VOLUME I

CAMPBELL ORTHOPAEDIC JOURNAL

2015

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CAMPBELL ORTHOPAEDIC JOURNAL

Volume 1, May 2015

A Joint Publication of

Campbell Clinic Orthopaedics
The Campbell Foundation
University of Tennessee-Campbell Clinic Department of Orthopaedic Surgery & Biomedical Engineering

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Departmental Update from the Chairman

S. Terry Canale, M.D.

Department Chairman, Harold B. Boyd Professor
UT-Campbell Clinic Department of Orthopaedic Surgery and Biomedical Engineering
University of Tennessee Health Science Center

RESEARCH

The department of Orthopaedic Surgery with its clinical and educational arms, the Campbell Clinic and Foundation, continues to be one of the top orthopaedic residency programs in the U.S. The challenge, in this day of reduced funding for research, is to also be one of the major orthopaedic "players" in the field of basic science and clinical research. Giant strides have been made in areas of clinical research with establishment of Research Nurse Coordinators at the Campbell Clinic, Regional One (the MED), and LeBonheur Methodist Hospital. As a result, the subspecialists at Campbell Clinic in shoulder and elbow, pediatrics, trauma, foot and ankle, hand, reconstruction, and spine have made significant clinical research contributions to the field of orthopaedics. In 2014, 53 peer reviewed articles were published, 71 scientific papers were presented, and 41 posters were shown at national meetings. Already in the first five months of 2015, 35 papers have been accepted for publication. (Obviously with this kind of volume and quality, we believe that we could and should publish our own journal each year.) Each one of our graduating residents is required to present a "peer-review journal-ready" manuscript for publication before graduation. From this experience we believe our residents get a good feeling for and experience in evaluating research. Once a year, we have a research collaboration night where basic science researchers from our department and clinical researchers present their material and a collaborative effort takes place. It has been quite successful in promoting translational research.

Most orthopaedic programs do not have a basic science research department, but to be ranked with the best and to be a complete entity from "bench to bedside," it is essential to have a musculoskeletal basic science research effort. The department has nine full-time basic science researchers. Hongsik Cho, PhD, Denis DiAngelo, PhD, Weikuan Gu, PhD, Karen Hasty, PhD, Yan Jiao, MD, Susan Miranda, PhD, Richard Smith, PhD, Lishi Wang, PhD, and clinician scientist, Bill Mihalko, MD, PhD. This includes three Chairs of Excellence:

- George Wilhelm Chair of Excellence,
- Harold Boyd Chair of Excellence,
- Hyde Chair of Excellence.

In 2014, the research faculty published 27 peer reviewed articles and 25 podium presentations. Numerous research grants have been obtained and Susan Miranda, PhD, received a prestigious RO1 grant from the NIH.

EDUCATION

Concerning education in the department, we are charged with educating the University of Tennessee medical students in orthopaedic and musculoskeletal diseases. We now give 9 lectures each month on every aspect of orthopaedics to the fourth year medical students; using our revised text "How to Nail Orthopaedics" as a syllabus and guide. Also, an Orthopaedic Interest Group is in place overseen by Dr. Quin Throckmorton, which counsels medical students interested in orthopaedics. Our experience is that orthopaedics is very popular with our U.T. students.

Over the last five years, the orthopaedic department has grown, and we have been able to consolidate the School of Biomedical Engineering into the Department of Orthopaedic Surgery. This MA and PhD program teaches the candidates engineering principals related to anatomical function and optimal research in orthopaedic devices. It is a joint (school) effort with the University of Tennessee and the University of Memphis with Drs. William Mihalko (University of Tennessee) and Gene Eckstein (University of Memphis) as Co-Directors.

In the clinical areas, our charge is quality patient care and resident education and supervision. Because of the national prominence of UT-Campbell Clinic and Campbell Foundation, we are able to attract top ranked students going into the field of orthopaedics. We have 40 residents and over 40 staff at Campbell Clinic — a better than 1:1 teaching ratio of staff to resident. Each subspecialty is well represented and each resident is able to rotate through each subspecialty. Dr. Quin Throckmorton, Residency Director, and Dr. Derek Kelly, Assistant Director, do an outstanding job in supervising and advising the residents. Fellowships in the subspecialties are available, and we average from 5-8 fellows per year.

Monday night continues as our traditional 2½ hour interactive didactic educational meeting sprinkled with case presentations. Weekly subspecialty conferences are held as well as a monthly journal club. The Visiting Professors Program is designed for distinguished orthopaedic surgeons to give "Grand Rounds" four times a year with our premier CME meeting, known as the Alvin J. Ingram Memorial Lecture held in the spring.

