentations that do not appear until dynamic evaluation during the physical examination, such as a J-sign. A J-sign is defined as the lateral movement of the patella over the lateral femoral condyle during active leg extension. However, these clinical findings do not rule out other anatomic or physiologic factors that may cause patellar instability.\textsuperscript{11} In order to choose the appropriate surgical intervention, evaluation of the patellofemoral joint during active quadriceps contraction is essential.\textsuperscript{12} MR images obtained during active quadriceps contraction coupled with established patellofemoral indices (Figures 2 and 3) allow quantitative evaluation of the patellofemoral joint, which is essential for diagnosis of patellofemoral pathology and for postoperative outcome.\textsuperscript{7,13} This quantitative evaluation allows for assessment of the patellofemoral joint that may otherwise be difficult to obtain solely by clinical means.

The modified Fulkerson osteotomy focuses on correcting malalignment of the quadriceps extensor mechanism through medialization of the tibial tubercle.\textsuperscript{14} This procedure is commonly used when the tibial tubercle-trochlear groove (TT-TG) distance exceeds 20mm.\textsuperscript{2,11,14} Rotational abnormalities, severe trochlear dysplasia, and patella alta must also be ruled out using preoperative imaging in order to verify that malalignment of the extensor mechanism is indeed the cause of patellofemoral pathology. Regardless of the medialization procedure performed in an attempt to correct patellar tracking, the degree to which the tibial tubercle is medialized relies on a great deal of clinical judgment intraoperatively.\textsuperscript{10} In order to reduce the reliance on static preoperative images and
passive motion evaluation, intraoperative femoral nerve stimulation has been employed by this senior author to allow dynamic evaluation of the patellofemoral joint intraoperatively to ensure adequacy of the tibial tubercle transfer.\textsuperscript{10,12} However, in order to determine the efficacy of tibial tubercle transfer on improving patellar tracking, the relationship between tibial tubercle transfer distance and patellar tracking must be assessed.

This study aims to quantitatively evaluate the effects of medialization procedures using established patellofemoral indices to establish a relationship between tibial tubercle transfer distance and patellar tracking. Significant findings will allow a relationship to be determined between tibial tubercle transfer distance and patellar tracking, using several established patellofemoral indices. The alternative hypothesis for this study states that medial tibial tubercle transfer of 15mm, a minimum value in the senior author’s (JFA) experience, will significantly affect patellofemoral kinematics.

**MATERIALS AND METHODS**

**Specimens**

Four fresh-frozen normal cadaver knees from a total of two donors were used in the study. The knees were both from female donors who were 69 and 76 years of age. The specimens were transected at mid-femur and mid-tibia.

**Procedure**

Following a 24-hr thawing period, each knee underwent a modified Southwick-Fulkerson osteotomy (as described previously) by the senior author (JFA).\textsuperscript{3}A single parapatellar incision spanned the length of the specimen in order to expose the distal attachment of the patellar tendon on the tibial tubercle. An oblique osteotomy of approximately 30 degrees in the axial plane was performed using an oscillating saw, and special care was taken to maintain a distal bony attachment (Figure 1A). Proximally, a dovetail cut made parallel to the joint line with an angle of 20-30 degrees in the sagittal plane was performed, 1cm above the insertion of the patellar tendon on the tibial tubercle (Figure 1B). To complete the procedure, the dovetail was then connected to the oblique osteotomy made previously. With the minimal load applied across the knee joint in this study, the dovetail and distal bony attachment provided sufficient support during simulated active quadriceps contraction and bicortical screws were not used. This also eliminated hardware artifact that might have interfered with quantitative measurements of the patellofemoral joint\textsuperscript{12}. In the event that the distal bony bridge could not be maintained, a suture anchor was placed distally to replicate the bony attachment. Each knee underwent a 15mm medial transfer of the tibial tubercle which was achieved by light tamping of the bony segment. The proximal ledge created by the dovetail along with the distal bone bridge provided adequate fixation to prevent shifting of the tubercle during dynamic assessment following medial transfer.

To simulate patellofemoral pathology in otherwise healthy cadaver specimens, the medial and lateral retinacula were dissected. In previous studies, this dissection resulted in an increased lateral patellar shift of up to 10mm\textsuperscript{6}. The skin and subcutaneous tissue were removed from the thigh, and a running suture was placed through the central quadriceps tendon using Fiberwire 2.0. Traction was applied to the suture to create a force vector parallel to the femoral axis when viewed in the coronal plane, which best mimics the resultant vector of the combined muscle tensions acting on the quadriceps tendon as it inserts on the patella during concentric contraction.\textsuperscript{1}

**Imaging**

Each knee was imaged prior to medial transfer of the tibial tubercle and again following 15mm medial transfer of the tibial tubercle. Knees were imaged at 30, 20, 10, and 0 degrees of flexion before and after medial transfer. This critical range of motion allowed investigation of patellofemoral kinematics as the patella moved proximally relative to the increasingly shallow trochlear groove.\textsuperscript{3,33} It is in this range where patellar instability is most often noted. Quadriceps contraction was simulated by applying traction to the running suture placed through the central quadriceps tendon, with enough force to maintain the leg in the degree of flexion desired. The vector of traction was parallel to the femoral diaphysis when viewed in the coronal plane. Knees were placed in a radiolucent apparatus that prevented femoral rotation during simulated contraction. The tibia was allowed to freely rotate during simulated quadriceps contraction, allowing for the natural external rotation as the leg approached full extension.

**MRI Parameters**

All images were acquired using a whole-body Siemens Tim Trio 3T with the knee positioned in the apparatus in the supine position. Images were acquired with a three-dimensional (3D) gradient-recalled echo (GRE) pulse sequence. Examination time was six minutes for each specimen in each evaluated degree of flexion.

The following imaging parameters were used to optimize time and contrast: Flip angle 10 degrees, TE 1.6ms, TR 12.0ms, one excitation, field of view 14.0cm x 14.0cm x 14.4 cm, with a slice thickness of 1.0mm using continuous coverage (0mm inter-slice gap).
### TABLE 1.
Comparison of Patellofemoral Indices in Control Specimens (0mm) and 15mm Medial Transfer

<table>
<thead>
<tr>
<th>Index</th>
<th>Control</th>
<th>15mm</th>
<th>Change</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BSO</td>
<td>0.51 ± 0.06</td>
<td>0.54 ± 0.05</td>
<td>0.03 ± 0.08</td>
<td>0.029*</td>
</tr>
<tr>
<td>LPD</td>
<td>(0.18 ± 2.3)</td>
<td>(3.8 ± 2.2)</td>
<td>3.7 ± 3.2</td>
<td>0.045*</td>
</tr>
<tr>
<td>LPE</td>
<td>2.5 ± 1.9</td>
<td>(2.03 ± 0.99)</td>
<td>2.7 ± 2.2</td>
<td>0.031*</td>
</tr>
<tr>
<td>PTA-S</td>
<td>14.4 ± 4.2</td>
<td>12.3 ± 2.85</td>
<td>2.1 ± 5.1</td>
<td>0.12</td>
</tr>
<tr>
<td>Sulcus</td>
<td>130 ± 7.3</td>
<td>127 ± 4.0</td>
<td>4.1 ± 8.2</td>
<td>0.15</td>
</tr>
<tr>
<td>Congruence</td>
<td>(-8.2 ± 11.9)</td>
<td>(-12.8 ± 2.9)</td>
<td>4.7 ± 14.9</td>
<td>0.13</td>
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<tr>
<td>TT·TG</td>
<td>8.3 ± 2.8</td>
<td>3.8 ± 1.7</td>
<td>4.6 ± 3.2</td>
<td>0.041*</td>
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</table>

### 20 Degrees Flexion

<table>
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<tr>
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<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BSO</td>
<td>0.53 ± 0.07</td>
<td>0.51 ± 0.04</td>
<td>0.03 ± 0.28</td>
<td>0.12</td>
</tr>
<tr>
<td>LPD</td>
<td>(-1.1 ± 2.1)</td>
<td>(-3.5 ± 1.6)</td>
<td>2.4 ± 2.1</td>
<td>0.028*</td>
</tr>
<tr>
<td>LPE</td>
<td>2.9 ± 1.4</td>
<td>0.73 ± 0.84</td>
<td>2.2 ± 1.4</td>
<td>0.035*</td>
</tr>
<tr>
<td>PTA-S</td>
<td>14.0 ± 4.72</td>
<td>11.7 ± 2.1</td>
<td>2.3 ± 3.1</td>
<td>0.15</td>
</tr>
<tr>
<td>Sulcus</td>
<td>133 ± 8.9</td>
<td>127 ± 2.8</td>
<td>5.0 ± 4.1</td>
<td>0.15</td>
</tr>
<tr>
<td>Congruence</td>
<td>(-8.1 ± 13.9)</td>
<td>(-8.1 ± 13.0)</td>
<td>0.008 ± 13.5</td>
<td>0.5</td>
</tr>
<tr>
<td>TT·TG</td>
<td>10.2 ± 3.0</td>
<td>4.0 ± 0.94</td>
<td>6.2 ± 2.0</td>
<td>0.006*</td>
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</tbody>
</table>

### 10 Degrees Flexion

<table>
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<tr>
<th>Index</th>
<th>Control</th>
<th>15mm</th>
<th>Change</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BSO</td>
<td>0.52 ± 0.05</td>
<td>0.51 ± 0.05</td>
<td>0.01 ± 0.07</td>
<td>0.39</td>
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<tr>
<td>LPD</td>
<td>(-1.7 ± 1.5)</td>
<td>(-3.2 ± 1.9)</td>
<td>1.5 ± 2.5</td>
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<tr>
<td>LPE</td>
<td>3.0 ± 1.1</td>
<td>1.9 ± 0.18</td>
<td>1.8 ± 1.4</td>
<td>0.045*</td>
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<tr>
<td>PTA-S</td>
<td>16.7 ± 8.2</td>
<td>12.9 ± 1.3</td>
<td>4.0 ± 8.3</td>
<td>0.17</td>
</tr>
<tr>
<td>Sulcus</td>
<td>136 ± 5.0</td>
<td>130 ± 4.4</td>
<td>6.2 ± 6.7</td>
<td>0.058</td>
</tr>
<tr>
<td>Congruence</td>
<td>(-11.4 ± 12.9)</td>
<td>(-12.3 ± 4.9)</td>
<td>0.93 ± 13.8</td>
<td>0.45</td>
</tr>
<tr>
<td>TT·TG</td>
<td>10.6 ± 1.7</td>
<td>4.0 ± 1.4</td>
<td>6.6 ± 2.2</td>
<td>0.0005*</td>
</tr>
</tbody>
</table>

### 0 Degrees Flexion

<table>
<thead>
<tr>
<th>Index</th>
<th>Control</th>
<th>15mm</th>
<th>Change</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BSO</td>
<td>0.53 ± 0.07</td>
<td>0.48 ± 0.08</td>
<td>0.06 ± 0.10</td>
<td>0.033*</td>
</tr>
<tr>
<td>LPD</td>
<td>(2.0 ± 3.8)</td>
<td>(5.1 ± 1.1)</td>
<td>3.1 ± 1.2</td>
<td>0.011*</td>
</tr>
<tr>
<td>LPE</td>
<td>3.9 ± 1.8</td>
<td>1.3 ± 1.8</td>
<td>2.5 ± 2.5</td>
<td>0.083</td>
</tr>
<tr>
<td>PTA-S</td>
<td>17.7 ± 4.7</td>
<td>16 ± 2.4</td>
<td>1.7 ± 5.2</td>
<td>0.22</td>
</tr>
<tr>
<td>Sulcus</td>
<td>138 ± 4.4</td>
<td>134 ± 5.7</td>
<td>4.0 ± 7.2</td>
<td>0.022*</td>
</tr>
<tr>
<td>Congruence</td>
<td>(13.5 ± 14.7)</td>
<td>(14.4 ± 8.7)</td>
<td>0.89 ± 17.2</td>
<td>0.43</td>
</tr>
<tr>
<td>TT·TG</td>
<td>12.4 ± 2.9</td>
<td>3.7 ± 1.9</td>
<td>8.7 ± 3.4</td>
<td>0.003*</td>
</tr>
</tbody>
</table>

**Measurement and Analysis**

These established indices were used to quantitatively assess the patellofemoral joint at each set degree of flexion, including the bisect offset (BSO), lateral patellar displacement (LPD), lateral patellar edge (LPE), patellar tilt angle of Sasaki (PTA-S), sulcus angle, congruence angle (CA), and tibial tubercle-trochlear groove distance (TT·TG). Descriptions of each index are listed below.

- Bisect offset (BSO), Figure 2A: As described by Stanford et al., a line is drawn tangential to the medial and lateral posterior femoral condyles. A perpendicular line is then drawn through the deepest point of the sulcus. BSO is the ratio of the patella lateral to the perpendicular line compared to the total width of the patella.
- Lateral patellar displacement (LPD), Figure 2B: Following the guidelines of Laurin et al., a line is drawn tangential to the medial and lateral anterior condyles. A perpendicular line is drawn through the apex of the medial condyle. The distance from this line to the most medial part of the patella is measured.
- Lateral patellar edge (LPE), Figure 2C: First described by Brossman et al. as the distance ‘d’, this
measurement is identical to LPD except the apex of the lateral condyle is used.

- Patellar tilt angle of Sasaki (PTA-S)\textsuperscript{19}, Figure 2D: This is defined as the angle between the line that passes through the widest part of the patella and a line tangential to the anterior femoral condyles. The patellar tilt angle of Sasaki (PTA-S) was chosen over other patellar tilt indices because it has been shown to be effective in measuring patellar tilt independent of femoral rotation.\textsuperscript{25}

- Sulcus angle\textsuperscript{19}, Figure 2E: As described by Merchant et al., this is the angle between the sulcus and the medial and lateral condyles.

- Congruence angle\textsuperscript{19}, Figure 2F: As described by Merchant et al., this is the angle created by the bisector of the sulcus angle and a line from the deepest point of the sulcus to the most posterior aspect of the patella.

- TT:TG\textsuperscript{14}, Figure 3: Using the guidelines established by Dejour et al., the horizontal distance between the tibial tubercle and trochlear groove was measured using axial MRI overlay.

Measures were made by a single investigator (KD). Four knees were used to calculate mean and associated standard deviation at each chosen degree of flexion for both the control (0mm transfer) and 15mm transfer. The resulting values allowed the mean change in each patellofemoral index to be calculated to evaluate the change in patellofemoral kinematics following medial transfer. A one-tail Student’s paired t-test was then used to determine the significance of the 15mm medial transfer on patellar tracking. A p-value of less than 0.05 was considered significant.

RESULTS

The patellofemoral joint was evaluated using measurements listed above to compare patellar tracking following 15mm medial tibial tubercle transfer. Patterns of patellar tracking were consistent across all four knee specimens used in this study, and means were used in order to determine the significance of the 15mm transfer on patellofemoral kinematics as compared to the control (0mm transfer).

Medial transfer of the tibial tubercle produced a reduced bisect offset (BSO) value at all degrees of flexion except 30 degrees. This reduction was statistically significant with a p-value of 0.03 at 0 degrees of flexion, as BSO was reduced 0.055 ± 0.104 percent following 15mm transfer (Table 1). The reduced BSO values following medial transfer (from 20 to 0 degrees of flexion) indicate that the patella was medialized as the percentage of patella lying lateral to the sulcus was reduced.

Lateral patellar displacement (LPD) was reduced at all degrees of flexion following 15mm medial transfer, resulting in statistically significant reduction at 30, 20, and 0 degrees of flexion. The largest reduction in LPD occurred at 30 degrees of flexion when the value changed 3.66 ± 3.17mm (Table 1). The negative values associated with all of the LPD measurements, including the control measures, indicate that the most medial aspect of the patella was, on average, medial to the apex of the medial femoral condyle when using non-pathologic knee specimens.

Similar to the LPD, lateral patellar edge (LPE) was reduced at all degrees of flexion following 15mm medial transfer. The reductions in LPE were statistically significant at 30, 20, and 10 degrees of flexion. Although it was not statistically significant, the reduction in LPE following medial transfer at 0 degrees of flexion was 2.53 ± 2.51mm, a reduction that surpassed statistically significant changes in LPE at 20 and 10 degrees of flexion. However, this was subject to high variability (Table 1). The greatest reduction in LPE was seen at 30 degrees of flexion, as LPE decreased from 2.45 ± 1.94mm to -0.233 ± 0.988mm, the negative value indicating that the most lateral aspect of the patella was medial to the apex of the lateral femoral condyle (Table 1). In both the control and 15mm-transfer specimens, LPE gradually increased as the knee reached full extension, suggesting that the patella translates laterally in near-full extension (Figure 4).

The tibial tubercle-trochlear groove distance (TT:TG) was reduced a statistically significant amount at all evaluated degrees of flexion. Despite an intraoperative measurement of 15mm from the edge of the bony cut to the transferred tubercle, the largest measured change in TT:TG resulted in 8.73 ± 3.41mm at 0 degrees of flexion (Table 1).

Following medial transfer, no statistically significant changes were detected at any evaluated degree of flexion for either the patellar tilt angle of Sasaki (PTA-S) or congruence angle. For both indices, 15mm transfer resulted in reduced or unchanged values when compared to the control at all investigated degrees of flexion (Table 1).

Although trochleoplasty was not performed in this study, the sulcus angle was reduced at all investigated degrees of flexion following 15mm transfer. The reduction was statistically significant at 0 degrees of flexion, resulting in a p-value of 0.02 as the sulcus angle changed 3.98 ± 7.15 degrees following 15mm transfer, as compared to the control (Table 1). The reduced sulcus angle values at all investigated degrees of flexion indicate that the surgical technique used to medialize the tibial tubercle in this study may have pulled the patella distally relative to the trochlear groove, placing the patella in a deeper portion of the trochlear groove when viewed in the axial plane.
DISCUSSION

The results of this study indicate that medialization of the tibial tubercle as little as 15mm can significantly affect patellar tracking in non-pathologic cadaver specimens. However, the magnitude of these changes was not as great as expected. Significant changes in BSO, LPD, and LPE (Table 1) across the critical range of motion from 0-30 degrees where patellar instability is greatest, indicates that medialization had the greatest effect in reducing lateral patellar translation. When looking specifically at the LPE measurement, which has been reported as the best pre- and postoperative parameter to analyze patellar lateralization, a 15mm medial transfer produced a 2.53 ± 2.51mm medialization (Table 1). These changes yielded a 6:1 (15.0mm/2.53mm) intraoperative medialization-to-translation ratio with the knee in full extension and the quadriceps actively contracted. LPE appears to be of particular value as it correlates to the qualitative clinical J-sign defined previously (Figure 5). Because the presence or absence of the J-sign is used preoperatively to provide a dynamic evaluation of the patellofemoral joint during the physical examination, and postoperatively to evaluate the outcome of surgery, the quantification of this clinical finding has important surgical value.

Patellar tilt and congruence were not significantly altered following 15mm tibial tubercle transfer (Table 1). One reason for this may be that the medial and lateral retinaculum were dissected in this experimental setup to create a more pathological situation by inducing lateral translation of the patella. Because of this, the influence of the medial and lateral retinaculum on patellar tilt and congruence was lost, eliminating the tethering effect that these structures have on the patella as the knee nears full extension.

When examining the TT-TG measurements in this study, the discrepancy between intraoperative bony measurements and postoperative radiographic measurements described in previous studies is apparent. By using calipers to measure from the edge of the bony cut
to the transferred bone block, the intraoperative tibial tubercle transfer distance was measured to be 15mm in every specimen. However, when making measurements on radiographs using the axial overlay technique as described by Dejour et al. (Figure 3), the mean change in TT-TG was only 8.73 ± 3.41mm with the leg in full extension (Table 1). This may be due to the external rotation of the tibia as the knee reaches full extension, altering the relationship between the tibial tubercle and trochlear groove when viewing axial radiographs. The inconsistencies in the intraoperative and postoperative TT-TG measurements have been investigated previously, and may be at least partially related to correctly and consistently locating the depth of the sulcus, accurately identifying the apex of the tibial tubercle, and the difficulty in making measurements on postoperative images with hardware artifact. The findings in this study follow the trends seen in previous research, and continue to call into question the reliability of the TT-TG measurement.

The setup for this study evaluated patellofemoral kinematics in a non-weightbearing setting, as the force exerted by traction on the quadriceps tendon was equivalent to the weight of the components of the transected lower leg, including the tibia, fibula, and associated musculature. These loads were much lower than forces exerted across the knee during even low-impact activities such as walking. However, weightbearing has been shown to have a centering effect on the patella, significantly reducing lateral patellar displacement as the force generated by the quadriceps is increased. Because of this, the experimental setup used in this study examined the knee in a low-load setting where patellar instability is the greatest, and therefore it is not seen as a limitation.

However, several limitations of this study should be acknowledged. The small number of cadaver specimens (n=4) substantially limits statistical power. Still, when using only four specimens, statistically significant changes in patellar tracking were detected. Future studies should
select a larger patient population exhibiting patellofemoral pathology requiring surgery. Retrospective analysis of pre- and postoperative MR images could be compared to the amount of tubercle transfer described in the surgical document to determine a relationship between intraoperative transfer distance and the effect on patellar tracking. Determining such a relationship would provide more objective guidance intraoperatively when medializing the tibial tubercle, reducing the dependence on clinical judgment currently required in medial transfer procedures.

Additionally, the non-pathologic knees used in this study do not have the same kinematics as pathological knees that the Southwick-Fulkerson osteotomy aims to correct in vivo. The cadaveric specimens in this study did not display any of the typical pathological anatomy commonly associated with severe cases of patellar instability including trochlear dysplasia, patella alta, malalignment of the extensor mechanism, TT-TG greater than 20mm,11 patellar tilt greater than 20 degrees, and imbalance of soft-tissue restraints.10,29 Previous research by Heegard et al. indicated that lateral translation of the patella could be increased by up to 10mm by dissecting the medial and lateral retinaculat6. While this step was taken in order to increase lateral patellar translation and simulate patellar instability, this simple dissection fails to fully mimic the complex bony and soft-tissue anatomy of a knee exhibiting severe patellar instability.

CONCLUSION

While the results of this study are limited by statistical power, it was found that quantitative evaluation of the patellofemoral joint following 15mm tibial tubercle medialization yielded significant changes in patellar tracking. These findings suggest that quantitative evaluation of patellofemoral kinematics may be a valuable pre- and postoperative tool when coupled with qualitative clinical findings. Although the results from this study were less than initially anticipated, they warrant future investigation using a larger sample size of pathologic knees in order to more accurately define the intraoperative medialization to translation ratio (TT-TG:LPE) proposed in this study. Accurately establishing such a measure could be of significant clinical value by reducing the amount of clinical judgment currently required to successfully perform tibial tubercle transfer procedures.

REFERENCES


INTEGRATING CARTILAGE-SPECIFIC T1ρ MRI INTO KNEE CLINIC DIAGNOSTIC IMAGING

Douglas R Pedersen, Ph.D.,* Noelle F Klocke, B.S.E., † Daniel R Thedens, Ph.D., ††
James A Martin, Ph.D., † Glenn N Williams, Ph.D., †‡ Annunziato Amendola, M.D. †

ABSTRACT

With a rise in post-traumatic osteoarthritis, OA no longer is considered just a disease of aging. The ‘gold standard’ for OA diagnosis has long been planar radiographs for visualizing osteophytes, joint space narrowing and sclerotic changes. A typical magnetic resonance imaging (MRI) protocol will acquire proton density, T1, T2, and fat suppressed images that give a comprehensive picture of morphologic changes associated with injury and subsequent degenerative processes. However, the earliest events of cartilage degeneration occur within the tissue, before measurable changes in morphology. MRI methods have been proposed to display and quantify changes in composition and integrity of such elements of cartilage extracellular matrix as collagen and proteoglycan (PG) content in vivo. T1ρ, the spin-lattice relaxation time in the rotating frame, has come to the forefront for visualizing water proton–PG interactions in articular cartilage.

The purpose of this T1ρ MRI study was to define an objective femoral condyle-specific registration method, in which zone-dependent cartilage compositional changes could be assessed from the bone outward through the existing cartilage, at pre-ACL reconstruction and subsequent follow-up times, when the loss of thickness to surface-down cartilage erosion might occur later in the OA pathogenesis. Additionally, this study explores the effects of reducing the number of spin-lock times on the absolute T1ρ relaxation times; a major parameter in expanding T1ρ coverage to the whole joint while satisfying clinical imaging time and specific absorption rate (SAR) safety constraints.

The developed image analysis tools serve as the first step toward quantitative functional assessment of cartilage health with noninvasive T1ρ MRI, which has the potential to become an important new tool for the early diagnosis of cartilage degeneration following ACL trauma.

INTRODUCTION

As recently as October, 2010, the CDC reported osteoarthritis as a growing public health problem that continues to be the most common cause of disability, at an annual cost of $128 billion.1 With a rise in post-traumatic osteoarthritis (PTOA) OA no longer is considered just a disease of aging.2 The ‘gold standard’ for OA diagnosis has long been planar radiographs for visualizing osteophytes, joint space narrowing and sclerotic changes. Exquisite soft-tissue definition from the multiplicity of contrast mechanisms available in a single exam have established magnetic resonance imaging (MRI) as the method of choice for visualization of cartilage and joint anatomy in a wide range of clinical applications. A typical MRI protocol will acquire proton density, T1, T2, and fat suppressed images, which give a comprehensive picture of morphologic changes associated with injury and subsequent degenerative processes.3 Nevertheless, a lack of noninvasive quantitative measures of cartilage condition in vivo prevents meaningful assessment of joint injuries, thus making early treatment effects difficult to verify.

Multi-center studies such as the Osteoarthritis Initiative (OAI) target identifying chemical and imaging biomarkers for evaluating the progression and risk factors of symptomatic knee OA.4 These studies stimulated development of 3-dimensional MRI to better quantify articular cartilage thickness changes earlier in the OA etiology, with several cartilage–bone–shape segmentation and analysis methods reported.5,6 Knee zones nomenclature5 and cartilage metrics (WORMS)5,6 have been defined to establish common comparative measurements. Recent reports from these large cohort studies document changes in femorotibial cartilage thickness and extent of denuded areas of bone as they relate to the radiographic stages of OA.7,8

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However, the earliest events of cartilage degeneration occur within the tissue, before measurable changes in morphology.\textsuperscript{5, 13} Therefore, detection and treatment of PTOA joint degeneration occurs later in the process. MRI methods have been proposed to display and quantify changes in composition and integrity of such elements of cartilage extracellular matrix as collagen and proteoglycan (PG) content in vivo.\textsuperscript{14-16} These cartilage-composition MRI sequences involve multiple time-step image captures and post processing of voxel-wise exponential fits to determine relaxivity time constants. In healthy cartilage, the collagen matrix restricts water molecule movement inducing an effective dipole-dipole interaction. This interaction depends on collagen fiber orientation within the external magnetic field; thereby making the T2 relaxation time sensitive to fiber orientation and water content in cartilage.\textsuperscript{17,20} Magic-angle imaging, in which the angle dependence of T2 is measured, can provide a specific measure of collagen ultrastructure. However, the difficulty in getting the angle dependence presently precludes its use clinically. Despite the fact that T2 relaxation time imaging is available on most clinical MRI platforms, the variety of hardware-software implementations produces differing ranges of T2 values that confound direct study results comparisons.

Delayed gadolinium-enhanced MRI of cartilage (dGEMRIC) provides a specific measure of glycosaminoglycan (GAG) concentration.\textsuperscript{21, 22} This method measures the distribution of a charged contrast agent, which in turn reflects the distribution of charge associated with GAG, of which proteoglycan (PG) is the dominant component. The exogenous agent requires 90-120 minutes to permeate the extracellular cartilage matrix after intravenous injection. The two hour delay between the baseline and the diagnostic T1-inversion recovery sequence imaging sessions make this logistically difficult in the clinical setting. Additionally, gadopentetate contrast injection Gd(DPTA),\textsuperscript{23, 24} has been associated with Nephrogenic Systemic Fibrosis or Nephrogenic Fibrosing Dermopathy (NSF/NFD), which renders the contrast agent unsuitable for patients with any glomerular filtration inadequacies.\textsuperscript{24, 25}

T1p, the spin-lattice relaxation time in the rotating frame, has come to the forefront for visualizing water proton–PG interactions in articular cartilage.\textsuperscript{26, 28} Non-invasive cartilage-specific T1p provides a continuous measure of joint condition by utilizing a pre-encoded spin-lock pulse cluster followed by a fast spin echo (FSE) image capture. In the research setting these have also been acquired in 3-D, where the longer data acquisition times can be accommodated.\textsuperscript{29} However, in the clinical setting, speed, resolution, joint coverage and signal-to-noise ratio (SNR) must be balanced with other diagnostic imaging demands as reported in a state-of-the-art review of imaging outcome measurement in OA.\textsuperscript{30}

Prior to cartilage-specific sequences, MRI was used as a diagnostic tool for suspected acute internal derangement of the knee. In a controlled, prospective study of suspected ACL injuries, the common orthogonal (sagittal) MRI images were compared to non-orthogonal (oblique sagittal) imaging of the knee.\textsuperscript{31} In all measures, 60-70% diagnosis success with standard orthogonal views jumped to 100% with the oblique sagittal views aligned to contain the mid-substance of the ACL. This orientation was maintained when we introduced T2, dGEMRIC and T1p in an on-going prospective clinical evaluation of cartilage-specific MRI sequences in acute ACL rupture patients. To keep the image sessions under an hour in length, selected 2-D oblique sagittal slices were acquired to provide compositional insight into immediate post-traumatic response in the load bearing lateral condyle cartilage where most of the initial injury occurs.

The purpose of this study was to define an objective condyle-specific registration method, in which zone-dependent cartilage compositional changes could be assessed from the bone outward through the existing cartilage, at pre-ACL or subsequent follow-up times, when the loss of thickness to surface-down cartilage erosion might occur later in the OA pathogenesis. Additionally, this study explores the effects of reducing the number of spin-lock times on the absolute T1p relaxation times; a major parameter in expanding T1p coverage to the whole joint while satisfying time and specific absorption rate (SAR) safety constraints.

**METHODS**

In an on-going prospective clinical evaluation of cartilage-specific MRI, we have gathered T1p FSE (fast spin echo) images to assess the sensitivity of T1p measures of water-PG interactions in vivo. Diagnostic MRI images were obtained from seven healthy subjects with no history of knee injury or symptoms of osteoarthritis (Table 1). Three scanning sessions of one knee in each normal subject were performed at the same hour of alternate days to assess the consistency of image quality and fluctuations in day-to-day cartilage condition. Study protocol and informed consent documentation were approved by the Institutional Review Board.

**Histology-based criterion for T1p cartilage sampling**

An above-knee amputation (AKA) for a proximal femur sarcoma was imaged intact and then disarticulated for coronal and sagittal safranin-O histology to provide a cartilage composition frame of reference for cartilage-specific T1p MRI (Figure 1). The osteochondral speci-
TABLE 1
Normal Subjects’ Demographics

<table>
<thead>
<tr>
<th>Normal</th>
<th>Gender</th>
<th>Age</th>
<th>Knee</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Male</td>
<td>59</td>
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</tr>
<tr>
<td>2</td>
<td>Female</td>
<td>23</td>
<td>Left</td>
</tr>
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<td>3</td>
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</tr>
<tr>
<td>7</td>
<td>Female</td>
<td>23</td>
<td>Left</td>
</tr>
</tbody>
</table>

mens were fixed, decalcified and embedded in paraffin. Multiple 5µm thick microtome slices were mounted serially for staining and image analysis similar to those utilized in cartilage repair scoring systems with their origins in the Mankin cartilage OA grading system. The sections were stained with Weigert’s hematoxylin, safranin-O, and fast green. Weigert’s hematoxylin stains chondrocyte nuclei black to enhance digital identification of nuclear material. Safranin-O is a cationic dye that binds specifically and stoichiometrically to sulfated glycosaminoglycans, and the intensity of the red stain indicates proteoglycan (PG) content. Fast Green provides a contrasting counter-stain. Each histology section samples a 5µm thick strip across the condyle weight-bearing width.

Bone-cartilage interface (BCI) definition

Image analysis was developed in Matlab® (Mathworks, Inc., Natick, MA). A multi-directional Canny edge detection operator applied to the T1p 20 ms image identified candidate points for a line growing search along the bone-cartilage interface (BCI). The user selected anterior and posterior points bounding the femoral terminal sulcus region on the sagittal image with all Canny filter detected edges overlain in red (Figure 2.A). The closest points on the Canny-derived line became endpoints between which detected bone-cartilage interface voxels were recorded by next voxel progression using a sliding logic matrix (SLM) technique that applied a 3 x 3 logic matrix around an image voxel of interest. If a voxel in the 3 x 3 neighborhood was detected as an edge by the Canny filter, and its position had not been previously recorded, it was added to the end of the line. The logic matrix traversed over each new end of the line until the target boundary point was reached.

Lack of curvature in the pixelated sulcus boundary impeded identification of the BCI in some images. Additional automated processing between the sulcus boundaries (red plus signs in Figure 2-B) constructed a list of single voxels and the midpoints of any contiguous horizontal regions, so that a piecewise cubic Hermite interpolating polynomial could be fit. Infections in the
### TABLE 2
#### Knee Injury Diagnostic MRI Panel

<table>
<thead>
<tr>
<th>MRI Sequence</th>
<th>Time mm:ss</th>
<th>Slice Thickness and Spacing mm – mm</th>
<th>In-Plane Resolution mm × mm</th>
<th>Primary Purpose</th>
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<tbody>
<tr>
<td>Axial Localizer</td>
<td>0:19</td>
<td>8.0 – 9.6</td>
<td>0.78 × 0.78</td>
<td>Planning</td>
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<td>Sagittal–Coronal Localizer</td>
<td>0:21</td>
<td>8.0 – 12</td>
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<td>Planning</td>
</tr>
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<td>0.31 × 0.31</td>
<td>Ligaments / meniscus</td>
</tr>
<tr>
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<td>2.2 – 2.2</td>
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<td>Bone bruise / osteochondral fracture / effusion</td>
</tr>
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<td>3.0 – 3.0</td>
<td>0.36 × 0.36</td>
<td>Bone bruise / osteochondral fracture / effusion</td>
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<tr>
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<td>3.1 – 3.3</td>
<td>0.44 × 0.44</td>
<td>Ligaments / meniscus</td>
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<tr>
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<td>3.5 – 4.2</td>
<td>0.63 × 0.63</td>
<td>Bone bruise / osteochondral fracture / effusion</td>
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<td>Optional Add-on</td>
<td>3:00</td>
<td>4</td>
<td>0.55 × 0.55</td>
<td>Sample Cartilage Composition</td>
</tr>
</tbody>
</table>

**Figure 2.** The direction-independent Canny filter identifies edges (red lines in A) on the 20ms T1P image. The user selects two points bounding the sulcus region (expanded in B) where geometric inflections objectively determine landmarks. The blue 7×7 grid test for objective posterior ridge location from likely user selected bounding points is added in C. The posterior condyle anthropometric reference center is located in panel D.
polynomial curve indicated geometric peaks and valleys in the knee's sulcus anatomy, thereby establishing the sulcus midpoint, anterior sulcus point, and posterior ridge point as anatomic landmarks. The anterior ridge was on the cusp between the anterior condyle and the rising slope of the sulcus; the sulcus midpoint was located at the peak of the sulcus dimple; and the posterior ridge point was on the cusp between the downward sulcus slope and the posterior condyle's curvature.

Variability of inter- and intra-user selection of anatomic landmarks was tested on three images that provided extremes in image clarity, definition of the variable geometry of the sulcus region, and typical sagittal slice geometries. After being briefly familiarized with general terms in the program, each of the three users was asked to pick the anterior and posterior cutoff points bounding the sulcus, four times for each image. Locations of these anatomic landmarks were recorded and compared for the 36 trials (3 images x 3 users x 4 trials). Sensitivity of the program to posterior cutoff point selection was further tested with a 7 x 7 grid (Figure 2-C). The user again selected two points bounding the sulcus region, and each posterior boundary's (x,y) coordinates were changed in single voxel increments, thereby examining 49 available voxels within a 3.8 x 3.8 mm² neighborhood as the potential posterior boundary site. The 49 adjusted posterior ridge locations were recorded to assess the program's objective correction for subjective user selection of sulcus bounds.

Once anatomic landmarks were identified, the SLM technique was applied along the posterior condyle's bone-cartilage interface from the posterior ridge point. An ellipse fit to the pixelated BCI line, using least-squares criterion, defined a smooth BCI arc near the calcified cartilage tidemark identified on histology (Figure 3). Biological variation in the size and shape of femoral condyles required anthropometric normalization to directly compare zone-dependent cartilage MRI relaxation times across patients' knees. A central reference point was placed directly above the posterior ridge site, at the height of the most posterior point on the lateral condyle (Figure 2-D). The average distance from this initial center to the posterior condyle and to the posterior ridge was defined as the anthropometric patient-specific femoral condyle radius, thereby placing the final center directly above the posterior ridge. This focal point approximated the posterior condyle's center of rotation, around which data were collected along the weight-bearing cartilage in a physiologically and biomechanically meaningful way.

The T1ρ relaxation times were sampled at 1° increments from the posterior ridge of the fitted bone-cartilage interface, and along 91 associated plane normals in 0.5 mm increments toward the cartilage surface, to create profiles approximating deep, radial and transitional cartilage zones. Each assigned T1ρ value resulted from the bilinear interpolation of the four nearest voxels. Inter-patient profile data along the 90° of knee flexion surface were combined into a normalized T1ρ database of zone-dependent weight-bearing articular cartilage.

In addition to the repeatability of anatomic landmark identification between scanning sessions and observers, the actual shapes of the bone-cartilage interface profiles were registered temporally across the Monday (Day 1), Wednesday (Day 3), and Friday (Day 5) scanning sessions for five normal knees, to verify anatomic coincidence. The posterior ridge point and a point 30 mm along the posterior condyle profile of each day's BCI line profile were identified. The line profiles for the latter two sessions were analytically translated and rotated to align with posterior ridge location on Day 1. The locations of each profile point were plotted directly on the common coordinate system from Day 1’s image and the distances between corresponding points were analyzed.

Clinical application of whole-joint 3-dimensional T1ρ evaluation may require fewer image capture times. To assess the effects of reducing the number of spin-lock times on absolute T1ρ values, all permutations of 4 or more spin-lock times were used to create 990 new images from 15 normal subject MRI data sets (15 studies x 3 slices per study x 22 combinations per slice; 1 with 6 times, 6 with 5 times, 15 with 4 times). Selected maps were compared to results from reported 3-D sequence studies.²⁹, ⁴²

RESULTS

Osteochondral histology section 14 from the AKA knee (Figure 1) was imaged through a microscope's 4x objective lens and displayed with the scaled outline of a typical MRI slice (Figure 3).

Objective BCI location and T1ρ cartilage composition sampling

The three users' selections of sulcus bounding landmarks (Figure 2B) on three images were recorded and compared with the algorithm-derived locations of the posterior ridges for the 36 trials (Table 3). Consistency of the objective posterior ridge point location was also tested systematically using an automated iterative process of a 7 x 7 grid in a 3.8 x 3.8mm square (Figure 2C). The algorithm reduced the 49 starting points to three locations of the posterior ridge on the Canny-derived bone-cartilage interface line. The preponderance of points (34) converged on one location; thirteen progressed to a point 1.5mm (3 voxels) closer to the sulcus, and two located 1 mm (2 voxels) farther.
Figure 3. Coronal cartilage composition sampled by a 3mm thick MRI slice that has 0.5mm×0.5mm sagittal plane resolution. The 5 voxels sample the entire signal from the bone-cartilage interface (BCI), deep, radial, transitional and superficial cartilage zones. The BCI and superficial voxels illustrate volume-fraction sampling at the cartilage perimeter.

Table 3

Distances (mm) between and number of unique landmark points found (12 possible for each point from 12 trials for each image). Average distances (standard deviation) and [maximum distance] are listed for each set of points in mm. AC-user-selected anterior cutoff points, PC-user-selected posterior cutoff points, PR-posterior ridge points after objective relocation to sulcus geometry. The combined maximum distances show the average of the maximum values (standard deviation) for the three images analyzed.

<table>
<thead>
<tr>
<th>Normal Subject # (slice)</th>
<th># of user AC</th>
<th>Distance Between AC</th>
<th># of user PC</th>
<th>Distance Between PC</th>
<th># of final PR</th>
<th>Distance Between PR</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 (lateral)</td>
<td>10</td>
<td>2.01 (± 1.27) [5.04]</td>
<td>7</td>
<td>0.96 (± 0.55) [2.25]</td>
<td>2</td>
<td>1.20 (± 1.13) [2.25]</td>
</tr>
<tr>
<td>4 (midline)</td>
<td>9</td>
<td>2.39 (± 2.18) [6.24]</td>
<td>4</td>
<td>0.75 (± 0.64)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>[2.25]</td>
<td>1</td>
<td>0.00 (± 0.00) [0.00]</td>
<td>6</td>
<td>0.75 (± 0.45) [1.73]</td>
<td>2</td>
<td>0.65 (± 0.62) [1.22]</td>
</tr>
<tr>
<td>5 (lateral)</td>
<td>7</td>
<td>0.95 (± 0.66) [2.95]</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Combined Maximum Distance</td>
<td></td>
<td>4.74 (±1.66)</td>
<td>2.08 (±0.30)</td>
<td></td>
<td>1.16 (±1.13)</td>
<td></td>
</tr>
</tbody>
</table>

down the sulcus wall. This demonstrated that for 49 potential user selections within a 7 x 7 neighborhood the program identified the same posterior ridge point 69.4% of the time.

The posterior ridge was selected as the anatomic reference point due to its clarity across subjects compared to the other landmark points (anterior ridge, sulcus midpoint). Anatomic coincidence of this common reference point in multi-day images was followed by image rotation to align the 30mm point along each posterior condyle (BCI profile in Figure 2D). The average distance between paired points was 0.289 mm ± 0.294 mm (approximately half the dimension of a voxel). The effect of MR technician alignment of oblique sagittal image planes on multiple days was evident in one outlier that showed curvature effects at the condyle edge increased average bone-cartilage interface point separation to approximately two voxels (1mm). In addition to anatomic coincidence, the range of T1ρ values from day1-to-day 3-to-day 5 for any given cartilage location was less than 10ms, demonstrating consistency of cartilage-composition sampling.

The establishment of an objective MR image co-registration with anthropometric normalization to the lateral femoral condyle enabled merging of data across knees to generate zone-dependent normal knee T1ρ relaxation values over the 90° weight-bearing region of the lateral condyle using the same six spin-lock times (Figure 4).

The AKA knee’s lateral condyle midline histology sections are displayed with the enclosing T1ρ slice’s
Integrating Cartilage-Specific T1rho MRI into Knee Clinic Diagnostic Imaging

Figure 4. Normal zone-dependent T1p relaxation values (±1 standard deviation). The inset image shows the Normal Subject 4’s bone-cartilage interface line, the anthropometric central reference point (diamond), and the posterior ridge (x). The squares indicate 10° increments along the bone-cartilage interface.

Figure 5. The AKA knee’s mid-condylar T1p relaxation time contours are presented with the enclosed cartilage histology sections along the midline from face 15 to 11 in Figure 1.

relaxation times calculated for a reduced set of 12, 20, 40 and 60 ms spin-lock times (Figure 5). The effects of reduced spin-lock times are also shown in T1p maps for a single slice using six, five and four spin-lock times in the calculation of water proton relaxation times (Figure 6).

DISCUSSION

Direct comparison of cartilage-specific MRI relaxation parameters and changes in those values over time is enhanced by consistent, objective identification of a local anatomic feature. The target of this investigation was to create an objective method that could track the response of the lateral knee condyle to the blunt trauma of acute ACL rupture using line profiles through the articular cartilage. This isolated trauma and the articular cartilage response are believed to play a role in the early pathogenesis of post-traumatic osteoarthritis.

Using histology slice 14 as an example (Figure 3), the cartilage composition perpendicular to the MRI slice displays relatively uniform distribution of PG content across the weight-bearing region (red Safranin-O stain). The 5μm thick section and its next 98 neighbors together provided the signal for each cartilage-specific MRI voxel. Due to the consistent PG content in the region there is obvious latitude to slide the MRI slices right-or-left within the section(s) and return a similar set of relaxation times. Moreover, similar continuity is expected among sections cut through areas of the lateral femoral condyle damaged by impact during tibial subluxation in an acute ACL rupture.

Overall, user-selected anatomic landmark locations varied from 2.95 to 6.24 mm separation for the anterior sulcus boundary, and from 1.73 to 2.25 mm for posterior sulcus boundary points (Table 3). Computer algorithm results with objective geometric adjustment in the poste-
rior ridge identification reduced variability by at least 50% from the user-selected sulcus boundary points. These results were formally verified by imposing a neighborhood grid and condensing 49 potential voxels to one site 70% of the time. The same site was identified as long as the user-selected point was not too near the sulcus.

Slice location imprecision from different scanning sessions is inherent within the setup of 2-D multi-slice MRI, potentially resulting in different geometries of the bone-cartilage interface and therefore different line profile curvatures. However, since our method yielded average differences in curvature geometry of much less than 0.5 mm (1 voxel) between corresponding points, in-plane differences should be minimal for this 2-D clinical application. Given the continuity of the underlying cartilage composition being assessed (Figure 2) and the dimensions of cartilage-specific T1ρ voxels sampling the FG-water proton interactions (Figure 3), 2-D T1ρ relaxation times through the midline of the lateral femoral condyle provide a step forward in noninvasive diagnostic assessment of cartilage condition. The composite normal T1ρ values within the weight-bearing cartilage of the posterior condyle demonstrated a consistently narrow envelope against which traumatic contusions of acute ACL rupture injuries may be quantified (Figure 4).

A limitation of this study was the incomplete MRI coverage of the knee. Because much of the initial damage occurs in the lateral compartment and subsequent PTOA observations and lesions often occur in the medial compartments, the initial focus was on early lateral knee articular cartilage response to injury. As 3-D methods of cartilage-composition imaging move from the necessary long scan-time constraints and complexities of research techniques for early injury diagnosis, they may well be combined with the needs of morphometric 3-D sequences used later in the OA disease progression to provide a more complete diagnostic and outcomes measure.

At this point in time, however, the reduced number of spin-lock times acquired to calculate T1ρ relaxation times for cartilage composition assessment requires more
validation and standardization. This is demonstrated by combining AKA lateral condyle mid-line histology with the T1ρ relaxation time profile generated for an MRI slice encompassing the sampled cartilage composition (Figure 5). The 12, 20, 40, 60 ms spin-lock time set did not produce T1ρ contours visually consistent with histologic staining. The sensitivity of reported T1ρ evaluations of articular cartilage was investigated using many permutations of spin-lock times to calculate the water proton-PG relaxation time constants. From a set of 6 spin-lock times used to generate the 2-D T1ρ evaluation in this study (Figure 6C), a subset using the 20, 40, 60, 80 ms subset reported by Li et al.20, 24, 47 (Figure 6A), and with an additional 10 ms time point (Figure 6B) are presented. Differences are visually apparent as well as quantifiably different. Add in the fact that different imaging hardware and different image capture protocols were used to acquire T1ρ relaxation times, it is apparent that direct comparisons of 3-D studies to 2-D evaluations of the underlying physical consistency of water proton interactions within the cartilage matrix require better standardization for clinical diagnostic applications.

For this study, relaxation times were recorded at set 0.5 mm increments outward from the bone-cartilage interface. This increment is consistent with attainable voxel size and it provides an observational path for retained cartilage based on the fact that erosion progresses downward from the surface. The method minimizes volume-fraction effects near the bone-cartilage-interface. Second, data sampled at normalized cartilage thickness levels would require segmentation of the superficial cartilage surface from surrounding tissue, which may be considered an elusive automation. And, in temporal series of post-traumatic osteoarthritis changes, thinning of the cartilage affects cartilage zonal definitions. By sampling at set intervals as here presented, the user is able to track changes at the same perpendicular locations over time.

CONCLUSIONS

A lateral condyle-specific registration method has been developed for T1ρ MRI, a sequence with demonstrated sensitivity to cartilage composition changes during recovery from acute ACL trauma. Validation tests of this method confirm bone-cartilage interface registration reliability, and multiple-day imaging of normal knees demonstrates consistency of zone-dependent T1ρ imaging of cartilage, even with variability in patient-specific posterior ridge geometry. The developed image analysis tools serve as the first step toward quantitative functional assessment of cartilage health with noninvasive T1ρ MRI, which has the potential to become an important new tool for the early diagnosis of cartilage degeneration following ACL trauma.

ACKNOWLEDGEMENTS

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REFERENCES


INTRODUCTION

Soft tissue reconstruction after digital injury can be challenging for hand surgery specialists and non-specialists alike given the number of reconstructive options, some of which employ microvascular techniques. Stable, mobile, and sensate digits with an adequate soft tissue envelope are the ultimate goals of soft tissue reconstruction of the hand. The purpose of this primer is to provide an overview of non-microvascular reconstruction techniques for digital injuries that can be employed by orthopaedic surgeons. We will also show some examples of more advanced options that are available for those injuries that may not be able to be treated by standard techniques.

INITIAL PATIENT EVALUATION

Management of the patient with an injured hand begins with a thorough history and physical examination. Important elements in the history include detailing the mechanism of injury such as whether this was a sharp, crush, or avulsion-type injury. Clean, sharp injuries may be amenable to replantation, while crush or avulsion type injuries cause extensive tissue damage which may prevent successful replantation. The time of the injury as well as the level of contamination or environmental exposure are important as they may dictate the ultimate decision for reconstruction. A history of smoking, diabetes, or peripheral vascular disease may be poor prognosticators of wound healing and should be kept in mind when considering soft tissue reconstruction. A point that cannot be over-emphasized is the requirement for a thorough screening based on history and physical examination as to whether it is an isolated or polytraumatic injury. Although most commonly these are isolated injuries, other concomitant life or limb threatening injuries may be present and can easily be missed. If the history or the physical examination suggests multiple injuries, evaluation in the emergency room by the general surgery trauma team is recommended.

Once the history and general physical examination are complete, a focused, thorough evaluation of the digit and any amputated tissue, if present, is carried out. Careful examination of the skin, nail elements, neurovascular status, flexor and extensor tendons, and skeletal structure is performed. Determination of skin color, turgor, and capillary refill are part of the vascular examination. The use of a portable Doppler placed gently at the palmar central tip as well as the palmar radial and ulnar borders of the digits can also be helpful in determining vascular status distally. The radial and ulnar digital nerves are typically gauged in the emergency room by the degree of light touch sensation and static two-point discrimination. Light touch sensation may simply be qualified as normal, diminished, or absent. Static two-point discrimination is quantified and, although there is some variation in normal values between different digits, a good general rule is that it is considered abnormal if it is greater than 6mm, provided that the uninjured digits have a normal baseline examination. This portion of the examination should be performed before any anesthetic blocks are administered. The flexor and extensor tendon function of the injured digit is tested though this is often limited by the pain of the injury and may be more easily determined after local anesthetic block. Radiographs are obtained to assess underlying bone and/or joint injury. Appropriate antibiotic and tetanus prophylaxis is given.

Many fingertip injuries can be treated under local anesthesia in a well-equipped emergency room with adequate tools and lighting. Individual digital blocks can be done by injecting at the level of the metacarpal head either palmarly into the flexor sheath or coming from the dorsal side with the needle directed into both the radial and ulnar webspaces of the injured digit. We typically use 5-10cc's total of plain lidocaine or bupivocaine.
per digit. Although we typically do not inject anesthetics with epinephrine into the digits, recent data suggests that, contrary to conventional wisdom, epinephrine may be safe to use in digital blocks. If the injury will require surgical attention on the dorsal aspect of the digit proximal to the PIP extension crease, a dorsal field block at the base of the digit will also be required. Full wrist block anesthesia is sometimes needed for more complex defects.

After adequate anesthesia has been achieved, our emergency room practice is to thoroughly cleanse the wounds by dipping the extremity in a mixture of Betadine and normal saline. Once this is complete, a Betadine prep is performed and a sterile field is set up with the patient’s extremity draped to at least the mid-forearm. Hemostasis can be achieved by using a small finger tourniquet when available, or alternatively, a Penrose drain may be used. We caution against cutting off a finger portion of a latex glove and using this as a tourniquet by rolling it onto an injured digit. We have seen these, as well as other small finger tourniquets, left on at the time of dressing the injured digit at the completion of the procedure. This can of course lead to venous and/or arterial ischemia of the digit. We therefore prefer to use a Penrose drain with a hemostat clamp which functions well as a tourniquet and serves as a reminder for removal prior to application of dressings. The Penrose drain is placed across the palmar base of the digit and the two ends of the drain are brought dorsally through the webspaces radial and ulnar to the injured digit. The digit can be squeezed distally for exanguination to improve surgical visibility. While squeezing the digit distally the two ends of the Penrose drain are pulled taut dorsally and the hemostat is used to clamp the two ends of the drain together near the dorsal skin. The distal end of the digit can now be irrigated, debrided, explored, and repaired or reconstructed as needed.

**FINGERTIP INJURIES WITH SOFT TISSUE LOSS**

Fingertip injuries are very common and are the result of sharp laceration, crush, or avulsive injury. Although often initially cosmetically unappealing to the patient, a good repair or reconstruction can provide a sensate, durable fingertip with excellent results.

Injuries to the distal phalanx can be grouped into 4 main injury patterns (figure 1). The ultimate soft tissue reconstruction will depend on the quantity and quality of the surrounding soft tissue. If local soft tissue is used for primary closure, it is important that the ultimate closure is tension-free so as to prevent soft-tissue necrosis and a non-durable, painful tip. Post-operative splinting should allow adequate soft tissue healing and tip protection but should not prevent motion of the proximal joints whenever possible, thereby limiting stiffness of the unaffected joints.

**Type I Injuries**

Type I injuries are transverse distal tip amputations involving only a portion of the nail bed. These injuries may or may not have exposed bone. Those injuries without exposed bone or tendon can simply be treated with irrigation and healing by secondary intention. Patients are instructed to soak the injured digit twice daily and dress with wet to dry dressings until the wound is healed. If a small amount of bone is exposed, this can be trimmed back with a small Rongeur until bone is covered by soft tissue. It is important to maintain enough distal phalanx length so that the nail bed does not extend beyond the distal phalanx in order to avoid a hook nail. The distal skin can be brought dorsally to be sutured to the distal nail bed but should not be excessively tight such that the nail bed is drawn over the distal end of the phalanx and would also result in a hook nail. Those injuries that
heal by secondary intention typically have good cosmetic and functional results.4

**Type II Injuries**
These injuries involve > 50% of the nail bed and a significant portion of the distal phalanx. These injuries are usually treated by shortening and closure of the wound. We feel that if more than 50-60% of the nail bed is involved it is not worthwhile to try to maintain the rest of the nail bed, as doing so is likely to result in more complications, such as a hook nail. It is imperative to excise the entire nail bed, including under the eponychial fold. In the trauma setting it can be difficult to be certain that the entirety of the nail bed, especially the germinal matrix, has been removed. We counsel patients that a nail horn may develop because, despite best efforts, even a small portion of retained germinal matrix can result in a horn. A Rongeur can be used to trim back the exposed bone and to allow soft tissue coverage. If possible, the shaft and base of the distal phalanx is conserved to maintain the insertion points of the flexor and extensor tendons.

**Type III injuries**
These injuries are amputations through the distal interphalangeal (DIP) joint. In sharp injuries, replantation can be considered at this level though relative risks and benefits should be strongly considered.5,6 Consider replantation especially in multiple digits, thumbs, and children. However, at this level revision amputation can also result in good or excellent results.7 Avulsion and crush injuries are typically best treated with revision amputation.

It is important to assess the level of bone and joint involvement. If the flexor tendon is resting in its native position it can be sutured to local tissue such as the volar plate or flexor sheath to try to prevent later development of a lumbrical plus finger and maintain flexion power. A lumbrical plus finger results in paradoxical proximal interphalangeal (PIP) joint extension when the patient attempts to perform fist flexion. This occurs when the flexor digitorum profundus (FDP) tendon retracts excessively and the lumbrical muscle, which originates from the FDP, becomes shortened and tight. A shortened, tight lumbrical leads to excessive tone in the radial lateral band of the intrinsic system. When the patient flexes the digit the FDP slides proximally and the excessively tight lumbrical, via the radial lateral band, leads to PIP extension. If the FDP is not in its resting position it should not be pulled out to length and sutured to soft tissue or to the extensor tendon as this may result in a quadregia effect. Since the FDP to the fingers share a common muscle belly, excessive lengthening of the FDP of the amputated finger prevents the other digits from achieving full flexion excursion. The effect is an inability to make a full fist or weakness of grip for the uninjured digits. Therefore, if the relative length position of the FDP of the injured digit is not clearly apparent it is better to just transect the FDP proximally and allow it to retract proximally as the risk and detriment of developing a lumbrical plus finger is less than that of creating a quadregia effect.8

Special attention must also be paid to the digital nerves. Our practice is to gently pull the nerves distally and use bipolar cautery to cauterize them as proximally as possible within the zone of injury. This practice may be helpful in diminishing the size and symptoms of the inevitable neuroma formation. Although data in human studies is still pending, animal studies and our clinical experience seem to support the idea that cauterizing the digital nerves proximally reduces the risk of painful neuroma formation compared to sharp transection.9

**Type IV injuries**
Type IV injuries spare a significant amount of dorsal tissue, with the soft tissue defect involving most of the volar surface of the distal phalanx. If the area of soft tissue loss is less than 1x1 cm and there is no exposed bone or tendon the wound will usually heal by secondary intention and provide the best result with regard to cosmesis and sensation. Larger areas may heal by secondary intention, especially in children, and this method of treatment may be attempted first as long as infection does not develop and there are no exposed structures that will be damaged if they do not have relatively early soft tissue coverage. Split thickness grafts in this area are discouraged, even if there is no exposed bone or tendon without paratenon, due to poor durability and sensation. If the other structures are adequate and only soft tissue coverage is required, cross-finger or other local flaps (discussed below) can be used. These flaps provide full thickness coverage for a durable surface with potential to restore protective sensation.

**NAIL BED INJURIES**
Nail bed injuries are usually related to crush injuries of the distal phalanx. Hematoma formation under the nail plate is usually a sign of an underlying nail bed injury. Upon finger examination, if the nail plate is damaged, any damaged part should be removed to search for injuries to the nail bed. We typically favor removal of the entire nail plate if there is any injury to the plate itself. This is best accomplished with the use of a Freer elevator. The curved portion of the elevator is pointed up towards the undersurface of the nail plate and the elevator is worked between the nail plate and nail bed in this fashion. The
entire undersurface of the plate is freed from the bed, including along the radial, ulnar, and proximal borders. Then the superficial area between the plate and the periychial and eponychial skin folds along the radial, ulnar, and proximal margins are also released with the elevator. At this point the plate is easily removed with forceps or a hemostat, usually by grabbing one corner and rolling the plate out and towards the other corner. Injuries with a subungual hematoma that involves greater than 50% of the space beneath the nail plate have traditionally been managed with nail plate removal and nail bed repair. However, recent studies have shown that simple trephination of the nail plate can give similar long-term results, especially in children.10 Our typical management is that, regardless of the size of the subungual hematoma, if the nail plate and underlying distal phalanx are not fractured we do not remove the nail plate or drain the hematoma unless it is significantly painful for the patient. We feel in this situation the nail bed is well splinted palmarly and dorsally and that trephination or nail plate removal with nail bed repair is potentially more harmful than beneficial. If there is significant pain due to the hematoma the nail plate can be removed or trephination of the nail plate can be done under local digital block with the use of a handheld cautery device, a #11 blade, or a large-gauge needle. Care is taken to not cause damage to the underlying nail bed.

Nail bed lacerations are common in crush injuries and are often associated with fractures of the nail plate and/or the underlying distal phalanx. If nail bed repair is to be performed it is important to remove enough nail plate to expose the entire laceration. Again, we typically favor complete nail plate removal for simplicity thus avoiding potential complications with attempts at partial nail plate excision and affording excellent exposure. For nail bed lacerations that extend near or beneath the proximal eponychial skin fold it may be necessary to perform skin incisions at each corner for adequate exposure. The skin is everted proximally, taking care to not injure the underlying germinal matrix of the nail bed or the terminal extensor tendon just proximal to the germinal matrix. It is helpful to suture the skin fold to the proximal dorsal skin of the finger as a means of retraction. Once exposed, the nail bed laceration can be repaired with 4-0 or 5-0 chromic suture. If there is an underlying tuft fracture, suturing the nail bed injury and the surrounding skin and soft tissue injury can provide enough stability. The goal is to prevent the underlying bone from deforming the nail bed. If this cannot be achieved with suture repairs, pinning the fracture with a K-wire or large gauge needle can prevent imminent nail deformities. Complete regeneration of the nail is usually expected within four to five months. However, patients are counseled that it usually takes two to three nail growth cycles before the final appearance and function of the nail will be known. As an alternative to suture repair for nail bed lacerations, recent studies have shown that, compared to traditional repair, the use of 2-octyl cyanoacrylate (Dermabond®) can yield a faster repair (10 versus 28 minutes) as well as equivalent patient and physician-judged cosmesis.11 Our preferred method is to apply 3 applications of Dermabond® spaced 30-60 seconds apart. A sterile dressing is placed for 7-10 days, at which time the patient returns for a wound check. Wound can subsequently be left to air or can be protected with a tip protector until healed.

**SPECIFIC FLAP TECHNIQUES**

**Palmar V-Y Advancement Flap (Atasoy Procedure)**

This flap is useful for distal tip injuries with good volar tissue proximal to the zone of injury. A proximally-based V incision is made extending up to, but not crossing, the DIP joint flexion crease. Full-thickness tissue is incised down to the level of the neurovascular structures and the flexor tendon. The underside is dissected free from the underlying tendon to facilitate advancement. The nerve and arteries are preserved with the advanced tissue. A “push” technique is useful whereby a scalpel is used to push through the fibrous septae but won’t as easily damage the neurovascular structures like a cutting or slicing motion may. Once the dissection is started it is useful to have gentle distal traction on the distal end of the flap. Once the proximal tissue is transposed distally, the tourniquet is let down to assure flap viability. The wide distal end of the triangular flap is sutured to the remaining nail bed or dorsal tissue, usually with chromic suture. The remaining tissue at the apex of the “V” is closed primarily—converting to the characteristic “Y” pattern. It is important to not close the wounds too tightly, which may jeopardize the flap. Depending on the amount of tissue available and the technique used, 5-10mm of distal tissue advancement is possible. We will often split initially to protect the soft tissues and for pain control. Postoperative care then progresses active range of motion of the DIP andPIP as pain and healing allow. This procedure is differentiated from the lateral V-Y advancement technique (Kutler Procedure) in which radial and ulnar flaps are advanced in a V-Y configuration. We do not currently employ the lateral V-Y advancement flap due to issues with wound healing and hypersensitive scar formation in our experience.
Cross-Finger Flap

The cross-finger flap is a good option for volar soft tissue finger defects, ideally at the middle or distal phalanx level, in patients where there is an adjacent digit with uninjured dorsal skin and soft tissue. Although joint stiffness may be less likely than with a thenar flap, patients are often immobilized 2-3 weeks, and as a result, this flap should be used with caution in elderly, arthritic patients, or patients that cannot tolerate the length or degree of immobilization.

The cross-finger flap is designed on the dorsal aspect of the middle phalanx of an adjacent digit as a 3-sided rectangular or rhomboidal flap with its hinge of intact skin at the midaxial line that is nearest to the injured digit (figure 3). The distal, proximal, and far-midaxial borders of the flap are incised. The flap is harvested as full thickness tissue down to the level of the paratenon of the extensor tendon. A full thickness flap is carried out, making sure to avoid taking the paratenon of the extensor tendon. Once the flap is free, it is reflected on its hinge adjacent to the injured digit and sutured to the palmar aspect of the injured finger with 4-0 chromic or nylon sutures or other suture of choice. The donor site is closed with an autologous full-thickness skin graft. We like to harvest our skin graft from the ipsilateral volar medial forearm or arm, as it gives us ample local tissue and good cosmesis. Care is taken to not injure or include the medial antebrachial cutaneous nerve during full-thickness skin graft harvest. The necessary dimensions to cover the cross-finger donor flap defect are measured and marked at the skin graft donor site. The skin graft donor site is then marked so that an ellipse of skin will be harvested to allow primary closure. It may be helpful to inject the skin graft donor site with local anesthesia with epinephrine. An incision is made with a 15 blade scalpel and we try to take as thin a graft as possible using the 15 blade scalpel. This “defats” the graft during harvest and increases the chance for suc-
Figure 4. Reversed cross-finger flap. A. Dorsal finger defect. B. Subcutaneous flap raised from adjacent finger. C. Deep paratenon layer identified and raised (D). E. Donor site closed with superficial layer. F. Deep layer placed over defect and skin graft sutured in place.

uccessful adherence and cosmesis. Some elevation of the skin/subcutaneous tissue may be needed to allow for good primary closure. We prefer to close the skin graft donor site with 4-0 monocryl subcutaneous sutures and a running 4-0 monocryl subcuticular suture and steristrips. The skin graft is sutured to the cross-finger flap donor site with suture of choice, which is typically 4-0 chromic for our cases. A pressure dressing or formal bolster-dressing may be applied to the dorsum of the full-thickness skin graft after it has been sutured. Once this is completed, the wounds are dressed with a bulky dressing, leaving the unaffected digits free for range of motion. We pass a dry gauze “fluff” between the donor and recipient digits in their workspace with care to not stress the sutures holding the digits together. The affected digits are immobilized with a plaster splint. One dressing change in the office prior to flap division may be required. Often the skin grafted donor site looks worse than the recipient site initially. At 2-3 weeks, the patient is brought back for flap division, debridement, and suturing as needed. We recommend avoiding division of the flap past 2-3 weeks, as this may lead to stiffness of the immobilized joints. Once the flap is divided, therapy for the affected digits is started depending on associated injuries.

Reversed Cross-Finger Flap

The reversed cross-finger flap can be used for dorsal defects of the fingers that will not support a skin graft. This flap is set up in an opposite fashion relative to the cross-finger flap. A dorsal 3-sided rectangular or rhomboidal skin flap is drawn out with the single longitudinal portion of the incision being along the midaxial border that is adjacent to the injured finger (figure 4). A thin layer of skin is elevated in the same way that a thin full-thickness skin graft would be harvested. This skin flap is elevated away from the injured finger keeping its base, on the midaxial side that is opposite to the injured finger, intact. Care is taken to leave as much subcutaneous tissue behind, as this tissue will be mobilized to cover the dorsal defect on the adjacent finger. Once this skin is raised, all of the subcutaneous tissue except the paratenon of the extensor tendon is raised as a flap based on the midaxial side adjacent to the injured finger. This is transferred to the injured finger and secured, usually with absorbable suture. This brings healthy vascularized subcutaneous tissue to the recipient finger’s dorsal defect so that it can support a skin graft. The skin flap on the donor digit is closed to cover the donor site. Finally, a full-thickness skin graft is applied to the recipient site and sutured. We dress and splint in a similar fashion as described above for the cross-finger...
flap. Post-operatively, patients are managed in a similar fashion to the cross-finger flap with flap division at 2-3 weeks.

**Thenar Flap**

This flap is usually used for palmar defects of the index and long fingers that are too large and deep to heal by secondary intention. Due to the concern for creating PIP contractures, this particular flap is recommended for children and young adults with defects of 1-1.5cm in length. However, some have suggested this is a safe flap to use in older adults provided the flap is divided no longer than two weeks after inset.\(^\text{12}\) Advantages to this flap include abundant subcutaneous tissue and an inconspicuous donor site.\(^\text{13}\) This may also be a consideration in darker skin patients, where volar hand tissue is more cosmetically compatible with the palmar finger defect than the darker dorsal hand tissue that would be used for a cross-finger flap.

The area of contact of the injured finger to the thenar eminence just proximal to the metacarpophalangeal (MCP) flexion crease is drawn out with a marking pen (figure 5). The optimal site is that which allows for the least amount of PIP flexion. However, no matter what
position the injured finger is placed in during flap inset it
will typically assume the most comfortable posture which
is around 80 degrees of flexion at the MCP and PIP joints
and around 45 degrees of flexion at the DIP joint. This
is not much different from the degree of recipient-finger
PIP flexion that is required for cross-finger flaps. It is
of course important to be certain that the finger tip can
comfortably reach the proposed thenar donor site and
will not be hindered by contracture, other wounds, etc.
Once this is identified, an H-shaped incision is made,
creating reciprocally proximal and distal rectangular full
thickness flaps. Alternatively, rhomboid or arch shaped
flaps that are proximal and radially based may be raised
depending on the shape and size of the defect. About
50% more width should be built into the flap relative to
the width of the defect. The flaps are raised to the depth
of the thenar muscle fascia. Care is taken to identify
and protect the digital nerves to the thumb, especially
the radial digital nerve. Once the flaps are elevated, the
distal flap is sutured to the proximal, volar aspect of
the injured finger. The proximal flap is then sutured to
the finger tip defect. Both flaps are then advanced until
the soft tissue defect is fully covered. A splint is used
postoperatively for comfort and to protect the flap from
excessive motion. Often the splint and dressing are not
changed until the flap is divided two weeks later in the
operating room. The proximal flap is used to cover the
finger soft tissue defect, while the distal flap will cover
the remaining soft tissue defect in the thenar eminence.
Undermining of the surrounding tissue, z-plasty, or full
thickness skin grafting may be required to achieve a
comfortable and cosmetically acceptable closure of the
donor defect.

**Moberg Advancement Flap for Thumb Injuries**

The Moberg advancement flap can be used to cover
volar and distal thumb defects. The relatively robust dor-
sal arterial supply to the thumb allows the palmar tissue
to be advanced without jeopardizing the dorsal tissue.
This is in contrast to the other digits. Advantages to us-
ing this flap are low donor-site morbidity and its ability
to provide coverage with highly sensate, functional, and
cosmetically pleasing skin. The main indication for this
flap is a thumb amputation at or distal to the interphalan-
geal (IP) joint that requires skin coverage palmarly and
distally which would otherwise require shortening of the
thumb proximal to the IP joint for closure. A potential
disadvantage is the possibility of introducing a thumb
interphalangeal joint flexion deformity or generalized
stiffness. As a result, this flap should be used carefully
in elderly, arthritic patients but is often still the best
option to obtain sensate coverage and maintain length.
Sometimes mild flexion at the IP joint is accepted to
obtain soft tissue coverage that is not excessively tight
at the tip.
The flap is designed with midaxial incisions on both sides of the thumb. A skin flap is raised off the flexor pollicis longus, keeping both digital arteries within the flap (figure 6). The tissue is subsequently transposed to cover the soft tissue defect. Care must be taken not to close the distal tissue under excessive tension to avoid tissue necrosis at the tip. Advancement of 1.0 to 1.5 cm of skin and tissue is possible with this technique.

In patients for whom additional soft tissue excision is required, a modified Moberg flap may be used. The modification essentially makes this an advancing island flap. The flap is divided proximally and can be advanced an extra 1.0 cm to cover the distal tissue. Care must be taken to preserve the neurovascular bundles and to advance them with the flap. If a tourniquet was used during flap elevation it may be released at this point to determine flap viability. If the flap initially appears to have poor arterial inflow warm saline-soaked sponges should be applied and up to 20 minutes of observation may be warranted to determine if vasospasm is the cause for the ischemia. A local anesthesia digital block at the base of the thumb may also be helpful. The flap is secured distally usually with absorbable sutures. A full-thickness skin graft is then used to cover the donor defect proximally.

ADVANCED SURGICAL OPTIONS FOR FINGER SOFT TISSUE COVERAGE

Apart from the techniques described above, several more advanced techniques have been described. The specific techniques have been well-described elsewhere and are beyond the scope of this text. However, we would like to show some other “non-microsurgical” techniques that are available for soft tissue coverage when the above options cannot be employed.
Digital soft tissue trauma: A concise primer of soft tissue reconstruction of traumatic hand injuries

First Dorsal Metacarpal Artery Flap

This particular flap is an island flap that is useful for thumb soft tissue reconstruction. The first dorsal metacarpal artery (FDMA) takes off from the radial artery and travels parallel to the dorsal surface of the second metacarpal. The FDMA flap is harvested at the level of the proximal phalanx just above the paratenon (figure 7). A small branch of the radial nerve can be harvested with the flap and even be sutured to the proximal digital nerve stumps of the injured thumb. The major advantage to this flap is providing vascularized, sensate skin where a skin graft would otherwise be less preferable.

Radial Forearm Flap/ Reversed Radial Forearm Flaps

The Radial forearm flap (figure 8) is a very versatile reconstruction option particularly in injuries with extensive dorsal hand soft tissue loss, such as degloving injuries. The harvesting of this flap with its intact vascular pedicle negates the need for microsurgery and is therefore an attractive option for non-micro surgeons who would like to avoid free flaps. The flap uses the radial artery as its pedicle and can be harvested with skin, subcutaneous tissue, bone, or tendons as necessary.

REFERENCES


ARTHROSCOPIC SUBACROMIAL DECOMPRESSION: ACROMIOPLASTY VERSUS BURSECTOMY ALONE—DOES IT REALLY MATTER? A SYSTEMATIC REVIEW

Jonathan A. Donigan, M.D.,¹ Brian R. Wolf, M.D., M.S.²

ABSTRACT
Background: Subacromial impingement is a common disorder that in some cases results in surgical management. Arthroscopic subacromial bursectomy alone or in combination with acromioplasty are treatment options when non-operative measures fail.

Methods: A systematic review of all level-I and level-II studies regarding subacromial bursectomy and acromioplasty for impingement was performed. Medline publications were reviewed for appropriate studies.

Results: A total of six studies that met inclusion criteria were identified. However, only one randomized study was identified that directly compared the treatments in question. Additionally, only one prospective study of subacromial bursectomy was identified. A comparison of similar outcome measures revealed bursectomy alone provided similar results to bursectomy with acromioplasty.

Discussion: Limited high-level studies are available regarding arthroscopic treatment of subacromial impingement. Data available currently suggests that bursectomy alone provides similar outcomes to bursectomy with acromioplasty.

INTRODUCTION
Subacromial impingement is the most common disorder of the shoulder, accounting for 44-65% of all shoulder complaints.¹² The etiology of subacromial impingement is controversial, with two main theories described: A degenerative (intrinsic) theory, where symptoms are thought to result from overload on degenerating rotator cuff tendons; and a mechanical (extrinsic) theory, where symptoms are caused by compression of the rotator cuff. Conservative, nonoperative management is often successful, but when it fails, current surgical treatment is arthroscopic subacromial decompression including bursectomy and acromioplasty. The rationale for acromioplasty is based on Neer's extrinsic impingement theory, which describes irritation of the subacromial tissue by impingement of the rotator cuff under the coracoacromial (CA) arch.³⁴ Alternatively, bursectomy alone without acromioplasty may be considered adequate by those who subscribe to the intrinsic theory, since symptoms are felt to be caused by degenerative tendinopathy and subsequent inflammation of the bursa with observed changes in the acromion felt to be secondary.⁵⁶ Avoiding acromioplasty is felt to be preferable by some due to concerns regarding alteration of the CA arch which could predispose to the loss of active glenohumeral elevation due to uncontrolled anterosuperior migration of the humeral head. In addition, there could be an economic benefit from bursectomy without acromioplasty as the result of shorter procedures and decreased equipment costs. Although basic-science and clinical data exist in support of both perspectives, no evidence-based consensus is available to guide decision making.

The purpose of this systematic review is to collect and present data comparing arthroscopic acromioplasty and bursectomy alone for treatment of subacromial impingement syndrome using an evidence-based medicine approach. Our hypothesis is that there is not sufficient data that demonstrating a clinical benefit of acromioplasty compared with bursectomy alone when performing an arthroscopic subacromial decompression.

MATERIALS AND METHODS
A literature search was performed to identify all English-language studies evaluating the management of subacromial impingement syndrome without a full-
thickness rotator cuff tear with: (1) Arthroscopic debride-
ment and bursectomy without acromioplasty; and (2) arthroscopic decompensation with acromioplasty. The lit-
erature search utilized PubMed MEDLINE, Embase, and
Cochrane Reviews and was performed in December 2009
(PubMed, Cochrane) and April 2010 (Embase). PubMed
and Embase search terms were “subacromial decom-
pression”, “acromioplasty”, “bursectomy”, “subacromial
decompression without acromioplasty”, “arthroscopic
subacromial decompression”, and “impingement”.
Cochrane search terms were “shoulder” and “impingem-
ent”. Only prospective, randomized, controlled trials
(Levels of Evidence I and II) with at least two years mean
follow-up were included. Only one study met criteria and
compared the two treatments. Level I and level II stud-
ies that evaluated either technique, but did not directly
compare the two techniques, were included (Table 1).
There were five studies that met criteria and evaluated
decompression with acromioplasty. Other than the study
by Henkus et al., no studies evaluating bursectomy
without acromioplasty were of sufficient quality to be
included. Thus, there were six studies included in the
review. Each study was individually analyzed and the
data collected (Table 1). Four major sources of bias were
evaluated for each study when sufficient information
was included in the publication: Selection, performance,
attrition and detection. Minimal accepted follow-up was
defined as 70% of the study population, and all six stud-
ies achieved this.

DEMOGRAPHICS
Consistent with their randomization, the included
studies reported no difference in groups in terms of gen-
der and age, with the exception of the study by Henkus
et al. In that study, which was randomized by ran-

domization code, there were higher percentages of females
and younger patients (average age of 43 versus 50) in
the bursectomy group compared to the acromioplasty
group. A multivariate analysis found that male gender
had a positive effect on the baseline constant and SST
scores, but otherwise gender and age had no statistically
significant effect on outcome measures.

SURGICAL TECHNIQUE
Most studies indicated that the coracoacromial
ligament was resected as part of the acromioplasty (see
Table 1). The amount of acromion resected was not
reported in most of the included studies. All studies
used a motorized shaver for bursectomy, with or without
electrocautery, and a motorized burr for acromioplasty
(when performed).

OUTCOMES
A wide variety of outcome measures was used, thus
preventing meaningful pooling of data. There was a lack
of consistent evaluation tools, with studies utilizing the
visual analog scale for pain (VAS), the Constant score,
the UCLA shoulder score, the Simple Shoulder test
(SST), the Neer score, and the Project on Research
and Intervention in Monotonous Work (PRIM) score,
among others. In the one study that directly compared
bursectomy alone to acromioplasty, there was not a
statistically significant difference between the VAS, SST,
and Constant scores of the two groups at a mean of 2.5
years. The only other study that included one of these
outcome measures which would allow further compari-
son between bursectomy alone and acromioplasty was
published by Spangehl et al., and the VAS score for
acromioplasty in that study was equal to that found by
Henkus et al. (4.3) in their bursectomy-only cohort.

REOPERATION
Unfortunately, only two studies reported their reop-
eration rates. The reoperation rate in the bursectomy-
only group was 7.7% compared to 10% in the acromio-
plasty group in one study, and 21% in the arthroscopic
acromioplasty group in the study by Spangehl et al.

COMPLICATIONS
Of the included studies, only Spangehl et al. com-
mented specifically on complications. They reported
no neurovascular complications, but 4/32 treated with
arthroscopic acromioplasty had significant stiffness.

EVIDENCE-BASED EVALUATION OF BIAS
Selection bias was minimized by study inclusion crite-
rion of randomized controlled trials, although studies by
Lindh et al., Husby et al. and Spangehl et al. failed to
provide sufficient information about their randomization
method to allow assessment.

Performance bias was minimal, as the included
studies excluded patients who underwent additional
procedures, and only studies of patients undergoing SAD
without rotator cuff repair were included. The procedure
was fairly standardized, with some variation in regard to
resection of the CA ligament, as discussed above.

Attrition bias was also minimized since follow-up was
generally excellent in the included studies, ranging from
71-100% with a mean of 84% (222/264).

Detection bias was minimized by utilization of an un-
biased evaluation method of results by an independent
examiner blinded to treatment, or by using a validated
patient-relevant outcome questionnaire. The studies by
Henkus et al., Haahr et al., and Spangehl et al. used
DISCUSSION

In this systematic review using principals of evidence-based medicine to compare arthroscopic subacromial decompression with and without acromioplasty for management of subacromial impingement, we found a profound deficiency of data. Only one study met criteria and directly compared the two treatments. This study, by Henkus et al., found no statistically significant differences. Although this was a randomized, controlled study, one relatively small study is not adequate grounds upon which to make evidence-based management decisions. There was one additional study identified that compared the two treatments but did not meet criteria for inclusion due to lack of randomization. In that study, which was performed in Brazil and published in Portuguese with the abstract in English, at minimum two-year follow-up of 18 patients they found no difference in ASES scores between those treated with or without acromioplasty.

Our review also included randomized controlled trials that included a group of patients who underwent arthroscopic subacromial decompression with acromioplasty. No other randomized, controlled trials were identified that included bursectomy without acromioplasty. Comparing the one cohort of bursectomy-alone to the acromioplasty groups in these other studies failed to identify any significant differences in comparable outcomes, although comparison was only possible with one other study due to different outcome measures utilized. Therefore, based on available data, no statistically significant difference in VAS scores, Constant scores, or Simple Shoulder Test scores was identified for patients with subacromial impingement treated with bursectomy alone compared with patients treated with arthroscopic decompression with acromioplasty.

It is surprising that such little data exists for a problem so common (subacromial impingent) and a treatment so frequently performed (arthroscopic subacromial decompression). The benefit of acromioplasty is believed to result from removal of the extrinsic cause of impingement—prominence and spurring of the anterior one-third of the acromion, the CA ligament, and the bursa. However, the data supporting this "extrinsic theory" is in contrast to evidence that suggests that primary intrinsic degeneration is responsible for impingement syndrome and rotator cuff disease. Budoff et al. published their cohort of patients treated with rotator cuff debridement without acromioplasty at four years and then at nine-and-a-half years. They found good long-term results at four years (87% good or excellent results) and at nine-and-a-half years (79% good or excellent results). They concluded that the preponderance of evidence suggests that in the majority of cases, extrinsic acromial compression is not the primary cause of impingement syndrome or rotator cuff disease. In support of this conclusion is evidence that rotator cuff pathology predate acromion pathology, rotator cuff dysfunction can lead to spurring of the acromion, and that functional outcome of subacromial decompression does not correlate with the amount of acromion resection. Perhaps the strongest support for an intrinsic rather than an extrinsic etiology for impingement is the success of nonoperative treatment in managing impingement syndrome. Clearly, rehabilitation and therapy cannot remove osseous structures. The effectiveness of bursectomy alone can be explained by evidence suggesting an inflamed and thickened bursa generates pain. The nociceptive feedback relayed by free nerve ends may be responsible for the pain associated with impingement syndrome, thus explaining the success in pain relief observed when the bursa is removed.

The theoretical benefit of bursectomy without acromioplasty includes preservation of the CA arch. Destruction of the CA arch may predispose to loss of active glenohumeral elevation and anterosuperior migration of the humeral head. The CA ligament and acromion are secondary stabilizers of the humeral head against anterosuperior migration. An increase in translation of the humeral head has been hypothesized to predispose to rotator cuff pathology. Current arthroscopic acromioplasty technique generally recommends some preservation of the CA ligament, however, resection of spurring and bony resection inevitably lead to at least some CA ligament thinning and disruption. Thus, if surgical alteration of the acromion through acromioplasty does not result in improved outcome compared to bursectomy and debridement alone, avoiding damage to the CA arch with bursectomy alone would be preferred. In addition, there would be expected economic benefits would be expected through decreased operating time and equipment costs.

Our systematic review has several limitations. The most significant limitation is the lack of more than one comparative study meeting evidence-based medicine criteria. The cohort of patients treated with one of the procedures being compared (bursectomy alone) consisted of 26 patients. A few of the other studies in this review suffered from inadequate reporting of randomization, surgical technique and blinding, making evaluation of bias incomplete. Reported outcomes were extremely variable and mostly interview based. In addition, our search was limited to the English language, and there may be well-designed level-I studies in the non-English literature.
<table>
<thead>
<tr>
<th>Authors</th>
<th>Journal, Year</th>
<th>Country</th>
<th>Surgeons</th>
<th>Study Method</th>
<th>Population</th>
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<tr>
<td>Henkus et al⁵</td>
<td>JBJS Br, 2009</td>
<td>Netherlands</td>
<td>Prospective, 1 randomized</td>
<td>n=57, mean age 47 yo</td>
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<td>Brox et al⁶</td>
<td>JSES, 1999</td>
<td>Norway</td>
<td>Prospective, randomized (vs. PT and 2)</td>
<td>n=125, 45 in acromioplast y group, avg age 48 yo</td>
<td>Random permuted blocks</td>
<td>39/45 (87%)</td>
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<td>Lindh et al⁷</td>
<td>CORR, 1993</td>
<td>Sweden</td>
<td>Prospective, randomized (vs open 1 acromioplasty)</td>
<td>n=20, 10 in arthroscopic group, avg age 42 yo</td>
<td>Not specified</td>
<td>10/10 (100%)</td>
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<td>Haahr et al⁸</td>
<td>Scand J Rheumatol, 2006</td>
<td>Denmark</td>
<td>Prospective, randomized (vs 2 PT)</td>
<td>n=90, 45 in acromioplast y group, avg age 44 yo</td>
<td>Computer generated random sequence, sealed opaque envelope selected from closed bag</td>
<td>40/45 (89%)</td>
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<td>Husby et al⁹</td>
<td>Acta Orthop Scand, 2003</td>
<td>Norway</td>
<td>Not specified</td>
<td>n=39, 20 in acromioplast y group, avg age 42 yo</td>
<td>Not specified</td>
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<tr>
<td>Spangehl et al²</td>
<td>J Shoulder Elbow Surg, 2002</td>
<td>Canada</td>
<td>Prospective randomized (vs open 3 acromioplasty)</td>
<td>n=62, 32 in acromioplast</td>
<td>Unclear</td>
<td>62/87 (71%)</td>
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$=$statistically significant difference
* = no statistically significant difference

**TABLE 1.**

**SUMMARY**

In summary, there is a marked sparsity of level-I and -II evidence available that compares arthroscopic bursectomy alone to arthroscopic bursectomy with acromioplasty for the treatment of subacromial impingement, despite some evidence that avoiding acromioplasty may be preferable due to preservation of the coracoacromial arch. Only one level I study comparing these two treatments was identified in the English literature, and it found no statistically significant difference. Clearly this is an area that would benefit from prospective, randomized controlled studies using validated outcomes. The ubiquity of this disease and the frequency of this surgical treatment should make these studies feasible.