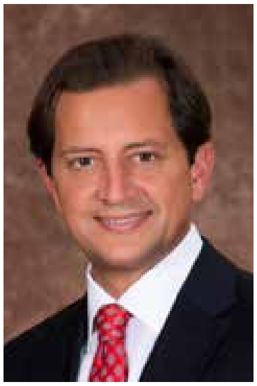
We continue to publish *Campbell's Operative Orthopaedics* every four-five years, with the 13th edition due out in November 2016. A "core" version of Campbell's is new this year entitled "Campbell's Core Operative Procedures," it is essentially the top 100 operative procedures performed by the Campbell Clinic staff.

As you can see we have accomplished a lot, but more still has to be done. I leave this department knowing the best is yet to come under the new department chair, Dr. Jim Beaty. A better choice could not have been made. I have been with Campbell Clinic and the University of Tennessee for 40 years. When I came aboard 40 years ago we were one of the top programs in the country and we still are "so this is where I came in." It has been a great journey.

News from Campbell Clinic

Frederick M. Azar, M.D.

Chief of Staff, Campbell Clinic Orthopaedics
Professor and Sports Medicine Fellowship Director



Campbell Clinic Orthopaedics and Campbell Surgery Center operate five outpatient clinics and two ambulatory surgery centers in the Mid-South region. Founded in 1909, our organization has treated patients suffering from musculoskeletal injury and disease both locally and nationally for more than a century.

Our tradition of teaching and research began by our founder, Dr. Willis C. Campbell, also continues today. Campbell Clinic's physicians comprise the Department of Orthopaedic Surgery at The University of Tennessee Health Science Center located in Memphis' burgeoning medical center corridor. We offer one of the nation's most competitive residency and fellowship training programs in orthopaedics. Each year, we receive more than 700 applications for one of our eight residency positions. We also receive applications from top residents across the country for our 12-month fellowship training programs. We search for compassionate physicians, who become skilled technicians, but retain a balance between faith, family, and patient care. In addition, as evidenced by this new journal, our scientific output has increased substantially, with a focus on clinical and translational research focused on finding innovative solutions to challenging clinical issues.

Improving access for patients through convenience and affordability has long been a critical issue for health care providers, not only in our region, but across the country and around the world. This remained true throughout the past year. I believe that each service enhancement or physical improvement our organization conceived or completed in 2014 worked to reach that singular goal: offering access to quality orthopaedic care for every patient in the Mid-South region.

Multiple capital improvements were made to our facilities throughout the year, and we expanded our geographic footprint as well. Campbell Surgery Center opened its second outpatient ambulatory surgery center (ASC) in the Midtown district of Memphis in the spring. The 18,000 square foot facility boasts four operating rooms, essentially doubling the number of OR suites our surgery centers operate. While expansion of our original ASC in Germantown remains a future option, the addition of our Midtown location addressed immediate needs while opening access to patients in the western half of Shelby County, much of Northwest Mississippi, and Eastern Arkansas.

In addition to the new surgery center, we continued to carefully review our Germantown campus master plan and leased space in North Germantown for a fifth clinic location. I am proud to say that site now operates as a Spine Center of Excellence devoted specifically to the treatment of back, neck, and spine disease. The center – an orthopaedic clinic dedicated to spine ailments – is the first and only of its kind in the region. The facility covers 17,200 square feet and includes 16 exam rooms, 2 X-ray rooms, and a physical therapy suite. We also employ a nurse navigator at the clinic who helps triage patients and reviews their medical history to route them to the appropriate physician more efficiently. Finally, in this new center and across all of our clinical sites, Campbell Clinic physicians will measure our value using technological outcomes measurement systems, in terms important to all key stakeholders - patients, physicians and payers - so that we can continually optimize patients' quality of life in efficient and effective ways.

Our staff continued to improve access through the provision of non-traditional patient care. Our After Hours clinic, offered during weeknights at two locations and on Saturday at our Germantown clinic, enjoyed its most successful year to date, treating nearly 20,000 patients. We also introduced the concept of additional, scheduled clinics in the evening. Unlike our After Hours clinic, which caters to urgent, acute injuries, the evening clinics enabled our providers to actually schedule patients during a "third shift." This allowed patients to see a specific provider for a specific need at a specific time that was convenient for their busy schedule. This program has been met with a great deal of satisfaction and gratitude from our patients. Recently, we expanded our After Hours walk-in model at all five of our clinics during the day. This has allowed us to serve the needs of local referring physicians and patients better than ever before.