**REFERENCES**

<table>
<thead>
<tr>
<th>Acr (a) or Burs (b)</th>
<th>CA Ligament Resection</th>
<th>Outcome</th>
<th>Reoperation</th>
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<th>Level of</th>
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<td>Both, randomized</td>
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<td>Constant: b:69,6 a: 75.8* SST; b: 9.0 a: 9.9* VAS: b:4.3 a: 3.6*</td>
<td>a:3/30, b:2/26</td>
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<td>Acromioplasty</td>
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<td>UCLA 32, VAS 0</td>
<td>Not indicated</td>
<td>8 years</td>
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<td>Acromioplasty</td>
<td>CA ligament “divided”</td>
<td>UCLA 28.8, VAS 4.3</td>
<td>7 of 32</td>
<td>Mean 25 months, min 12 mo</td>
<td>I/II</td>
<td>Selection: unknown Performance: no Detection: Interview based, blinded Attrition: no</td>
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</tbody>
</table>


12. **Spangehl MJ, Hawkins RH, McCormack RG, Loomer RL.** Arthroscopic versus open acromio-


MECHANICAL BEHAVIOR OF CARPAL TUNNEL SUBSYNOVIAL CONNECTIVE TISSUE UNDER COMPRESSION

Jessica E. Goetz & Thomas E. Baer

ABSTRACT
Subsynovial connective tissue (SSCT) is a fluid-permeated loose connective tissue that occupies the majority of the space in the carpal tunnel not occupied by the digital flexor tendons or the median nerve. It is arranged in layers around these more discrete structures, presumably to assist with tendon gliding. As a result of this arrangement, the compressive behavior and the fluid permeability of this tissue may substantially affect the stresses in the median nerve resulting from contact with its neighboring tendons or with the walls of the tunnel itself. These stresses may contribute to damage of the median nerve and the development of carpal tunnel syndrome. In this study, the fluid permeability and the compressive behavior of the SSCT were investigated to better understand the mechanics of this tissue and how it may mediate mechanical insult to the median nerve. A custom experimental apparatus was built to allow simultaneous measurement of tissue compression and fluid flow. Using Darcy’s law, the average SSCT fluid permeability was 8.78x10^-15 m^4/Ns. The compressive behavior of the SSCT demonstrated time dependence, with an initial modulus of 395 kPa gradually decreasing to a value of 285 kPa. These baseline tissue data may serve as a mechanical norm (toward which pathological tissue might be returned, therapeutically) and may serve as essential properties to include in future mechanical models of the carpal tunnel.

INTRODUCTION
Carpal tunnel syndrome (CTS) is a result of chronic mechanical insult to the median nerve. Historically, this insult has been assumed to result from median nerve compression due to an aberration in the normal ratio of tunnel contents to tunnel volume. Consequently, the primary modality of treatment has been based upon increasing available space within the carpal tunnel to relieve the pathological median nerve constriction responsible for inducing CTS symptoms. To that end, transverse carpal ligament release has proven very successful for treating CTS patients, with a 70%-90% success rate. However, given the relatively high prevalence of CTS (1%-5% of the US population) and the associated financial burden, poor treatment outcomes in even a small fraction of CTS patients still represents a large societal burden.

Deviations from normal carpal tunnel tissue mechanics may indicate CTS-inducing pathological mechanisms other than static nerve compression, and basic biomechanical research of these deviations may prove very productive in identifying alternative therapeutic treatments. Normally, the median nerve and digital flexor tendons are enveloped in sleeves of a loose, highly-collagenous subsynovial connective tissue (SSCT) that facilitates smooth gliding of the median nerve and the flexor tendons during finger flexion. Recent biomechanical studies have investigated the progressive recruitment of different layers of the SSCT with increasing finger flexion, quantifying the behavior of this tissue in terms of a shearing index and a shearing modulus. Similar research has identified decreased longitudinal and transverse movement of the median nerve within the carpal tunnel during hand movement in CTS patients.

However, contribution to gliding is not the only form of interaction between the SSCT and other carpal tunnel tissue structures. Magnetic resonance imaging (MRI) and ultrasound studies have shown that the carpal tunnel boundary itself changes shape and that the flexor tendons and the median nerve slide not only longitudinally, but rearrange transversely during typical hand movement. During these transverse rearrangements, the potential arises for direct impingement of the median nerve by the tendons and the tunnel boundary. The result is locally elevated contact stresses in the nerve. Because of its interposition between the flexor tendons and the median nerve, the SSCT must be compressed between these structures during their transverse movements, thereby greatly mediating stresses on the nerve due to tendon impingement. However, the effects of the
SSCT on impingement-related nerve stress have not yet been adequately investigated. Additionally, SSCT affects the distribution of fluid pressure within the carpal tunnel. Free fluid flow through the SSCT would lead to relatively uniform fluid pressure in the tunnel and would tend to dampen nerve contact stresses resulting from contact with either the tendons or the tunnel wall. On the other hand, if fluid cannot readily permeate the SSCT, localized regions of high and low pressure within the carpal tunnel could develop and significantly influence stresses on the median nerve.

From a biomechanical standpoint, both the SSCT compressive behavior and its permeability to fluid flow are key mechanical properties influencing median nerve stresses resulting from both tunnel fluid pressure and tendon impingement. To date, only one study has been conducted to investigate fluid flow properties of the SSCT. The study applied fluid pressures far higher than in vivo carpal tunnel pressures. In this present study, it is hypothesized that such high fluid pressure physically deforms the tissue, and that measurement of the change in SSCT thickness under pressure allows characterization of the SSCT’s compressive behavior. Thus, concurrent fluid permeability and deformation measurements should provide a more comprehensive understanding of the role of SSCT mechanics in the etiology of carpal tunnel syndrome.

METHODS

Fluid permeability and tissue compression were measured simultaneously using a custom-built tissue chamber and pressurization system (Figure 1). The chamber consisted of two cylindrical aluminum sections which clamped together with screws. The upper section was fitted with a glass window to allow measurement of the SSCT thickness. Below the window, the aperture tapered to a 4.4mm opening where the SSCT was mounted. Given the 40° angle between the incident and reflected beams of the laser scanner, the region of tissue from which thickness measurements could be taken was approximately 2.3mm in diameter. The tissue was supported by a stack of three stainless steel woven wire mesh disks during testing. The SSCT specimen was placed on a very fine upper mesh disk (0.019" wire diameter @165 wires/in). To prevent sagging of the SSCT specimen under fluid pressurization, this fine mesh was supported by two successively stiffer (but coarser) mesh disks (0.0075" wire diameter @ 60 wires/in and 0.023" wire diameter @ 20 wires/in). This arrangement was designed to avoid extrusion of the SSCT sample through the mesh while minimizing impedance of the fluid flow. The volume between the window and the top surface of the tissue was sealed with an O-ring set into

the underside of the upper section and bearing directly on the top surface of the tissue sample. The lower section of the tissue chamber had an outlet port below the mesh disks from which to collect fluid passed through the SSCT sample.

The pressurized fluid reservoir was connected to the inlet of the tissue chamber via thick-walled polymer tubing. The fluid reservoir was filled with saline solution, and a precision pneumatic regulator (Type700 High Flow, ControlAir Inc, Amherst, NH; MGA-30 SSI Technologies Inc., Janesville WD) was used to pressurize the air above the fluid in the reservoir. Measurements of the thickness of the SSCT were taken using a charge-coupled laser displacement scanner (LK-G37, Keyence Corporation of America, Elmwood Park, NJ) mounted above the tissue chamber. Fluid that flowed through the SSCT was collected from the outlet of the tissue chamber using an absorbent wick. Fluid volume was calculated from the mass of the fluid collected in the wick using a 1mg precision balance (M333i Veritas Precision Balance, Hogentogler & Co, Inc, Columbia, MD).

Three SSCT samples measuring approximately 1cm x 1cm were excised from each of six fresh-frozen cadaveric forearms (two female and four male, 69-90 years of age). For each sample (n=18), the chamber was assembled empty, and the laser scanner was zeroed on the surface of the fine support mesh. The chamber was then opened, the SSCT specimen was positioned on the mesh, and the tissue chamber was sealed for testing. The chamber, with tissue in place, was repositioned under
the beam of the laser and five measurements of tissue thickness were made across the specimen. These thickness measurements were averaged into an overall tissue thickness value. Next, the weight of a dry absorbent wick was measured prior to its insertion into the outlet on the bottom of the tissue chamber. The tissue chamber between the SSCT sample and the glass window was filled with normal saline solution using a syringe, and the inlet of the tissue chamber was connected to a fluid reservoir. Care was taken to not introduce air bubbles into the system.

The fluid-filled tissue chamber was then again placed under the laser displacement scanner. The beam was positioned on the center of the circular exposed tissue area and zeroed on the tissue surface prior to permeability testing. To begin testing, the fluid reservoir was pressurized pneumatically to 100kPa over the course of 90 seconds. Displacement of the SSCT surface was recorded at 10kPa increments during pressurization. The 100kPa load was maintained for a period of 60-90 minutes depending on tissue thickness, and SSCT surface displacements were recorded at five-minute intervals over the duration of the test. Upon completion of the test, the fluid pressure was relieved, and the absorbent wick was removed from the outlet of the tissue chamber. The fluid-filled wick was weighed and the difference between the post- and pre-test weights was the amount of fluid that had passed through the tissue during the test. The fluid volume was calculated from the weight and divided by the duration of the test; this value was the volumetric fluid flow rate through the SSCT.

Darcy’s law was used to calculate tissue permeability:

\[ k = \frac{Qh}{\Delta P A} \]

In this equation, \( Q \) is the volumetric flow rate (m^3/s), \( h \) is the thickness of the tissue (m), \( \Delta P \) is the pressure gradient across the tissue, and \( A \) is the surface area of tissue exposed to the pressure gradient (m^2). Permeability \( (k) \) is expressed in m^2/Ns.

All measured SSCT surface displacements were corrected for compliance of the three-mesh stack supporting the SSCT while under pressure. The compliance of the SSCT support was measured prior to testing the SSCT specimens by placing a piece of foil (assumed to be non-permeable) in the device and measuring its displacement as a function of fluid pressure. These displacements were then subtracted from the displacements measured from each SSCT sample at the corresponding pressures. The corrected displacements were then scaled according to an experimentally derived calibration curve generated for CCD laser scanner measurement of a receding surface through increasing fluid volume. All corrected tissue displacements were divided by the original average tissue thickness to obtain a strain value. These strains were plotted versus time and used to calculate creep modulus (\( E = \rightarrow \)) versus time.

**RESULTS**

The thickness and permeability values of the SSCT samples varied between cadaveric donors, as well as between sites within a given carpal tunnel. The average thickness of the SSCT samples was 0.22mm (S.D.: 0.17mm, range: 0.05–0.76mm). Detectable fluid flow occurred during all but one of the experiments, which allowed for permeability determination in 17 of the 18 tested specimens (Table 1). The average fluid permeability for the SSCT was 8.78 x 10^{-15} m^2/Ns (S.D.: 1.48 x 10^{-14} m^2/Ns, range: 0 to 6.47 x 10^{-14} m^2/Ns).

Incomplete data were collected for a select few specimens due to non-uniform distortion of the tissue surface under pressure, which deflected the laser beam out of range of the scanner and prevented measurement. SSCT deformation data were successfully collected for 13 of the 18 specimens. The average elastic modulus value of the SSCT specimens upon initial loading was 395kPa (S.D. 214 kPa). The SSCT modulus was highest initially and decreased asymptotically, reaching a near-steady state value of approximately 285kPa at 25 minutes into the test. The SSCT underwent progressive deformation under constant pressure throughout the duration of the experiment. The average SSCT strain upon initial loading was 33%, which increased over the course of sixty minutes to 45%.
TABLE 1.
Average (SD) fluid permeability \((10^{15} \text{ m}^3/\text{Ns})\) for each SSCT specimen tested. Site A was overlying the median nerve volarly, Site B was overlying the superficial middle and ring finger tendons, and Site C was taken from between the deep and superficial tendons of the middle and little fingers. Site 4C (xx) had no measurable fluid flow, which prevented calculation of tissue permeability.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Site A</th>
<th>Site B</th>
<th>Site C</th>
<th>Specimen Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.48</td>
<td>3.65</td>
<td>8.70</td>
<td>4.94 (3.30)</td>
</tr>
<tr>
<td>2</td>
<td>0.39</td>
<td>17.45</td>
<td>4.74</td>
<td>27.53 (33.34)</td>
</tr>
<tr>
<td>3</td>
<td>0.75</td>
<td>10.21</td>
<td>0.21</td>
<td>3.72 (5.62)</td>
</tr>
<tr>
<td>4</td>
<td>6.02</td>
<td>1.70</td>
<td>xx</td>
<td>3.72 (3.11)</td>
</tr>
<tr>
<td>5</td>
<td>4.52</td>
<td>4.39</td>
<td>13.58</td>
<td>7.50 (5.27)</td>
</tr>
<tr>
<td>6</td>
<td>8.92</td>
<td>1.36</td>
<td>5.15</td>
<td>5.14 (3.78)</td>
</tr>
<tr>
<td>Site Average</td>
<td>3.85 (3.30)</td>
<td>6.46 (6.26)</td>
<td>15.40 (24.72)</td>
<td>8.78 (14.84)</td>
</tr>
</tbody>
</table>

DISCUSSION

The fluid permeability and the compressive behavior of subsynovial connective tissue were successfully measured during the same experiment using a custom-built testing apparatus. The average thickness of the SSCT measured in this work (0.22 mm) compared very favorably to the values of 0.2-0.5 mm previously reported in the literature.\(^{17,18}\) The permeability of the SSCT measured in this work was in a similar range to that reported for other biological soft tissues. A review of soft tissue permeability by Sander and Nauman (2003) lists the permeability of articular cartilage to be 0.1-2.0 \(10^{15} \text{ m}^3/\text{Ns}\), meniscus to be 0.6 \(10^{15} \text{ m}^3/\text{Ns}\), and ligament to be 1.0-6.0 \(10^{16} \text{ m}^3/\text{Ns}\). Similar to what has been found previously,\(^{17}\) SSCT appears to be appreciably more permeable than ligament and meniscus, and slightly more permeable than cartilage.

There was a very wide range of compressive behavior of the SSCT under constant load. The differences in compressive behavior were not associated with age, gender, or harvest location. While it was not possible to measure displacements on five of the specimens, it would not be expected that the mechanical behavior of these specimens would have differed substantially from that of those measured successfully.

Although formal medical histories were not available for the cadaveric donors, none of them had any overt signs of having had a history of CTS (carpal tunnel release scar, thenar muscle atrophy, constricted median nerve). However, the possibility exists that these donors may have had other hand or wrist pathologies. A significant challenge in this work was measuring SSCT specimen thickness. The thinnest SSCT specimens were nearly transparent, making it very challenging for the laser scanner to register their surface. For future work, it would be useful to identify a dye that would adhere to the SSCT surface without changing the permeability.
This would ensure tissue displacements were consistently acquired for all specimens.

The 100kPa pressure used during the experiments was chosen to ensure measurable fluid flow through the SSCT would occur within a relatively short period of time. However, this pressure is still significantly larger than the typical pressure values that have been measured in the resting, healthy carpal tunnel.\textsuperscript{16-21} While 100kPa exceeds normal in vivo hydrostatic tunnel pressures, this value is well within the range that could develop during contact between flexor tendons and the nerve\textsuperscript{16} and is therefore a source of useful data. It has been well established that the fluid-flow properties of biological tissue change under different load magnitudes.\textsuperscript{17,22-24} It would be of great interest to measure fluid flow through the SSCT under both lower and higher pressure conditions, but it would be necessary to develop a method of preventing evaporation over the long time course required to obtain measurable fluid flow at significantly lower pressures.

Non-inflammatory fibrosis and thickening of the SSCT in carpal tunnel syndrome patients is routinely observed during carpal tunnel release surgery.\textsuperscript{25} It would be very interesting to determine how those visible structural changes would manifest in terms of altered mechanical behavior. The present work has established the baseline behavior of carpal tunnel SSCT under compression. Determining methods to return the mechanical behavior of pathological subsynovial connective tissue toward normal may provide an alternative, non-surgical treatment option for carpal tunnel patients who decline, or are ineligible for, surgical carpal tunnel release.

ACKNOWLEDGEMENTS

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REFERENCES


THE VALUE OF PHYSICAL EXAMINATION IN CONJUNCTION WITH A SURVEY FOR IDENTIFYING YOUTH PITCHERS WITH ARM PAIN

Chloe Mellecker, BS,' Greg Scallon, BS,' Caitlin Wooldridge,'’ Alan Edwards,’’ John Albright, MD’’

ABSTRACT

Objective
The purpose of this study is to evaluate the effectiveness of a screening survey in identifying injuries in youth baseball pitchers. It is hypothesized that a standalone survey is unlikely to give a complete picture and that an additional physical examination is necessary to identify all injuries.

Methods
Seventy-seven youth baseball players who pitched in the last 12 months completed the survey. Players underwent physical examination if they reported a history of time-loss injury (16 players) or if they had any current complaints of pain without a history of time-loss injury (22 players).

Results
This screening protocol resulted in positive physical examination findings in 37.6% of all 77 players. This included a rate of 56.3% of pitchers with a positive time-loss injury history and 90.9% of pitchers with a negative time-loss injury, but positive complaint of pain. The most common complaint in both groups was elbow tenderness with the most common location being the medial epicondyle.

Conclusion
While the survey was effective at identifying time-loss injuries, it may neglect more mild injuries, underestimating the percentage of players with pain and positive physical examination findings. The high frequency of positive examination findings in athletes without a history of time-loss injury demands further investigation.

INTRODUCTION
The recent growth of travel baseball leagues reflects increasing specialization and intensity in youth sports. Fewer children are participating in Little League baseball, but those who do play tend to play for multiple teams and play longer seasons. In a retrospective cohort of adolescents with serious injury warranting ulnar collateral ligament surgery, Olsen et al showed a 5-fold increased risk of injury for pitchers throwing competitively for more than 8 months per year.1 This trend is further illustrated by a 4-fold increase from 1994 to 2008 in the proportion of ulnar collateral ligament reconstructive surgeries performed on high school adolescents and younger players.2 Despite recent increases in serious injury requiring surgery in youth pitchers, the incidence of throwing arm injury is not known at the national level.

The American Orthopaedic Society for Sports Medicine (AOSSM) is currently conducting phase one of a triphasic study to identify the incidence of these injuries. Phase one will identify the incidence of injury in Little League through High School pitchers in different regions of the United States and the risk factors associated with these injuries. The AOSSM study currently proposes collection of these data exclusively through a survey. Results of the AOSSM phase one will be published separately from the current study. While the AOSSM survey identifies any time-loss injuries experienced in the last 12 months, it may overlook current pain that has not yet manifested as lost time and may include remote, presently asymptomatic injuries.

Phase two of the AOSSM triphasic study will evaluate risk factors, pain, and time-loss injury through the same survey and a physical examination in youth pitchers presenting in a clinical setting. It is believed that shoulder and elbow anatomical differences such as internal and external rotation, strength, tenderness, laxity, and pain will be more prominent in the athletes seeking clinical assessment. Additionally, phase two will examine the correlation between reported exposure levels in this cohort and positive physical findings.
Traditionally, sports injuries are defined as a loss of game or practice time eliciting on-field or clinical evaluation. However, this definition varies widely between studies, with some stratifying the severity of injury into major injury causing time-loss and minor injury causing recurrent shoulder or elbow pain without time loss. The conventional definition of a sports injury has been contested recently.

The purpose of this study is twofold. First, we aim to assess the incidence and distribution of pain in youth pitchers with a physical examination. Second, we aim to assess the correlation of physical examination findings with time-loss injury reported from the AOSSM survey. Our hypothesis is that time-loss injury assessed in the survey alone is too strict a criterion for determining the incidence of arm degeneration, and time-loss injury does not accurately reflect the incidence of pain in youth baseball pitchers.

METHODS

The research protocol was approved by the University of Iowa Institutional Review Board. Baseball players ages 9 to 18 in the Iowa City area were approached and asked to complete a survey if they had pitched in at least one organized game in the past 12 months. The survey was obtained from the AOSSM national study “A National Study of Youth Baseball Regarding Pitching Exposure and Elbow and Shoulder Problems.” In addition to injury and pain information, the survey identified demographic information, frequency of pitch types, pitch counts, multiple team involvement, participation in other sports, and outside training. While the coaches were not involved in the completion of the survey, some of the younger athletes required parental assistance.

Athletes were divided equally by age group between two research teams for physical examination based on screening criteria. The first team screened athletes by asking if they responded positively to the survey question: “In the last 12 months, have you had a pitching-related injury (such as shoulder or elbow pain) that caused you to miss pitching in at least one practice or game?” Any athlete who responded yes to this question was given a physical examination. The second research team screened athletes by asking the question: “Is your arm sore after pitching or do you ice it regularly?” If the athlete had pain, soreness or used ice frequently, he was given a physical examination. The research team consisted of medical professional students trained in the performance of a physical examination by a board certified orthopedic surgeon.

The physical examination evaluated tenderness in the elbow and shoulder. The teams checked shoulder range of motion, strength, laxity, and impingement. Elbow carrying angle, extension angle, strength, and valgus laxity were all assessed with any associated pain. Positive physical findings were only considered meaningful when there was a difference between the throwing and non-throwing arm.

Participants from both research teams were analyzed together. Data were only used from players who completed both the survey and the physical examination. Participants were divided into two groups: those with a history of injury in the past 12 months and those who did not report a history of injury on the survey. These populations were subdivided into age groups from 12 years and younger (Little League), 13 to 15 years (junior high and early high school), and 16 year and older (varsity high school).

Demographic information, number of teams played for in a season, and weekly competitive pitch count were compared with unpaired Student’s t-tests between these groups. The incidence of specific physical findings was compared between the two groups using a two-tailed Fisher’s exact test. The two groups were also compared for each age category.

RESULTS

Seventy-seven players completed the survey. Of these, 38 had either a history of time-loss injury or current pain without a history of time-loss injury and underwent physical examination. Table 1 shows the demographic characteristics of each group including age, weight, and height in addition to the number of competitive pitches per week and teams played for in a single season. Sixteen physical examinations were performed on athletes with a history of time-loss injury (Table 1). The average age of the positive time-loss history group was 15.2 years. The average height and weight for this group was 178.3cm and 158.1lbs respectively. The average athlete in the positive time-loss history group played on 1.6 teams simultaneously during a season, and averaged 76.0 game pitches per week. Twenty-two physical examinations were performed on athletes with a negative time-loss injury history and positive current symptoms of pain. The average age of this group was 14.9. The average height and weight for this group was 174.1cm and 153.5lbs respectively. The average athlete with a negative time-loss injury history played for 1.6 teams simultaneously during a season, and averaged 77.8 game pitches per week. There was no statistical difference between the two groups in any of these categories ($p > 0.05$).

A positive physical examination was common in both groups (Table 2). Of the athletes with a history of time-loss injury, 56.3% had at least one positive finding on physical examination. In the group reporting no time-loss injury in the last year, but current symptoms of
TABLE 1
Description of the study populations

<table>
<thead>
<tr>
<th>Survey (Hx) Descriptors</th>
<th>Time-Loss Injury n=16 Mean ± 95% CI</th>
<th>No Time-Loss, Current Pain n=22 Mean ± 95% CI</th>
<th>( p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>15.2 ± 1.0</td>
<td>14.9 ± 0.9</td>
<td>0.30</td>
</tr>
<tr>
<td>Height</td>
<td>178.3 ± 4.7</td>
<td>174.1 ± 4.4</td>
<td>0.30</td>
</tr>
<tr>
<td>Weight</td>
<td>158.1 ± 15.6</td>
<td>158.3 ± 13.6</td>
<td>0.32</td>
</tr>
<tr>
<td>Teams Played for in Single Season</td>
<td>1.6 ± 0.3</td>
<td>1.6 ± 0.2</td>
<td>0.37</td>
</tr>
<tr>
<td>Weekly In-Game Pitch Count</td>
<td>76.0 ± 33.8</td>
<td>77.8 ± 12.5</td>
<td>0.40</td>
</tr>
</tbody>
</table>

Age Distribution

<table>
<thead>
<tr>
<th></th>
<th>Overall</th>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>16</td>
<td>22</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 and Under</td>
<td></td>
<td>2 (33.3%)</td>
<td>4 (66.7%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>13 to 15</td>
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<td>6 (33.3%)</td>
<td>12 (66.7%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16 and Over</td>
<td></td>
<td>8 (57.1%)</td>
<td>6 (42.9%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Individual physical examination resulted in only one significant difference between groups (Table 2). The finding of any elbow complaint in the age 16 and above age group was significantly different between groups, being found in 37.5% of players with a positive time-loss injury history and 100% of players with a negative time-loss injury history and positive current pain \( p=0.03 \).

**DISCUSSION**

Overuse injury in youth pitchers is difficult to monitor. It is commonly believed that pitching injuries at the high school, collegiate, and professional levels are the result of repetitive microtrauma as a youth.\(^{30}\) Although the correlation of time-loss injury with age is widely accepted, its insidious nature makes it difficult to observe warning signs in younger populations. For this reason, several studies have assessed joint pain in addition to time-loss injury in this population.\(^{11,13}\)

The overall incidence of positive physical examination findings in our series was 37.6%. The most noticeable result of this study was the consistently higher incidence of positive physical examinations in the negative time-loss history, positive current pain group compared to the positive time-loss history group. This trend was significant for any physical examination as pain was observed in 90.9% of the negative time-loss history, positive current pain group and 56.3% of the positive time-loss history group \( p=0.02 \). It was also significant for elbow physical examination findings in all age groups which were observed in 72.7% of the negative time-loss history, positive current pain and 37.6% of the positive time-loss history groups \( p=0.05 \). Finally, elbow physical examination findings in the oldest group of athletes (16 years and over) were significantly different between groups with 100.0% of the negative time-loss history, positive current pain group having positive examination findings compared to only 37.5% of the positive time-loss history group \( p=0.03 \). A similar relationship was observed in overall positive shoulder examination findings, simultaneous positive shoulder and elbow examinations, tenderness, and valgus elbow laxity, though none of these relationships were statistically significant. The group with a history of time-loss injury only demonstrated a greater incidence of pain in one category, shoulder impingement, but this pertained to just two athletes. The rate of positive examination findings for all 77 players (37.6%) was similar to those observed by Lyman et al. After examining all players, they found a complaint frequency of 25.5% in the elbow, 28% in any other arm location and 47% in either the elbow or shoulder.\(^{11}\)
### TABLE 2
Description of the study populations

<table>
<thead>
<tr>
<th>Physical Findings</th>
<th>Time-Loss Injury</th>
<th>No Time-Loss, Current Pain</th>
<th>( p )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of Players</td>
<td>Number of Players</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(% of Age Group)</td>
<td>(% of Age Group)</td>
<td></td>
</tr>
<tr>
<td>Any Shoulder or Elbow Physical Finding</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall</td>
<td>9 (56.3%)</td>
<td>20 (90.9%)</td>
<td>0.02</td>
</tr>
<tr>
<td>12 and Under</td>
<td>2 (100%)</td>
<td>4 (100%)</td>
<td>1.00</td>
</tr>
<tr>
<td>13 to 15</td>
<td>3 (50.0%)</td>
<td>10 (83.3%)</td>
<td>0.27</td>
</tr>
<tr>
<td>16 and Over</td>
<td>4 (50.0%)</td>
<td>6 (100%)</td>
<td>0.08</td>
</tr>
<tr>
<td>Any Positive Shoulder Finding</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall</td>
<td>5 (31.3%)</td>
<td>13 (59.1%)</td>
<td>0.11</td>
</tr>
<tr>
<td>12 and Under</td>
<td>1 (50.0%)</td>
<td>4 (100%)</td>
<td>0.33</td>
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<tr>
<td>13 to 15</td>
<td>2 (33.3%)</td>
<td>5 (41.7%)</td>
<td>1.00</td>
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<tr>
<td>16 and Over</td>
<td>2 (25.0%)</td>
<td>4 (66.7%)</td>
<td>0.28</td>
</tr>
<tr>
<td>Any Positive Elbow Findings</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Overall</td>
<td>6 (37.5%)</td>
<td>16 (72.7%)</td>
<td>0.05</td>
</tr>
<tr>
<td>12 and Under</td>
<td>1 (50.0%)</td>
<td>2 (50.0%)</td>
<td>1.00</td>
</tr>
<tr>
<td>13 to 15</td>
<td>2 (33.3%)</td>
<td>8 (66.7%)</td>
<td>0.32</td>
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<tr>
<td>16 and Over</td>
<td>3 (37.5%)</td>
<td>6 (100%)</td>
<td>0.03</td>
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<tr>
<td>Shoulder Tenderness</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Overall</td>
<td>4 (25.0%)</td>
<td>9 (40.9%)</td>
<td>0.49</td>
</tr>
<tr>
<td>12 and Under</td>
<td>1 (50.0%)</td>
<td>1 (25.0%)</td>
<td>1.00</td>
</tr>
<tr>
<td>13 to 15</td>
<td>2 (33.3%)</td>
<td>4 (33.3%)</td>
<td>1.00</td>
</tr>
<tr>
<td>16 and Over</td>
<td>1 (12.5%)</td>
<td>4 (66.7%)</td>
<td>0.09</td>
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<tr>
<td>Elbow Tenderness</td>
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<td></td>
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<tr>
<td>Overall</td>
<td>5 (31.3%)</td>
<td>12 (54.5%)</td>
<td>0.20</td>
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<tr>
<td>12 and Under</td>
<td>0 (0.0%)</td>
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<td>2 (33.3%)</td>
<td>6 (50.0%)</td>
<td>0.64</td>
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<tr>
<td>16 and Over</td>
<td>3 (37.5%)</td>
<td>4 (66.7%)</td>
<td>0.59</td>
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<tr>
<td>Shoulder or Elbow Tenderness</td>
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<tr>
<td>Overall</td>
<td>7 (43.8%)</td>
<td>16 (72.7%)</td>
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</tr>
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<td>12 and Under</td>
<td>1 (50.0%)</td>
<td>3 (75.0%)</td>
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</tr>
<tr>
<td>13 to 15</td>
<td>3 (50.0%)</td>
<td>8 (66.7%)</td>
<td>0.63</td>
</tr>
<tr>
<td>16 and Over</td>
<td>3 (37.5%)</td>
<td>5 (83.3%)</td>
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<tr>
<td>Shoulder Impingement</td>
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<tr>
<td>Overall</td>
<td>2 (12.5%)</td>
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<td>0.17</td>
</tr>
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<td>0.33</td>
</tr>
<tr>
<td>13 to 15</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>1.00</td>
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<tr>
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<tr>
<td>Shoulder Laxity</td>
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<td></td>
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<tr>
<td>13 to 15</td>
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<td>1 (8.3%)</td>
<td>1.00</td>
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<tr>
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### Table 2 (continued)

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<tr>
<th>Elbow Valgus Laxity</th>
<th>Overall 0 (0.0%)</th>
<th>5 (22.7%)</th>
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<td>13 to 15</td>
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<td>1.00</td>
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<tr>
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<td>1 (12.5%)</td>
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<table>
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<tr>
<th>Active Shoulder Weakness or Pain</th>
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<th>5 (22.7%)</th>
<th>0.06</th>
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<td>2 (50.0%)</td>
<td>0.50</td>
</tr>
<tr>
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<td>0 (0.0%)</td>
<td>1 (8.3%)</td>
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<table>
<thead>
<tr>
<th>Elbow Active Weakness or Pain</th>
<th>Overall 1 (6.3%)</th>
<th>2 (9.1%)</th>
<th>1.00</th>
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<td>12 and Under</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>1.00</td>
</tr>
<tr>
<td>13 to 15</td>
<td>1 (16.7%)</td>
<td>1 (8.3%)</td>
<td>1.00</td>
</tr>
<tr>
<td>16 and Over</td>
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<table>
<thead>
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<th>Any Active Weakness or Pain</th>
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<th>1 (4.5%)</th>
<th>0.11</th>
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<td>0.47</td>
</tr>
<tr>
<td>13 to 15</td>
<td>1 (16.7%)</td>
<td>0 (0.0%)</td>
<td>1.00</td>
</tr>
<tr>
<td>16 and Over</td>
<td>1 (12.5%)</td>
<td>1 (16.7%)</td>
<td>0.05</td>
</tr>
</tbody>
</table>

In our study group it was more likely that positive physical examination findings were elicited from a pitcher with no history of a time-loss injury, but current complaints of pain (90.9%), than a pitcher with a history of time-loss injury (56.3%) (p=0.02). While it is possible that our examination exaggerated the result, we compared the throwing and non-throwing arms. An identical protocol was used for both groups studied. Additionally, this trend held up for more serious symptoms such as valgus laxity and pain. Despite our small numbers, we can observe this consistent trend through almost all of the physical examination parameters.

We believe pitchers who have missed game time due to an injury may be much more cognizant of pain and more cautious during games. Seven out of the 16 participants reporting a history of time-loss injury had a negative physical examination. Additionally, there may be many pitchers who continue to pitch despite pain and become more symptomatic than their “injured” counterparts. In a study by Harada et al., several athletes 9 to 12 years old denied pain despite significant findings during ultrasound, however all these athletes admitted pain after the positive ultrasound was revealed. This may indicate the existence of a group of athletes who are reluctant to report pain or miss game time as a result of pain. This may represent a group with a high risk of injury in more advanced divisions. Additionally, Lyman et al. found 70% of their injuries to be classified as mild. It is possible athletes are willing to play through this pain and would not consider it an injury while completing the survey.

There are several reasons why youth pitchers completing the survey may have under-reported past injury. First, the question specifically asked participants to identify “pitching-related” injuries. In cases of insidious symptom development, participants may not associate a time-loss injury exclusively with pitching. Second, a
participant may not recognize a loss of game or practice pitching as “time-loss,” especially if he was temporarily shifted to another position or simply adjusted his intensity during practice and games. Finally, participants may not be able to retrospectively recall time-loss over 12 months.

Reported elbow pain in Little League pitchers (12 and younger) varies widely from 17% to 60% compared to 11.5% in our study.\textsuperscript{4,13,14,15} In these studies, the incidence of time-loss injury is considerably lower, if non-existent.\textsuperscript{4,13,14} The incidence of an abnormal shoulder physical in this study, 19.2%, was lower than the literature, 32% to 35%.\textsuperscript{15,16} Pain in several of these other studies was self-reported and may lack some objectivity.

We acknowledge several limitations of the present study. While the average age of the two groups was similar, the distribution was slightly different. There were more pitchers 15 years and under in the negative time-loss history, positive current pain group, but more 16 years and over pitchers in the positive time-loss history group. Pitchers may have been evaluated at different points in their recovery cycles. Some pitchers were examined immediately before or after a game, while some were examined before a weekday practice. Finally, not enough athletes were screened to observe differences between age groups; for example, only 2 athletes in the 12 years and under group reported time-loss injury.

Many other studies have linked the incidence of injury in pitching to characteristics of the child including age, height, and weight, in addition to aspects of the game such as type of pitch, number of warm-up pitches, number of innings pitched, and pitch counts.\textsuperscript{4,13,14,15,16} The exact mechanism of injury is not completely known, but instead classified as overuse. It is likely that these players experienced minor injuries which could indicate impending major injury. The difference in positive response to these questions shows the insidious progression of overuse which may be leading to these injuries. While the two groups were equivalent in age, pitch counts, years played and training, one group demonstrated a much higher incidence of pain. The physical examination provides evidence that the complaints were valid and proves that this group of athletes could be missed by simply asking about time-loss injuries. If used in combination with this survey, a physical examination could more accurately reflect the incidence of arm pathology in this population.

While time-loss injury is important in a clinical and epidemiologic sense, it likely does not fully identify overuse injuries in youth pitchers. The current definition of sports injury precludes observation of pitchers who endure pain and pitchers who experience more insidious progression of symptoms. These players likely contribute to a substantial portion of injuries observed in collegiate and professional leagues. In the interest of identifying early warning signs for overuse injury, we should expand our focus beyond time-loss injury. This study suggests that physical examination may provide a more sensitive measure of elbow and shoulder pathology. We recommend the use of a physical examination in conjunction with a baseball survey to assess risk factors for young pitchers.

REFERENCES


CLINICAL, RADIOGRAPHIC, AND PATIENT-REPORTED RESULTS OF SURFACE REPLACING PROXIMAL INTERPHALANGEAL JOINT ARTHROPLASTY OF THE HAND

Mohana Amirtharajah, 'Duretti Fufa, "Nina Lightdale,' Andew Weiland***

ABSTRACT
The purpose of this study was to evaluate the one-year clinical, radiologic and patient-reported results of surface-replacing proximal interphalangeal joint arthroplasty (SR-PIP) of the hand. Fifteen patients with 18 joints underwent the procedure, and nine patients with 11 joints had follow-up of at least one year's duration. Of these joints, six had a diagnosis of osteoarthritis with no history of trauma, three had post-traumatic arthritis, one had psoriatic arthritis, and one had erosive arthritis. The mean clinical follow-up was at 3.3 years, and the mean radiographic follow-up was at 3.1 years. The average post-operative gain in range of motion at the PIP joint was 28 degrees and was statistically significant. Six patients completed self-reported questionnaires at a mean of 4.8 years post-operatively. The mean Disabilities of the Arm, Shoulder and Hand (DASH) score post-operatively was 17, and the Michigan Hand Questionnaire (MHQ) score for overall satisfaction was 70. There were three complications but only one reoperation. Seven of 11 joints showed some evidence of subsidence on follow-up radiographic examination. However, no joints were revised secondary to loosening. Longer follow-up is needed to determine if this observable radiologic subsidence leads to symptomatic loosening of the implant.

Introduction
Degenerative disease of the proximal interphalangeal (PIP) joint of the hand is a very difficult condition to treat. Arthrodesis at this joint is not always well-tolerated, particularly in the ulnar digits where a lack of flexion has a significantly detrimental effect on grip strength. Historically, silicone implants were used at this joint to try and restore motion. Although patients did report good relief of pain, these implants were complicated by breakage and decrease in survivorship after nine years.¹ Pyrolytic implants have also been developed, and some studies have reported good patient satisfaction with their use.² However, other studies have shown the results of these implants to be unpredictable and somewhat disappointing in patients with post-traumatic arthritis.³⁴ In addition, these pyrolytic implants are also susceptible to “squeaking”.³⁵

More recently, a surface-replacement PIP-joint arthroplasty (SR-PIP) has been developed with Linscheid et al reporting particularly good results in patients with degenerative arthritis.⁶ During the course of this series, the authors observed somewhat better results in patients who had a dorsal approach.⁷ In another series of patients receiving this implant, Jennings and Livingstone report that 60% of their patients found their results of this procedure to be very satisfactory; however, they also report a revision rate of 26% in a total of 43 joint arthroplasties at average follow-up of 37 months.⁷ Similarly, Luther et al reported 14 of 24 patients in their series needing re-operating.⁸ In that study, patients did have an increase in PIP joint range of motion of 21 degrees as well as a mean DASH score of 24 at an average of 27 months. Furthermore, multiple studies have shown lower rates of loosening in cemented versus non-cemented implants.⁹

The purpose of this study is to report the results of a single-surgeon series of patients undergoing SR-PIP arthroplasty. In this series, all implants were inserted through a dorsal approach and cemented. Results are reported using clinical, radiographic, and patient-reported outcomes.

METHODS

Materials
The implant used in this study was the SR-PIP system, previously of Avanta, now produced and marketed by Small Bone Innovations (SBI, New York, NY). The proximal phalangeal component consists of a metallic cobalt chromium alloy. The middle phalangeal component is made from ultra-high molecular weight polyethylene and titanium.
Study Design
Institutional Review Board approval was obtained for this study. A retrospective chart review revealed 15 patients with 18 joints who had undergone PIP joint arthroplasty by the senior author with this implant. Of these 18 joints, there was one index, seven middle, eight ring, and two small fingers. Eight patients with a total of 11 joints had radiographic and clinical follow-up of at least one year. Six patients completed the patient-reported outcomes questionnaires after surgery.

Outcomes
All patients were evaluated with PA and lateral radiographs of the operated finger. Radiographs were evaluated for signs of subsidence, periprosthetic radiolucency, and loosening. Range of motion measurements were made by the senior author using a small joint goniometer. At follow-up, patients were assessed with the Disabilities of the Arm, Shoulder, and Hand and Michigan Hand Questionnaire. The DASH is scored from 0-100 with 100 showing greater disability. The MHIQ consists of six categories: function, activities of daily living (ADLs), work, satisfaction, aesthetics and pain. The MHQ is scored from 0-100 with 100 showing better function except for the pain portion that is scored from 0-100 with 0 indicating no pain. Statistical analysis was performed using an unpaired t-test.

Surgical Technique
All surgeries were performed by the senior author in accordance with the implant technique guide. A dorsal tendon-splitting approach was used in all cases. The collateral ligaments and volar plate attachments were preserved and the joint opened in a “shotgun” fashion. The distal and proximal bone cuts were made with a sagittal saw. The intramedullary cavities were opened manually with an awl. Trial implants were used to test for fit and stability in all cases prior to choosing the final implant. All cases were cemented. The extensor mechanism was repaired in all cases.

RESULTS
Demographics
Fifteen patients (three men and 12 women) underwent PIP arthroplasty on a total of 18 joints. Of these patients, eight had osteoarthritis with no history of trauma, six had post-traumatic arthritis, one had rheumatoid arthritis, one had psoriatic arthritis, and one had erosive arthritis. The mean age at the time of surgery was 53 (range 22-74). Of the nine patients with 11 joints that had at least a one-year follow-up, six had osteoarthritis with no history of trauma, three had post-traumatic arthritis, one had psoriatic arthritis, and one had erosive arthritis. The average age at time of surgery for these patients (three men and six women) was 59 (range 38-74). This data set included six middle, four ring, and one small finger.

Clinical and Radiologic Outcomes
Average clinical follow-up was 3.3 years (range 1.0-6.8) and radiographic follow-up was 3.1 years (range 1.0-5.7). Pre-operative range of motion of the PIP joint averaged 22-55 degrees (33-degree arc of motion) and post-operative range of motion averaged 13-74 degrees (61-degree arc of motion). The final average gain in arc of motion was 28 degrees. This difference was statistically significant (p=0.025). On serial radiographs, seven of 11 joints (64%) showed some signs of subsidence (Figures 1 and 2). In two of these patients, subsidence was seen as early as one year (Figures 3 and 4).

Complications included one superficial infection treated with oral antibiotics, and one dislocation treated with closed reduction and a period of immobilization. One patient underwent reoperation consisting of an extensor tenolysis for stiffness approximately seven months after the initial surgery.

Self-Reported Outcomes
Six patients completed questionnaires at an average of 4.8 years post-operatively (range 3.6-8.2). The mean DASH score was 17. For the operated hand, the MHQ score for function averaged 66, for ADLs 78, for work performance 80, and for aesthetics 65. Pain scores on the MHQ averaged 22 (0 indicates no pain). The MHQ score for overall satisfaction averaged 70. For the contralateral, non-operated hand, MHQ score for function averaged 82, ADLs 85, aesthetics 70, pain 15, and satisfaction 78. None of these results reached statistical significance. One patient had bilateral surgeries so results for the “normal”

![Figure 1. Radiographs taken immediately post-operatively.](image)
hand were excluded. Four of the six patients stated they would have the procedure again. Of the two who would not, one patient cited lack of motion postoperatively, and the other patient’s clinical course was complicated by dislocation of the joint.

**DISCUSSION**

Treatment of arthritis at the PIP joint has remained one of the unsolved problems in hand surgery. The index and middle fingers are subject to such strong lateral forces during pinch activities that an implant at the PIP joint would need significant lateral stability for long-term survival. Arthrodesis at these joints provides good lateral stability but at the expense of motion. In contrast, although arthrodesis may be fairly well-tolerated in the index finger, fusion of the ulnar digits causes significant difficulty with power grip. Thus, surgeons have looked toward developing a durable implant that can withstand lateral forces but preserve motion.

Swanson introduced a constrained silicone implant for the PIP joint in the 1960s. Good pain relief has been reported from this procedure, although restoration of range of motion has been somewhat variable. Periprosthetic bone resorption as well as implant breakage have been noted over time in these implants.

In contrast to earlier constrained implants, newer implants have been developed in order to more closely recreate the normal joint anatomy. These types of im-
plants rely on the intact surrounding soft tissues for stability and require resection of only small amounts of bone. Minimally constrained pyrolytic carbon implants have been used as an alternative to silicone arthroplasty. Tuttle and Stern reported a total of 24 complications in 15 of these joints, with the most common being noticeable squeaking of the joint. Fifty percent of patients in this series had incomplete pain relief. Only two joints showed radiologic evidence of loosening. Nunley et al. showed inadequate relief of pain and lack of improvement in range of motion in patients who underwent pyrolytic carbon arthroplasty for post-traumatic arthritis of the PIP joint. Interestingly, Bravo et al. reported radiographic settling in 20 of 50 joints undergoing pyrolytic carbon arthroplasty. However, only four cases in this series were revised for loosening. These authors speculate that the implants “settle” into a stable position. Branan et al. compared the outcomes of silicone PIP implants to that of pyrolytic carbon implants. These authors found that both groups had good pain relief and self-reported satisfaction with similar numbers of complications.

The original version of the SR-PIP joint arthroplasty (Avanta) consisted of a chromium cobalt proximal component and a pure ultra-high molecular weight polyethylene (UHMWPE) distal component designed to be cemented. Linscheid et al. reported on 66 joints at an average of 4.5 years with 32 good, 19 fair, and 15 poor results. Interestingly, radiologic loosening was seen in only one joint. This study also found that results were better using a dorsal rather than a lateral or volar approach. A kinematic study in cadavers of this implant, also by Linscheid’s group, revealed that the SR-PIP implant had a similar center of rotation and similar kinematics to a native joint.

A later version of the implant (SBI) consisted of a distal component with a UHMWPE surface with a textured titanium stem allowing for press-fit, uncemented fixation. Johnstone et al. compared the results of cemented versus uncemented SR-PIP arthroplasty and found that although patients had similar pain relief and gains of motion after surgery, there were significantly more cases with radiologic evidence of loosening in the uncemented group. Thirteen out of 19 uncemented joints showed radiologic evidence of loosening compared with only one out of 24 cemented joints. The lead author now exclusively uses cement in his PIP joint arthroplasties. Jennings et al. also reported increased loosening in uncemented versus cemented prosthesis with 10 of the 11 revisions in his series associated with lack of cement. In this series, although range of motion was not significantly improved after surgery, 88% of patients had a very satisfactory or satisfactory result. In the series published by Luther et al., the mean DASH score was 24 and patients had an average improvement in range of motion of 21 degrees. However, 14 of 24 patients required reoperations.

Our study showed a 28-degree average gain of motion at the PIP joint as well as minimal disability as reported on the DASH questionnaire. Both results are similar to those reported by Luther et al. Our series was substantially smaller than the prior study; however, only one of our patients required reoperation. The MHQ showed a trend toward slightly worse scores on the operated hand; however, the small number of patients who responded to the questionnaire precludes meaningful statistical analyses.

The most striking feature in this series is the amount of subsidence seen radiologically. Early signs of subsidence were in some cases quite subtle, but careful evaluation of serial radiographs showed some subsidence in seven of 11 joints. All cases in our series were cemented in contrast to prior series which showed increased rates of radiologic subsidence or loosening mainly in their non-cemented implants. Interestingly, none of these cases has been revised for symptomatic loosening. These radiographic changes may represent stable “settling” of the implant as seen by Bravo et al. in pyrolytic carbon implants, or they may represent early loosening that could eventually become symptomatic.

In this small series of patients with SR-PIP arthroplasty, patients showed an increase in range of motion and reported fairly good function and pain relief on validated questionnaires. However, a large amount of radiographic subsidence was also seen on follow-up. Longer-term follow-up is needed to assess the survivorship of this implant.

REFERENCES


EXTREMITY SARCOMA SURGERY IN YOUNGER CHILDREN: TEN YEARS OF PATIENTS TEN YEARS AND UNDER

Ryan B. Israelsen,“” Benjamin E. Illum,“” Susie Crabtree, RN,‘‘ R. Lor Randall, MD,‘‘ Kevin B. Jones, MD

ABSTRACT

Sarcoma surgeons face unique challenges in younger patients with significant skeletal growth remaining. The heightened concerns regarding radiation in the very young and the drastic changes expected in the lengths and cross-sectional areas of bones affect the decision-making for both soft-tissue and bone sarcomas in this population. Nonetheless, there is sparse literature focused on sarcoma surgery in this age group. The records of one tertiary regional sarcoma treatment program were reviewed to identify all patients ten years old or younger at the time of local control surgery for limb or limb-girdle sarcomas. Demographic information, diagnosis, surgery performed, complications, and general outcomes were gleaned from the medical records. 43 patients were identified, including 15 with osteosarcomas, 11 Ewing’s sarcoma family tumors, five rhabdomyosarcomas, and two synovial sarcomas, among others. Location of tumors varied widely, but demonstrated a predilection for the upper extremity more than is typical in adolescents with the same tumor types. Survival was favorable overall, with only five patients dying from disease. Most patients continued to function well at latest follow-up, but 16 experienced additional surgical interventions following the index procedure. Sarcoma surgery in the younger growing child presents challenges for the surgeon, patient, and parents, but is usually successful in the long-term.

INTRODUCTION

Over the last thirty years, surgical options for limb and limb-girdle sarcomas have expanded far beyond the prior, almost exclusive use of proximal amputation. Improved imaging and successful adjuvants such as cytotoxic chemotherapy for most bone sarcomas and radiotherapy for most soft-tissue sarcomas have narrowed the thickness of margins considered necessary to achieve local control of these neoplasms. The surgical practice of limb salvage has become a subspecialty unto itself with the rise of these options and the technologies available to perform them.

Sarcomas generally have a bimodal distribution in the population according to age. Most complex genetic soft-tissue sarcomas favor older populations beyond middle age. Bone sarcomas and balanced chromosomal translocation-associated soft-tissue sarcomas, however, have a predilection for adolescents and young adults.

Certainly, the adolescent and young-adult cancer populations proffer plentiful challenges to multidisciplinary sarcoma treatment teams, both surgically and psychosocially. The same sarcomas common in these young populations can also occur much more rarely in the very young. Unique psychosocial, anatomic, mechanical, and biological factors all increase the challenges in sarcoma surgery for the very young child with considerable growth potential remaining. There are few papers in the literature focusing on this population. We determined to review the experience at our center with surgery in this younger population, hoping to inspire others to do the same.

METHODS

With the approval of our institutional review board for human subjects research, and following all appropriate legal and ethical guidelines for the same, records were retrospectively reviewed of patients treated at our tertiary referral center for multidisciplinary sarcoma care. Patients 10 years old or younger at the time of surgery were included if they underwent surgery with the intent of wide resection for bone or soft-tissue sarcomas during the first decade of the 21st century. Amputations were not excluded; neither were sarcoma-like wide resection surgeries for borderline, non-malignant diagnoses. Patient medical records and imaging were reviewed. De-
mographic information, diagnosis, surgery performed, complications, follow-up duration, and general outcome were gleaned from the medical records, and tabulated.

RESULTS

Mean age at index procedure was five years plus six months, ranging from ten days old to ten years (Table 1). The diagnoses included 15 osteosarcomas, 11 Ewing’s sarcoma family tumors, five rhabdomyosarcomas, three pleomorphic sarcomas, three fibromatosis-related neoplasms, two infantile fibrosarcomas, and two synovial sarcomas, among others. Of these, 17 were located in the upper extremity or shoulder girdle and 26 in the lower extremity or pelvic girdle. All bone sarcomas received neoadjuvant and adjuvant chemotherapy, as did all synovial sarcomas, rhabdomyosarcomas, and Ewing’s sarcoma family tumors in the soft tissues. Three patients received adjuvant radiation; two for narrow margins following resection of Ewing’s sarcoma family tumors and one for a rhabdomyosarcoma in the soft tissues.

Surgically performed included wide resection alone, or with radiation in 18 patients, resection followed by endoprosthetic reconstruction in nine patients, regional graft reconstructions in four patients, primary amputation in five patients, modified amputations in three patients, distant-site autografting in two patients, and intercalary allograft reconstruction in one patient. Specifically, there were three clavicular pro humerus reconstructions (Figure 1) and one ulnus, or creation of a single-bone forearm (Figure 2).

Among complications, infection and wound healing difficulties were most common, especially in the younger children, with seven affected in total. The sequelae of some of these infections were severe, resulting in rotationplasty in two and tibial turn-up in one. Of note, only one patient under 10 years old, out of four managed initially with long-bone endoprosthetic reconstruction, retains that endoprosthesis at latest follow-up (Figure 3). Most infections were late.

Limb length inequality (LLI) was also common, noted as significant in seven patients. Three patients developed local recurrence; two were managed with re-resection, the other with proximal amputation. One patient had unacceptable margins on initial resection of a tumor that
Table 1
Limb and limb-girdle sarcoma surgery patients ten years old and younger, treated at a single tertiary referral sarcoma center in the first decade of the 21st century.

<table>
<thead>
<tr>
<th>Age (y)</th>
<th>Gender</th>
<th>Diagnosis</th>
<th>Anatomic Location</th>
<th>Local Control/Reconstruction</th>
<th>Complications and Management</th>
<th>F/U</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 d</td>
<td>M</td>
<td>Infantile FS</td>
<td>Hindfoot</td>
<td>Wide resection alone</td>
<td>None</td>
<td>92</td>
<td>Good</td>
</tr>
<tr>
<td>5 m</td>
<td>F</td>
<td>Pleomorphic</td>
<td>Forefoot</td>
<td>Chopart amputation</td>
<td>None</td>
<td>86</td>
<td>Good</td>
</tr>
<tr>
<td>9 m</td>
<td>M</td>
<td>Pleomorphic</td>
<td>Axilla</td>
<td>Wide resection alone</td>
<td>None</td>
<td>83</td>
<td>Good</td>
</tr>
<tr>
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<td>M</td>
<td>Fibromatosis</td>
<td>Periscapular</td>
<td>Wide resection alone</td>
<td>None</td>
<td>13</td>
<td>Good</td>
</tr>
<tr>
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<td>M</td>
<td>Infantile FS</td>
<td>Scapula</td>
<td>Wide resection alone</td>
<td>None</td>
<td>34</td>
<td>Good</td>
</tr>
<tr>
<td>16 m</td>
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<td>Pleomorphic</td>
<td>Periscapular</td>
<td>Wide resection alone</td>
<td>None</td>
<td>3</td>
<td>Good</td>
</tr>
<tr>
<td>18 m</td>
<td>F</td>
<td>ESFT</td>
<td>Supraclavicular</td>
<td>Wide resection alone</td>
<td>Managed by resection, local recurrence</td>
<td>111</td>
<td>Good</td>
</tr>
<tr>
<td>18 m</td>
<td>M</td>
<td>ESFT</td>
<td>Periscapular</td>
<td>Wide resection alone</td>
<td>Recurrence and recurrence, each managed by resection</td>
<td>92</td>
<td>Good</td>
</tr>
<tr>
<td>18 m</td>
<td>M</td>
<td>ESFT</td>
<td>Scapula</td>
<td>Wide resection including partial scapulectomy</td>
<td>None</td>
<td>104</td>
<td>Good</td>
</tr>
<tr>
<td>20 m</td>
<td>M</td>
<td>ESFT</td>
<td>Proximal calf</td>
<td>Wide resection and radiation</td>
<td>LLI: equinus contracture</td>
<td>85</td>
<td>Good</td>
</tr>
<tr>
<td>2 y</td>
<td>F</td>
<td>RMS</td>
<td>Presacral</td>
<td>Sacrectomy and proctectomy</td>
<td>Infection managed with debridement and flap closure</td>
<td>62</td>
<td>Good</td>
</tr>
<tr>
<td>3 y</td>
<td>F</td>
<td>OS</td>
<td>Distal femur</td>
<td>Tibial turn-up</td>
<td>Local recurrence managed with hip disarticulation</td>
<td>17</td>
<td>DOD</td>
</tr>
<tr>
<td>3 y</td>
<td>F</td>
<td>RMS</td>
<td>Thigh</td>
<td>Wide resection alone</td>
<td>None</td>
<td>84</td>
<td>Good</td>
</tr>
<tr>
<td>4 y</td>
<td>M</td>
<td>Fibromatosis</td>
<td>Third toe</td>
<td>Toe amputation</td>
<td>None</td>
<td>58</td>
<td>Good</td>
</tr>
<tr>
<td>4 y</td>
<td>F</td>
<td>OS</td>
<td>Proximal Tibia</td>
<td>Knee disarticulation</td>
<td>Metastasis</td>
<td>17</td>
<td>DOD</td>
</tr>
<tr>
<td>5 y</td>
<td>F</td>
<td>OS</td>
<td>Proximal humerus</td>
<td>Clavicular pro humero with fibular autograft addition</td>
<td>Metastasis</td>
<td>9</td>
<td>Good</td>
</tr>
<tr>
<td>5 y</td>
<td>F</td>
<td>Angiomatoid fibrous histiocytoma</td>
<td>Elbow</td>
<td>Wide resection alone</td>
<td>None</td>
<td>10</td>
<td>Good</td>
</tr>
<tr>
<td>5 y</td>
<td>F</td>
<td>SS</td>
<td>Foot</td>
<td>Wide resection alone</td>
<td>None</td>
<td>2</td>
<td>Good</td>
</tr>
<tr>
<td>5 y</td>
<td>F</td>
<td>RMS</td>
<td>Thigh</td>
<td>Wide resection and sentinel lymphadenectomy</td>
<td>None</td>
<td>40</td>
<td>Good</td>
</tr>
<tr>
<td>6 y</td>
<td>F</td>
<td>OS</td>
<td>Proximal humerus</td>
<td>Clavicular pro humero</td>
<td>Non-union and late displacement managed by revision fixation</td>
<td>25</td>
<td>Good</td>
</tr>
<tr>
<td>6 y</td>
<td>M</td>
<td>OS</td>
<td>Proximal humerus</td>
<td>Clavicular pro humero</td>
<td>Non-union and late displacement managed by revision fixation</td>
<td>12</td>
<td>Recent fixation</td>
</tr>
<tr>
<td>6 y</td>
<td>F</td>
<td>ESFT</td>
<td>Distal femur</td>
<td>Rotationplasty</td>
<td>None</td>
<td>6</td>
<td>Good</td>
</tr>
<tr>
<td>7 y</td>
<td>M</td>
<td>OS</td>
<td>Distal femur</td>
<td>Attempted resection, then above knee amputation</td>
<td>Pathologic fracture during neoadjuvant chemotherapy, metastasis</td>
<td>13</td>
<td>DOD</td>
</tr>
<tr>
<td>7 y</td>
<td>F</td>
<td>OS</td>
<td>Distal femur</td>
<td>Expandable endoprosthesis</td>
<td>Hardware failure managed by revision; LLI managed by contralateral epiphysiodesis</td>
<td>48</td>
<td>Good</td>
</tr>
<tr>
<td>7 y</td>
<td>M</td>
<td>OS</td>
<td>Distal femur</td>
<td>Expandable endoprosthesis</td>
<td>Infections managed with rotationplasty</td>
<td>36</td>
<td>Good</td>
</tr>
</tbody>
</table>
Table 1 (continued)
Limb and limb-girdle sarcoma surgery patients ten years old and younger, treated at a single tertiary referral sarcoma center in the first decade of the 21st century.

<table>
<thead>
<tr>
<th>Age</th>
<th>Gender</th>
<th>Diagnosis</th>
<th>Anatomic location</th>
<th>Local Control/Reconstruction</th>
<th>Complications and Management</th>
<th>F/U</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 y</td>
<td>F</td>
<td>OS</td>
<td>distal femur</td>
<td>intercalary allograft</td>
<td>LLI, contralateral epiphysioseis</td>
<td>80</td>
<td>good</td>
</tr>
<tr>
<td>7 y</td>
<td>M</td>
<td>ESFT</td>
<td>paraspinal</td>
<td>wide resection alone</td>
<td>delayed healing managed by wound revision</td>
<td>48</td>
<td>good</td>
</tr>
<tr>
<td>7 y</td>
<td>M</td>
<td>Hemangioendothelioma</td>
<td>elbow</td>
<td>wide resection alone</td>
<td>none</td>
<td>2</td>
<td>good</td>
</tr>
<tr>
<td>7 y</td>
<td>F</td>
<td>RMS</td>
<td>thigh</td>
<td>wide resection and radiation</td>
<td>none</td>
<td>52</td>
<td>good</td>
</tr>
<tr>
<td>8 y</td>
<td>M</td>
<td>OS</td>
<td>distal femur</td>
<td>rotationplasty</td>
<td>skeletal and pulmonary metastasis</td>
<td>38</td>
<td>disease progress</td>
</tr>
<tr>
<td>8 y</td>
<td>M</td>
<td>ESFT</td>
<td>periscapular</td>
<td>scapulectomy and endoprosthes</td>
<td>none</td>
<td>145</td>
<td>good</td>
</tr>
<tr>
<td>8 y</td>
<td>F</td>
<td>ESFT</td>
<td>ilium</td>
<td>type I internal hemipelvectomy and fibular strut grafting</td>
<td>LLI, epiphysioseis</td>
<td>87</td>
<td>good</td>
</tr>
<tr>
<td>9 y</td>
<td>F</td>
<td>ESFT</td>
<td>calcaneus</td>
<td>below knee amputation</td>
<td>metastasis on presentation; stump breakdown managed by flap revision; osteoporotic femur fracture managed by internal fixation</td>
<td>24</td>
<td>good</td>
</tr>
<tr>
<td>9 y</td>
<td>M</td>
<td>OS</td>
<td>distal femur</td>
<td>expandable endoprosthes</td>
<td>LLI, late infection managed by tibial turn-up; contractures managed by stump revisions</td>
<td>110</td>
<td>good</td>
</tr>
<tr>
<td>9 y</td>
<td>M</td>
<td>RMS</td>
<td>distal femur</td>
<td>expandable endoprosthes</td>
<td>LLI, late infection managed by rotationplasty; metastasis</td>
<td>28</td>
<td>good</td>
</tr>
<tr>
<td>9 y</td>
<td>M</td>
<td>ESFT</td>
<td>proximal radius</td>
<td>subtotal radiectomy and distal synostosis, radiation</td>
<td>non-union managed by revision fixation and autografting</td>
<td>9</td>
<td>good</td>
</tr>
<tr>
<td>9 y</td>
<td>M</td>
<td>SS</td>
<td>hand</td>
<td>wide resection alone</td>
<td>none</td>
<td>26</td>
<td>good</td>
</tr>
<tr>
<td>10 y</td>
<td>M</td>
<td>OS</td>
<td>distal femur</td>
<td>expandable endoprosthes</td>
<td>LLI</td>
<td>24</td>
<td>good</td>
</tr>
<tr>
<td>10 y</td>
<td>F</td>
<td>OS</td>
<td>distal femur</td>
<td>expandable endoprosthes</td>
<td>metastasis on presentation; insufficiency fracture from disuse osteopenia, managed in walking boot</td>
<td>6</td>
<td>in boot treatment</td>
</tr>
<tr>
<td>10 y</td>
<td>M</td>
<td>OS</td>
<td>distal femur</td>
<td>expandable endoprosthes</td>
<td>stitch abscesses managed with drainage; LLI; metastasis</td>
<td>42</td>
<td>DOD</td>
</tr>
<tr>
<td>10 y</td>
<td>M</td>
<td>OS</td>
<td>distal humerus</td>
<td>expandable total elbow endoprosthes</td>
<td>metastasis on presentation; hardware failure managed by revision to total humerus endoprosthes</td>
<td>16</td>
<td>DOD</td>
</tr>
<tr>
<td>10 y</td>
<td>M</td>
<td>fibromatosis</td>
<td>calf</td>
<td>wide resection alone</td>
<td>none</td>
<td>18</td>
<td>good</td>
</tr>
<tr>
<td>10 y</td>
<td>F</td>
<td>ESFT</td>
<td>periscapular</td>
<td>wide resection</td>
<td>none</td>
<td>16</td>
<td>good</td>
</tr>
</tbody>
</table>

Abbreviations: d = day, m = month, y = year; M = male, F = female; FS = fibrosarcoma; ESFT = Ewing's sarcoma family tumor; OS = osteosarcoma; RMS = rhabdomyosarcoma; SS = synovial sarcoma; LLI = limb length inequality; F/U = follow-up in months.
had become complicated by pathologic fracture during neoadjuvant chemotherapy; this recognition was not unanticipated and prompted proximal amputation under the same anesthetic. Two patients developed fractures from disuse osteopenia shortly after completion of adjuvant chemotherapy.

Nine patients either presented with or developed metastatic disease during their course of treatment and surveillance. Five patients have died from disease and a sixth is alive, but moribund with currently progressing disease.

DISCUSSION

The ten-and-under population makes up a small portion of the overall volume of sarcoma-related medical care at our institution and also more generally. While many of the same treatment principles and practices are brought to bear on the tumors arising in this younger population, there are unique considerations that our series highlights. For example, a local recurrence rate near five percent remains the goal, but generates a much higher rate of amputation in these young children than in their adolescent counterparts. There were eight primary amputations or modified amputations (Figure 4), and another four performed as secondary procedures. For most of these children, these procedures were chosen among available options as the most function-preserving operations. Other considerations are also unique to this young population, such as avoidance of radiation, difficulties with skeletal growth, and preference of biologic reconstructions for expected durability.

Radiotherapy is especially undesirable in the very young child due to the increased severity of reactive fibrosis, the growth disturbances expected in radiated bones and other tissues, and a greater concern for secondary cancers arising from irradiated cells that are actively proliferating. Although three patients in our series received radiation as part of their initial local control, another ten patients would have likely received adjuvant radiation had they been adults with tumors of similar grade, size, and location. A fourth patient received radiation as part of the management of a local recurrence. In the patients who received radiation, only one specific radiation morbidity, that of equinus contracture following calf radiation, was noted, but at present the follow-up remains short in total duration.
For these patients, doses were minimized - most were guided by Children’s Oncology Group trial protocol specifications - and administered by a pediatric radiation oncology specialist.

Anticipated skeletal growth challenges the decision-making for parents, patients, and surgeons when sarcomas arise in the bones of these young children. Eight patients underwent expandable endoprosthetic reconstructions in our series. Other patient series have focused specifically on such implants.\textsuperscript{11-13} While the technology for such implants continues to improve, including both non-invasively and minimally-invasively lengthened options, these reconstructions are usually limited to the older patients among this very young population. In patients under ten years old, both the lengthening expected and the smaller diaphyseal cross-sectional areas add additional challenges. Even most successful endoprosthetic reconstructions with expandable implants will require revision to definitive adult implants after skeletal maturity. The cortical atrophy expected around cemented or even press-fit stems in younger children can shorten the usable bone for such secondary reconstructions.\textsuperscript{14-15} It is with this in mind that, at our center, we often utilize Compress (Biomet) interfaces between the host bone and implant, to both minimize the atrophic changes, and shorten the diaphyseal length utilized that might require subsequent resection on revision reconstruction.\textsuperscript{16} Nonetheless, no endoprosthetic reconstructive options available on the market today are without inherent pitfalls in the ten-years-old-and-under population. Two of our patients had hardware-related problems requiring revisions prior to skeletal maturity. We noted specifically that only one patient under ten years old in our series of four (in this age range) retained a long-bone endoprosthetic reconstruction at latest follow-up. The difficulty with soft-tissue coverage of unavoidably over-bulky implants in this very young population, as well as the on-going need for subsequent interventions, puts these patients at the highest risk. While rotationplasty remains an excellent secondary salvage operation for many of these patients, it can be much more difficult to perform in the setting of failed endoprosthetic reconstruction, given the stiffening of peri-vascular and perineural tissues, the compliance of which is critical to successful rotationplasty.

Allografts pose other unique problems for this population wherein significant growth is expected. Although healing of allograft-host junctions may be more readily achieved in younger patients, aggressive cytotoxic chemotherapy likely decimates this healing advantage. There are growth-related issues as well. When allografts must cross or replace physes, longitudinal growth and angular deformities are the expectation in these very young patients, as exemplified by one in our series (Figure 5). These may be managed with guided growth of remaining physes, but such anticipated subsequent interventions must be reviewed with patients and their parents at the initial decision-making discussions. Even when diaphyseal resections can spare physes to permit continued longitudinal growth (rare by the anatomic extent of most tumors), the cross sectional area of the allografts that will fit very young bones will not usually be suitable for the adult bodies that these bones will ultimately support. This creates the necessity for additional surgeries during skeletal growth in most cases.

Such challenges with endoprosthetic or allograft reconstructions in these younger patients led many of the surgical discussions toward more creative biological reconstructive options. Three patients with proximal humerus sarcomas in our series were reconstructed by disarticulating the sternoclavicular joint and swinging the clavicle down, suspended from the acromioclavicular joint to serve as the proximal humerus, termed the clavica pro humero reconstruction.\textsuperscript{8, 17} As essentially all proximal humerus reconstructive options following wide resection create some form of a hanging arm,\textsuperscript{14} these clavica pro humero reconstructions are especially attractive, given the chance for bidirectional active bone healing and a native joint for suspension. Nonetheless, even healthy bone from both the medial clavicle and
the distal humerus can be thwarted from healing to each other in the setting of adjuvant chemotherapy, as exemplified by one of our patients. Further, the clavicle is limited in the length it can provide for reconstruction, prompting the use of a fibular autograft between the down-rotated clavicle and the residual humerus in another patient in this series with long involvement of the humerus.

We encourage appropriate patients to strongly consider rotationplasty in its varied forms when segmental skeletal resections are required in the lower extremity in the very young. There were two primary and two secondary rotationplasties in our series as well as one primary tibial turn-up and one secondary tibial turn-up (Figure 6). Although rotationplasty remains less popular in the United States than in Europe or Canada, it has many advantages over some other resection/reconstructive options. The prosthetics that these patients utilize permit essentially unlimited activities. Further, rotationplasty eschews the neurological complications and cut bone-end overgrowth problems of proximal amputation in the very young. In cases where concern for popliteal soft-tissue extension might otherwise make margins unacceptably close following popliteal dissection, the vascular resection and reanastomosis possible in rotationplasty can leave a popliteal vessel segment as an additional layer of marginal tissue. The primary challenges to rotationplasty remain the peer-perception issues that can be expected during adolescence and the lifetime need for specialized prosthetic fittings. This latter concern remains a major impediment for some patients pursuing rotationplasty in the United States as opposed to in nations where medical costs are covered by socialized systems.

The ten-years-old-and-under population represents a portion of sarcoma surgery to which William Enneking’s adage, “There are no rules in tumor surgery,” is aptly applied. Nonetheless, we hope that this publication of our experience, with its inherent challenges, will prompt others to put theirs on more open display as well. There is clearly more art than science advising these surgeries, but just like the best guesses, we hope that art can become better educated. It will be educated by the exchange of ideas and experiences in the literature by those willing to face these challenging cases openly.
ACKNOWLEDGEMENTS

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REFERENCES


CHONDROSARCOMA OF THE SPINE: A SERIES OF 16 CASES
AND A REVIEW OF THE LITERATURE

Sophia A. Strike, B.S.E. and Edward F. McCarthy, MD.

ABSTRACT
Only a few major studies of chondrosarcoma of the mobile spine have been reported. These studies have shown that spinal chondrosarcomas require complete surgical resection and are notoriously resistant to chemotherapy and radiation. We present 16 cases of chondrosarcoma of the mobile spine diagnosed at a median age of 54.5 (range 20 – 79) years. Diagnosis and treatment studies were based on both CT scans and MRI. Fifteen of our 16 patients had low-grade (grade 1-2) chondrosarcomas. All patients were treated with surgical resection. Fourteen patients had total resection while two patients had subtotal resection. The two patients who had subtotal resection died of their disease. Five of the fourteen patients who had total resection also died. The mean interval to death was 3.6 years. This study confirms that although chondrosarcomas of the spine are low grade, they are dangerous neoplasms. Even with complete resection, they have a high rate of recurrence and metastasis.

INTRODUCTION
Chondrosarcoma is a malignant cartilage-forming bone neoplasm that accounts for 10% of all primary bone tumors.1 Typically low grade, these neoplasms can arise de novo or from a pre-existing cartilage lesion such as an osteochondroma or enchondroma.12 Less than 10% of all chondrosarcomas occur in the spine.124 Most occur in the thoracic spine, and patients typically present in middle age with back pain and/or neurological symptoms.1358 Men are affected more often than women.13357 Radiologically, these tumors appear as destructive lesions in the spine or as a paraspinal mass with calcification.1

The most successful treatment for spinal chondrosarcoma is complete en bloc resection of the tumor.1478 This often requires spinal reconstruction involving a multidisciplinary team of orthopedic, plastic and neurosurgeons.579 Intralesional removal almost always results in recurrence.7 Chondrosarcomas in general are resistant to chemotherapy and radiation treatment, although postoperative proton-beam therapy, especially for spinal lesions, has shown positive results.5310 When en bloc resection is not possible, partial removal followed by radiotherapy may provide palliation of pain and improve neurological deficits.1113 This paper reports 16 cases of spinal chondrosarcoma.

MATERIALS AND METHODS
These sixteen cases were culled from the IRB-approved database maintained by the senior author. Available data included history and follow-up, radiographic images, and histologic slides.

CASE DESCRIPTIONS
Six patients were female and ten were male (see Table 1). The median age at presentation was 54.5 (range 20 – 79) years. Four cases occurred in the cervical spine alone and seven cases involved only the thoracic spine, while two cases involved the cervicothoracic spine (patients 10 and 13). Three cases involved the lumbar spine.

RADIOGRAPHIC FINDINGS
Radiographic images of thirteen of the sixteen cases were available for study. All thirteen cases had CT scans. Twelve of these thirteen cases also had MRI studies.


The lesions were poorly visualized on plain radiographic studies. Lesions were best visualized with a combination of CT and MRI studies.

Both central and surface chondrosarcomas were represented in this study. There were seven central sarcomas and six surface lesions. Of the central chondrosarcomas, three involved the vertebral body (Figure 1) and four involved the pedicle (Figure 2). Lesions in the pedicle usually had extraosseous extensions. Often, the extraosseous extensions were best visualized with an MRI scan (Figure 3). All but one of the CT scans showed rings and stippled characteristic of cartilage matrix (Figure 4). Lesions on MRI were lobulated and bright on T1-weighted images. One patient (patient 16) had synovial chondromatosis of a cervical vertebra with secondary chondrosarcoma (Figure 5).

**HISTOLOGICAL FINDINGS**

Histologic study was available on all 16 cases. In all but one case, the diagnosis was made on the CT-guided needle biopsies. One case required an open biopsy. The histologic findings of hyaline cartilage were interpreted in the light of the radiographic images. After resection of the lesion, the diagnosis of chondrosarcoma was confirmed in all cases.

Histologic grading of the chondrosarcomas ranged from grade 1 to grade 3. However, there was only one grade 3 chondrosarcoma. There were six grade 1 chondrosarcomas (Figure 6) and nine grade-2 chondrosarcomas.

**TREATMENT**

All cases were treated with surgical resection. Fourteen patients had total resection of their tumors. Ten of these cases were treated with one procedure, while two cases required a two-stage procedure (patients 1 and 16) and two cases required a three-stage procedure (patients 2 and 9).

Two patients had subtotal excision of their tumors. Patient 12 underwent resection of the tumor down to the

---

**TABLE 1.**

<table>
<thead>
<tr>
<th>Patient #</th>
<th>Age/Gender</th>
<th>Location</th>
<th>Pathological Grade</th>
<th>Treatment</th>
<th>Outcome</th>
<th>Time to Follow-Up (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>76M</td>
<td>T11</td>
<td>I</td>
<td>R</td>
<td>A</td>
<td>1.17</td>
</tr>
<tr>
<td>2</td>
<td>60F</td>
<td>C2-C4</td>
<td>I</td>
<td>R</td>
<td>D</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>37F</td>
<td>C4-C5</td>
<td>I</td>
<td>PR/H+</td>
<td>D</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>41M</td>
<td>T9-T10</td>
<td>III</td>
<td>R</td>
<td>A</td>
<td>7</td>
</tr>
<tr>
<td>5</td>
<td>20M</td>
<td>T9-T10</td>
<td>I</td>
<td>R</td>
<td>A</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>39F</td>
<td>T9-T10</td>
<td>I</td>
<td>R/H+</td>
<td>D</td>
<td>4</td>
</tr>
<tr>
<td>7</td>
<td>79M</td>
<td>C5-C6</td>
<td>II</td>
<td>R</td>
<td>A</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>63F</td>
<td>T8</td>
<td>II</td>
<td>R</td>
<td>A</td>
<td>1.25</td>
</tr>
<tr>
<td>9</td>
<td>52M</td>
<td>L1</td>
<td>II</td>
<td>R/H+</td>
<td>A</td>
<td>3</td>
</tr>
<tr>
<td>10</td>
<td>58M</td>
<td>Cervicothoracic</td>
<td>II</td>
<td>R/H+</td>
<td>A</td>
<td>3</td>
</tr>
<tr>
<td>11</td>
<td>49M</td>
<td>T1-T4</td>
<td>II</td>
<td>R</td>
<td>D</td>
<td>7</td>
</tr>
<tr>
<td>12</td>
<td>49F</td>
<td>T3-T4</td>
<td>II</td>
<td>PR</td>
<td>D</td>
<td>3</td>
</tr>
<tr>
<td>13</td>
<td>57M</td>
<td>Cervicothoracic</td>
<td>II</td>
<td>R</td>
<td>D</td>
<td>3</td>
</tr>
<tr>
<td>14</td>
<td>74F</td>
<td>L5</td>
<td>II</td>
<td>R</td>
<td>D</td>
<td>3</td>
</tr>
<tr>
<td>15</td>
<td>61M</td>
<td>L1</td>
<td>II</td>
<td>R</td>
<td>A</td>
<td>3</td>
</tr>
<tr>
<td>16</td>
<td>46M</td>
<td>C1-C2</td>
<td>I</td>
<td>R</td>
<td>A</td>
<td>6.5</td>
</tr>
</tbody>
</table>

T = thoracic; C = cervical; L = lumbar; I = grade one; II = grade two; III = grade three; IR = resection; PR = partial resection; H+ = adjuvant proton beam radiation therapy; A = alive; D = deceased.
Figure 1. Axial CT scan of the L1 vertebra of patient #15. There is a poorly defined lytic lesion mixed with nodular radiodensities characteristic of cartilage.

Figure 2. Axial CT scan of the T8 vertebra of patient #8 showing a poorly defined lytic lesion in the pedicle with associated ring-like radiodensities.

Figure 3. A) Axial CT scan of the C8 of patient #10. There is a poorly defined lytic lesion with cortical destruction. B) A T1 weighted sagittal MRI of patient #10 showing the anterior extraosseous extension of the lobulated cartilage mass which was not visible on CT scan.
FOLLOW-UP AND OUTCOME

Follow-up was available for all sixteen patients with a mean time of follow-up of 3.5 (range 1 – 7) years.

Of the 16 patients, seven (43.8%) had died of their disease due to pulmonary metastasis. Both patients who had only subtotal resection and five of the 14 who had total en bloc resection died. The interval to death ranged from two to seven years (mean 3.6 years). Four of the patients who died had a local recurrence before pulmonary metastasis. The interval to local recurrence ranged from 1.3 to four years. No surviving patient has serious neurologic deficit.

Seven patients developed pulmonary metastases; one of these patients also had metastases to the chest wall and ribs (patient 11). Five of these seven originally had total resection of their tumors while the other two were the only patients who had subtotal tumor resection (patients 3 and 12). Therefore five of 14, or 35.7% of patients with total tumor resection later had metastases, while 100% of patients with subtotal tumor resection suffered metastases. The interval from surgical treatment to metastatic disease was available for two of the seven patients. For the patient who had subtotal tumor resection (patient 3) the interval to metastases was four years, while the patient who underwent total tumor resection had metastases within two years (patient 11).

DISCUSSION

Three other similar large series of spinal chondrosarcoma have been reported. Shives et al. described 20 patients from Mayo Clinic while York et al. described 21 patients cared for at the University of Texas M.D. Anderson Cancer Center. Boriani et al. reviewed 22 cases of chondrosarcoma of the mobile spine. Lloret
et al. described a smaller series of five patients.6 Other studies include smaller series and case reports,2, 4, 6, 8, 11

Our study confirms some clinical observations by these previous authors. Similar to the Mayo Clinic series, our series shows that men are most commonly affected. However, an equal gender distribution was observed at M.D. Anderson Cancer Center. The median age of our patients was 54.5 (range 20 – 79) years, similar to that observed in series at all sites and consistent with the literature.5-8, 13, 14 Also, the increased involvement of the thoracic spine compared to the cervical and lumbar spine seen in our patients is similar to previous studies.6, 13, 14

Chondrosarcoma of the spine may present diagnostic difficulties. Differential diagnosis includes three lesions that can be ruled out based on radiographic and histologic findings. The first, synovial chondromatosis of the facet joint, may masquerade as an aggressive cartilage lesion. Our case #16 showed synovial chondromatosis, but there was a secondary chondrosarcoma that invaded the bone. Second, chondroblastic osteosarcoma must be ruled out. This can only be excluded by examination of multiple sections after resection of the tumor. The presence of neoplastic osteoid among the cartilage is diagnostic of osteosarcoma. This diagnosis is extremely difficult to make based on a small-needle biopsy sample. Finally, the diagnosis of chordoma must be excluded. Although most chordomas are either in the skull base or the sacrum, ten percent occur in the mobile spine and may be mistaken for chondrosarcoma.15 Histologically, both lesions have abundant extracellular matrix and both are positive with an S-100 immunostain. Chordoma may be distinguished by the presence of keratin-positive cells, a feature not present in chondrosarcoma. Therefore, keratin stains should be performed on all suspected chondrosarcomas of the spine to rule out chordoma.

Surgical resection is the recommended treatment for chondrosarcoma of the spine; these tumors are notoriously resistant to chemotherapy or radiation therapy. All patients in our series underwent surgical treatment, either gross total resection or subtotal resection, similar to those in all other studies.6, 13, 14

Our study confirms the poor prognosis of spinal chondrosarcoma reported by other investigators. The Mayo Clinic authors observed a five-year survival of 55% with a median time to death of six years, while York et al. observed five-year and ten-year survivals of 64% and 40% with a median survival of six years after surgery.14

Our study strongly suggests that surgical margins are an important prognostic factor when predicting disease progression and recurrence. Both of our patients who had subtotal resection died of pulmonary metastases. Our nine surviving patients all had total resection with tumor-free margins. York et al found a significant in-crease in disease-free interval after gross resection of the tumor versus subtotal excision. Local recurrence was noted in one of five patients who had a total resection with an average time to recurrence of 5.4 years, while nine of 13 patients with subtotal tumor excisions had disease recurrence at an average of 3.7 years.14 Furthermore, Shivies et al. described survival to be significantly related to the surgical margin obtained - in all eleven patients who underwent intralesional excision, disease progression was observed. Half of the six patients with contaminated marginal excision had local disease recurrence, and both patients who had gross total resections had no evidence of disease at five years.13 Boriani et al. observed three recurrences in 12 patients treated with en bloc excision while all ten out of ten patients treated with intralesional excision experienced recurrence.7

Post-operative radiation therapy may be tried when complete resection of the tumor is not possible. However, radiation therapy provided no survival benefit for the 21 patients in the M.D. Anderson Cancer Center series.14 Similarly, Boriani et al. found that conventional radiation therapy did not affect outcomes. Three of their eleven patients who had intralesional tumor excision underwent post-operative radiation; two patients had disease recurrence while one patient progressed.7 None of our patients received conventional radiation therapy, however, four patients received postoperative proton-beam radiation therapy, and two of these patients died. Our sample size is not large enough to make conclusions regarding the success of proton-beam radiation therapy.

Our study confirms that chondrosarcomas of the spine are aggressive and many are lethal. This is despite the finding that most lesions are low to intermediate grade (grade 1 or grade 2). Whereas in the long bones, only 10 to 15% of grade 1 and 2 chondrosarcomas metastasized, this figure is much higher in spinal chondrosarcomas.16 This is most likely due to the incomplete resection of the tumor that leads to local recurrence and ultimately to pulmonary metastasis. Therefore, early and wide en bloc excision is the treatment of choice for chondrosarcomas of the spine. Tumor-free margins should be obtained. In order to obtain tumor-free margins, MRI studies should be performed on all patients since this can map the extraosseous extension of the tumor, a feature common to spinal chondrosarcoma.

The poor prognosis is unexpected given that most chondrosarcomas of the spine are low grade. In longbone chondrosarcomas, a low-grade lesion is an indicator of a better prognosis. In the spine, where incomplete resection often occurs, chondrosarcomas of any histologic grade are not responsive to adjuvant measures such as chemotherapy or radiation. Thus, the prognosis of spinal chondrosarcomas, even for low-grade lesions,
is poor if total resection is not achieved. In this location and for these lesions, therefore, wide en bloc excision with tumor-free margins is the only possible curative procedure.

REFERENCES


PATTERNS OF IMPROVEMENT FOLLOWING ONCOLOGIC RECONSTRUCTION COMPARED TO TOTAL KNEE ARTHROPLASTY AND REVISION KNEE ARTHROPLASTY

Mai P. Nguyen, M.D., Joseph A. Buckwalter, M.D. and Benjamin J. Miller, M.D.

Abstract

Limb salvage surgery for primary malignant bone tumors of the lower limbs requires complete resection of the tumor, followed by a reconstruction to restore function. In contrast to the abundant information on total knee arthroplasty, data on the recovery pattern of limb salvage surgery is largely limited. With the aim of guiding patient expectations and optimizing care, we retrospectively compared the clinical outcomes among patients following oncologic knee reconstruction, primary total knee arthroplasty, and revision total knee arthroplasty. From January, 2001 to June, 2009, we identified a cohort of 503 primary total knee arthroplasties, 55 revision knee arthroplasties, and 15 oncologic reconstructions. Outcomes were assessed by the validated Short Form-36 (SF-36) health questionnaire. We found that oncologic patients significantly improved their Physical Component Score at one and minimum two-year follow up compared to baseline (p< 0.05) with the majority of improvement (90%) made within the first year following surgery. This is a similar pattern to that observed following primary and revision total knee arthroplasty.

Introduction

The distal femur and proximal tibia are among the most common sites for primary malignant bone tumors to occur. In this location, limb salvage is possible nearly 90% of the time. Besides providing favorable oncologic outcomes for patients, successful limb salvage surgery also shares a common goal with total joint arthroplasty in restoring a functional limb. Multiple surgical options for reconstruction are available with endoprostheses, ostearthroplasty, and allograft-tissue composite being the most popular. Previous studies have made comparisons among different techniques of oncologic knee reconstruction. However, there has not been a study in the literature comparing quality of life measures of oncologic versus non-oncologic knees.

Oncologic reconstruction is different from conventional total knee arthroplasty in many ways. To ensure negative margins, wide resection mandates en bloc removal of bone along with associated soft tissues leaving behind significant osseous and soft tissue defects. This can lead to difficulty in functional restoration. Moreover, perioperative chemotherapy and radiation therapy can impede healing and recovery for the patients. In contrast, most oncologic patients are young and otherwise healthy while those with degenerative joint disease are generally older with multiple comorbidities. Arthroplasty revision surgery faces similar challenges as oncologic reconstruction, and they both are typically more technically demanding than primary total knee arthroplasty. Several studies have indicated poorer clinical outcomes for patients with revision compared to patients with primary knee replacement.

Patients' preoperative expectations have been shown to highly correlate with postoperative expectations. Since most patients are familiar with conventional total knee arthroplasty, they may have similar expectations for functional outcomes after oncologic reconstruction. Therefore, preoperative discussions of appropriate expectations for oncologic reconstruction are of paramount importance in order to fully educate those involved. The goal of this study was to investigate the recovery pattern of oncologic reconstruction compared to primary total knee arthroplasty (TKA) and total knee arthroplasty revision (TKR) using the SF-36. Our null hypotheses were (1) there is no improvement following oncologic reconstruction and (2) there is no difference in the pattern of recovery between oncologic knee reconstruction and total knee arthroplasty TKA or TKR.

Materials and Methods

Institutional Review Board approval was obtained for the study. It was designed as a retrospective review of our institution's orthopaedic database between January, 2001 and June, 2009 for Current Procedural Terminology (CPT) codes involving radical resection of tumor, bone, femur or knee (27365), radical resection of tibia...
Patterns of Improvement Following Oncologic Reconstruction Compared to Total Knee Arthroplasty

The data were exported to Statistical Analyzing System for statistical analysis. We compared the following baseline characteristics among the three patient groups: age, sex, BMI, and number of comorbidities. Chi-square testing was used for categorical variables and t-tests were used for continuous variables. For each time point, unadjusted 2-sample t-tests were performed comparing means at baseline and follow-up scores of the oncologic group. Unbalanced ANOVA analysis was also used to compare SF-36 scores across the three groups of patients at each time point. An alpha p-value < 0.05 was accepted for statistical significance.

RESULTS

Baseline demographic and clinical data:
The three patient groups included 15 patients with oncologic knee reconstruction, 55 patients with revision knee arthroplasty and 503 patients with primary total knee arthroplasty. The three groups were compared by age, gender, comorbidities, and BMI (Table 1). There were no significant differences in gender distribution and number of comorbidities. Oncologic patients were much younger compared to the primary and revision groups (30.1 vs. 62.6 vs. 64.5, p<0.001). The oncologic group also had a lower BMI compared to the respective measurements of the TKA and TKR groups (25.0 vs. 34.6 vs. 33.9, P<0.001). The baseline scores of the three cohorts were markedly similar.

Demographic and clinical characteristics for the oncologic group were reviewed (Table 2). Osteosarcoma was the most common diagnosis in this patient group. Modular endoprosthesis and allograft reconstruction were performed in all but one patient in the study group. Over half of our patients received neo-adjvant chemotherapy treatments.

Improvement pattern of oncologic group:
We demonstrated significant improvement of the PCS at the one year and two-year follow up time points (p < 0.05) compared to baseline (Table 3 and Figure 1). There was no significant improvement in terms of the MCS throughout with p-value > 0.05 at all follow up points (Table 3 and Figure 2). In terms of total SF-36 score and PCS, patients made most of their improvement within the first year following surgery. On average, they made more than 90% of their total improvement by the first year following surgery for the PCS and total SF-36. Improvements observed initially at one year postoperatively plateaued until 2-3 years following surgery. We then observed a slight decline in SF-36 scores with longer follow up at a minimum of three years.
TABLE 1
Baseline characteristics for the three cohorts

<table>
<thead>
<tr>
<th></th>
<th>Primary (n=503)</th>
<th>Revision (n=55)</th>
<th>Oncology (n=15)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Oncology vs Primary</td>
</tr>
<tr>
<td>Age</td>
<td>$62.6 \pm 10.1$</td>
<td>$64.5 \pm 11.1$</td>
<td>$30.1 \pm 18.1$</td>
<td>$&lt;0.001$</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>64.1%</td>
<td>45.5%</td>
<td>40.0%</td>
<td>0.06</td>
</tr>
<tr>
<td>Male</td>
<td>35.9%</td>
<td>54.5%</td>
<td>60.0%</td>
<td></td>
</tr>
<tr>
<td>BMI</td>
<td>$34.6 \pm 8.6$</td>
<td>$33.9 \pm 7.5$</td>
<td>$25.0 \pm 6.1$</td>
<td>$&lt;0.001$</td>
</tr>
<tr>
<td>Number of co-morbidities</td>
<td>3.4 $\pm$ 2.5</td>
<td>4.1 $\pm$ 3.5</td>
<td>2.7 $\pm$ 1.7</td>
<td>0.38</td>
</tr>
<tr>
<td>PCS</td>
<td>$31.8 \pm 8.8$</td>
<td>$34.7 \pm 11.5$</td>
<td>$33.2 \pm 8.2$</td>
<td>0.54</td>
</tr>
<tr>
<td>MCS</td>
<td>$49.0 \pm 11.8$</td>
<td>$46.1 \pm 12.8$</td>
<td>$47.3 \pm 10.7$</td>
<td>0.59</td>
</tr>
<tr>
<td>Total</td>
<td>$80.8 \pm 16.1$</td>
<td>$80.8 \pm 18.4$</td>
<td>$80.5 \pm 17.7$</td>
<td>0.95</td>
</tr>
</tbody>
</table>

Table 2
Characteristics of oncologic group (n=15)

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>30.2 $\pm$ 18.1</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>6 (40.0%)</td>
</tr>
<tr>
<td>Male</td>
<td>9 (60.0%)</td>
</tr>
<tr>
<td>BMI</td>
<td>25.0 $\pm$ 6.1</td>
</tr>
<tr>
<td>Number of co-morbidities</td>
<td>2.7 $\pm$ 1.7</td>
</tr>
<tr>
<td>Site</td>
<td></td>
</tr>
<tr>
<td>Distal femur</td>
<td>11 (73.3%)</td>
</tr>
<tr>
<td>Proximal tibia</td>
<td>4 (26.7%)</td>
</tr>
<tr>
<td>Diagnosis</td>
<td></td>
</tr>
<tr>
<td>Osteosarcoma</td>
<td>8 (53.3%)</td>
</tr>
<tr>
<td>Chondrosarcoma</td>
<td>3 (20.0%)</td>
</tr>
<tr>
<td>Metastatic carcinoma</td>
<td>2 (13.3%)</td>
</tr>
<tr>
<td>Adamantinoma</td>
<td>1 (6.7%)</td>
</tr>
<tr>
<td>Bone cyst</td>
<td>1 (6.7%)</td>
</tr>
<tr>
<td>Surgery</td>
<td></td>
</tr>
<tr>
<td>Oncology prosthesis</td>
<td>7 (46.7%)</td>
</tr>
<tr>
<td>Allograft</td>
<td>7 (46.7%)</td>
</tr>
<tr>
<td>Total knee arthroplasty</td>
<td>1 (6.7%)</td>
</tr>
<tr>
<td>Chemotherapy</td>
<td>8 (53.3%)</td>
</tr>
<tr>
<td>Oncologic outcomes</td>
<td></td>
</tr>
<tr>
<td>(average follow up of 38 months)</td>
<td></td>
</tr>
<tr>
<td>Revision</td>
<td>4 (26.7%)</td>
</tr>
<tr>
<td>Recurrence</td>
<td>4 (26.7%)</td>
</tr>
<tr>
<td>Metastasis (excluding metastasis at presentation)</td>
<td>5 (33.3%)</td>
</tr>
<tr>
<td>Deceased</td>
<td>6 (40.0%)</td>
</tr>
</tbody>
</table>

Oncologic group compared to total knee arthroplasty and total knee revision:

Total SF-36 scores (Figure 3) as well as individual components (Figure 1 and 2) were compared among the three cohorts of patients. Patients who underwent oncologic knee reconstruction consistently had better functional scores than patients who had primary total knee arthroplasty and total knee arthroplasty revision at follow up. However, with the limited number of data in the oncologic group compared to the other two groups we were not able to demonstrate significant differences. While the recovery pattern of the oncologic group modeled after the pattern of the primary TKA group with the major improvement of the PCS and total SF-36 during the first year following surgery, the revision arthroplasty group experienced a less predictable outcome pattern with little change in SF-36 scores throughout the entire course of follow up (Figure 1, 3).

DISCUSSION

Arthroplasties are among the most successful and common surgeries in orthopaedics. There were 498,169 primary total knee arthroplasties and more than 30,000 revision knee arthroplasties performed in the United States in 2005, while the incidence of sarcoma is only approximately 10,000 new cases each year. Comparing the recovery pattern of oncologic reconstruction to the pattern of similar and more common surgery can help oncologic patients envision their recovery and relate their expectation to that of more familiar surgery. Because primary bone tumors are far less prevalent than degenerative joint disease, the literature is lacking in describing the pattern of improvement following onco-
TABLE 3
Average SF-36 scores of the oncologic group

<table>
<thead>
<tr>
<th>Survey</th>
<th>Baseline n = 15</th>
<th>One year n = 4</th>
<th>Two to three years n = 4</th>
<th>More than three years n = 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean score with standard deviation and p value compared to baseline</td>
<td>Mean score with standard deviation and p value compared to baseline</td>
<td>Mean score with standard deviation and p value compared to baseline</td>
<td>Mean score with standard deviation and p value compared to baseline</td>
</tr>
<tr>
<td>SF-36 PCS</td>
<td>33.2 ± 8.2</td>
<td>44.0 ± 12.2</td>
<td>45.3 ± 8.7</td>
<td>41.2 ± 25.2</td>
</tr>
<tr>
<td>SF-36 MCS</td>
<td>47.3 ± 10.7</td>
<td>55.2 ± 7.4</td>
<td>54.8 ± 10.7</td>
<td>56.6 ± 0.8</td>
</tr>
<tr>
<td>Total SF-36</td>
<td>80.5 ± 17.7</td>
<td>99.2 ± 10.1</td>
<td>99.8 ± 19.1</td>
<td>97.8 ± 26.0</td>
</tr>
</tbody>
</table>

* Significance with p < 0.05 compared to baseline score

Figure 1. Progression of the PCS following surgeries

Figure 2. Progression of the MCS following surgeries

逻辑重建手术。这是第一项研究，我们的知识表明，这可能有助于比较功能改善后的功能。

We have observed several interesting trends in the study. We demonstrated that physical function improved in patients following oncologic reconstruction up to three years postoperatively (p < 0.05). The MCS was essentially stable throughout follow up. Similarly, previous studies regarding the quality of life of oncologic patients have noted discrepancies between the mental and physical functioning domains. Oncologic reconstructive surgery seems to be more effective in improving the PCS rather than the MCS. Our postoperative scores (PCS 41.4–49.1 and MCS 52.1–57.3) were similar to previously reported scores with reported ranges of PCS 39-52 and MCS 45-54. Perhaps of greatest value for preoperative counseling is the finding that oncologic patients made the majority of their improvement (90% of maximum improvement) within the first year following surgery. This pattern is similar to that reported following primary and revision knee arthroplasty.

Despite being younger and having a lower BMI, oncologic patients seemed to have similar preoperative scores compared to patients with degenerative joint disease. Unlike degenerative joint disease patients who underwent primary or revision total knee arthroplasties in their 60s, most patients with primary bone tumors were younger (average age 30.2 years). The BMI of the oncologic group was borderline between the normal and overweight category (25.0) while the BMI of the other
two groups was well into the obese category (34.6 and 33.9). Although we did not find a significant difference in the number of comorbidities among the three groups of patients, we were limited by the number of patients who filled out the comorbidity survey (60% for the oncolic group and > 80% for the other two groups).

Possible explanations for lower than expected baseline physical and quality of life scores include pain and loss of function from oncologic lesions, side effects from neo-adjuvant chemotherapy and the psychological effect from a diagnosis of cancer. Specifically, a 30-year-old patient with asthma and a bone tumor can expect to have a similar health related quality of life as a 60-year-old obese patient with osteoarthritis, COPD and hypertension. This observation emphasizes the devastating effects that bone tumors have on patients. Our oncolic group reported a PCS range of 31.1- 49.1 and MCS of 47.3 - 57.3. In contrast, studies looking at normative SF-36 values in the general population observed much better scores. Jenkinson et al. reported subscale scores related to the PCS to be 76.7-93.9 and those related to the MCS to be 64.5 – 91.3 for the similar age group. Even after surgery, it has been shown that oncolic patients experience lower scores for the domains of physical functioning, physical role and general health compared to age-matched healthy peers. Although our study may lack the statistical power to detect differences in SF-36 scores among the groups of patients, the oncolic group consistently demonstrated higher scores than both the primary and revision total knee arthroplasty groups. The dramatic improvement may be attributed to the success of modern oncologic reconstruction techniques in the past decade. As these patients are also younger without other chronic disease, their overall short-term function is understandably superior to their degenerative joint disease counterparts. The small oncolic population in this study did not allow for further assessment of outcome predictors.

The greatest weakness of this study is our limited number of patients and missing data. Due to missing data, we assessed functional improvement by averaging the scores at each time point rather than following individual patients over time. We only looked at SF-36 scores, which is a general patient-reported health related quality of life measurement rather than specific objective knee function measurements. Prior studies have reported discrepancies in findings between knee-specific performance and general health instruments emphasizing that both assessments are necessary to determine functional improvement. However, the SF36 is a validated health measurement that has been used in previous joint reconstruction studies. Another drawback is that we could not match the patients across groups by age or number of comorbidities. This limitation is difficult to correct due to the inherent differences between oncologic and conventional joint arthroplasty patients.

In summary, with modern advancements in orthopaedic oncology we observed good functional improvement for patients following oncologic reconstructions of the knee. More data on recovery patterns following oncologic reconstruction is needed for surgeons to provide adequate preoperative counseling for patients. Due to the rarity of primary bone tumors, a multicenter study would be required to ensure an adequate number of patients and more complete follow up data.

ACKNOWLEDGMENTS

We would like to thank Alison Klaassen and Yubo Gao, PhD for assistance with data collecting and statistical analysis with this project.

REFERENCES


A RANDOMIZED, PROSPECTIVE STUDY COMPARING INTERROCHANTERIC HIP FRACTURE FIXATION WITH THE DYNAMIC HIP SCREW AND THE DYNAMIC HELICAL HIP SYSTEM IN A COMMUNITY PRACTICE

Daniel C. Fitzpatrick, MD, MS, Daniel V. Sheerin, MD, Brian R. Wolf, MD, MS, Thomas K. Wuest, MD

ABSTRACT

Objective
To evaluate the clinical performance of the Dynamic Helical Hip System (DHHS) spiral blade relative to the Dynamic Hip Screw (DHS) lag screw.

Design
Randomized prospective study.

Setting
One level-2 trauma center and one level-3 trauma center.

Patients
Fifty-one consecutive patients were recruited into the trial. Inclusion criteria included patients over 50 years of age with AO/OTA 31A1 or 31A2 fracture.

Intervention
Surgeries were performed by one of 15 participating community orthopaedic surgeons. The patients were randomized to either a DHHS or DHS implant. Follow-up occurred at two weeks and six weeks and then at six-week intervals until healing occurred.

Main Outcome Measures
Primary outcome variables included sliding of the implant on the final AP radiographs, failure by cut-out and implant failure.

Results
There were 24 patients in the DHS group and 27 in the DHHS group. There was no difference in age, gender, ASA score, fracture classification or in the quality of reduction measured on the immediate postoperative radiographs (p=0.28) between the two groups. The tip apex distance was 18.7 mm in the DHHS group and 18.5 mm in the DHS group (p=0.40). The DHHS group had average blade sliding of 7.4 mm while the DHS group had an average lag-screw sliding of 7.7 (p=0.45). The DHHS group had two failures by central protrusion of the blade through the femoral head without significant varus collapse or superior migration. One was revised to a DHS and healed, the other was revised to a proximal femoral locking plate, which also failed and eventually required revision to a total hip arthroplasty. Investigation of the implants post failure showed evidence of binding of the blade shaft in the barrel as a mechanism of failure in both cases. No DHS implants cut out in this series, although one patient was revised to a total hip arthroplasty for symptomatic segmental osteonecrosis.

Conclusion
Both implants performed well in a majority of cases. The higher incidence of failure in the DHHS group is concerning, despite the low numbers. The mechanism of failure of the DHHS implant left adequate bone stock for attempts at revision fixation.

INTRODUCTION

The incidence of hip fractures in the United States is nearly 300,000 annually, with approximately half of these fractures occurring in the intertrochanteric region. This number is expected to increase significantly in the next decades with estimates in the range of 500,000 fractures annually by 2050. Intertrochanteric hip fractures are typically fixed with a dynamic lag screw implant, associated with either a side plate or nail, which allows controlled compression of the fracture as the patient ambulates. Despite the widespread use of these implants, failure rates as high as 8-17% are reported in some series. The dominant failure mode is superior migration of the lag screw, leading to varus collapse and cut-out of the lag screw from the femoral head. Recently a novel pair of implants, the Dynamic Helical Hip System (DHHS) and the Trochanteric Femoral Nail (TFN) (Synthes, West Chester, PA, USA), were developed for the fixation of intertrochanteric hip fractures (Figure 1).
Both of these implants replace the lag screw with a spiral blade which blade-compresses bone in the femoral head as it is inserted. The compressed bone around the DHHS and TFN theoretically provides improved resistance to cut-out relative to the osteoporotic, non-compressed bone surrounding the DHS. Additionally, these spiral blade implants may provide better rotational control of the fracture construct, especially when the lag screw is placed in an eccentric position. Improved resistance to rotational forces provided by spiral-blade type devices may lead to lower rates of implant cut-out and improved patient outcomes. Although spiral-blade implants hold a theoretical advantage, few clinical studies have been completed using a spiral blade for intertrochanteric fractures, and no clinical studies have been performed specifically using the DHHS.

Our hypothesis was that the results of intertrochanteric hip fractures treated in a community orthopedic surgery practice with a DHHS implant are superior to that of a DHS implant. The primary outcome measure was the amount of collapse of the implant. The secondary outcome measures included femoral head cut-out and implant failure, as these are the most common causes for revision surgery following this fracture. The study has the unique strength of being performed in a community practice, making the results more applicable to the general orthopedic surgeons who perform the majority of these surgeries.

**PATIENTS AND METHODS**

All patients over 50 years old with intertrochanteric hip fractures (AO/OTA classification 31A1, 31A2) admitted to either Sacred Heart Medical Center (level 2 trauma center) in Eugene, Oregon or McKenzie-Willamette Medical Center (level 3 trauma center) in Springfield, Oregon were eligible for inclusion in the study. Prior to randomization, these patients were excluded from the study: Patients with reverse obliquity fractures (31A3), basivertebral fractures (31A2.3), fractures extending into the subtrochanteric region (31A2.3), and pathologic fractures, as well as patients with previous ipsilateral hip surgery, patients with multiple injuries, patients who were non-ambulators prior to their injury, and patients with dementia severe enough to limit their ability to comply with post-operative rehabilitation.

All qualifying patients were offered participation in the study by way of an informed consent approved by the Institutional Review Board at each hospital. Patients who accepted participation were assigned to the DHS group or the DHHS group using a using simple randomization process wherein a random-numbered envelope was opened by the nursing staff prior to the beginning of each case. The random numbers were generated using a computer random-number generator. A research coordinator not involved in the implementation of the study produced the envelopes.

When the study began, all participating surgeons routinely used the DHS implant for intertrochanteric hip fractures. The DHHS represented new technology that was not significantly different from the DHS, but it did have a slightly different surgical technique. A sawbones session was held to allow each surgeon to become familiar with the recommended technique and instrumentation. A similar session was held for operating room personnel. Additionally, a three-month 'break-in' period was instituted during which all participating surgeons were asked to use the DHHS exclusively to gain additional familiarity with the implant prior to beginning the study.

Medical clearance was obtained as needed and the fractures were fixed as soon as possible. Fractures were classified using the Evans and the OTA/AO rating system. Fracture classification was performed at the time of surgery by the treating surgeon using a standard preoperative worksheet. The time from admission to surgery was recorded. Anesthetic was spinal or general, with the decision for anesthetic type deferred to the anesthesiologist. A fracture table and traction using a well-padded boot were used in all cases to perform a closed reduction.
TABLE 1
Descriptive Statistics for Patient Demographic and Surgical Characteristics

<table>
<thead>
<tr>
<th></th>
<th>DHS (N=24)</th>
<th></th>
<th>DHHS (N=27)</th>
<th></th>
<th>Test Statistics</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
<td>t-value</td>
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<td>Age</td>
<td>80.04</td>
<td>11.49</td>
<td>80.41</td>
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<td>Operative time in minutes</td>
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<td>21.33</td>
<td>34.52</td>
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<td>-0.21</td>
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<td>Fluoroscopy time in seconds</td>
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<td>58.69</td>
<td>29.77</td>
<td>16.97</td>
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<td>Delay in surgery in days</td>
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<td>1.00</td>
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<th></th>
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<th>N</th>
<th>%</th>
<th>(df)</th>
<th>p-value</th>
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<tr>
<td>Gender (female)</td>
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<td>18</td>
<td>66.7</td>
<td>3.06</td>
<td>.080</td>
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<td>Minimal medical co-morbidities</td>
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<td>43.5</td>
<td>6</td>
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<td></td>
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<tr>
<td>Major medical co-morbidities</td>
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<td>52.2</td>
<td>20</td>
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<td>2</td>
<td></td>
<td>2.27</td>
<td>.687</td>
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<tr>
<td>31A1.1 - Along IT line</td>
<td>5</td>
<td>20.8</td>
<td>8</td>
<td>29.6</td>
<td></td>
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<tr>
<td>31A1.2 - Through GT</td>
<td>6</td>
<td>25.0</td>
<td>4</td>
<td>14.8</td>
<td></td>
<td></td>
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<tr>
<td>31A1.3 - Below LT</td>
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<td>8.3</td>
<td>8</td>
<td>7.4</td>
<td></td>
<td></td>
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<tr>
<td>31A2.1 - Single fragment</td>
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<td>37.5</td>
<td>8</td>
<td>29.6</td>
<td></td>
<td></td>
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<tr>
<td>31A2.2 - Several fragments</td>
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<td>8.3</td>
<td>5</td>
<td>18.5</td>
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<td>Even’s Class</td>
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<td>17.4</td>
<td>4</td>
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<td>Class 3</td>
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<td>3</td>
<td>11.1</td>
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<td>Class 4</td>
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<td>Class 5</td>
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<td>5</td>
<td>18.5</td>
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<td></td>
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</tbody>
</table>

1The minimal medical co-morbidities and major medical co-morbidities rates were compared and without the healthy category and did not significantly differ at p<.05.
2The A1 and A2 classification rates were compared and did not significantly differ at p<.05.
DHS = Dynamic Hip Screw, DHHS = Dynamic Helical Hip System, M = Mean, SD = standard deviation.

No attempt was made to fix posteromedial fracture fragments unless the fragment could be reduced and held without excessive soft tissue dissection. The implant was placed according to recommended technique. A 135-degree side plate was the preferred device. The length of the side plate was the choice of the operating surgeon. Fluoroscopy and total surgical times (from incision to closing of the wound) were recorded.

All patients were placed on our standard hip-fracture postoperative care plan. Antibiotic prophylaxis was provided for 24 hours. In the absence of bleeding concerns, patients were placed on low-molecular-weight heparin beginning post-operative day one, which continued two weeks post-operatively, at which time patients were switched to aspirin. Compression hose and compression devices were used routinely while patients were in the hospital. All patients were allowed weight bearing as tolerated with physical therapy beginning on postoperative day one. Pain control was provided using a postoperative pain control protocol. Patients were discharged to a skilled nursing facility or home when medically stable.

Immediate postoperative radiographs were evaluated by a single observer, who was not blinded to the implant (DCF). The location of the screw in the femoral head was recorded. The tip-apex distance was also calculated. Quality of fracture reduction was assessed on the postoperative films on the basis of displacement and alignment of the fracture, as good, acceptable or poor. The amount of blade or screw sliding occurring between immediate postoperative and final follow-up radiographs was determined using the technique of Bendo.

A statistical consultant assisted with data analysis. Tests involving differences between group means were assessed with an independent samples t-test. Assumptions of equality of variance were tested with Levene’s test. The Pearson chi-square test was used to assess...
the relationship between groups on dichotomous and categorical measures. For all tests, a p<0.05 was considered significant. Prior to testing the main study outcome variable (collapse), the two groups were compared on study-demographic and surgical characteristics to determine whether randomization resulted in initially equivalent groups. In addition, groups were compared to determine if they were radiographically similar in the quality of surgery performed.

RESULTS

Fifty-one patients, total, were randomized to treatment in the study, 24 into the DHS group and 27 into the DHHS group. The DHS and DHHS groups did not statistically differ on any of the patient-demographic or surgical characteristics as shown in Table 1.

To compare the quality of surgery, groups were compared on tip-apex distance, screw-tip location, and fracture reduction. The DHS group had a mean tip-apex distance of 18.5 mm (SD = 5.2) and the DHHS group a mean of 18.7 mm (SD = 5.6). The group means were not statistically different (p=0.89). When the “center-center” location (Figure 2) was defined as the ideal position for the screw/blade tip, groups did not statistically differ (p=0.21). The DHS group had the screw in the ideal position for 79.2% (n=19) of the implants compared to 63.0% (n=17) for the DHHS group. Finally, the groups did not statistically differ on the quality of fracture reduction (p=0.57).

The DHS group had a mean amount of sliding of 7.7 mm (SD=10.4 mm) compared to a mean sliding of 7.4 mm (SD=8.1 mm) for the DHHS group. The amount of sliding did not statistically differ between the two groups (p=0.91). The DHHS group had two failures by central cut-out of the blade through the femoral head without significant varus collapse or superior migration (Figure 3). One failure (at 14 weeks) was revised to a DHS and healed. The other failure (at eight weeks) was revised to a proximal femoral locking plate which also failed, eventually requiring revision to a total hip arthroplasty. Investigation of both implants showed evidence of binding of the blade shaft in the barrel as the mechanism of failure in both cases, with burnish marks on the blade shaft indicative of impingement (Figure 4). No DHS implants cut out in this series, although one patient was revised to a total hip arthroplasty for symptomatic segmental osteonecrosis.

Previous clinical results for the DHHS have not been reported, so the study was powered to detect a one-half standard-deviation change in the mean DHS collapse rate, our primary study outcome. Power analysis estimates based on previous prospective DHS studies suggested recruitment of 52 patients into each group would provide 80% power to detect a five-point change in collapse rate (assuming a standard deviation of 9.0). A five-point difference was thought to be clinically mean-
ingful. However, recruitment was slower than expected and only 24 patients were randomized to the DHS group and 27 to the DHHS group. Based on the study sample size, a two-tailed test with a critical p-value less than 0.05, a post-hoc power analysis showed we had 80% power to detect a d-statistic of 0.80, which corresponds to a large effect. For a test involving dichotomous outcomes the study had 80% power to detect a medium effect ($\omega=0.39$).

**DISCUSSION**

Despite recent advances in implant design and surgical technique, failure rates remain high for intertrochanteric fractures of the hip. Theoretically, the introduction of blade-type devices can improve fixation in the osteoporotic femoral head by compressing bone around the blade rather than removing bone, as occurs during drilling for the DHS screw.13 The similarities in the DHHS and DHS devices make a direct clinical comparison of fixation in the femoral head with the blade and the screw possible.

Very few published studies exist concerning fixation of intertrochanteric hip fractures with spiral-blade type implants. Several mechanical studies have been performed using spiral blade devices designed for intertrochanteric fracture fixation. Ehmk et al. measured forces and energy required to insert a DHS screw and a DHHS blade.20 They found that the total energy required to insert a DHS was significantly higher than that observed with the DHHS. A majority of the force required to insert the DHHS was axial in direction, a force that is reasonably well resisted by the intact acetabulum. The force required to insert the DHS screw was mostly torsional, a force that is unsupervised and may lead to a rotational malreduction as the screw is inserted. Sommers et al. inserted the DHS and Gamma nail/lag screws and the DHHS and TFN spiral-blade implants into foam femoral heads designed to simulate osteoporotic bone.13 They simulated a worst-case scenario for implant location in which the screw or blade was 7mm posterior to the center of the femoral head. The construct was loaded in a quasi-static manner to simulate walking. They noted that the DHS lag screw cut out significantly earlier than any of the other implants. The TFN and DHHS spiral blades performed the best, suggesting better performance of the blade-type devices when placement is in a non-ideal position. Windolf et al. compared the mechanical performance of the DHS and the DHHS in paired cadaveric specimens under dynamic loading.21 They noted 100% cut-out in the DHS group, but only 50% cut-out in the DHHS group. They also noted increased fracture collapse in the DHHS group relative to the DHS group.

To our knowledge, no clinical studies comparing the DHS and DHHS blade have been performed. One retrospective study compared the TFN (which has a similar blade design) to a sliding hip screw. Gill et al. retrospectively reviewed 95 patients and noted a statistically non-significant trend toward a higher complication rate with the sliding hip screw (19.6%) than with the TFN (11.4%).22

The results of our study showed no significance difference in the performance of the devices with respect to our major outcome parameter, collapse of the femoral neck. The community orthopedic surgeons who participated in this study achieved adequate-to-excellent fracture reductions. They also placed the tips of the DIHS screw and DHHS blade in ideal locations in nearly every case, with an average tip-apex distance of less than 19 mm in both groups. It is likely that the 'ideal' placement of the lag screw and blade led to lower failure rates.

There were two implant failures by penetration of the DIHS blade through the central aspect of the femoral head. In both cases, radiographs showed no collapse of the implant. Inspection of the implants on retrieval showed burnishing of the blade shaft from impingement on the barrel, indicating that jamming or binding of the blade shaft on the barrel occurred, preventing sliding of the blade in the barrel. This observation led to a closer inspection of the barrel characteristics of the DIHS relative to the DHS. The 135-degree DIHS barrel used in this study had a 9-mm long key that engages the blade shaft to prevent rotation. This is different from the DHS where the screw shaft engages the barrel over its entire length. It is likely that the short shaft engagement of the DIHS led to binding of the blade in the barrel, converting the dynamic implant into a fixed-angle implant. The relatively flat blade then cut centrally through the femoral head rather than cutting out superiorly. Fortunately, this caused minimal bone destruction and both patients were thought to have enough bone stock remaining to attempt revision fixation rather than salvage to a hip arthroplasty. This represents a different failure mechanism than that seen with the DHS screw, which typically causes enough bone destruction during superior cut-out that revision fixation is difficult or not possible.
ACKNOWLEDGEMENT

The authors would like to thank Crystal Mills for assistance in collecting data and acknowledge Jeff Gau for assistance with statistical evaluation of the data.

REFERENCES


20. Ehmke, M, Kam, B, Sommers, M, Bottlang, M. Screw and Blade Type Implants Produce Distinct Insertion Forces. 4th World Congress of Biomechanics 2002.


CHILDREN HOSPITALIZED WITH LOWER EXTREMITY FRACTURES IN THE UNITED STATES IN 2006: A POPULATION-BASED APPROACH

Yubo Gao, PhD

ABSTRACT

OBJECTIVE
The purpose of this study was to examine the demographic and hospitalization characteristics of children hospitalized with lower extremity fractures in the United States in 2006.

METHODS
Children aged 0 to 20 years with a diagnosis of lower extremity fracture in the 2006 Healthcare Cost and Utilization Project Kids' Inpatient Database (KID) were included. Lower extremity fractures were defined by International Classification of Diseases, 9th Revision, Clinical Modification codes 820–829 under “Injury and Poisoning (800-999).” Patient demographic and hospitalization-related data were analyzed by chi-square testing and unbalanced analysis of variance.

RESULTS
There were more boys than girls with lower extremity fractures and 53% had private insurance as their primary payer. About one half of the children were between the ages of 13 and 20 years, but all ages were represented from age 0 to 20. White children accounted for 56%. Urban hospitalizations accounted for 93% of cases and 66 percent of admissions were to teaching hospitals. All patients had an average length of stay (LOS) 4.04 days, and infant patients had the longest average LOS of 5.46 days. The average number of diagnoses per patient was 3.07, and the average number of procedures per patient was 2.21. The average charge per discharge was $35,236, and the oldest patients had the largest average charge of $41,907. The average number of comorbidities increased with increasing patient age. There was a 55.6% greater mortality risk in non-teaching hospitals than in teaching hospitals and there was at least ten times the mortality risk in rural hospitals than in urban hospitals.

CONCLUSIONS
This study provides an understanding of the demographic and hospitalization characteristics of children with lower extremity fractures in the United States in 2006. This information may be useful in implementing measures to help prevent similar injuries in the future. Further research is required to determine causality of the associations found including increased mortality risk for this population at rural and non-teaching hospitals.

INTRODUCTION
Lower extremity fractures are quite common in the pediatric population due to falls, non-accidental trauma, and motor vehicle collisions. To our knowledge, no national population-based study had been conducted to date that examined the demographic and hospitalization characteristics of pediatric patients who were hospitalized for lower extremity fractures. We report the specific demographic and hospitalization characteristics for children with lower extremity fractures in 2006 in the United States. The results were derived from a database of inpatient hospitalization usage by children across the United States. We hypothesized that inpatient mortality risk in patients with lower extremity fractures was lower in urban and teaching hospitals than rural and non-teaching hospitals.

METHODS
The Healthcare Cost and Utilization Project (HCUP) Kids’ Inpatient Database (KID) is the only dataset on hospital use, outcomes, and charges designed to study children’s use of hospital services in the United States. The 2006 KID contains approximately 3.1 million pediatric discharges from 3,739 community, non-rehabilitation hospitals in 38 states, representing all four geographic census regions (northeast, midwest, west, and south). It includes a sampling of all hospital discharges where the patient was age 20 or less at admission during the year 2006. This can be extrapolated to a national estimation of 7.6 million pediatric hospital discharges. Patient demographic variables included age at time of admission, sex, race, and median household income quartiles based on the ZIP code of the family’s residence. Hospitalization variables included admission month and source.


### TABLE 1

<table>
<thead>
<tr>
<th>ICD-9 Codes</th>
<th>General Fractures Description</th>
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<tbody>
<tr>
<td>820</td>
<td>Neck of femur</td>
</tr>
<tr>
<td>821</td>
<td>Other and unspecified parts of femur</td>
</tr>
<tr>
<td>822</td>
<td>Patella</td>
</tr>
<tr>
<td>823</td>
<td>Tibia and fibula</td>
</tr>
<tr>
<td>824</td>
<td>Ankle</td>
</tr>
<tr>
<td>825</td>
<td>One or more tarsal and metatarsal bones</td>
</tr>
<tr>
<td>826</td>
<td>One or more phalanges of foot</td>
</tr>
<tr>
<td>827</td>
<td>Other, multiple, and ill-defined fractures of lower limb</td>
</tr>
<tr>
<td>828</td>
<td>Multiple fractures involving both lower limbs, lower with upper limb, and lower limb(s) with rib(s) and sternum</td>
</tr>
<tr>
<td>829</td>
<td>Unspecified bones</td>
</tr>
</tbody>
</table>

Diagnostic and procedure codes, duration of stay, total charges, expected payer, and discharge disposition. Hospitals included in this database were divided into strata using six characteristics: ownership/control, bed size, teaching status, rural/urban location, US region, and hospital type (pediatric vs other). Bed capacity was categorized into small, medium, or large, and varied in specific bed capacity depending on whether the hospital was located in a rural area or was an urban non-teaching or urban teaching hospital.

Data for this study was culled from the 2006 KID database using the *International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM)* codes for LEF (Table 1).

Patients were included in this study if they were age 0 to 20 and had at least one of the above lower extremity fracture codes from the 15 available diagnosis codes in the database. The study group was then further divided into four age groups based on ages that would likely participate in common activities from a developmental standpoint. The four groups were: (1) infants (age <1 yr), (2) toddlers (age 1-2 yrs), (3) children (age 3-12 yrs), and (4) adolescents (age, 13-20 yrs). Data was presented in two categories: patient demographics and hospitalization-related data. Descriptive statistics were reported, and chi-square testing and unbalanced analysis of variance was used for determining the differences between age groups. Univariate logistic regression was used to analyze the impact of teaching hospital status and hospital location on mortality. A p-value less than 0.05 was considered statistically significant for all analyses. Data were analyzed using SAS software.

**RESULTS**

There were a total of 11,903 patient admissions associated with lower extremity fractures out of 3.1 million records in the KID. Since there were 391 records without age, the final study group consisted of 11,512 records. Generally, increasing age was associated with increasing incidence of lower extremity fracture (Figure 1). The correlation between age and the admission volume was 0.8054 (p<0.0001).

Table 2 shows 60.41% of lower extremity fractures occurred between the ages of 13 and 20. The vast majority of these injuries (72.77%) occurred in boys and there was a male predominance in each of the four age groups (P<0.0001). This is consistent with previous studies. The most prevalent racial group was white, accounting for 56% of admissions and 53% of all patients had private insurance. Increasing age was associated with a progressive shift of patients from low income households to high income households (p=0.0057). This implies that the household income is greater for older children with lower extremity fractures than their younger counterparts. There were more lower extremity fracture admissions in summer than other seasons.

Non-elective admission accounted for 92% (Table 3) of all admissions (p<0.0001) and also predominated in all four age groups. Large capacity hospitals accounted for 61% of admissions. (p<0.0001) and the majority of patients in each age group were admitted to large capacity hospitals. The vast majority of hospitals (93%) were located in urban areas (p=0.0001). Most hospitals (66%)
### TABLE 2
Demographics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>&lt;1 y, No. (%)</th>
<th>1-2 y, No. (%)</th>
<th>3-12 y, No. (%)</th>
<th>13-20 y, No. (%)</th>
<th>Total (%)</th>
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<tr>
<td>No. patients (total)</td>
<td>383 (3.33)</td>
<td>841 (7.31)</td>
<td>3334 (28.96)</td>
<td>6954 (60.41)</td>
<td>11512(100)</td>
</tr>
<tr>
<td>Average age (y)</td>
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<td>8.8</td>
<td>16.88</td>
<td>12.87</td>
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<td>Sex</td>
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<td>Female</td>
<td>160 (41.88)</td>
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<td>2987 (27.23)</td>
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<td>551 (67.03)</td>
<td>2082 (69.35)</td>
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<td>7983 (72.77)</td>
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<td></td>
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<td>84 (24.42)</td>
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<td>1885 (20.67)</td>
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<td>17 (2.51)</td>
<td>50 (2)</td>
<td>121 (2.16)</td>
<td>202 (2.22)</td>
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<td>3 (0.9)</td>
<td>19 (27)</td>
<td>23 (20)</td>
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<td>Medicaid</td>
<td>263 (68.63)</td>
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<td>1179 (35.44)</td>
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<td>3608 (31.41)</td>
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<td>Private</td>
<td>93 (24.28)</td>
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<td>3856 (55.61)</td>
<td>6050 (52.68)</td>
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<td>184 (5.33)</td>
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<td>888 (7.73)</td>
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TABLE 3
Hospitalization Characteristics: Categorical Data

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<td>550(16.5)</td>
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had teaching status (p<0.0001). The deaths among the four age groups were not uniformly distributed with the youngest group having the highest death rate 1.82% (p<0.0001).

A separate analysis was performed for length of stay (LOS), number of diagnoses, number of procedures, total charges, and number of comorbidities (Table 4).

The average LOS for all patients was 4.04 days. The infants stayed the longest in hospital.

The average number of diagnoses for all patients was 3.07. The average number of procedures each patient received was 2.21. Strictly, the average number of procedures patients received increased with patient age. The average charge for all patients is $35,235 with the oldest patients having the largest charges. The average number of comorbidities was 0.25. The unbalanced analysis of variance model showed these age-specific means within each parameter category were significantly different (p<0.0001).

We further tabulated the number of patients by age group and number of comorbidities (Table 5). The majority (81%) of admissions were not associated with a comorbidity, only seven were associated with five or more comorbidities, and these seven admissions were in the oldest age group. The adolescent group had a smaller proportion of admissions not associated with a comorbidity while having higher proportions of higher number of comorbidities than any other patient age.
### TABLE 4
Hospitalization Characteristics: Continuous Data

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### TABLE 5
Comorbidities

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<th>1-2 y, No. (%)</th>
<th>3-12 y, No. (%)</th>
<th>13-20 y, No. (%)</th>
<th>Total (%)</th>
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<tr>
<td>Total</td>
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<td>841 (100)</td>
<td>3334 (100)</td>
<td>6954 (100)</td>
<td>11512 (100)</td>
</tr>
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</table>

categories. Chi square testing showed these proportions were significantly different (p<0.0001).

Table 6 shows the anatomic distribution of the fractures. Approximately half (49.9%) of fractures were related to the tibia, fibula, or ankle. We also made a preliminary analysis on the place-of-injury using the E-code, see Table 7. The results showed that (62%) of the infants had accidents at their home, other residential, or an institutional location, while adolescents tended to be injured on a street or highway. These findings are similar to those previously published.13,15
TABLE 6
Anatomic Distribution of Fractures

<table>
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<th>Age Group</th>
<th>Age Group</th>
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<td>3-12 y</td>
<td>13-20 y</td>
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<td>Femoral neck/Femur</td>
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<td>1671</td>
<td>2039</td>
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<td>672</td>
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<td>74</td>
<td>134</td>
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<td>3334</td>
<td>6954</td>
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TABLE 7
Place of Injury

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<th>Age Group</th>
<th>Age Group</th>
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</thead>
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<td>3-12 y</td>
<td>13-20 y</td>
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<td>556</td>
<td>820</td>
<td>709</td>
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<td>932</td>
<td>1744</td>
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<td>62</td>
<td>671</td>
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<td>896</td>
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<td>Total patients</td>
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<td>3334</td>
<td>6954</td>
</tr>
</tbody>
</table>

The impact of hospital teaching status and hospital location on inpatient mortality was examined by using univariate logistic regression analyses\(^\text{16}\) (Table 8). There was a 55.6% greater mortality risk in non-teaching hospitals than in teaching hospitals and there was at least a ten times greater risk of mortality in rural hospitals than in urban hospitals.

TABLE 8
Odds Ratio Analyses

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<th>Odds Ratio</th>
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<tr>
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<td>&gt;11</td>
</tr>
<tr>
<td>Urban</td>
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</table>

DISCUSSION

This study analyzed the KID data with children aged 0 to 20 years who were hospitalized with lower extremity fractures in the United States in 2006. This included 11,512 admissions and $405 million in hospital charges. These injuries have a major impact on the health and well-being of children and their families including mental, physical and economic burdens.\(^\text{17}\)

This study has limitations. Costs, reported in the KID as billed charges, may differ from the actual amount paid because of discounts, deductibles, copayments, and coinsurance. The true costs are likely to be underestimated in this study because uncovered charges, professional fees, time lost from school/work by caregivers, and other societal costs are not included in these estimates. Although the database allows for extrapolation to national estimates there is the potential for error in the extrapolation with this particular population since the KID does not include all US states and does not sample the regions of the United States equally. Some degree of regional variations in lower extremity fracture incidence is likely.
Studying racial disparity was particularly difficult given that nine out of 38 states did not report information on race in the KID. This creates a potential source of bias as racial distribution and other demographics vary by region and state. There were 2394 records missing race (20.8%). According to the 2000 US Census data\(^{18}\) regarding children younger than 20 years, the racial breakdown is 61% white, 15% black, 17% Hispanic, and 7% other races, compared with 56% white, 16% black, 21% Hispanic, and 7% other races in this study with race information. Hispanic children are relatively over-represented in this study, however, the lack of complete data regarding race makes drawing conclusions on this finding difficult.

Additionally, the KID database contains discharge-level records, not patient-level records. Therefore, individual patients who are hospitalized multiple times in one year may account for multiple records in KID. There is no uniform patient identifier available that allows a patient-level analysis with the KID.

**CONCLUSIONS**

The results show an increasing incidence of lower extremity fractures as children age, along with a clear gender disparity in which males were considerably more likely to sustain these injuries than females. Our findings show that children with lower extremity fractures were more likely to be admitted to large, urban, teaching hospitals. Additionally, urban and teaching hospitals were associated with a lower risk of inpatient mortality. These findings may guide hospital triage and transfer agreements.

There were more admissions for lower extremity fracture in summer than in other seasons, likely reflecting climate variation. The physical damage and financial burden that result from such an injury have a significant and sometimes lifelong impact on children and their families. Research has demonstrated that most of these injuries are preventable.\(^{19,20}\) Orthopaedists and pediatricians can be instrumental in preventing pediatric injuries by participating in patient education, research, and programs that promote safe play. For example, driving-habit education may have a big effect on reducing highway accidents. More research is needed to identify factors that are associated with different age groups so that age-specific measures may be designed and implemented. A quantitative model analyzing total charges, length of stay and number of procedures would be useful in quality improvement efforts.

**REFERENCES**


GLUTEAL COMPARTMENT SYNDROME AND SUPERIOR GLUTEAL ARTERY INJURY AS A RESULT OF SIMPLE HIP DISLOCATION: A CASE REPORT

Benjamin C. Taylor, M.D., Craig Dimitris, M.D., Alex Tancevski, M.D., Jerry L. Tran, M.D.

ABSTRACT

Gluteal compartment syndrome as a result of hematoma from a ruptured superior gluteal artery is exceedingly rare; to date, one similar case in a pelvic fracture model has been reported. We report a case of acute gluteal compartment syndrome from a ruptured superior gluteal artery resulting from a simple posterior hip dislocation in an otherwise healthy young male. Timely surgical exploration, evacuation of the hematoma, and achievement of hemostasis allowed for an excellent outcome at follow-up. We review the gluteal compartments as well as treatment protocols for this injury.

INTRODUCTION

Gluteal compartment syndrome is a rare condition that usually results from prolonged immobilization, but it has also rarely been reported as sequelae of traumatic events. Other reported etiologies include poor intraoperative positioning, abdominal aortic aneurysm repair or arterial embolization, iliopsoas muscle biopsy or harvest, injections, physical exertion, and even infection. Recognition of its presence is imperative, as an inability to diagnose and treat this syndrome can lead to irreversible consequences such as rhabdomyolysis, renal failure, permanent neurological deficit and even death.

Superior gluteal artery injury, however, is well reported in the medical literature. The position of the superior gluteal artery in anatomical position in the sciatric notch makes it prone to laceration from acetabular fracture fragments or to traction injury from displacement of an unstable hemipelvis. To our knowledge, there is only one report of rupture of the superior gluteal artery causing gluteal compartment syndrome in a trauma patient without pelvic fracture; this patient was struck by a motor vehicle. We believe the case presented here to be the first reported case of superior gluteal artery disruption leading to gluteal compartment syndrome as a result of a simple posterior hip dislocation.

CASE REPORT

A 28-year-old healthy man was involved in a head-on motor vehicle collision. He presented to our hospital trauma bay complaining of severe right hip pain. Advanced trauma life support (ATLS) protocols were followed appropriately; other serious injuries were ruled out and he remained hemodynamically stable. Radiographs taken in the trauma bay showed a posterior right hip dislocation (Figure 1). Successful closed reduction was performed and the patient had no neurosensory or neuromotor deficits to the distal right extremity prior to or after reduction. Treatment included the use of an abduction pillow between his lower extremities as well as a knee immobilizer on the right knee to limit his placing the hip in potentially compromising positions. The patient reported improved but continuing mild pain in his right hip.

Post-reduction radiographs and computed tomographic (CT) scans revealed a concentrically reduced hip joint devoid of any other bony abnormalities (Figure 2). Loss of soft-tissue planes and edema of the ipsilateral posterior hip musculature were also seen, with no evidence of a large hematoma.

Since the bony architecture created a stable hip joint under normophysiologic forces, the patient was allowed to ambulate and bear weight as tolerated, with the addition of posterior hip precautions. The patient first ambulated in the radiology suite the following morning. He subsequently reported a sharp increase in pain in his right hip as he moved back to his bed. A small but palpable hematoma was noted in his right posterior-lateral gluteal region at that time. He returned to the orthopaedic unit but continued to complain of worsening
and unrelenting pain that prohibited ambulation, with decreased sensation to the plantar aspect of his right foot. On physical examination, his gluteal hematoma had increased substantially and much of his right buttock and proximal lateral hip region was appreciably tense.

The patient was taken emergently to the operating room for decompression of his gluteal compartment syndrome, approximately four-and-one-half hours after first reporting the sharp increase in pain while in the radiology suite. An interventional radiologist and vascular surgeon were readily available if bleeding was unable to be controlled in the operating room. The patient was placed in a lateral decubitus position and a Kocher-Langenbeck approach to the posterior hip[1] was performed. After the gluteus maximus was split, substantial hematoma was encountered and evacuated. On direct visualization, the gluteus medius remained intact, but the piriformis, obturator internus, and superior and inferior gemelli muscles were all torn as a result of his dislocation. The sciatic nerve was visualized and appeared to be devoid of notable injury. It was protected carefully throughout the procedure. Intermittent irrigation and suction revealed a ruptured superior gluteal artery trunk emerging from the sciatic notch, posteriorly. This vessel had largely clotted off; thus the superior gluteal artery trunk was definitively controlled using ligation and very careful electrocautery. A small amount of Gelfoam® (Pfizer, New York, NY) was then placed on top of the coagulated vessel for further prevention of hemorrhage.

With hemostasis achieved, the decision was made to close the incision primarily, as the large hematoma had been removed and was not re-accumulating. Minimal amounts of nonviable muscle from the piriformis and gluteus maximus were removed. Enveloping fascia of the gluteus maximus and gluteus medius were released and not repaired; however, the fascia of the tensor fasciae latae muscle was not released, as this area was not clinically involved. The subcutaneous fat and skin were closed in standard fashion and no drain was utilized. A hemoglobin level obtained near the end of the procedure was 10.8 g/dL, down from 15.8 g/dL on admission the previous day. Anesthesia staff reported hemodynamic stability throughout the procedure.

Postoperatively, the patient remained hemodynamically stable with minimal further change to his hemoglobin levels. Full sensation in his lower extremity returned immediately after the procedure. He ambulated with physical therapy assistance and proceeded to bear weight as tolerated utilizing posterior hip precautions. There was
no return of buttock or hip fullness throughout the remainder of his hospitalization, although a large area of corresponding ecchymosis was present upon discharge two days postoperatively.

At last follow-up, 15 months postoperatively, the patient had returned to work as a mechanic and had minimal complaints of pain. He did experience intermittent clicks and pops when flexing and abducting his right lower extremity. Subsequently, he underwent eight weeks of outpatient physical therapy in an effort to improve hip abductor strength and slightly alter his gait, but despite compliance he continued to have mild weakness of his abductor musculature and a slight Trendelenburg gait. The remainder of his neuromuscular and neurosensory examination was normal. Repeat radiographs of the involved hip and pelvis showed no abnormal findings or changes (Figure 3).

DISCUSSION
Rupture of the superior gluteal artery has been associated with acetabular fractures extending into the greater sciatic notch\textsuperscript{28-30} and from movement of an unstable ipsilateral hemipelvis\textsuperscript{38} but, to our knowledge, no traumatic rupture of a superior gluteal artery has been reported as a result of simple hip dislocation. It is possible that the femoral head or traction on the soft tissue from the forceful dislocation event caused the injury and that mobilization the following day caused disruption of the clotted vessel, but the exact mechanism remains obscure.

Although the gluteal compartment is an uncommon location for compartment syndrome, it has all the components necessary for the syndrome to occur — a large muscle mass encased in an osseofascial layer. The anatomy of the gluteal region is described particularly well by David et al in a cadaveric dissection study.\textsuperscript{12} The gluteal region is enveloped in a tight fascia, which splits to enclose three sub-compartments of muscle: the gluteus maximus, gluteus minimus and medius, and tensor fasciae latae.\textsuperscript{32} The anatomic constraints of the area do not accommodate excessive edema or mass effect of hemorrhage, and cellular ischemia can develop, as it can in more common sites for compartment syndrome, such as the distal extremities. The large amount of muscle tissue in the area can lead to substantial morbidity or even mortality; cellular necrosis causing hyperkalemia, acidosis, and myoglobinemia deposition in the distal renal tubules can lead to renal failure and death.

Recognition of gluteal compartment syndrome remains rooted in having an increased index of suspicion and performing an appropriate physical examination. No major neurovascular structures are found in the gluteal compartment and, therefore, often no classic neurological deficits are noted. However, in this case, as well as in approximately half of the reported cases in the literature, sciatic nerve dysfunction can occur.\textsuperscript{12} This is thought to be secondary to ischemic changes in the sciatic nerve from an external pressure effect, as the nerve is not enclosed in a fascial compartment in this area.\textsuperscript{12} Physical examination findings include severe, unrelenting gluteal region pain at rest, pain with passive motion of the affected hip, tense swelling of the buttock region, and possibly paresthesias of the buttock, proximal thigh, or in the sciatic nerve distribution.

With a comatose patient or an indeterminate physical examination, compartment pressures should be measured expeditiously to help with diagnosis. Needle placement for compartment pressure measurements is shown in Table 1.\textsuperscript{32} As with any anatomical compartment, measured pressures of ≥30 mm Hg are suggestive of compartment syndrome; however, measured absolute values must always be correlated with the patient’s diastolic blood pressure at time of compartment pressure measurement.\textsuperscript{33}
TABLE 1. Needle placement for gluteal compartment pressure measurements.\textsuperscript{32}

<table>
<thead>
<tr>
<th>Region of Evaluation</th>
<th>Needle Placement</th>
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<tbody>
<tr>
<td>Gluteus Maximus</td>
<td>Proximal-medial buttocck, 2 cm inferior to the posterior superior iliac spine</td>
</tr>
<tr>
<td>Gluteus Minimus and Medius</td>
<td>2 cm inferior to the iliac crest, over the middle 1/3 of the iliac wing</td>
</tr>
<tr>
<td>Tensor Fascia Latae</td>
<td>2 cm anterior and 3 cm distal to the tip of the greater trochanter</td>
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Although surgeons in this case felt justified in performing the fasciotomy prior to an attempt at angiography and potential embolization, the proper procession of interventional events can be debated. The likely delay in embolization and subsequent fasciotomy in this case were thought to be a substantial negative risk factor for permanent functional and neurological sequelae, as cellular necrosis increases with increased duration of elevated intersitial pressure.\textsuperscript{34} Conversely, intraoperative bleeding from a superior gluteal artery injury can be difficult to control due to the volume of bleeding or difficulty with intraoperative identification of the artery.\textsuperscript{25} Blind attempts at clamping the vessel at its exit from the sciatic notch are unwise, as the sciatic nerve can easily be clamped and injured with these maneuvers. Multiple authors have recommended performing angiography and embolization preoperatively in a pelvic fracture model,\textsuperscript{36-39} but only one anecdotal recommendation for these procedures exists in a model similar to our patient's injury.\textsuperscript{35} For our patient, much of the approach and exposure of the superior gluteal artery had occurred from the damage done by the hip dislocation and mass effect of the sizeable hematoma, making recognition of the offending structure relatively simple. If retraction of the superior gluteal artery into the pelvis had been seen intraoperatively, emergency plans were in place for packing the posterior surgical field followed by ligation of the internal artery through an abdominal approach. This is a well-described operative technique\textsuperscript{37,39} and a fellowship-trained vascular surgeon was available for this procedure, if the situation had occurred.

CONCLUSION

In gluteal compartment syndrome, as in other compartment syndromes, it is imperative to correctly diagnose and treat the patient as early in the process as possible. Reported incorrect diagnoses have included deep venous thrombosis and gluteal contusions.\textsuperscript{23,25,40,41} We report the first gluteal compartment syndrome resulting from a simple posterior hip dislocation and wish to increase awareness of this clinical possibility, as poor outcomes and even death have been reported in missed or delayed diagnosis. Adherence to well-formed clinical principles of compartment syndrome diagnosis and treatment allows for minimization of morbidity and mortality associated with this rare, often unrecognized location of pathology.

COMPETING INTERESTS

The authors declare that they have no competing interests or financial disclosures to make related to this case report.

AUTHOR'S CONTRIBUTIONS

BCT treated the patient, collected data, and participated in the draft and finalization of the manuscript. CD and AT participated in the draft and finalization of the manuscript. JLT participated in the literature review, data collection, and finalization of the manuscript. All authors have read and approved this final manuscript.

ACKNOWLEDGEMENTS

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REFERENCES


TREATMENT OF POST-TRAUMATIC LABRAL INTERPOSITION WITH SURGICAL HIP DISLOCATION AND LABRAL REPAIR

Jeffrey J. Neppe, MD,* Perry L. Schoenecker, MD,* John C. Clohisy, MD*

ABSTRACT

We report a case of a 12-year-old male with delayed presentation of a spontaneous incongruous reduction of a hip dislocation due to labral-chondral acetabular rim fragment entrapment. The patient was treated with a staged hip arthroscopy and subsequent surgical dislocation and open repair. At two-year follow-up, the patient had an excellent clinical and radiographic outcome.

INTRODUCTION

Traumatic hip dislocation in children is a relatively uncommon injury. Failure to achieve concentric reduction of the hip is a complication of the injury,1 2 and can be overlooked,2,3,4,5 especially in patients with spontaneous reduction.6,12 Labral interposition has been reported as a potential mechanical block to concentric reduction in both children1,2,3,4,5,11,15 and adults.4,16,20 Labral interposition has historically been treated with excision1,6,11,16-18,20 to enable anatomic reduction. However, as our understanding of the importance of labral function has changed, surgical techniques of labral repair have been popularized.

To minimize the risk of femoral head osteonecrosis, open reduction of the dislocated hip with labral interposition has generally been performed through a surgical approach from the direction of dislocation.21 As our understanding of the vascularity of the femoral head has improved, open surgical hip dislocation has been applied to the treatment of a variety of intra-articular hip disorders.22-23 We report the case of a 12-year-old male child with a history of a spontaneously reduced traumatic hip dislocation and delayed presentation with a painful, incongruous hip reduction. Diagnostic arthroscopy revealed an incarcerated labral-chondral acetabular rim fragment that was repaired definitively via a surgical hip dislocation approach.

CASE REPORT

A 12-year-old male presented to our clinic with persistent left hip pain two months after a left hip injury. The patient was involved in an accident during competitive waterskiing, and he reported a flexion/adduction injury with immediate onset of severe left hip pain. He was unable to bear weight on the extremity and was evaluated in a local emergency room. Radiographs were reportedly normal at that time and the patient was managed with symptomatic measures, crutches and protected weight bearing. After four weeks, he continued to have pain that prevented him from progressing his weightbearing status. MRI obtained four weeks after injury showed sequelae of a hip dislocation including osteochondral fragments within the joint, fracture of the lip of the posterior acetabular wall, and ligamentum teres rupture. The patient was evaluated by an orthopaedic surgeon who recommended continued conservative treatment given that the osteochondral fragments appeared to involve the non-weightbearing portion of the femoral head. The patient was maintained non-weightbearing for an additional four weeks.

Eight weeks after injury, the patient continued to show minimal improvement in his symptoms and progression of weight bearing was not tolerated. A repeat MRI was performed which demonstrated unchanged osteochondral fragments within the joint and a widened medial joint space. The patient was referred to our institution for evaluation and treatment.

Physical examination demonstrated a healthy appearing 12-year-old male. With attempted ambulation the patient experienced severe hip pain and demonstrated a severe limp. The left hip was very irritable with range of motion testing and he had positive impingement and Patrick’s tests. Range of motion was 95 degrees of flexion, 20 degrees internal rotation in flexion, and 30 degrees external rotation in flexion. Plain radiographs demonstrated persistent medial joint-space widening with a possible loose body entrapped in the medial joint (Figure 1A-B). A CT scan demonstrated a small avulsion

*Department of Orthopaedic Surgery
Washington University School of Medicine
St. Louis, MO

Correspondence to:
John C. Clohisy, MD
Department of Orthopaedic Surgery
Washington University School of Medicine
One Barnes-Jewish Hospital Plaza
Suite 11300 West Pavilion
Campus Box 8233
St. Louis, MO 63110
Phone: 314-747-2666
Fax: 314-747-2599
E-mail: clohisy@wumc.wustl.edu
fracture of the posterior rim and a small intra-articular loose body (Figure 1C-D). Therefore, the patient was diagnosed with an incongruous reduction due to labral and/or osteochondral fragment incarceration.

Due to persistent pain, an incongruous reduction and mechanical obstruction to anatomic head reduction, hip arthroscopy was recommended for definitive diagnosis and potential definitive treatment. The patient was taken to the operating room for arthroscopic assessment with loose body removal, reduction of labral interposition, and possible labral debridement or repair. At arthroscopy, we observed a large posterosuperior, labral/acetabular rim chondral avulsion fragment entrapped within the acetabular fossa (Figure 2A). This tissue was relatively immobile due to surrounding fibrous scar tissue. The anterior labrum appeared intact and stable, but was confused and had adjacent synovitis (Figure 2B). No major chondral injury to the acetabular surface was noted. Abrasions were observed on the femoral head over a 2 x 2 cm area in the superior and anterosuperior regions. Due to the large size, posterior location and established scarring, the decision was made to offer definitive treatment of the posterior rim avulsion with an open surgical dislocation procedure.

One week after arthroscopy, an open surgical hip dislocation with trochanteric flip osteotomy was performed. The entrapped posterior labrum was attached to a 2 x 1 cm avulsed epiphyseal fragment from the acetabular rim that was adherent to the acetabular fossa (Figure 2C). The fragment and labrum were dissected free from surrounding scar tissue and the epiphyseal fragment was excised. A small portion of the posterior-inferior labrum was severely macerated and was excised. The remainder of the labrum was repaired to the posterior rim (Figure 2D-F).

The patient was managed postoperatively with continuous passive motion (CPM), isometric exercises and progressive weight bearing and strengthening. Specifically, he was toe-touch weight bearing for four weeks and then progressed to full weight bearing. Active exercises were initiated at four weeks and resistance strengthening started eight weeks after surgery. The patient was
released to full activities four months after the surgical dislocation procedure. At two-year follow-up, the patient had no residual pain or limitations. His Harris Hip Score was 100 points. He demonstrated full symmetric range of motion and no radiographic changes of avascular necrosis or joint-space loss (Figure 3). He was able to return to unrestricted activities including competitive water-skiing.

**DISCUSSION**

We present a case of a 12-year-boy with a presumed hip dislocation and spontaneous incongruous reduction following a waterskiing accident. This patient presented to us eight weeks after the injury with persistent pain and inability to bear weight. Arthroscopy revealed an entrapped posterior labrum and rim epiphysis fragment. An open surgical dislocation with excision of the entrapped posterior labrum from the acetabular fossa and labral repair was then performed. At two-year follow-up, the patient had an excellent clinical result and radiographic outcome.

In children with hip dislocations, soft tissue interposition preventing congruous hip reduction has historically been reported to be rare, but more recent series have noted it to be present in 7.5-25% of cases. Incongruous reductions have been most commonly reported secondary to labral interposition, osteochondral fragments, and capsular interposition. In one large series, approximately 25% of patients required surgical intervention for labral interposition or osteochondral fragments. One study noted difficulty in obtaining a concentric reduction as more common in children six to ten years old.

Several authors have reported acute labral entrapments with associated epiphyseal avulsion fragments in children. Chun et al. reported a case of entrapment of a posterior labral avulsion with an attached epiphyseal fragment in a child following posterior dislocation. This was treated with fragment excision and labral repair from a posterolateral approach.

In cases of spontaneous reduction, the lack of radiographic confirmation of dislocation may lead to delayed
diagnosis and failure to recognize incongruous reduction, as occurred in this case. Only a few cases of soft tissue interposition after spontaneous reductions of hip dislocations in children have been reported. Cases of unrecognized incongruous reductions have been associated with poorer outcomes, but rarely avascular necrosis. Incongruous reductions are most commonly noted by widening of the medial joint space on plain radiographs. Additionally, a break in Shenton’s line has also been reported as a significant finding. In this case, even at presentation to our institution two months after injury, medial joint space widening was evident on plain radiographs. Some authors have reported that up to 3 mm of joint space widening may be due to hematoma or joint laxity, while other have questioned this assertion. Nevertheless, this finding should raise suspicion regarding an entrapped labrum or osteochondral fragment, especially when this radiographic finding is associated with persistent hip symptoms.

Evidence of joint-space widening should be investigated with further imaging, including computed tomography (CT) or magnetic resonance imaging (MRI). Radiographs may not demonstrate subtle widening or noncalcified loose bodies that can be seen with CT. However, advanced imaging techniques may fail to accurately identify the cause of incongruous reduction, as occurred in this case.

In children with hip dislocations, avascular necrosis is of particular concern. Rates of avascular necrosis after isolated hip dislocation in children have been reported to be 3-15%. As with adults, posterior hip dislocations in children are much more common than anterior dislocations. Open reductions of irreducible or incongruous hip dislocations have generally relied on posterior approaches, with authors generally recommending a surgical approach which protects femoral head vascularity. In adults, Epstein recommended avoiding anterior approaches after posterior dislocations due to concern for the ascending branch of the lateral femoral circumflex artery and several cases of avascular necrosis. In a recent review of dislocations in children, Herrera-Sota et al. recommended an approach from the direction of dislocation. However, anecdotic studies have not supported this, with evidence that the primary blood supply is from the medial femoral circumflex artery. Siebenrock and Ganz have demonstrated that based on this knowledge, open surgical hip dislocation can be performed without compromising the femoral head vascularity in patients with acetabular fractures or femoroacetabular impingement. Open surgical dislocation has been reported to be successfully utilized in patients with fractures associated with hip dislocations, including acetabular fractures and femoral head fractures. The use of surgical dislocation has also been reported in children for slipped capital femoral epiphysis and other hip deformities.

This approach allows for superior visualization compared to traditional posterior approaches. Several authors have reported missed intra-articular pathology at open reduction if the femoral head is not redislocated. Good visualization of intra-articular pathology, especially labral interposition, is important for not only detection but treatment at time of open reduction in cases where labral interposition is present. Leunig et al. reported the use of surgical dislocation in a series of adults with acetabular fractures and concomitant labral avulsions.

The importance of the labrum to normal hip function has been only recently recognized. In patients with femoroacetabular impingement, preliminary evidence has shown superior outcomes of patients with labral repair compared to labral debridement. Labral preservation is likely equally important in hips after traumatic dislocation. The use of a surgical approach, which allows for adequate visualization and access for labral repair, is important when open reduction is performed. Preoperative imaging studies can aide in identifying the cause of incongruous reduction.

CONCLUSION

We report a case of a 12-year-old male with delayed presentation of spontaneous incongruous reduction of a hip dislocation due to a labral-epiphyseal fragment entrapment. The patient was treated with a staged hip arthroscopy and subsequent open repair. At two-year follow-up, the patient had an excellent clinical and radiographic outcome.

In this case we utilized hip arthroscopy for diagnostic purposes and for potential treatment as loose body removal or labral excision could have been performed arthroscopically. Due to the size, location, scarring and possibility for labral repair, definitive treatment was performed with a surgical dislocation approach.

REFERENCES


OPEN PELVIC FRACTURES: THE UNIVERSITY OF TENNESSEE MEDICAL CENTER AT KNOXVILLE EXPERIENCE OVER TEN YEARS

Emily Anne Black, MD, Christy M. Lawson, MD, Scott Smith, MD, FACOS, Brian J. Daley, MD, MBA, FACS

ABSTRACT

Introduction

Open fractures of the pelvis remain a devastating injury with a high mortality and morbidity. Such injuries require an aggressive treatment plan and the coordination of trauma and orthopaedic surgeons to achieve the best outcomes. We report our experience at the University of Tennessee Medical Center at Knoxville with open pelvic fractures over the last ten years.

Methods

After IRB and institutional approval, we reviewed patients admitted with a diagnosis of open fracture of the pelvis from 1999 to 2009. Demographic and admission data were recorded in the trauma registry (TRACS) of the Level I Trauma Center, serving the 1.2 million people living in the regions of east Tennessee, western North Carolina and southeastern Kentucky. Data on fractures were obtained from review of the medical records and radiographs within the chart.

Results

There were 3053 pelvic fractures from January 1999 to December 2009. There were 231 deaths in this group (6%) and ages ranged from 18 to 89 years old and Injury Severity Scores ranged from 4 to 75, with a mean of 18.3. Seventy five percent of patients were able to be discharged home.

Fifty-two fractures were open. There were 43 men and the mean age was 39 years old. Average ISS was 23 and ranged from 5 to 50. There were 10 deaths (19%) and eight patients underwent angioembolization for control of bleeding (3 deaths). Motorcycle crashes were the most frequent cause of an open fracture, with lateral compression injuries representing 71%.

A defined algorithm for fracture management has been in place and employed to assure adequate resuscitation and fracture care and is presented.

Discussion

Open pelvic fractures are usually the result of a high energy transfer, and convey a high morbidity and mortality. A defined resuscitation and fixation strategy improves outcome from historical reports. Injuries from penetrating mechanisms are associated with less morbidity and lower mortality.

INTRODUCTION

Pelvic fractures are the result of high-energy trauma and therefore have high morbidity and mortality due to the likelihood of associated life threatening injuries. In fact, several studies have demonstrated that the primary cause of death in patients with pelvic fractures is something other than the fractures themselves or the resultant blood loss.\textsuperscript{1,2,3} Even fractures that do not affect stability of the pelvic ring can be associated with serious and potentially life-threatening injuries to soft tissue, abdominal organs, and blood vessels.\textsuperscript{4} The type of mechanical force (anteroposterior compression, lateral compression, and vertical shear) according to the Young-Burgess scheme has been shown to influence transfusion requirement and mortality rate. This correlation of sufficient energy to disrupt the bony pelvis creates the devastating soft tissue injuries that lead to transfusion and increased mortality.\textsuperscript{5} The mortality rate from pelvic fractures continues to range from 3-20% despite modern improvements in injury prevention, initial resuscitation management, intensive care therapies, damage control and definitive fracture stabilization techniques.\textsuperscript{6}

Open pelvic fractures have traditionally had a literature-quoted mortality rate that approached 50% due to the additional risk of hemorrhage and pelvic sepsis.\textsuperscript{7} Open fractures have been shown to have up to four times the transfusion requirement compared to similar

\textsuperscript{1}...

Divisions of Trauma and Critical Care and Orthopaedics, Department of Surgery, The University of Tennessee Medical Center at Knoxville, Knoxville, TN
The contact author will be:
Brian J. Daley
The University of Tennesse Medical Center at Knoxville
Department of Surgery
1924 alcoa Highway, Box U-11
Knoxville, Tennessee 37920-6999
(865) 305-9230
BDaley@mc.utmck.edu

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closed injuries, and open fractures are more likely to have rotationally or vertically unstable fracture patterns compared to closed fractures. Risk factors for increased mortality from open pelvic fractures include an injury severity score >25, a triage-revised trauma score <8, an age >65 years, initial systolic blood pressure <100, GCS <8, blood transfusion of >10 units in 24 hours, and colloid infusion of >6 liters in 24 hours.

Management of open pelvic fractures has conventionally had four critical elements: 1) control of hemorrhage, 2) treatment of soft-tissue wound and prevention and treatment of subsequent sepsis, 3) recognition and treatment of associated injuries, and 4) treatment of the fracture itself. Attention to soft tissue preservation and skin care, appropriate use of antibiotics, thorough irrigation and debridement, and early open reduction with stable fixation have been shown to reduce infection rates associated with open pelvic fractures. However, in one large multicenter trial comparing outcomes of patients with pelvic fractures from two separate time periods the mortality rate from closed pelvic fractures decreased while the rate from open pelvic fractures remained stable despite the five year difference and the advances in medical care and treatment strategies. A recent review of the changes in treatment of pelvic fractures over the past 50 years mentioned the particularly troublesome nature of open pelvic fractures with regards to exsanguination or contamination, but the last comprehensive review of open fractures was nearly twenty years ago. The proliferation of motorized vehicles, especially those on which the operator rides externally, and the ability to quickly and safely transport such victims, have presented the modern trauma center with the difficult task of treating these injuries and these patients. We sought to describe our incidence, injury patterns and outcomes with this devastating injury at the University of Tennessee Medical Center at Knoxville over the last ten years.

MATERIAL AND METHODS

IRB and institutional approval were obtained. There were 27,492 patients were admitted through the Trauma Services at the University of Tennessee Medical Center, a Level I trauma center, from January of 1999 through December of 2009. In this cohort, there were 3053 pelvic fractures identified. Demographic and injury specific data were retrieved from the Trauma Registry of the American College of Surgeons (TRACS).

Patients suffering pelvic fractures were further classified into blunt vs. penetrating mechanisms, open vs. closed fractures, and whether or not they received angioembolization. Detailed medical records and radiographs of the patients with open pelvic fractures were then reviewed. Fractures were classified according to the Young-Burgess classification scale (Table 1) into lateral compression injury patterns and anteroposterior compression injury patterns. Each fracture type was then reviewed and information on hospital length of stay, intensive care unit length of stay, injury severity score, mortality, and whether or not the patient was discharged to home or to and extended care facility was collected.

RESULTS

Within the 3053 pelvic fractures admitted through the Trauma Services at the University of Tennessee Medical Center between January 1999 through December 2009, there were 231 deaths, which represent a 6% mortality rate. Overall for the trauma patient population, the incidence of pelvic fracture was 11%. Patients ranged in age from 18-89, with the mean age of 44 years; 1889 or 62% were male, 1164 were female. These demographics are similar to the trauma center's population as a whole, and representative mortality rate for the Center as a whole during this time period was 7%.

Hospital lengths of stay ranged between 1-110 days and ICU lengths of stay ranged from 0-101 days. Injury severity scores ranged from 4-75 with the mean being 18.3. Of these patients, 75% were able to be discharged home, with the remaining 19% being transferred to various rehabilitation facilities or extended care facilities.

Of the 3053 pelvic fractures, 52 were open fractures. There were 43 men and 9 women, with the mean age being 39 years (range 19-85.9). Hospital length of stay ranged between 1-119 days with the mean being 23.4 days. ICU length of stay ranged from 0-101 days with the mean being 10.9 days. Injury severity scores ranged between 4-50 with the mean ISS being 23. Of the 52 open pelvic fractures, 9 received angioembolization for control of bleeding. There were 10 deaths, representing a mortality rate of 19%. Three of these deaths occurred in the angioembolization group and occurred within the initial resuscitation period.

The predominant mechanism of injury in open fractures was blunt force from a motorcycle crash. Penetrating injuries accounted for eight open pelvic fractures in this series, all from gunshot wounds. All penetrating injuries recorded were open iliac fractures, with one death that resulted from multiple other injuries from other projectiles. Open fractures from GSW were treated with tetanus prophylaxis and antibiotics for the duration of the hospital stay. If found at laparotomy for intra-abdominal injuries, the area was irrigated but not debrided. None of the survivors returned with a complication related to their pelvic fracture.

Of the remaining 44 open pelvic fractures, 20 involved motorcycle crashes, 15 motor vehicle collisions, 4 falls, 4 industrial accidents, and 1 pedestrian struck by a vehicle.
TABLE 1
Classification of Pelvic Fractures
(Young-Burgess)

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type I</td>
<td>Disruption of the pubic symphysis with &lt;2.5 cm of diastasis, no significant</td>
</tr>
<tr>
<td></td>
<td>posterior pelvic injury</td>
</tr>
<tr>
<td>Type II</td>
<td>Disruption of the pubic symphysis with &gt;2.5 cm of diastasis, with tearing of</td>
</tr>
<tr>
<td></td>
<td>the anterior sacroiliac, sacrotuberous and sacrospinous ligaments</td>
</tr>
<tr>
<td>Type III</td>
<td>Complete disruption of the pubic symphysis and posterior ligament complexes</td>
</tr>
<tr>
<td></td>
<td>with hemipelvic displacement</td>
</tr>
</tbody>
</table>

Lateral Compression

| Type I  | Posterior compression of the sacroiliac joint without ligament disruption; oblique |
|         | pubic ramus fracture                                                          |
| Type II | Rupture of the posterior sacroiliac ligament; pivotal internal rotation of    |
|         | hemipelvis on the anterior SI joint with a crush injury of the sacrum and an  |
|         | oblique pubic ramus fracture                                                   |
| Type III| Findings consistent with a Type II injury plus evidence of an anteroposterior |
|         | compression injury to the contralateral hemipelvis                            |

These open fractures were further subdivided according to the Young-Burgess Classification Scale (See Table 1). Only 29% of patients sustained an anteroposterior compression injury, the fracture pattern that would result from a head on collision. There were 11 LC Type I injuries, 10 LC Type II, 8 LC Type III, 1 AP Type 1, 3 AP Type II, and 11 AP Type III. Unfortunately, crash dynamics were not available for most of the crashes. Lateral compression fractures would likely represent two commonly seen crashes: T-boning of the motorcyclist or the bike skidding to one side.

Associated injuries were seen commonly with open pelvic fractures (See Figure 1). Patient with greater than five associated injuries had a predictably higher mortality rate than patients with less or no associated injuries. The most commonly associated injury was fractures to other extremities, including 10 associated femur fractures and 24 other extremity fractures. There were 5 associated rectal tears, 5 associated vaginal/perineal tears, 4 associated urethral tears, and 4 associated bladder ruptures. Although these injuries are commonly thought to be associated with open pelvic fractures, they do not exceed other orthopaedic injuries. The remaining associated injuries are illustrated in the attached table (See Table 2).

Transfusions were required in 66% of patients. The average amount of blood transfused was 14 units. Mortality increased as the amount of blood transfused increased. There were no deaths in the patients who did not require blood transfusions. Four patients required in excess of 40 units of PRBCs, and of these patients, there were 2 deaths. (See Figure 2)

DISCUSSION

Upon review of open pelvic fracture data at our institution, associated mortality was higher with these injuries than in closed pelvic fractures. The mortality rate from open pelvic fractures was 19% (10 deaths out
of 52 patients). The mortality rate from closed pelvic fractures was 7.4% (221 deaths out of 3001 patients). Using a Fisher’s exact test, the difference in mortality is statistically significant with a p=0.0047. This is also seen in literature review.

A defined algorithm for the management of hemodynamically unstable pelvic fractures has been in place in the literature. It is presented here (See Figure 3). This algorithm has been derived through careful consideration of the resources available and the needs of the patient. The utilization of defined algorithms and ongoing collaboration from the Trauma Service, Orthopaedics and Interventional Radiology have together demonstrated a reduction in the historically expected mortality rate for pelvic fractures. For open pelvic fractures at our institution that rate is 19%, which is within previously reported range of mortality.7,10

Open pelvic fractures are usually the result of a high energy transfer and are most often seen as part of a blunt mechanism of trauma. Penetrating mechanisms are, of course, seen in our trauma population, but overall, injuries sustained from penetrating mechanisms to the pelvis are less morbid and without the significant mortality as those sustained from blunt mechanisms. Open
pelvic fractures often are accompanied by many other attendant injuries, and these attendant injuries often carry a high morbidity and mortality in and of themselves. Even in isolation, open pelvic fractures have a higher mortality rate than closed pelvic fractures, with more severe anteroposterior compression patterns carrying the highest mortality. This trend is easily demonstrated and is perhaps a reason for this much higher mortality rate with open fractures as demonstrated in our study.

Our center provides coverage to a large rural area and the time to arrival can often exceed 6 hours with ensuing derangements in physiology and recovery due to the delayed resuscitation. This has been demonstrated to increase attendant morbidity and mortality. As a result of this, many efforts have been employed in rural trauma settings to improve prehospital care and decrease transit times. Improved EMS care and techniques may bring patients who formerly would have expired in the field to the medical center, which could potentially increase observed in-hospital mortality. Blunt trauma accounted for the vast majority of open pelvic fractures in our study and this mechanism is known to be associated with higher morbidity and mortality than penetrating injuries. These reasons likely contributed to the 19% mortality in our study, which is greater than the best outcomes that have been reported in the literature. However, a defined resuscitation and fixation strategy initiated by the trauma response team and coordinated with orthopaedic surgical teams still resulted in better outcomes and less mortality compared to classic historical reports. A strategic multidisciplinary response is a critical component in the management of these complex and difficult injuries.

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PROXIMAL JUNCTIONAL KYPHOSIS IN ADULT RECONSTRUCTIVE SPINE SURGERY RESULTS FROM INCOMPLETE RESTORATION OF THE LUMBAR LORDOSIS RELATIVE TO THE MAGNITUDE OF THE THORACIC KYPHOSIS

Sergio Mendoza-Lattes, M.D.; Zachary Ries, B.Sc.; Yubo Gao, Ph.D.; Stuart L. Weinstein, M.D.

ABSTRACT

Background
Proximal junctional kyphosis (PJK) is defined as: 1) Proximal junction sagittal Cobb angle ≥10°, and 2) Proximal junction sagittal Cobb angle of at least 10° greater than the pre-operative measurement. PJK is a common complication which develops in 39% of adults following surgery for spinal deformity. The pathogenesis, risk factors and prevention of this complication are unclear.

Methods
Of 54 consecutive adults treated with spinal deformity surgery (age=59.3±10.1 years), 19 of 54 (35%) developed PJK. The average follow-up was 26.8 months (range 12 – 42). Radiographic parameters were measured at the pre-operative, early postoperative (4-6 weeks), and final follow-up visits. Sagittal alignment was measured by the ratio between the C7-plumbline and the sacral-femoral distance. Binary logistic regression model with predictor variables included: Age, BMI, C7-plumbline, and whether lumbar lordosis, thoracic kyphosis and sacral slope were present.

Results
Patients who developed PJK and those without PJK presented with comparable age, BMI, pelvic incidence and sagittal imbalance before surgery. They also presented with comparable sacral slope and lumbar lordosis. The average magnitude of thoracic kyphosis was significantly larger than the lumbar lordosis in the proximal junctional kyphosis group, both at baseline and in the early postoperative period, as represented by (-lumbar lordosis – (thoracic kyphosis)); no- PJK versus PJK; 6.6°±23.2° versus -6.6°±14.2°; p=0.012. This was not effectively addressed with surgery in the PJK group [(C-L-L-TK): 6.2°±13.1° vs. -5.2°±9.6°; p=0.004]. This group also presented with signs of pelvic retroversion with a sacral slope of 29.3°±8.2° pre-operatively that was unchanged after surgery (30.4°±8.5° post-operatively). Logistic regression determined that the magnitude of thoracic kyphosis and sagittal balance (C7-plumbline) was the most important predictor of proximal junctional kyphosis.

Conclusions
Proximal junctional kyphosis developed in those patients where the thoracic kyphosis remained greater in magnitude relative to the lumbar lordosis, and where the sagittal balance seemed corrected, but part of this correction was secondary to pelvic retroversion.

Level of Evidence
Prognostic case-control study – Level III.

INTRODUCTION
The prevalence of degenerative scoliosis of the lumbar spine has been reported as high as 68% in a healthy population over age 60. The most significant features include loss of lordosis in the lumbar spine, asymmetric disc space collapse, and translational or rotational subluxation. Surgery is recommended for the treatment of intractable low back pain, spinal stenosis with radiculopathy or neurogenic claudication, and for progressive deformity and imbalance. Following neural decompression and stabilization, restoration of sagittal balance may be the most critical factor determining clinical outcomes. Multiple surgical techniques are available to achieve these goals, and include a variety of posterior segmental instrumentations, inter-body spacers, and osteotomies. The proximal extent of the instrumentation is critically determined by choosing the upper instrumented vertebra (UIV) at a segment...
without posterior column deficiency, without listhesis or rotation, and without junctional kyphosis while also avoiding the apex of a deformity in either the coronal or sagittal planes. In spite of these considerations, proximal junctional kyphosis has been described in up to 39% of patients following instrumentations of the lumbar spine for the correction of degenerative deformities, at an average 7.8 year follow-up, with 59% of the total progression occurring within the first eight weeks after surgery.

Few studies have sought to identify predictors for PJK following adult deformity surgery. The goal of the present study is to identify predictors for this complication, with particular emphasis on the contribution from spinal-pelvic alignment resulting after surgical reconstruction, as measured in standing films at four-to-six weeks postoperatively. Our hypothesis is that those patients in whom the correction of the sagittal balance includes pelvic retroversion are prone to develop proximal junctional kyphosis.

Study Subjects and Methods
Our study design was that of a retrospective case control (Level III) which included 54 patients (45 female, nine male) with an average age of 59.3±10.1 years, who were subject to reconstructive surgery for deformity of the spine. These patients presented with at least one of the following criteria: Coronal Cobb-angle measurement of >30°, lumbar lordosis Cobb angle <30°, thoracic kyphosis Cobb angle >60°, sagittal imbalance (C7-plumbline >5 cm from the sacral endplate), coronal imbalance (C7-P >5 cm from the central sacral vertical line). The clinical records and standing posterior-anterior and lateral scoliosis films were reviewed and measured. IRB approval was obtained.

Radiographic parameters were measured at the preoperative, early postoperative (six weeks), and final follow-up visits (average 26.8 months; range 12–42 months). Cases (PJK) and controls (no-PJK) were compared by age, sex, BMI, sagittal alignment, and pelvic incidence. Postoperative predictor variables included sagittal balance, lumbar lordosis and thoracic kyphosis Cobb-angle measurement and sacral slope. Proximal junctional kyphosis was defined according to Glattes et al. by the following criteria: 1) proximal junction sagittal Cobb angle ≥10°; and 2) proximal junction sagittal Cobb angle at least 10° greater than the preoperative measurement. Our study population was divided into two groups. The control group (without PJK) consisted of 35 patients who did not develop this complication. A second group consisting of 19 patients who did develop (PJK) following the index procedure.

Radiographic Measurements
Standing scoliosis postero-anterior and lateral 36-inch films were measured. The positioning of the patients was standardized in 2002 in our Division of Musculoskeletal Radiology, following guidelines recommended by the Spinal Deformity Study Group. Sagittal alignment was measured by using the C7-plumbline, which is represented as the horizontal distance in millimeters between a vertical line extending from the center of the C7 vertebrae and the posterior-superior corner of the sacral endplate.

Fixed and postural parameters were measured to describe the anatomic characteristics of the lumbar-pelvic junction. The pelvic incidence corresponds to the angle formed between a perpendicular line to the sacral endplate at its midpoint, and a line projecting from this same point to the center of the femoral heads. If the femoral heads did not completely overlap on the standing lateral film, then the midpoint between the lines connecting the centers of both femoral head was used.

Postural parameters included sacral slope, which is the angle formed between the sacral endplate and a line horizontal to the ground; lumbar lordosis, or the Cobb-angle measurement between T2 and S1 endplates; and thoracic kyphosis, or the Cobb-angle measurement between T1 and T12. Finally, the sacral-femoral distance is the offset between the center of the femoral heads and the posterior superior corner of the sacrum.

The ratio between the C7-plumbline and the sacral femoral distance was used to describe the position of the C7-plumbline with respect to the posterior superior corner of the sacral endplate and the center of the femoral heads. This positional value is relative and is affected by the dimensions of the thoracic kyphosis and lumbar lordosis Cobb-angle measurement, as well as the degree of pelvic retroversion. A C7-plumbline/sacral femoral distance >1 represents a C7-plumbline projected anterior to the center of the femoral heads. If this ratio is equal to 0, then the C7-plumbline falls directly over the sacral endplate, and finally, if the ratio is <0, then the C7-plumbline falls behind the posterior superior corner of the sacral endplate. Finally, if the ratio is in the 0–1 range, this represents a C7-plumbline projecting between the posterior superior corner of the sacral endplate and the center of the femoral heads.

Data Analysis
Patient data was accessed from the University of Iowa electronic medical record. Patients without PJK and those who developed PJK were compared for their baseline demographic characteristics. Non-parametric analysis was performed using the Chi-squared test, and Student’s t-test was used to compare continuous vari-
TABLE 1.

<table>
<thead>
<tr>
<th>Baseline</th>
<th>NoPJK</th>
<th>PJK</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>C7-P/SDF</td>
<td>1.8±2.8</td>
<td>1.2±1.0</td>
<td>0.305</td>
</tr>
<tr>
<td>ILLI-TK</td>
<td>6.6±23.2</td>
<td>6.6±14.2</td>
<td>0.012</td>
</tr>
<tr>
<td>SS</td>
<td>31.4±16.1</td>
<td>29.6±8.5</td>
<td>0.578</td>
</tr>
<tr>
<td>PI</td>
<td>58.4±16.6</td>
<td>56.6±10.0</td>
<td>0.650</td>
</tr>
</tbody>
</table>

| 6-week Follow-Up | C7-P/SDF | 1.4±2.1 | 0.2±1.3 | 0.040   |
| ILLI-TK         | 6.2±13.1 | -5.2±9.6 | 0.004   |
| SS              | 35.7±8.0 | 30.0±7.9 | 0.034   |

| Final Follow-Up  | C7-P/SDF | 1.1±1.4 | 1.4±0.9 | 0.515   |
| ILLI-TK         | 2.6±14.9 | -17.5±21.0 | 0.002   |

Comparison of measured values of sagittal alignment between patients who did not develop PJK (no PJK group) and patients who developed PJK (PJK group) at baseline, early post-operative period (six weeks) and final follow-up. Difference between the magnitude of the thoracic kyphosis and the lumbar lordosis Cobb-angle measurement = (-LL - TK); ratio between the C7-P distance to the sacral endplate and the sacral femoral distance = C7-P/SDF; sacral slope = SS; pelvic incidence = PI. All values are expressed as mean ± SD. A p<0.012 was considered statistically significant.

TABLE 2.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Univariate Model</th>
<th>Multivariate Model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OR (95% CI)</td>
<td>p value</td>
</tr>
<tr>
<td>Age</td>
<td>1.085 (1.015-1.161)</td>
<td>0.0122</td>
</tr>
<tr>
<td>BMI</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>C7-P</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>(-LL - TK)</td>
<td>0.924 (0.865-0.986)</td>
<td>0.01</td>
</tr>
<tr>
<td>PI</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>SS</td>
<td>0.912 (0.834-0.997)</td>
<td>0.0349</td>
</tr>
</tbody>
</table>

Results from binary logistic regression model. The dependent variable, PJK, represents the development of proximal junctional kyphosis. Odds ratio (OR) and 95% confidence intervals (CI) are described for measures at early follow-up (six weeks). The predictor variables include the difference between the magnitude of the thoracic kyphosis and the lumbar lordosis Cobb-angle measurement = (-LL - TK) expressed in degrees, the C7-P distance to the sacral endplate in mm's, sacral slope = SS in degrees, pelvic incidence = PI in degrees. All values are expressed as mean ± SD. A p<0.012 was considered statistically significant.

Following reconstructive surgery, the early postoperative radiographs (at six weeks) revealed that PJK patients had an improvement in their lumbar lordosis from -34.1°±15.6° before surgery to -46.5°±11.9° six weeks after surgery. This was comparable to the average lumbar lordosis improvement from -29.9°±28.2° to -44.5°±11.6° in patients without PJK. Nevertheless, the average difference between the magnitude of the lumbar lordosis and the thoracic kyphosis remained significantly smaller in PJK patients (6.2±13.1 vs. -5.2±9.6; p=0.004) (Table 1). The average sacral slope increased in patients without PJK (from 31.2°±15.9° to 35.7°±8.0°, while it was unchanged in the PJK group (29.3°±8.2° to 30.4°±8.5°) (Figure 1). Subsets of patients with and without PJK, in which the C7-plumbline was restored closer to the sacral endplate after surgery (C7-plumbline/sacral femoral distance <1), were compared separately. The sacral slope was significantly higher in this subgroup of patients without PJK (40.3°±7.7° vs. 30.4°±8.2°; p=0.01).

Results from the logistic regression model are displayed in Table 2. The univariate model weighed age, the difference in magnitude between lumbar lordosis and thoracic kyphosis, and the sacral slope as significant predictors of PJK. In this model, for every additional year of life the risk of developing PJK increases by 8.5% for every additional decade, the risk increases 85%. In the multivariate model, the most significant finding is that the greater the difference in magnitude between lumbar lordosis and thoracic kyphosis (odds ratio 0.861, 95% CI

RESULTS

Of the 54 patients identified during the study period, 19 (35%) developed PJK. The average follow-up was 26.8 months (range 12-42 months). The average age of the study group was 59.2±10.2 years and the average BMI was 29.1±6.4.

Both the group that developed PJK and the group that did not develop PJK were comparable in age, sex distribution and BMI. Prior to the index surgery, both groups were presented with comparable positive sagittal balance (Table 1). Although the average lumbar lordosis was comparable for both groups prior to surgery (29.9±28.2 vs. 34.1±15.6; p=0.494), the average thoracic kyphosis was of greater magnitude in PJK patients (25.9±12.4 vs. 37.3±19.2; p=0.044). As a result, the average difference between the magnitude of the lumbar lordosis and the thoracic kyphosis was significantly smaller in PJK patients (6.6±23.2 vs. -6.6±14.2; p=0.012).
0.771–0.961), the lower the risk of developing PJK. For every 10° of difference, the risk is decreased by 14%.

The position of the C7-plumbline was also a significant predictor. This parameter is measured in millimeters, and for every centimeter of increase in the position of the C7-plumbline, the risk of PJK decreased by 30%.

At final follow-up, the C7-plumbline of PJK patients had returned to a position closer to its pre-operative location, anterior to the centers of the femoral heads, as demonstrated by the average C7-plumbline/sacral femoral distance ratio of 1.35 ±0.9 (Table 1). Simultaneous to the development of PJK, the sacral slope was reduced to values similar to the pre-operative average (Chart 1), and was significantly smaller than that of patients that did not develop PJK (34.1° ±9.7° in no PJK vs. 26.2° ±10.6° in PJK; p=0.011).

The type of instrumentation was classified between screw-only constructs (25/54) and hybrid constructs with the use of proximal hooks (29/54). These types of constructs were used variably but with similar proportions in patients who developed PJK (12/19 hybrid constructs) and those that did not develop PJK (17/35 hybrid constructs) (p=0.14).

The extent of the instrumentation was divided into three groups: 19/54 patients were fused to the upper thoracic segments (from T2-T6); 22/54 patients were fused to the lower thoracic segments (from T8-T12); and 13/54 patients were fused to the lumbar segments (from only L1 or L2). Of the patients undergoing lumbar instrumentations, including from L1 or L2 level to S1, five of eight (62.5%) developed PJK, which contrasts with five of 22 (22.7%) of the patients instrumented from lower thoracic T8 or T10 to S1 (p=0.014).

**DISCUSSION AND CONCLUSIONS**

The prevalence of proximal junctional kyphosis was found to be 35% of this study cohort, which is comparable to previously described prevalence of 39% at 7.8-year
follow-up in adult patients. Both studies report a higher prevalence than the 26% of PJK described following surgery for scoliosis in adolescents, at 7.3-year follow-up.

In the present study, the predictor variables associated with an increased risk of developing PJK included a thoracic kyphosis Cobb-angle measurement exceeding that of the corresponding lumbar lordosis Cobb-angle measurement, and correction of sagittal balance. For every 10° increase in the difference between the magnitude of the lumbar lordosis and the magnitude of the thoracic kyphosis, the risk of developing PJK diminished by 140%. This implies that pre-operative planning should include sufficient correction of the lumbar lordosis, or should additionally address the thoracic kyphosis. Unfortunately, in patients with sagittal imbalance and a decreased lumbar lordosis Cobb-angle measurement, we can frequently observe thoracic hypokyphosis or even lordosis, making it difficult to assess the true magnitude of this curve. Once the lumbar lordosis is corrected, the thoracic kyphosis will correspondingly increase. This has been recently documented, and the reciprocal regional alignment changes in the non-instrumented thoracic curve are proportional to the correction of the sagittal lumbar deformity.
The second predictor variable in the multi-variate model was the position of the C7-plumbline. Previous studies concluded that there is a lack of association between postoperative positive sagittal balance and the development of PJK in adults, as well as in adolescent scoliosis. Our results show that in adults, with an average age of 59.2 ±10.2 years, the more positive the sagittal balance is found to be, the less risk there is for development of PJK - there is a 3% decrease for every 1mm in the position of the C7-plumbline. This also means that a 5cm increase in the C7-plumbline would represent a 150% decrease in the chance of developing PJK. In a recent review of the literature, there was a progressive increase in positive sagittal balance throughout a lifetime, reaching average C7-plumbline values of 40 ±37mm in asymptomatic individuals, with an average age of 76.3 years. Particularly in elderly individuals, correcting the C7-plumbline to close to 0 may represent overcorrection, and will eventually force patients to carry their C7-plumbline forward by developing PJK. A likely target goal should be approximately 50mm in front of the posterior corner of the sacral endplate. Additionally, values for sacral slope in these patients (average 30.0 ±7.9°) are significantly lower than those found in normative data. The sacral slope from asymptomatic individuals from different age groups shows a high variability, but this remains relatively unchanged throughout a lifetime, from an average of 41.1 ±8.2° in adolescents to an average of 42 ±9.6° in individuals with an average age of 76.3 years. A low sacral slope in the early postoperative period should warn of the persistence of pelvic retroversion (Figure 2), representing incomplete correction of the sagittal alignment, corroborating our hypothesis.

In pelvic retroversion, the hips are in a position of maximal extension (Figures 1, 2). Additionally, the pelvis is "locked" to the spine by the instrumentation. During the terminal stance phase of gait, under normal conditions, the pelvis presents a transitory increase in its tilt angle which is rapidly followed by 5°-10° of hip extension during heel-rise. If the spine is fixed to the pelvis, the C7-plumbline necessarily needs to be thrust into an anterior position to effectively extend the hip during heel raise and toe-off. Repeated cycles of translation of the C7-plumbline likely have an effect on the transition between the rigid instrumentation and the movable spine, resulting in failure of either the bony or ligamentous architecture. Future gait analysis studies are necessary to demonstrate the presence of abnormal kinematics and excessive moments at the transitional segment.

Lordosis in the lumbar spine results mostly from the trapezoidal shape of the lumbar intervertebral discs. The two most caudal intervertebral discs are responsible for 70% of the lumbar lordosis. Particularly in these segments, the degenerative process of the lumbar spine leads to progressive loss of lordosis. As these discs degenerate, the endplates become progressively parallel, resulting in anterior displacement of the C7-plumbline (Figure 2). Several mechanisms are available to correct this loss of sagittal balance, including flattening of the thoracic kyphosis Cobb angle, pelvic retroversion and flexion of the knees while standing.

Pelvic retroversion has been previously described as the forward displacement of the center of the femoral heads (sacral femoral distance), carrying a concomitant change in the sacral slope and pelvic tilt. As a result, a progressively horizontal sacral endplate can be observed (Figure 2). This mechanism contributes to the correction of a positive sagittal balance, bringing the C7-plumbline back to the sacral endplate. It is limited by the anterior iliofemoral ligament and the available degree of extension of the hip joints. Normal gait requires approximately 30° of flexion at heel-strike and 10° of extension at toe push-off. This implies that if the hips are at maximal extension to achieve pelvic retroversion, the trunk must necessarily pitch forward into an imbalanced posture to accomplish a step. In the presence of a spinal-pelvic fusion, the ground reaction forces produced during locomotion are thus transmitted to the junctional region.
Different combinations of compensatory mechanisms for sagittal imbalance are observed in different patients and depend on the degree of flexibility and strength of the involved joints and muscles. For example, a patient with a hip flexion contracture would not be able to use the mechanism of pelvis retroversion. The same is valid for a patient with a thoracic kyphosis that has been stiffened by osteoporotic collapse and advanced spondylosis, who will not be able to provide for thoracic hypokyphosis.

Factors related to the type and extent of the instrumentation have also been studied. Specifically, the use of hook-claw constructs with compressive forces at the upper instrumented vertebrae have also been implicated in the development of PJK.\textsuperscript{15} Particularly in adolescents.\textsuperscript{13,20} In the present study, all patients were instrumented posteriorly and no differences were found in the proportion of screw-only versus hybrid constructs when comparing patients that did and did not develop PJK. The number of instrumented levels seemed to be a contributing factor for the development of PJK, particularly when comparing instrumentation extending to the thoracic-lumbar junction. In the present series, PJK seemed to be significantly more frequent in patients who were instrumented from L1 or L2 to the sacrum (5/8 cases) as opposed to those who were instrumented from T8 or T10 to the sacrum (5/22 cases). Our preference today is to end these instrumentations in the lower thoracic spine instead of the upper lumbar spine.

Finally, other patient characteristics, such as age and body mass index have been previously evaluated.\textsuperscript{18} In the present study, these variables did contribute in the multivariate analysis and were also comparable for patients with and without PJK.

This study is a retrospective case control study (Level III evidence), with an average follow-up of two years. One limitation of this study is our relatively small group of cases and controls - the multi-factorial nature of this problem warrants further multi-center efforts with greater case volume. With regards to the follow-up period, PJK seems to develop early in both adolescents\textsuperscript{20} and adults,\textsuperscript{18} with much less significant progression after two years of follow-up. A previously published prevalence study with 7.8 years of follow-up demonstrated that 59% of the cases developed this complication during the first eight weeks after surgery.\textsuperscript{14} There seems to be little change between eight weeks and the following two years of follow-up, but more significant changes seem to occur thereafter, which was evidenced at the end of the minimum five-year follow-up (average 7.8 years, range 5–19.8 years).\textsuperscript{18}

In conclusion, our results should guide surgeons in some of the necessary goals of reconstructive surgery of the spine. The results suggest the most important factor is achieving a lumbar lordosis Cobb angle that exceeds the thoracic kyphosis Cobb angle. This is achieved by either a greater restoration of the lumbar lordosis and/or by reducing the thoracic kyphosis to a smaller value. Also of importance in elderly patients, the C7-plumbline should be restored to within 5 centimeters of the posterior endplate of the sacrum.

Finally, in certain cases, the C7-plumbline may seem adequately restored due to the fact that the patient is using retroversion of the pelvis to compensate for sagittal imbalance. Fusing the lumbosacral spine in retroversion increases the risk of PJK.

REFERENCES


ABSTRACT

STUDY DESIGN:
Experimental and finite element investigation of cervical laminoplasty.

OBJECTIVE:
To determine the stability of the construct post cervical laminoplasty.

SUMMARY OF BACKGROUND DATA:
Cervical laminoplasty is a widely used technique to widen the spinal canal dimensions without permanently removing the dorsal elements of the cervical spine. Although various laminoplasty procedures have been developed recently, the use of mini-plates to hold the lamina open and prevent restenosis of the spinal cord is a fairly new method and has not been thoroughly investigated.

METHODS:
Biomechanical compression tests and finite element analyses were performed in this study. Sixteen cervical vertebrae (C3 - C6) were isolated from six cadaveric cervical spines (age at death 68 to 91 years; mean 85 years) and were used for compression tests. Out of the 16 vertebrae, four were without any surgical intervention and the remaining 12 were implanted with one of the two laminoplasty plates: open door (OD) graft. Each vertebra was randomly assigned to one of the three groups: OD plate (6), graft plate (6) or intact vertebrae (4). The intact and implanted vertebrae were potted and loaded to failure. Cross-head dis-
placements and the corresponding reaction force throughout the test were recorded to determine the failure loads. A finite element model of the C5 cervical vertebra was created to accommodate the laminoplasty implants. Experimental loading and boundary conditions were simulated and the stress distribution in the lamina was predicted in response to the compressive loads.

RESULTS:
A substantial increase in the sagittal canal diameter (27%-33%) and the spinal canal area (31.2%-47%) was observed at all levels. The strength of the implanted specimens was considerably decreased (by six to eight times) as compared to the intact specimens.

CONCLUSION:
Experimentally obtained data can be combined with mathematical models, such as finite element models, to accurately predict the biomechanical behavior (stresses and strains) of implants and the posterior bone which may not be possible by the use of any other method.

INTRODUCTION
Cervical spondylotic myelopathy (CSM) is the most common cause of cervical spinal cord dysfunction in the aging population.1,2 Spondylotic changes result in a narrowing of the spinal canal, ultimately compressing the spinal cord. Myelopathy, resulting from cord compression, typically leads to progressive and stepwise deterioration of neurological function.2 Consequently, a large percentage of CSM patients require surgical intervention to decompress the spinal cord.

Laminectomy was once regarded as the gold standard for management of CSM due to the decompression afforded by the procedure. Unfortunately, a number of complications (e.g., segmental instability, post-surgical kyphosis, and subsequent neurologic deterioration) have limited the indication of laminectomy alone as a corrective procedure. Posterior fusions have been used to augment a laminectomy, thereby reducing the likelihood of segmental instability and kyphosis. Cervical fusions, however, alter the biomechanics of the spine. Such altered conditions have been associated with degeneration of the adjacent segment(s).3,7

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1Department of Biomedical Engineering, The University of Iowa, Iowa City, IA.
2Department of Orthopaedics and Rehabilitation, The University of Iowa, Iowa City, IA.
3Center for Computer Aided Design, The University of Iowa, Iowa City, IA.
Corresponding Author
Nicole M. Grosland
1418 Seamans Center for the Engineering Arts and Sciences
The University of Iowa
Iowa City, IA 52242
Email: nicole-grosland@uiowa.edu
(319) 335-6425
Fax: (319) 335-5631
Laminoplasty is a motion-preserving alternative to multi-level cervical decompression. The objective of the laminoplasty procedure is to relieve pressure on the spinal cord (i.e., by increasing the diameter of the spinal canal), while maintaining the stabilizing effects afforded by the posterior elements of the vertebrae. The laminoplasty procedure involves 'hinging' one lamina and cutting the contralateral side to form a 'door'. A number of technique-related innovations (e.g., suture fixation, autograft bone, allograft bone, pre-machined allograft bone, and plates), coupled with various opening/hinge combinations, have been used to hold the lamina open. No single method has proven to be more effective than any other in terms of neurological outcome, cervical alignment, or range of motion.

The rigid fixation afforded by plating, however, may allow for rapid mobilization of the cervical spine in ways that were formerly inhibited by early techniques. To our knowledge, there are no reports regarding the mechanical stability of such mini-plates once they are implanted. Therefore, the objective of this study was to evaluate the stability afforded by mini-plate constructs using both cadaveric and computational models. The computational models enabled quantification of the stresses developed in the posterior elements of the vertebrae as a result of the hinge being opened, as well as in response to the implanted plate. The stresses experienced by the plates were also considered.

METHODS

Experimental Study

Sixteen human cervical vertebrae (C3 - C6) obtained from six cadaveric spines (ages 68-91 years; mean 85 years), were considered. Once the individual vertebrae were dissected and denuded of all soft tissues, they were randomly assigned to one of three groups: intact/control (n=4), open door (OD) plate (n=6), or graft plate (n=6). As illustrated in Figure 1, the OD and graft plates (Medtronic Sofamor Danek, Memphis, TN, USA) differ slightly in design, but the objective is the same (i.e. to hold the lamina open post-laminoplasty). The laminoplasty surgeries were performed by the same experienced spine surgeon to avoid inconsistencies in the surgical procedure. A 3.0 mm high-speed cutting burr (Stryker TPS) was used to create a hinge (unicortical defect) and a laminar opening (bicortical defect) in the posterior region of the vertebra. Both the door and the hinge were created at the junction of the lamina and the lateral mass; care was taken to ensure this placement was consistent for all 12 surgically treated vertebrae. Using straight and angled curettes, the lamina was opened to create a deformation at the hinge thereby allowing for laminoplasty plate placement (note: specimens experiencing hinge failure/fracture during plate insertion were omitted from the study). Laminoplasty plates of 10-mm length were used. Four screws were used to fix the plate to the bone (Figure 2). Once the plate and screws were secured, the spinous process was resected. Thereafter, detailed digital photographs were taken and imported into ImageJ for postoperative measurements of the sagittal canal diameter, spinal canal area, and laminar opening. Each vertebra was then potted using Bondo (Bondo Corp, Atlanta, GA) and tested in one of two modes of loading: Direct compression and parasagittal compression. For direct compression loading, the vertebral body was potted so that the posterior surface of the body was parallel to the potting surface (Figure 3a). An indenter of 9-mm-diameter circular cross section was used to apply compression to the specimen as illustrated. To accommodate the parasagittal loading condition, the vertebra was potted so that the spinous process was oriented at an angle of approximately 45° to the base of the loading fixture. A customized fixture with a rectangular cross-section (15mm X 5mm) was used to apply compressive load to the lamina (Figure 3b). The fixture was designed to saddle the laminar bone in an effort to prevent slippage. All potted specimens were mounted on an 858 MTS Mini Bionix II (MTS, Eden Prairie, MN) via a custom-designed fixture. The specimens were loaded to failure at the rate of 1mm/min. Cross-head displacements and the corresponding reaction forces were recorded throughout the test.

Computational Model

A 3D finite element (FE) model of a C5 cervical vertebra was developed using CT data from a 74-year-old male cadaveric specimen. The image data was manually segmented to yield a 3D triangulated surface of the C5 vertebra. The intact vertebral surface (Figure 4a) was modified to create the bicortical (laminar opening) 'door' and the unicortical 'hinge', 4 mm and 3 mm in width respectively (Figures 4b and c). The spinous process was resected and holes were introduced to accommodate the screws (Figure 4d). The techniques used to simulate the surgical procedure are detailed by Tadepalli et al.
Once preparations for the laminoplasty procedure were complete, the FE mesh was generated. An all-hexahedral mesh of the surgically altered C5 cervical vertebra was created using custom-built meshing software.\textsuperscript{19,22} Based on the results of a convergence study, a mesh consisting of 8000 elements in the posterior region was considered optimal for this model.

A uniform force was applied to a set of nodes at the laminar opening to reposition the posterior element nodes to accommodate the laminoplasty plate (Figure 5). The FE model was used to quantify the relationship between laminoplasty opening size, increase in spinal canal area, and increase in sagittal canal diameter. The OD and graft plates, as well as the associated screws, were modeled using Pro-Engineer (PTC, Needham, MA) and meshed via tetrahedral elements using NETGEN.
after placement of the laminoplasty plates. The average failure loads of the specimens implanted with graft plate and OD plate, under direct compression and parasagittal compression loading obtained from the experimental data, were used as external loads in the FE model.

**RESULTS**

Experimental

The mean pre-operative and post-operative sagittal canal diameter, spinal canal area, and laminar opening for all the vertebrae in the study are summarized in Table 2.

A positive correlation ($r^2 = 0.996$) was found between the laminoplasty opening size, the increase in sagittal canal diameter, and the increase in spinal canal area. The average failure load (standard deviation) measured experimentally for the intact and the laminoplasty specimens (graft plate and OD plate) under direct compressive loading were 695.32N (33.2N), 65.05N (3.6N) and 114.69N (47.8), respectively. Each of the intact specimens failed visibly at the spinous process while the implanted specimens failed at the hinge. The average failure load for the intact and the implanted specimens (graft plate and OD plate) under parasagittal compressive loading were 481.38N (171.2N), 96.18N (38.6N) and 81.74N (47.4N), respectively. The intact specimens visibly failed at the intersection of the lateral mass and the lamina, while all the laminoplasty specimens, again, failed at the hinge.

Finite Element Analysis

The pre- and the post-operative spinal canal areas predicted by the FE model were 220.8 mm$^2$ and 330 mm$^2$ (increase of 33%), respectively. Moreover, the pre- and the post-operative sagittal canal diameters measured 13.6 mm and 18.4 mm (increase of 35.3%), respectively. The FE model of the C5 vertebrae implanted with the graft-plate predicted a bony peak von Mises stress of 184.1MPa (Figure 6a) and 166 MPa under direct and parasagittal compressive loads, respectively. The corresponding peak stresses in the graft plate were 368.2 MPa and 424.2 MPa. The model implanted with the OD-plate

(JKU, Linz, Austria). Table 1 summarizes the number of elements defining each structure.

To accurately capture the stresses and strains at the interface of the bone and the laminoplasty constructs (plates and screws), frictional contact (coefficient of friction = 0.3) was defined between the posterior bone and the laminoplasty implants (plates and screws). Image-based material properties were assigned to the vertebral bone directly from the CT image data from which the model was generated. The FE models provide a means to augment the experimental study by predicting the stress distributions throughout the structures of interest. In addition to addressing the implanted constructs, our goal was to analyze the stresses that arise as the hinge is displaced to accommodate the plate and how these stresses are transferred to the plate and screws once they are implanted. Consequently, the principal stresses predicted in the posterior bone during laminar opening were applied to the laminoplasty model as the initial condition.

To simulate the experimental testing conditions, the nodes of the vertebral body were fixed in all directions (six degrees of freedom). Apart from the initial loads that built up in the posterior bone during laminar opening, additional modes of loading - namely direct compression and parasagittal compression - were considered
### Table 1

<table>
<thead>
<tr>
<th>Structure</th>
<th>Number of Elements</th>
<th>E (GPa), ν</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertebral body</td>
<td>20800</td>
<td>10, 0.35</td>
</tr>
<tr>
<td>Posterior Bone</td>
<td>8520</td>
<td>3.5, 0.35</td>
</tr>
<tr>
<td>Open-Door Plate</td>
<td>2274</td>
<td>116, 0.33</td>
</tr>
<tr>
<td>Graft Plate</td>
<td>2972</td>
<td>116, 0.33</td>
</tr>
<tr>
<td>Screws</td>
<td>4248</td>
<td>116, 0.33</td>
</tr>
</tbody>
</table>

Table 1: Number of elements; Young's modulus and Poisson's ratio for each structure.

### Table 2

<table>
<thead>
<tr>
<th>Level</th>
<th>Pre-op Sagittal Canal Diameter (mm)</th>
<th>Pre-Op Spinal canal area (mm²)</th>
<th>Laminar Opening (mm)</th>
<th>Post-op Sagittal Canal Diameter (mm)</th>
<th>Mean Post-op Spinal canal area (mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C3</td>
<td>13.6 (0.31)</td>
<td>263.8 (9.8)</td>
<td>9.95</td>
<td>18.1 (0.7)</td>
<td>389.9 (30.7)</td>
</tr>
<tr>
<td>C4</td>
<td>13.5 (0.30)</td>
<td>265.7 (5.0)</td>
<td>10.46</td>
<td>17.4 (0.8)</td>
<td>366.8 (42.4)</td>
</tr>
<tr>
<td>C5</td>
<td>13.6 (0.36)</td>
<td>273.2 (7.6)</td>
<td>11.40</td>
<td>17.4 (1.8)</td>
<td>358.5 (50.1)</td>
</tr>
<tr>
<td>C6</td>
<td>13.5 (0.78)</td>
<td>266.6 (22.4)</td>
<td>10.25</td>
<td>17.2 (1.1)</td>
<td>363.5 (34.5)</td>
</tr>
</tbody>
</table>

Table 2: Mean pre- and post-operative spinal canal diameter, canal area, and laminar opening as measured experimentally. Standard deviation shown in parenthesis.

predicted a peak von Mises stress of 202.4MPa (Figure 6b) and 185MPa in the posterior bone under direct and parasagittal compressive loading. Likewise, the peak stresses in the graft plate were 271MPa and 319.2MPa under direct and parasagittal compressive loading conditions.

### DISCUSSION AND CONCLUSION

The primary goal of surgery when treating cervical spondylotic myelopathy is to increase the spinal canal area/sagittal canal diameter, thereby sufficiently decompressing the spinal cord and associated nerve roots. Several operative techniques have been developed to treat cervical spondylotic myelopathy. All the other methods except laminoplasty have been well described in the literature.

Very few experimental and computational studies have been published describing the advantages of laminoplasty from a biomechanical perspective. It is still unclear to what extent the lamina has to be opened to sufficiently decompress the spinal cord and increase the spinal canal area and sagittal canal diameter.

An increase in vertebral sagittal canal diameter of 4-5mm has been shown to be sufficient to decompress the spinal cord. An average increase in diameter of 4.1 mm has been correlated with a laminar opening of 8mm or more. In the present study, for all 12 specimens implanted with graft plates and OD plates, pre-operative and post-operative sagittal canal diameter, spinal canal area and the laminar opening were measured. For an average laminar opening of 9.9mm to 11.5mm at different levels (C3-C6), an average increase of 3.7-4.5 mm in the sagittal canal diameter and an average increase of 96.9mm² to 126.12mm² in the spinal canal area was observed.

A total of 16 individual vertebrae from different levels ranging from C3-C6 were loaded to failure. Twelve vertebrae were implanted with either a graft plate or an OD plate and the rest (four) were left intact. Load displacement curves for all the specimens were obtained. Similar failure load patterns were observed under direct and parasagittal compressive loading. It was evident from the failure loads that the strength of the implanted vertebral segments (graft plates and OD plates) was reduced by six-to-ten-fold as compared to the intact specimens. Also, in all implanted specimens, neither screw pull-out nor plate failure was observed, unlike what has been reported in the literature.

Although cervical laminoplasty surgical technique is aimed at providing adequate stability to the spinal column as compared to laminectomy, the cervical vertebral strength post laminoplasty decreased considerably compared to the intact vertebrae.
Figure 6. von Mises stresses in the C5 Cervical vertebrae. (a) Peak stress of 184.1MPa observed in the hinge region in the specimen implanted with the graft plate under direct compressive loading. (b) Peak stress of 202.4MPa observed in the hinge region in the specimen implanted with the OD plate under direct compressive loading. Note: The plates have been removed to focus on the stresses developed in the bone.

An anatomically accurate 3D FE model of the fifth cervical vertebra (C5) was developed to study the biomechanics of the single vertebral segment post laminoplasty. Sufficient model accuracy was achieved by the use of convergence tests. Material and geometric nonlinearities such as large deformation and frictional contact have been included in this model. Laminoplasty was simulated using a custom-written program. Using this 3D FE model, we found that an opening of 9.54mm resulted in a 35.3% increase in the spinal canal diameter and a 33.3% increase in the spinal canal area respectively. Finite-element results correlated very well with the experimental data in terms of laminar opening and increase in the canal area and diameter. In the present model, all the contact interfaces—namely bone-screw, bone-plate and plate-screw interface—were modeled using frictional contact conditions. This helped in predicting the interface phenomena more realistically. Specimen-specific image-based material properties were applied to the vertebral segment in both implanted FE models (graft plate and OD plate). Implanted FE models under direct and parasagittal compressive loading conditions predicted a peak von Mises stress in the posterior bone to be greater than the yield stress of the cortical bone (160MPa). This was indicative of a failure of the bone at the hinge region. A closer look at the stress distribution in the laminoplasty plates (graft and OD) revealed that the peak von Mises stress in the graft plate (368.2MPa and 424.2MPa) and OD plate (271MPa and 319.2MPa) under direct and parasagittal compression were much below the yield strength of titanium alloy (917MPa). It can be clearly seen that the posterior bone had already failed at the hinge under the given loading conditions even before the peak stresses in the laminoplasty plates reached half the value of their yield strength. Similar trends were observed for both loading conditions.

The sole purpose of using static loads instead of dynamic loads in this study was to analyze the stresses and strains at clinically relevant points of fracture (hinge) in the posterior bone as well as in the laminoplasty plates. The stress values in the posterior bone obtained from the FE models at clinically relevant points (hinge region) correlate very well with failure locations in the posterior bone obtained from the experimental results. The failure locations of bone in the experimental and FE model were compared and the trend was very similar in both direct compression and parasagittal compression loading.

When comparing the failure patterns between the experimental and finite element methods, the mechanical strength, bone quality and geometrical differences across different levels were assumed to be uniform. This may not be the case since studies in the past have shown that geometrical differences exist across different levels. Nonetheless, this study gives us insight into the strength and mechanical failure patterns of the cervical vertebrae post laminoplasty.

Proper definitions of the contact interfaces between the bone and the implants during an FE analysis will ensure a more realistic scenario. It also helps in better understanding the biomechanical performance of implants. Such models can be further used to optimize the design of implants. Complex finite-element models incorporating specimen-specific material properties provide insight to better understanding the failure mechanisms of the vertebral segments and laminoplasty plates. By using such anatomically accurate complex FE models, the stresses and strains in bone as well as in the implants under physiological loading conditions can be measured, which might not be possible using other methods. To our knowledge, this is one of the first studies aimed at investigating failure loads and stress patterns in posterior bone and laminoplasty constructs (plates and screws). Via the use of cadaveric experiments, failure loads of the lamina post laminoplasty can be determined.
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17. ImageJ http://rsbweb.nih.gov/ij/]


CERVICAL SYNOVIAL CYST: CASE REPORT

Ernest Found, MD and Dennis Bewyer, PT

ABSTRACT
A 47-year-old female school teacher with a six-week history of left-sided scapular and arm pain is presented. We report her evaluation and treatment. Although lumbar degenerative synovial cysts have been reported over 200 times in the literature, cervical synovial cysts are much more rare. This case reports a cervicothoracic junction degenerative synovial cyst presenting as radiculopathy.

INTRODUCTION
Synovial cysts are relatively common, particularly in the wrist and hand. Synovial cysts in the spine are relatively rare and cervical synovial cysts are particularly rare. Diagnoses of synovial cysts have increased with increased use of magnetic resonance imaging. Symptoms may involve pain, radiculopathy or myelopathy. The authors have over 40 years experience with spinal disorders and this is their first case of a cervical synovial cyst. This case involves a 47-year-old woman with a symptomatic synovial cyst at the C7-T1 level.

CASE REPORT
The patient is a 47-year-old school teacher who presented with a chief complaint of left scapular pain and left-sided paresthesias into the medial arm and little and ring fingers. Her scapular pain began without precipitating traumatic event six weeks prior to presentation. The arm and finger symptoms began two weeks prior to presentation. She had sought previous treatment through a chiropractor and her primary care physician. The chiropractic treatment was somewhat helpful, but only very temporarily. Her physician prescribed tramadol which provided additional benefit. She was first seen through our Physical Therapist Spine Screening Clinic. The

Figure 1. Plain cervical films indicate spondylosis at C5-6 and C6-7.

Department of Orthopaedics and Rehabilitation,
UI Spine Center, University of Iowa,
200 Hawkins Drive
Iowa City, IA 52240-1009

Corresponding Author:
Ernest Found, MD
Director UI Spine Center
University of Iowa Hospital and Clinics
200 Hawkins Drive
Iowa City, IA 52246-1009
physical examination by the physical therapist revealed normal motor function and symmetrical reflexes at the biceps, triceps, and brachioradialis tendons. There was no hyperreflexia or clonus at the ankles. Cervical range of motion was normal. Shoulder motion was normal and pain free. Spurling maneuver to the left was negative. Her medical history involved multiple-site primary osteoarthritis and a sinus surgery. She began a home program involving the use of cold packs and postural stretching exercises. She returned for a recheck approximately two weeks later without significant improvement in her symptoms and was referred to an orthopaedic spine surgeon for further evaluation and treatment.

Her physical examination by the spine surgeon was unchanged. Further evaluation consisted of x-rays (Figures 1a, and 1b) and then an MRI (Figure 2a,b) of the cervical spine. The x-rays indicated age-related degenerative changes. Axial T1-weighted magnetic resonance images revealed a left-sided epidural lesion measuring 9x6 mm. The lesion was continuous with the left C7-T1 facet joint. This was identified to be a large synovial cyst extending into the spinal canal and foramen on the left side. A steroid burst and taper provided significant relief, but not after the medication was discontinued. A rheumatology consult was advised and indicated primary osteoarthritis in several locations.

Surgical intervention was discussed and the patient elected to proceed. A CT scan (Figure 3) was performed.
for surgical planning. A posterior approach with left laminectomy and C5-T1 facetectomy was performed. The cyst was removed and sent for histologic examination which revealed a degenerative synovial cyst. A posterior C5-T1 fusion with iliac crest bone autograft was completed with screw-and-rod placement. Follow up at 18 months indicated all radicular symptoms and scapular pain was completely resolved. There were no hardware complications noted upon cervical flexion/extension films. (Figures 4a, b, c). This patient participated in a physical therapy program for range of motion and strengthening exercises.

DISCUSSION

Synovial cysts occur frequently in the wrists and hands, but are more rare in the spine. There are over 200 lumbar degenerative synovial cyst accounts in the literature since first described by Von Gruker in 1880. The natural history and mechanism for formation of intraspinal synovial cysts remains poorly understood. Evidence seems to point to degenerative processes in the facet joint producing hyperplasia and exudation of fluid, thereby forming a cyst. Most often, the cysts tend to enlarge. There are only 28 accounts of cervical synovial cysts described in the literature. Two-thirds of the reported cases are at the C1-2 level, often related to rheumatoid arthritis. The remaining reported cysts are mostly at the cervicothoracic junction. The average age for intraspinal cysts is 60.8 years of age. Reported symptoms involve pain, radiculopathy, or myelopathy. Most reported cases have been treated surgically. One report describes spontaneous resolution of a cervical synovial cyst. There are cases of attempted CT-guided percutaneous aspiration/injection reported in the lumbar spine, but not in the cervical spine. We did not identify any reports of cyst recurrence following surgical resection.

CONCLUSION

This is a case of a relatively young woman with insidious onset of pain and radicular symptoms. Diagnostic evaluation revealed a large synovial cyst. Treatment involved surgical resection and posterior fusion. Follow up at 18 months demonstrated complete resolution of her symptoms.

REFERENCES


EARLY SPONDYLODISCITIS PRESENTING WITH SINGLE VERTEBRAL BODY INVOLVEMENT: A REPORT OF TWO CASES

Joel Ziegelbein, MS,* Georges Y. El-Khoury, MD, FACP**

ABSTRACT

Infectious spondylodiscitis is an uncommon disease with increasing incidence that typically presents with abnormalities in two adjacent vertebral bodies and the intervening disk. We describe two cases that initially presented with imaging abnormalities in only a single vertebral body. Both patients had a history of lumbar back pain and elevated inflammatory markers, but the lack of classical spondylodiscitis imaging findings led to diagnostic delay and confusion. It is likely that the incidence of atypical presentations of spondylodiscitis will increase as the disease incidence increases and imaging is performed at an earlier stage. It is important to recognize the disease early because early diagnosis is the key to preventing serious complications like epidural abscess and spinal cord compression.

INTRODUCTION

Infectious spondylodiscitis or infectious spondylitis is an infectious process involving two vertebral bodies and the disk between them. The incidence of this disease is estimated to be around 0.4 to 2.4 per 100,000 per year and tends to increase with increasing age.1,2 Many authors expect these numbers to increase because of better diagnostic techniques, increasing numbers of immunocompromised patients, growing IV drug use in young people, increased use of intravenous access devices, and increasing prevalence of genitourinary surgery in the elderly.3,4 Accurate and timely diagnosis is important because a missed or delayed diagnosis of spondylodiscitis can potentially lead to the development of epidural abscess and spinal cord compression along with vertebral bone destruction and spinal instability.5

Hematogenous spread of septic emboli is generally accepted as the most common mechanism by which infection is seeded into the vertebrae.6,7 The most common source of infection is thought to be the urinary tract.4 Classically, pyogenic spondylodiscitis presents with lesions in two adjacent vertebral bodies and the corresponding intervertebral disk. This is thought to be due to the segmental nature of the supplying arteries that bifurcate to supply two adjacent vertebral bodies.6,8 In children, the presence of vascular channels that directly feed the disk allows for direct hematogenous infectious seeding of the disk. In adults, the direct blood supply to the disk is reduced and thus disk infection usually arises via direct spread from the vertebral body after the end-plate has been destroyed.1,6 Rarely, spondylodiscitis may affect only a single vertebral body with or without disk involvement and this may lead to diagnostic confusion. In this scenario, metastatic disease and mycobacterial infection become more prominent in the differential diagnosis. Thus, awareness of the variability of imaging findings in spondylodiscitis is important in minimizing delays in diagnosis. Our purpose here is to report two cases of spondylodiscitis that presented with imaging abnormalities in only one vertebra.

CASE PRESENTATION

Case 1

A 10-year-old boy, who was previously healthy prior to experiencing lumbar back pain and fever for several days, presented to his primary care provider (PCP). He had no radicular pain and no lower extremity weakness. Vital signs were within normal limits but he did have a subjective history of fevers. The only positive physical examination finding was point tenderness in the lumbar spine. The PCP obtained conventional lumbar radiography and blood tests. Imaging was interpreted as negative but the erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP) were elevated at 42 mm/hr (normal: 0-15 mm/hr) and 4.1 mg/dL (normal: <0.5 mg/dL), respectively. He did not have leukocytosis. Lumbar spine magnetic resonance imaging (MRI) was obtained.
Figure 1. Initial MRI for patient one. (a) Sagittal T1-weighted MRI showing hypointense lesion in L4 vertebral body. (b) Sagittal T2-weighted MRI with hypointense lesion in L4 vertebral body. (c) Sagittal T1-weighted post-gadolinium contrast MRI with fat suppression showing no enhancement.

Figure 2. Lumbar spine CT for patient one. (a) Sagittal and (b) axial views showing a rounded lucent area in the posterior-inferior portion of the L4 vertebral body.

(Figure 1) which showed a hypointense lesion in the L4 vertebral body on both T1- and T2-weighted images. This was initially thought to most likely represent a hemangioma. He was discharged on non-steroidal anti-inflammatory drugs (NSAIDs) for analgesia and was to closely follow up with his PCP.

Five days later the patient came to our emergency treatment center with worsening lumbar back pain not relieved by NSAIDs; he was admitted to our hospital for pain control. He underwent a lumbar spine CT which showed a subtle hypodensity in the L4 vertebral body (Figure 2). A repeat MRI (Figure 3) showed L4 vertebral body abnormalities consisting of low T1 and high T2 signal as well as post-contrast enhancement that extended into the epidural and paravertebral spaces. Further workup included blood cultures and CT-guided needle biopsy of the L4 vertebral body (Figure 4). The blood and biopsy cultures both grew methicillin sensitive Staphylococcus aureus (MSSA). Treatment was initiated with IV vancomycin. At that time, lumbar spine plain radiography (Figure 5) showed narrowing of the L4-L5 disk space.

Figure 3. MRI performed six days after initial presentation. (a) Sagittal T1-weighted MRI showing low signal intensity of the entire L4 vertebral body. (b) Sagittal T2-weighted image showing a small hyperintense lesion in L4 vertebral body. (c) Sagittal T1-weighted post-gadolinium image with fat suppression showing L4 vertebral body enhancement. (d) Axial T1-weighted post-gadolinium image showing epidural (black arrow) and paravertebral (white arrow) enhancement.

Figure 4. CT-guided needle biopsy of L4 vertebral body.
The patient was discharged but readmitted one week later for worsening back and leg pain. Lumbar spine plain radiography at that time continued to show L4-L5 disk-space narrowing (Figure 6). An MRI of the lumbar spine was repeated and showed progression of the L4 osteomyelitis to include the L5 vertebral body and the L4-L5 intervertebral disc (Figure 7). An epidural abscess was also present. The infectious disease consultation team discontinued the IV vancomycin and started a continuous IV infusion of nafcillin along with oral rifampin. Antibiotic treatment was continued uneventfully for a total of six weeks and the patient was symptom free at three-month follow-up.

Case 2

A 52-year-old woman with a past medical history of hypertension, chronic obstructive pulmonary disease, and melanoma presented to her local hospital with three weeks of intermittent back and leg pain with episodes of lower extremity weakness. Prior treatment included NSAIDs and muscle relaxants, but both had been unsuccessful at alleviating her pain. At presentation, she also had cellulitis of the left elbow but no history of fevers or chills. Initial lab work was significant for a white blood cell count of 25.3 x 10^9/μL (normal: 3.7-10.5 x 10^9/μL), ESR of 81 mm/hr (normal: 0-15 mm/hr), and CRP of 30 mg/dL (normal: <0.5 mg/dL). The initial lumbar spine MRI (Figures 8a and 8b) showed low T1 and high T2 signal in the L5 vertebral body and high T2 signal in the

Figure 5. Lateral lumbar radiograph nine days after initial presentation showing L4-L5 disk space is narrowing.

Figure 6. Lateral lumbar radiograph 19 days after initial presentation showing L4-L5 disk height loss (arrow) and endplate blurring (curved arrows).

Figure 7. MRI of the lumbar spine performed 17 days after initial presentation. (a) Sagittal T1-weighted image showing hypointense lesions in L4 and L5 vertebral bodies (arrows) and disk height loss (arrowhead). (b) Sagittal T2-weighted image showing hyperintense lesion in L4 vertebral body and hypointense lesion in L5 vertebral body (arrows). There is loss of signal intensity in L4-L5 disk (arrowhead). (c) Sagittal T1-weighted post-gadolinium image with fat suppression showing L4 and L5 vertebral body enhancement. (d) Axial T1-weighted post-gadolinium image showing epidural (black arrow) and paravertebral (white arrow) enhancement.

Figure 8. Initial MRI for patient two. (a) Sagittal T1-weighted image showing hypointense lesion in the L5 vertebral body. (b) Sagittal T2-weighted image with hyperintense lesion in the L5 vertebral body and hypointense L5-S1 disk. (c) Sagittal T1-weighted post-gadolinium image with fat suppression showing L5 and S1 vertebral body enhancement (arrows) and epidural abscess (arrowhead). (d) Axial T1-weighted post-gadolinium image showing epidural (arrowhead) and paravertebral (arrow) enhancement.
L5-S1 disk. This MRI study was performed without intravenous gadolinium. The follow-up examination two days later was performed with gadolinium and it highlighted an epidural abscess, paravertebral inflammation, and S1 vertebral body enhancement (Figures 8c and 8d). Plain radiography of the lumbar spine showed normal alignment and no bony changes (Figure 9). The MRI findings were initially concerning for infectious spondylodiscitis versus metastatic melanoma because of the patient’s previous history of melanoma.

The patient underwent CT-guided needle biopsy of her L5-S1 intervertebral disc (Figure 10). The biopsy specimen and one of her blood cultures were positive for MSSA. Vancomycin was initiated to treat the MSSA until sensitivity studies returned, at which point treatment was shifted to nafcillin. On follow-up at one month she continued to have back and leg pain. Conventional radiography of the lumbar spine showed progressive loss of L5-S1 disk space height and blurring of the inferior endplate of L5 and the superior endplate of S1 (Figure 11). An MRI of the lumbar spine showed progression of spondylodiscitis to include the vertebral bodies of L5 and S1 as well as the L5-S1 disk (Figure 12). Upon completion of eight weeks of nafcillin therapy, her back and leg pain had improved but had not completely resolved.

**DISCUSSION**

Our cases are unique in that both patients presented with MRI findings different from those typically reported in the literature. Most studies on spondylodiscitis report the classic finding of involvement of two adjacent vertebrae in the majority of cases. The fact that only a single vertebral body showed abnormalities on MRI led to diagnostic confusion. In addition, patient one also presented with hypointense T2 signal in the single affected vertebral body.

Although most studies in the literature do not focus on cases like ours, several studies have noted the small prevalence of cases with single vertebral body involvement. Shih, et al. focused specifically on this topic and found nine cases of single-segment vertebral osteomyelitis out of a series of 107 patients (8.4%). Three of these cases were due to tuberculosis and the other six were pyogenic in nature. Their study found that the presence
of anterior cortical disruption of the vertebra and upward subligamentous spread of the infection are the two most prevalent features that can aid in earlier diagnosis of single-segment spondylodiscitis. In another study with 44 patients having disk infection where tuberculous and postoperative infections were excluded, only three of these patients showed signs of involvement of a single vertebral level for an incidence of 6.8%. In all three patients with single segment spondylodiscitis, only the superior vertebra was affected. This is the same pattern we observed in our two cases.

Other investigators have studied the MR characteristics of spondylodiscitis and noted some atypical appearances. Gillams, et al. reported on a series of 25 patients and found that early imaging tended to show atypical MR presentations. One patient presented with single vertebral body involvement that later evolved to include the disk and adjacent vertebral body. Two other patients in this study had single vertebral body and disk involvement initially which later progressed to include the adjacent vertebral body as well. The incidence of single vertebral body involvement with or without disk involvement in this study was three out of 25 (12%). Another series with 27 patients reported that four of them (15%) had single vertebral body involvement with or without disk involvement initially, which also later progressed to include the adjacent vertebra. Thrush, et al. reported one case out of 14 patients with a similar presentation. Other atypical appearances of spondylodiscitis reported in the literature include a single vertebral compression fracture with a normal disk, and initial presentation in an 81-year-old woman with only disk involvement and no vertebral body findings.

Similar to our case one is the atypical finding of hypointense T2 signal in the involved vertebral body also observed in 17 of 39 cases (44%) documented by Dagirmanjian, et al. Sclerosis of the bony trabeculae was postulated as an explanation. They did not, however, find a statistically significant correlation between sclerosis on the plain radiographs and the hypointense foci on T2 weighted images.

While plain radiography is often used as an initial imaging modality for patients with back pain, MRI is considered the most sensitive and specific imaging study for early spondylodiscitis. The typical MRI characteristics of spondylodiscitis are low T1 and high T2 signal intensity in the vertebral bodies and the intervertebral disk between them. Avid gadolinium enhancement on T1-weighted imaging in the affected tissues is also characteristic. One study looked at 46 patients with culture-positive pyogenic spondylodiscitis and found that certain imaging parameters had very good sensitivity for diagnosing spinal infection (paraspinal or epidural enhancement—98% sensitivity, disk enhancement—95% sensitivity, hyperintense T2 disk signal—93% sensitivity, and erosion of at least one vertebral end plate—84% sensitivity) while other parameters were less sensitive (decreased intervertebral disk height—52% sensitivity, and hypointense T1 disk signal—30% sensitivity).

The general consensus from the literature is that spondylodiscitis with single vertebral body involvement reflects early presentation of the disease. This assertion is supported by the cases presented here as they both progressed to include the adjacent vertebral body. Many of the cases reported in the literature have shown a similar progression.

In summary, infectious spondylodiscitis is a disease that affects both adults and children and is becoming more prevalent. Early presentation of this disease may have an atypical appearance such as involvement of a single vertebra on MRI. As disease incidence increases and more patients are scanned earlier in the disease process, atypical presentations such as these may become more common. To avoid delays in diagnosis, spondylodiscitis should be included in the differential diagnosis when imaging studies reveal atypical findings.

REFERENCES


ULNAR NERVE COMPONENT TO
INNERRATION OF THUMB CARPOMETACARPAL JOINT

Ryan U. Riel, M.D.," Philip G. Robinson, M.D.,† Patrick W. Owens, M.D."  

ABSTRACT

Purpose:
Thumb carpometacarpal (CMC) joint arthritis is one of the most common problems addressed by hand surgeons. The gold standard of treatment for thumb CMC joint arthritis is trapeziectomy, ligament reconstruction and tendon interposition. Denervation of the thumb CMC joint is not currently used to treat arthritis in this joint due to the failure of the procedure to yield significant symptomatic relief. The failure of denervation is puzzling, given that past anatomic studies show the radial nerve is the major innervation of the thumb CMC joint with the lateral antebrachial nerve and the median nerve also innervating this joint. Although no anatomic study has ever shown that the ulnar nerve innervates the CMC joint, due to both the failure of denervation and the success of arthroscopic thermal ablation, we suspect that previous anatomic studies may have overlooked innervation of the thumb CMC joint via the ulnar nerve.

Methods:
We dissected 19 formalin-preserved cadaveric hand-to-mid-forearm specimens. The radial, median and ulnar nerves were identified in the proximal forearm and then followed distally. Any branch heading toward the radial side of the hand were followed to see if they innervated the thumb CMC joint.

Results:
Eleven specimens (58%) had superficial radial nerve innervation to the thumb CMC joint. Nine specimens (47%) had median nerve innervation from the motor branch. Nine specimens (47%) had ulnar nerve innervation from the motor branch.

Conclusions:
We believe this is the first study to demonstrate that the ulnar nerve innervates the thumb CMC joint. This finding may explain the poor results seen in earlier attempts at denervation of the thumb CMC, but the more favorable results with techniques such as arthroscopy with thermal ablation.

INTRODUCTION

Osteoarthritis affects 27 million Americans and accounts for almost $128 billion per year in medical care and indirect expenses. Following the knee and hip, the hand is the third most common location for osteoarthritis. The thumb CMC joint is the second most common location for osteoarthritis in the hand. The radiographic prevalence of thumb CMC arthritis in persons over the age of 75 is 25% in men and 40% in women.

Surgical interventions are commonly performed to treat symptomatic thumb CMC arthritis when nonsurgical interventions fail. The gold standard of treatment is trapeziectomy with ligament reconstruction and tendon interposition. Although this procedure has a success rate between 87% and 95%, even at long-term follow up, it has many features which make it less popular among younger and more active patients, such as an extensive period of immobilization, a prolonged recovery time, and weakness of both pinch and grip strength. Because of these limitations, other surgical treatments have been attempted.

Denervation of the CMC joint is one surgical treatment that has been attempted. Studies examining denervation of the thumb CMC joint as a treatment for osteoarthritis symptoms are scarce; the few studies that exist have mixed results. Denervation of the CMC joint, specifically the radial and median nerve...
branches, provided satisfactory pain relief in 12 of 14 patients at five-month follow up. In contrast, Foucher et al. performed denervation of the thumb CMC joint and reported only 35% of patients had satisfactory pain relief. Due to the mixed results of this procedure, open denervation as a treatment for thumb CMC arthritis has not gained in popularity.

The failure of open denervation of the CMC joint as a treatment for thumb osteoarthritis is puzzling given the success of wrist denervation for the treatment of these symptoms in the wrist. Studies suggest that wrist denervation has a success rate ranging from 51 to 68%. Anatomic studies of the thumb CMC joint suggest that denervation of the radial and median nerves should provide similar symptomatic relief to that seen in denervation in the wrist. Numerous anatomic studies have found that the palmar cutaneous, thenar motor, superficial radial sensory and lateral antebrachial nerves all can provide innervation of the thumb CMC joint. Given this, it is surprising that denervation of the radial sensory nerve and the median nerve does not provide symptomatic relief of osteoarthritis in the CMC joint. The discrepancy between the efficacy of denervation of the wrist and denervation of the thumb CMC joint is puzzling and has yet to be explained.

Unlike denervation, arthroscopic thermal ablation of the CMC joint, at least in short-term studies, has proven to be a promising surgical intervention for the relief of osteoarthritis symptoms in the thumb. Advocates of arthroscopic thermal ablation claim that the procedure could be used for younger and higher-demand patients in earlier stages of the disease.

Due to the failure of denervation of the radial and median nerves and the relative success of arthroscopic
thermal ablation in the CMC joint, we suspect that previous anatomic studies may have overlooked other nerve innervations of the thumb CMC joint, specifically the ulnar nerve. The purpose of this anatomic study was to identify the presence and distributions of all terminal nerve branches to the thumb CMC joint.

**MATERIALS AND METHODS**

Nineteen formalin-preserved cadaveric mid-forearms and hands from the Department of Anatomy were dissected under 2.5x loupe magnification. The arms selected did not have any evidence of previous surgery, dissection, or trauma to soft or deep tissue structures. Dissections were performed by a fellowship-trained hand surgeon, a post-graduate 3rd-year orthopaedic surgery resident, and two medical students. The superficial branch of the radial nerve was identified proximally deep to the brachioradialis and traced distally. The median nerve was located in the proximal forearm and traced distally to visualize the palmar cutaneous branch of the median nerve as it arises between the palmaris longus and flexor carpi radialis. The transverse carpal ligament was transected and reflected back to identify the thenar branch of the median nerve and this was followed to its terminal branches. The ulnar nerve was found proximally between the muscle bellies of the flexor carpi ulnaris and the flexor digitorum profundus and was then dissected distally through Guyon's canal. The deep motor branch was dissected around the hook of the hamate and followed to its most radial terminal branch. The terminal nerve branches were followed, and nerves sending visible articular branches to the thumb carpometacarpal joint capsule under 2.5x loupe magnification were considered to be positive. All positive results were documented with digital photography. One of the suspected ulnar nerve specimens was sent to pathology for confirmation under light microscopy.

**Figure 2.** The superficial radial sensory branch (blue arrows) innervating the thumb CMC joint (red arrow).

**Figure 3.** The median motor branch coursing through the thenar muscles (blue arrows). The red arrow marks the median nerve.
RESULTS

A total of nineteen cadaveric dissections of the thumb CMC joint were performed. There were twelve female (63%) and seven male (37%) specimens, of which nine (47%) were left and ten (53%) were right hands. Three specimens (16%) had triple innervation from the radial, median, and ulnar nerves. Six specimens (32%) had double innervation - three (16%) from the median and radial nerves, two (11%) from median and ulnar innervation, and one (5%) from radial and ulnar innervation. Eight specimens (42%) had single-nerve innervation, with three (16%) from the ulnar nerve, four (21%) from the radial nerve, and one (5%) from the median nerve. Two (11%) of the specimens had no identifiable terminal branches to the thumb CMC joint.

No palmar cutaneous branches innervated the thumb CMC joint. All the median nerve innervations came from terminal branches of the thenar motor branch. All of the ulnar nerve innervations came from the ulnar motor branch (Figures 1 and 1a). Eleven (58%) specimens had radial nerve innervation (Figure 2). Nine (47%) specimens had median nerve innervation (Figure 3). Nine (47%) specimens had ulnar nerve innervation.

The suspected ulnar nerve to the thumb CMC joint was sent to pathology. Under light microscopy the specimen was confirmed to be nerve tissue (Figures 4 and 5).

DISCUSSION

Early anatomic studies by Wilhelm primarily focused on the anatomic patterns of wrist innervation and noted that innervation of the thumb CMC joint was primarily attributable to branches of the median and radial nerves.\(^7\,10\,14\,18\,21\) Fukumoto et al. performed dissections of twenty upper extremities looking at the innervation of the wrist joint. They noted that branches of the median, superficial radial, and lateral antebrachial cutaneous nerves contributed to innervation of the thumb CMC.\(^16\)

More recent studies that have focused on the innervation of the thumb CMC joint, by Cozzi et al., described the superficial branch of the radial nerve as the innervation to the thumb CMC.\(^10\) In contrast, Lorea et al. dissected ten forearm and hand specimens and found multiple nerves were responsible for innervation of the thumb CMC.\(^17\) They investigated the thenar branch of the median nerve, the palmar cutaneous branch of the median nerve, the superficial radial sensory nerve, and the lateral antebrachial cutaneous nerve and found that all four nerves contributed to thumb CMC innervation. Poon at al. found that the median nerve supply to the CMC appeared to be more significant, particularly for the palmar cutaneous and thenar branches.\(^16\)

None of the studies mentioned above have reported contributions of the ulnar nerve to the innervation of the thumb CMC, as we found in our study. Fukumoto et al. described the innervation pattern of the deep branch of the ulnar nerve, which contributed to the volar aspects of the second, third, fourth, and fifth carpometacarpal joints but not the thumb CMC joint.\(^16\) Our findings confirm that the innervation pattern of the thumb CMC involves multiple nerves and may be highly variable from person to person. This individual variability may help explain why results of thumb CMC denervations have, to this point, been highly variable for patients and disappointing over all. Our findings suggest that a more detailed understanding is required of the differing patterns of thumb CMC innervation.

A better understanding of the anatomy of the CMC joint may allow hand surgeons to once again consider joint denervation for treatment of pain secondary to thumb CMC arthritis. Theoretically, CMC joint denervation is appealing for a number of reasons: it could potentially alleviate pain without compromising ligamentous stability; it would allow for future reconstructive options; and, it would require minimal postoperative rehabilitation.

As discussed earlier, the limited studies which report results for denervation of the thumb CMC have shown variable efficacy.\(^7\,8\,10\,22\) A study by Foucher et al. reported
a success rate of only 35% for alleviation of symptoms due to osteoarthritis. Our study suggests that poor results from denervation of the CMC joint may be due to the highly variable anatomy of the CMC joint among individuals. Our study demonstrated that the thumb CMC joint has highly variable innervation, ranging from an absence of terminal branches to triple innervation. This is a contradiction of the findings of Lorea et al. in a series of ten cadavers, showing only radial and median terminal nerve branches to the thumb CMC joint.

This study documents ulnar nerve innervation of the CMC joint, an anatomic finding that has never been described in the literature. We found ulnar nerve terminal branches in 47% of specimens, indicating that ulnar innervation of the thumb CMC joint is common. The ulnar nerve component is quite deep and typically on the ulnar side of the flexor pollicis longus. Since denervation of the ulnar nerve component requires a much deeper dissection, this may be a reason for the limited success of previous attempts at denervation. A potential explanation of thumb CMC arthritic pain after conventional denervation is the presence of ulnar nerve terminal branches that were not ablated.

Differing patterns of innervation may explain the failure and success of various surgeries for treatment of thumb CMC arthritis. Trapezectomy's success may be partially attributed to denervation of the joint with excision of the trapezium. Success with arthroscopic thumb CMC joint thermal shrinkage of the beak ligament and capsule may be attributed to the possible denervation of the joint with the thermal probe rather than the theorized tightening of the ligament. This hypothesis may be further supported by studies in the shoulder that have demonstrated the faulty logic of thermal shrinkage in creating tighter and/or stronger tissue. Surgeries that fail to address the possibility of ulnar innervation may not give complete pain relief for the thumb CMC joint. Further studies, which would account for the differing innervation patterns of the thumb CMC joint, may enhance our understanding of current surgical options and increase our ability to treat this common and painful condition.

REFERENCES
THE COURSE OF THE DISTAL SAPHENOUS NERVE:
A CADAVERIC INVESTIGATION AND CLINICAL IMPLICATIONS


ABSTRACT

Introduction
Injury to the saphenous nerve at the ankle has been described as a complication resulting from incision and dissection over the distal tibia and medial malleolus. However, the exact course and location of the distal saphenous nerve is not well described in the literature. The purpose of this study was to determine the distal limit of the saphenous nerve and its anatomic relationship to commonly identified orthopaedic landmarks and surgical incisions.

Methods
Sixteen cadaveric ankles were examined at the level of the distal tibia medial malleolus. An incision was made along the medial aspect of the lower extremity from the knee to the hallux to follow the course and branches of the saphenous nerve under direct visualization. We recorded the shortest distance from the most distal visualized portion of the saphenous nerve to the tip of the medial malleolus, to the antero-medial arthroscopic portal site, and to the tibialis anterior tendon.

Results
The saphenous nerve runs posterior to the greater saphenous vein in the leg and divides into an anterior and posterior branch approximately 3 cm proximal to the tip of the medial malleolus. These branches terminate in the integument proximal to the tip of the medial malleolus, while the vein continues into the foot. The anterior branch ends at the anterior aspect of the medial malleolus near the posterior edge of the greater saphenous vein. The posterior branch ends near the posterior aspect of the medial malleolus.

The average distance from the distal-most visualized aspect of the saphenous nerve to the tip of the medial malleolus measured 8mm +/- 5mm; from the nerve to the medial arthroscopic portal measured 14mm +/-2mm; and from the nerve to the tibialis anterior measured 16mm +/-3mm. In only one case (of 16) was there an identifiable branch of the saphenous nerve extending to the foot and in this specimen it extended to the first metatarsophalangeal joint. The first metatarsophalangeal joint was innervated by the superficial peroneal nerve in all cases. Small variations were also noted.

Discussion and Conclusions
This study highlights the proximity of the distal saphenous nerve to common landmarks in orthopaedic surgery. This has important clinical implications in ankle arthroscopy, tarsal tunnel syndrome, fixation of distal tibia medial malleolar fractures, and other procedures centered about the medial malleolus. While the distal course of the saphenous nerve is generally predictable, variations exist and thus the orthopaedic surgeon must operate cautiously to prevent iatrogenic injury. To avoid saphenous nerve injury, incisions should stay distal to the tip of the medial malleolus. The medial arthroscopic portal should be more than one centimeter from the anterior aspect of the medial malleolus which will also avoid the greater saphenous vein. Incision over the anterior tibialis tendon should stay within one centimeter of the medial edge of the tendon.

INTRODUCTION
Saphenous nerve injury has long been recognized as a potential complication after a variety of orthopaedic procedures, including knee arthroscopy, leg fasciotomies, and procedures about the ankle. Despite this fact, there are relatively few anatomic studies that evaluate the course of the saphenous nerve distally at the level of the ankle.
Saphenous nerve injury during ankle arthroscopic portal placement has been described. This topic was investigated by Saito and Kikuchi in 77 ankles. They found that the average distance from the saphenous nerve to the medial border of the ankle and the tibialis anterior tendon were 6mm and 11mm respectively. They concluded that the saphenous nerve is not at risk with arthroscopic antero-medial portal placement.

Ballmer et al. dissected 30 ankles evaluating the neurovascular network about the medial malleolus. Their results showed the use of a distally based saphenous neurocutaneous island flap to be viable because of the close relationship of the saphenous nerve and vein. They established that the larger anterior and smaller posterior saphenous nerves correlated with the saphenous vein in 100% and 90% of the specimens respectively at the ankle.

Williams and Sugars anatomically evaluated the course of the L4 nerve root, a root that contributes to the saphenous nerve and the anterior division of the femoral nerve. They concluded that the L4 nerve root terminates in most cases near the medial malleolus and proximal to the first metatarsophalangeal joint of the forefoot. They also found that the saphenous nerve entered the dermis at an average of 14.7 mm distal to the tip of the medial malleolus.

Anatomic reference books include the distal saphenous nerve, though there is a discrepancy between commonly used textbooks and the course of the saphenous nerve at the level of the ankle. In “Gray’s Anatomy,” it is written that the saphenous nerve “...descends behind the internal border of the tibia, and, at the lower third of the leg divides into two branches: one continues its course along the margin of the tibia, terminating at the inner ankle; the other passes in front of the ankle, and is distributed to the integument along the inner side of the foot, as far as the ball of the great toe, communicating with the [medial branch of the superficial peroneal nerve].” Hoppenfeld’s “Surgical Exposures in Orthopaedics,” fails to describe the exact course of the saphenous nerve distally. Instead, it is written that the saphenous nerve “...runs with the long saphenous vein in front of the medial malleolus, where it usually divides into two branches that lie on either side of the vein and bind closely to it.” Hoppenfeld’s cautions that the nerve is often small and difficult to identify, and it is recommended in Hoppenfeld’s that in order to avoid a post-operative neuroma of the saphenous nerve, the nerve should be preserved by preserving the long saphenous vein. Hoppenfeld’s also includes a figure demonstrating the saphenous nerve continuing to the first metatarsophalangeal joint as a discrete structure, and it would appear, based on the drawing, that in a medial approach to the ankle or foot, one could identify and retract the saphenous nerve distal to the medial malleolus. Netter’s Atlas does not have a close-up depiction of the distal saphenous nerve, but in a sketch involving the entire nerve, a bifurcation is seen just above the medial malleolus with a large anterior branch continuing to the great toe, as in Hoppenfeld’s. Our experience is that this is not the case.

The purpose of our investigation was to determine the distal limit of the saphenous nerve and its anatomic relation to other structures, particularly common orthopedic landmarks.

METHODS

Eight cadavers with an age range of 69 to 95 years were used for this study providing a total of 16 ankles. A medial curvilinear incision was made from the knee to the hallux. Care was taken to avoid laceration of underlying structures. The saphenous vein was identified in the mid leg. The tip of the medial malleolus was used as a reference point for the location of the saphenous nerve. Branching of the nerve was identified and the location noted. The nerve branches were followed distally to the point of entry into the integument where they could no longer be dissected as distinct structures. The saphenous nerve, tip of the medial malleolus, antero-medial arthroscopic portal site, and tibialis anterior tendon were referenced and the shortest distance from the most distal visualized portion of the saphenous nerve to each structure was measured (Figures 1 and 2).

The saphenous nerve runs posterior to the greater saphenous vein in the leg and divides into an anterior and posterior branch 3 cm (+/- 4 mm) proximal to the tip of the medial malleolus. These branches terminate in the dermis proximal to the tip of the medial malleolus, while the vein continues into the foot. The anterior branch ends at the anterior aspect of the medial malleolus near the posterior edge of the greater saphenous vein. The posterior branch ends near the posterior aspect of the medial malleolus (Figures 1 and 2).

We found that the average distance of the most distal visualized aspect of the saphenous nerve to the tip of the medial malleolus was 8 mm (+/- 5 mm). The average distance to the antero-medial arthroscopic portal site was 14mm (+/- 2mm). The shortest distance to the tibialis anterior tendon was 16mm (+/- 3mm).

In all specimens, the saphenous nerve divided into an anterior and posterior branch 3 cm +/- 4 mm proximal to the tip of the medial malleolus; both branches were posterior to the greater saphenous vein. These two branches were grossly the same size and continued for approximately 2 centimeters before entering the integument. In 15 of the 16 specimens, these branches ended approximately 8mm proximal to the tip of the medial malleolus.
There was one variation in which the anterior branch of the saphenous nerve extended distally past the tip of the medial malleolus and ended at the first metatarsophalangeal joint. The size of this anterior branch was larger than that in the other specimens. The posterior branch of this specimen had the same location, termination, and size as that in the other specimens.

**DISCUSSION**

Knowledge of anatomy is critical for the foundation of any surgeon. Surgeons-in-training often focus on common textbooks for an understanding of pertinent anatomy. We have observed that a discrepancy exists in the description of the course of the saphenous nerve at the medial malleolus in textbooks and current journal articles.

The most common depiction of the saphenous nerve is that there is a branch (usually the anterior branch) that extends to the first metatarsophalangeal joint and communicates at this level with branches of the superficial peroneal nerve. In our study, only one case of sixteen demonstrated an anterior branch of the saphenous nerve extending to the first metatarsophalangeal joint, similar to that depicted in major anatomic references. In Gray’s Anatomy, the saphenous nerve is described as communicating with the superficial peroneal nerve. This communication was not observed in any of our specimens. It appears that the most common depiction of the distal saphenous nerve is more aptly described as an uncommon variation. The most common pattern is for the nerve to divide into two branches approximately
those branches to terminate in the integument proximal to the tip of the medial malleolus.

Our study highlights the proximity of the distal saphenous nerve to common landmarks in orthopaedic surgery about the ankle. The distances that we observed from the distal-most visualized portion of the saphenous nerve to common orthopaedic landmarks were similar to those found in recent studies. Consistent with other anatomic studies, this has important clinical implications in orthopaedic surgical procedures centered around the medial malleolus. We have also observed distal saphenous nerve injury following the placement of distal interlocking screws for tibial intramedullary nails position of the distal locking hole puts the nerve at risk. Although we were not able to identify a safe zone in this study, the incision for distal locking screws in tibial nails should be placed as posteriorly as possible to minimize the risk of saphenous nerve injury. Saphenous nerve injury, most often noted as a painful neuroma, can contribute to significant procedure-related morbidity. Ideally, with a better understanding of anatomy, such potential complications could be avoided. To avoid saphenous nerve injury, incisions should stay distal to the medial malleolus. The medial arthroscopic portal should be more than one centimeter lateral to the anterior aspect of the medial malleolus and this location will also avoid
The Course of the Distal Saphenous Nerve: A Cadaveric Investigation and Clinical Implications

Table 1
Average observed distances of the most distal branch of the saphenous nerve to common orthopaedic landmarks

<table>
<thead>
<tr>
<th>Distance</th>
<th>Interval</th>
<th>Average</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Nerve to Medial Malleolus</td>
<td>8mm</td>
<td>5mm</td>
</tr>
<tr>
<td>B</td>
<td>Nerve to Antero-Medial Portal Site</td>
<td>14mm</td>
<td>2mm</td>
</tr>
<tr>
<td>C</td>
<td>Nerve to Tibialis Anterior</td>
<td>16mm</td>
<td>3mm</td>
</tr>
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</table>

the greater saphenous vein. Incision over the anterior tibialis tendon should stay within 1 cm of the medial edge of the tendon.

Our study, as well as the studies by Ballmer et al. and Saito and Kikuchi, differ from the more generalized saphenous nerve description in Hoppenfeld’s, Netter’s and Gray's Anatomy. Furthermore, despite the fact that the distal saphenous nerve has a generally predictable course, individual variations are known to exist. Thus, the orthopaedic surgeon must place incisions carefully to prevent iatrogenic injury.

REFERENCES


Lynn Calvert, R.N.*

It seems I have reached that age where others are asking for my memories of times past. Here are a few thoughts from an "experienced" orthopaedic nurse - I know they will bring back memories for some of you, and some will be startled or amazed at how things used to be.

In 1978, the orthopaedic department moved into the new Roy Carver Pavilion. The New York Yankees won the World Series versus the LA Dodgers. The Bee Gees "Staying Alive" was everywhere on the airwaves. Grease was a hit movie and LaVerne and Shirley was a hit television show. James Michener's "Chesapeake" was on the best-seller list. Medicare was only 13 years old, patient representatives had been around for just six years and all of the orthopaedic nurses were young and beautiful.

There were no warning labels on cigarette packages or alcoholic beverage containers. Fee-for-service payments for medical care prevailed. Doctors were the "captains of the team." Advancements in medical technology and pharmacology were accelerating. The inpatient areas were always full. Hospital stays for back pain were not uncommon. Total joint replacements required a stay of approximately ten days. There were virtually no outpatient surgeries.

Most residents were single and without children, and spent most of their waking (and many sleeping) hours in the hospital. There were no female residents. Scrub suits were not tolerated in clinic. There were no computers anywhere in the clinics. The cast room was not physically connected to the clinic. There were curtains in the examination rooms but no doors, and patients were expected to be compliant.

During the 1980s, changes came rapidly. Ash trays were moved to the lounges only, then into specific rooms and finally out the door. Video games, aerobics, minivans, camcorders, and talk shows became part of our lives. The decade began with double-digit inflation, President Reagan declared a war on drugs, Kermit didn't find it easy to be green, hospital costs rose, and the world lost many fine talents to a newly discovered disease, AIDS.

Many patients were admitted to surgery directly from the orthopaedic clinic. They arrived as early as 6:00 AM to be prepared for the operating room. The most memorable patient for me was a man who came in for thumb surgery. He had never been to The University of Iowa Hospitals and Clinics before, but he had received a letter telling him the date and time of his appointment. There were apparently two men with the same name in his small Iowa town, and the letter was delivered to the wrong man. After everything was sorted out, the gentleman said, "I wondered how they knew my thumb hurt."

Outpatient surgery became more routine in the 1980s and hospital stays became shorter. The department accepted a female resident. Cable was born and MTV had an enormous impact on music and young people. America was reading Ken Follett, Robert Ludlum, Frederick Forsyth and Tom Clancy. Computers could be found in homes and could be seen in offices, but they were still not in the clinics. The internet was impacting businesses and health care. Patients were asking more questions and becoming better informed. Teams of health care providers were being formed, with physicians as one of the team members.

In 1993, the orthopaedic clinic moved into their current location in the lower level of the John Pappajohn Pavilion. Almost immediately, we began to outgrow our new space. More people were seen as outpatients, more specialties within the department were defined. The general population was living longer and required care for their chronic conditions. Obesity was increasingly impacting the care for orthopaedic patients.

The inpatient area remained in the Roy Carver Pavilion (RCP) but went from occupying all of 4RCP and 3RCP to only 3RCP. Secretaries became administrative assistants. Clinic nurses began to be assigned to specific teams. Many residents were now married with children. The number of females in the residency program gradually increased.

Medical dramas became popular on television. Hip-hop and alternative rock went mainstream. Major League Baseball players went on strike in 1994, prematurely ending the season. The World Series was canceled for the first time in 90 years. The Goosebumps book series was very popular among pre-teens and older children.

*Staff Nurse, 1978 to present
Department of Orthopaedics and Rehabilitation
The University of Iowa
200 Hawkins Drive
Iowa City, IA 52242

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Globalization, which had intensified during the post-Cold-War '90s, continued to influence the world in the decade following 2000. The internet was a prime contributor to globalization, and it began to also influence health care. Via the internet, more information could be shared among providers and much more information could be obtained by patients. The popularity of and knowledge about the Ponseti Method for treatment of clubfoot particularly benefited from internet-based information sharing.

Subspecialties within orthopaedics became much more clearly defined and teams became more specialized. Clinic patients often had more severe orthopaedic problems. Attracting patients to The University of Iowa Department of Orthopaedics became a prime focus. The number of staff physicians and residents increased substantially. Medical technology and pharmacology exploded. Physician assistants, advanced nurse practitioners, medical assistants, social workers and other professionals became valuable additions to the healthcare team.

The “War on Terrorism” and the War in Afghanistan began after September 11, 2001. The Human Genome Project was completed in 2003. Television saw an increase in reality shows. E-readers were on the rise. Harry Potter and Twilight were the books to read.

Now it is 2011. It has been fun to look back. We have gone from a busy day consisting of 100 patients to expecting 200 or more patients on any given day. We have stopped packing all wounds with acetic acid and use Wound Vacs® (KCI) more often. Casting has changed – most casts are now fiberglass and are applied by nursing staff. We have a female staff doctor and more female residents. The changes within our department and in the practice of orthopaedics in general have been enormous.

Our department has gone from having a patient come to clinic just because he got a letter, to actively recruiting patients. We have traveled an often arduous road with third-party payers. We have incorporated the use of technology into every phase of our work life.

I miss some of what I know ‘used to be’, mostly the family feeling in the orthopaedic department of the past. Do I want to go back? Honestly, I must say, “No, I do not want to go back.” I am proud of my small part in the development of the Department of Orthopaedics and Rehabilitation at The University of Iowa Hospitals and Clinics. As a group, our department has always strived for perfection. We are constantly learning to improve our system of care. There is only one thing that is painfully clear, now. The residents are still under 30 and I . . . am not.
PREDICTIVE MEASURES OF A RESIDENT'S PERFORMANCE ON WRITTEN ORTHOPAEDIC BOARD SCORES

Bradley W. Dyrstad, M.D., David Pope, B.A., Joseph C. Milbrandt, Ph.D., Ryan T. Beck, M.D., Anita L. Weinhoeft, C-TAGME, Osaretin B. Iduusuyi, M.D.

ABSTRACT

Objective
Residency programs are continually attempting to predict the performance of both current and potential residents. Previous studies have supported the use of USMLE Steps 1 and 2 as predictors of Orthopaedic In-Training Examination (OITE) and eventual American Board of Orthopaedic Surgery success, while others show no significant correlation. A strong performance on OITE examinations does correlate with strong residency performance, and some believe OITE scores are good predictors of future written board success. The current study was designed to examine potential differences in resident assessment measures and their predictive value for written boards.

Design/Methods
A retrospective review of resident performance data was performed for the past 10 years. Personalized information was removed by the residency coordinator. USMLE Step 1, USMLE Step 2, Orthopaedic In-Training Examination (from first to fifth years of training), and written orthopaedic specialty board scores were collected. Subsequently, the residents were separated into two groups, those scoring above the 35th percentile on written boards and those scoring below. Data were analyzed using correlation and regression analyses to compare and contrast the scores across all tests.

Results
A significant difference was seen between the groups in regard to USMLE scores for both Step 1 and 2. Also, a significant difference was found between OITE scores for both the second and fifth years. Positive correlations were found for USMLE Step 1, Step 2, OITE 2 and OITE 5 when compared to performance on written boards. One resident initially failed written boards, but passed on the second attempt. This resident consistently scored in the 20th and 30th percentiles on the in-training examinations.

Conclusions
USMLE Step 1 and 2 scores along with OITE scores are helpful in gauging an orthopaedic resident’s performance on written boards. Lower USMLE scores along with consistently low OITE scores likely identify residents at risk of failing their written boards. Close monitoring of the annual OITE scores is recommended and may be useful to identify struggling residents. Future work involving multiple institutions is warranted and would ensure applicability of our findings to other orthopedic residency programs.

INTRODUCTION
Prior to being certified by the American Board of Orthopaedic Surgery (ABOS), each resident must pass both the written (Part I) and oral (Part II) examinations administered by the ABOS. For individual residents, failure to pass Part I on the first try potentially causes delays in taking Part II and subsequent board certification. For residency programs there are two important incentives for assuring residents perform well on these examinations. First, the performance of a program’s residents on these tests can be considered a good indicator of the quality of education received from that residency program. Second, the Orthopaedic Residency Review Committee, as one of its criteria, reviews a program’s performance by assessing whether 75% of its residents pass written boards on their first attempt.1,2 The quality of a residency program hinges on the success of its individual residents. Predicting a resident’s likelihood of passing their examinations is important since 10%
of post-residency orthopaedic surgeons fail the written boards every year.\(^1\)

Numerous studies have been performed attempting to determine parameters that will successfully predict the success of future/current orthopaedic surgery residents while they are in residency and their success on post-residency board examinations.\(^3\)\(^4\)\(^6\) A quantitative composite scoring tool was developed at the Mayo Clinic to predict success of residency applicants. A high quantitative composite score was associated with strong performance on OITE and ABOS examinations, but more investigation and analysis needs to be done before the tool is ready for widespread use.\(^7\) Other studies have indicated that honors during the third year clerkship, medical school GPA, and AOA status are indicators of future resident performance.\(^7\)\(^8\)

The literature remains controversial when trying to uncover the predictive value of standardized tests taken in medical school. Some studies support the ability of USMLE Step 1 and Step 2 to predict future Orthopaedic In-Training Examination (OITE) success,\(^9\)\(^10\) while others found no significant correlation.\(^4\) Developed in 1961 as the first test of its kind, the OITE is taken yearly by orthopaedic residents. OITE scores have been shown to correlate with residency performance.\(^10\) After acceptance into an orthopaedic surgery residency, the OITE examination is the only standardized examination prior to written board examinations that residency programs can use to track resident progress and identify early problems. Determination of the appropriateness of the OITE as a predictor of future written board performance is important. Previous studies suggest the OITE does predict future written examination success.\(^1\)\(^8\) Specifically, Klein et al found that residents who failed written boards had OITE scores below the 32\(^{nd}\) percentile in PGY – 3, and below the 27\(^{th}\) percentile in PGY - 4.

Few definitive answers exist when evaluating the ability of USMLE Step 1 and 2 scores and OITE scores to predict the ability of a residency applicant or resident to perform well on written boards. The current study was designed to simultaneously examine potential differences in USMLE Step 1, USMLE Step 2, and OITE scores and their predictive value for written boards. We hypothesized there will be a significant correlation between performance on written boards and USMLE Step 1, USMLE Step 2, and OITE percentile scores for residents at the Southern Illinois University (SIU) School of Medicine Orthopaedic Surgery residency program. In addition, we hypothesized that a significant difference would be observed between the residents who scored above the 35\(^{th}\) percentile on the written board examination and those scoring below the 35\(^{th}\) percentile on all outcome measures.

### MATERIALS AND METHODS

Southern Illinois University Orthopaedic Residency consists of 15 residents, or three residents per year. The program is academically based, but many community faculty members participate in resident education, particularly in the operating room. Emphasis is placed on producing competent clinical and surgical orthopaedic residents; a mixture of our residents begin practice in general orthopaedics and others complete fellowships.

A retrospective review was performed of data held by the residency coordinator for all graduating residents in the last 10 years (2000-2009) in search of USMLE step 1, USMLE step 2, in-service training examinations (from second and fifth years of training), and written orthopaedic specialty board scores. Institutional IRB approval was obtained under the institution's exemption criteria. All personal information was removed by the residency coordinator including year of graduation, name, birth date, medical school attended, fellowship attendance, or any other identifiable information.

To be included in the study, the scores for the USMLE Step 1, the OITE, and written boards needed to be available. Based on these criteria, data from all 30 residents in our program during the past 10 years was included in the study. Two groups were compared based upon those scoring above the 35\(^{th}\) percentile on written boards and those scoring below the 35\(^{th}\) percentile. The 35\(^{th}\) percentile was chosen as a subjective cut-off based upon a previous study showing residents who consistently performed in that range were at a greater risk for potential failure on the ABOS written boards.\(^1\)

Descriptive statistics were performed on all data elements. Scores were summed to obtain averages for each test when a group comparison was made. Group comparisons were made using t-tests for comparing means between 2 groups and regression analysis was used to examine the relationship between USMLE scores and written board results or OITE scores and written board (GraphPad Software, Inc., San Diego, CA USA). Data were tabulated and basic descriptive statistics performed using Microsoft Excel (Microsoft Corporation, Redmond, WA). A p<0.05 was considered statistically significant. Comparison between OITE year 5 scores for those scoring above and below the 35\(^{th}\) percentile on written boards scores was used to calculate the power of the current study. The power calculation utilized the identified standard deviation (SD) of 15 percentile points and the sample size (11 and 19) for each group. Based upon those chosen parameters, our study had an 80% power to detect a difference between means of 17.28 with a significance level (alpha) of 0.05 (two-tailed).

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RESULTS

We identified a potential of 30 residents from our program during the previous 10 year period. Complete data (30/30) were obtained from all residents during this time frame for USMLE Step 1, OITE-Year 2, OITE-Year 5, and Orthopaedic Written Boards (Table 1). Data for USMLE Step 2 scores were available for 22 of the 30 residents. With regards to the overall performance in the standardized testing reviewed for this study, residents in our program had an average USMLE Step 1 score of 221 with a confidence interval (CI) of 216-226 (range of 190 to 257) and a USMLE Step 2 score of 223 with a CI of 214-232 (range 184 to 265) (Table 1). With regards to orthopaedic-specific examinations, our residents had an overall average percentile ranking of 72 (CI=64-80) for OITE year 2 and 72 (CI=65-80) for OITE year 5. Our residents on average obtained orthopaedic written board scores at the 55th percentile.

A significant difference was noted between the two groups (those scoring above the 35th percentile and those scoring below the 35th percentile on their written boards) in regards to USMLE scores for both Step 1 and 2 (Figure 1). In addition, a significant difference was observed between OITE scores for both the second and fifth years between the two groups based upon the written board 35th percentile breakpoint (Figure 2). Positive correlations were found for USMLE Step 1, Step 2, OITE 2 and OITE 5 when compared to performance on written boards (Figure 3).

The first attempt pass rate for the written board examination was 97% (29/30). One resident, in 10 years, initially failed written boards on their first attempt, but subsequently passed, on the second attempt. This resident consistently scored in the 20th and 30th percentiles on the in-training examinations.

DISCUSSION

Our data indicated significantly higher levels of performance on USMLE Step 1, USMLE Step 2, OITE 2, and OITE 5 for residents whose scores were above the 35th percentile on written boards. Those who performed well on their written board examination tended to perform well on the other evaluations studied. Positive correlations were observed between ABOS Part I examinations and both USMLE Step 1 and 2 in addition to OITE 2 and 5 scores. An interesting finding was that only 1 resident out of the 30 examined during the past 10 years failed written boards initially, but subsequently passed on the second attempt. This resident was consistently in the 20th and 30th percentile for OITE scores, had a USMLE Step 1 score of 192, and a Step 2 score of 220. This is very similar to the study conducted by Klein et al. which indicated that all residents who failed ABOS Part I had OITE scores below the 32nd percentile in PGY-3 and 27th percentile in PGY-4. Considering this data, a resident at risk of failing could be defined by relatively low USMLE scores with subsequent low OITE scores.

Our data correlates performance on Step 1, 2, and OITE examinations with written board results. What this data does not answer is why the correlation exists. As Swanson et al stated, it could be as simple as “good students are good students.” Motivation, good study habits, superior intelligence, and work ethic lead to consistently strong performances on standardized testing. An alternative explanation, also offered by Swanson et al, is that a firm understanding of anatomy, physiology, and pathology needed to perform well on Step 1 and strong comprehension of pediatrics, medicine, and surgery needed to do well on Step 2 ensures a good foundation of knowledge and potentially implies the appropriate work ethic necessary to succeed on future OITE and ABOS examinations.
Predictive Measures of a Resident’s Performance on Written Orthopaedic Board Scores

Figure 1. Significant differences in Step 1 and Step 2 scores were seen between groups based upon their written board scores.

The literature regarding the ability of USMLE Step 1 and 2 to predict performance on written boards is mixed. Klein et al., ultimately determined that USMLE Step 1 examinations were not good for predicting failure on written boards. On the contrary, Swanson et al and Case et al found USMLE Step 1 and 2 to be good predictors of future written board success, while Herndon et al found USMLE Step 1 to be a strong predictor of written board success. Similar correlations between USMLE Step 1 scores and performance on pediatric board examinations have been shown.

In contrast to USMLE Step 1 and Step 2 examinations, the literature is more consistent regarding the predictive use of the OITE examinations in regard to performance on written boards. Three studies reported consistent findings that OITE examinations are strong predictors of future written board success. Similarly, studies in family practice, internal medicine, general surgery, and OB/GYN have shown similar correlations between their respective in-training examinations and board certification examinations.

Figure 2. Average orthopaedi in-service training exams were significantly different between groups based upon the written board scores.

This study highlights some very important relationships between standardized test scores, but it is not without limitations. Our data was collected from a single residency program with 30 residents included during a 10 year period. This is not only problematic due to the obviously small sample size but also the single residency program may not be reflective or applicable to other residency programs. Lastly, this study examines the relationship between test scores and does not take into account other qualities that a good orthopaedic surgeon must possess. Previous work has stated that strong performance on ABOS examinations does not always correlate with strong faculty evaluations of residents.

Considering our results and other literature available on the topic, standardized testing taken before and during residency can be useful in gauging a resident’s performance on written boards. However, given the wide variation in scores on each examination for the individual residents, standardized testing has limited ability to predict the actual score of an individual resident on boards.
CONCLUSION

USMLE Step 1 and 2 scores along with OITE scores are helpful in gauging a resident's performance on written boards. A low USMLE score along with consistently low OITE scores may identify a resident who is at risk of failing written boards. By being aware of these scores, residency programs can choose to admit applicants with the greatest chance of performing well on written boards and similarly may be able to identify struggling residents. Future work involving multiple institutions is warranted and would ensure applicability of our findings to other orthopedic residency programs.

REFERENCES