Our outpatient joint replacement program that began more than two years ago continues to be a game-changer for our clinic and its patients. More of our total joint surgeons have begun to move hip, knee, and shoulder replacement surgeries from the hospital to the outpatient setting. For healthy patients with otherwise stable medical histories, the convenience of having such a significant procedure performed on a same-day basis has been overwhelmingly successful. In addition to joint replacement, we also continued to perform a number of minimally-invasive spine surgeries in the outpatient setting. Not only does this program provide added efficiencies and comfort for patients, it also helps lower the overall cost burden and carries improved clinical outcomes. The infection and re-admission rate for total joint patients at our surgery centers remains zero.

In all, we treated nearly 162,000 patients in 2014 – up nearly 10 percent from the previous year. Our operational and financial successes were a true team effort and remain a testament to the dedication of my partners and our staff.

State of the Residency

Thomas W. 'Quin' Throckmorton, M.D

Orthopaedic Residency Director, Associate Professor
UT-Campbell Clinic Department of Orthopaedic Surgery and Biomedical Engineering

For nearly 100 years, the Campbell Clinic, in conjunction with the University of Tennessee-Campbell Clinic Department of Orthopaedic Surgery and Biomedical Engineering, has been proud to train orthopaedic surgeons from all over the country and, indeed, all over the globe. Over 550 orthopaedic surgeons have trained at our institution and our graduates include 8 presidents of the American Academy of Orthopaedic Surgeons (AAOS), 9 directors of the American Board of Orthopaedic Surgery (ABOS), 4 presidents of the American Orthopaedic Association (AOA), and numerous presidents of subspecialty societies. Surgeon education is a hallmark of our program, and the staff, in addition to our responsibilities for teaching our residents, continue to author Campbell's Operative Orthopaedics, now in preparation for the 13th edition. While orthopaedic knowledge continues to expand, our educational goal has remained constant: to produce excellent, well-rounded orthopaedic surgeons who have the opportunity to pursue the subspecialty training of their choice.

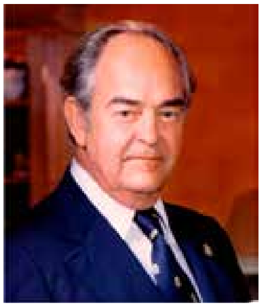
Our residents train in all orthopaedic subspecialties, both as junior and senior residents, and our rotations combine an exposure to the academic/tertiary medical center environment as well as the private practice setting. This comprehensive approach offers the ability to see all subspecialties from different angles and maximizes true understanding of orthopaedic principles and their application. Our training program is designed to prepare residents for the Orthopaedic In-service Training Examination (OITE) and Step I of the American Board of Orthopaedic Surgery examination, through a combination of Core Curriculum training combined with subspecialty conferences in trauma, pediatric orthopaedics, sports medicine and shoulder/elbow surgery, hand surgery, foot and ankle surgery, and spine surgery.

Additionally, we have focused on strengthening and building our clinical and biomechanical research infrastructure, which includes research nurse coordinators, database access to track patient outcomes, a biomechanics laboratory and an extensive orthopaedic staffed by a full-time librarian. We currently are conducting over 90 active clinical and biomechanical research projects. Investigators have been awarded funding from both internal and external sources to conduct these studies, in addition to additional extramural (NIH, NSF, etc.) awards among our basic science research staff. We have been committed to sharing our research at regional, national, and international meetings, and in academic and scientific publications. And in 2014, the program published 59 articles in major orthopaedic journals.

Our international elective medical mission program continues, with sponsorship of an international community service medical mission. Our residents have served in Nicaragua, Guatemala, and, this year, Honduras. In this way, we imbue a commitment to community service within our residents.

In 2015, we will celebrate the graduation of our 90th residency class, whose members are profiled within this publication. We are proud of these eight skilled orthopaedic surgeons, and we will continue to monitor the development of their professional stories. Their senior research efforts are depicted within these pages, and thousands of patients will benefit from the clinical discoveries these projects have yielded.

We are proud of our heritage at the Campbell Clinic, but we are equally proud of our present and we look forward to our future. With our comprehensive, diverse, high-volume brand of training, we will continue to strive for excellence in the training of orthopaedic surgeons.



Alvin J. Ingram, M.D.

Dedicated Lectureship Series:

Alvin J. Ingram, MD Memorial Lecture 2014 and 2015

Each year, the Campbell Foundation is privileged to host a Distinguished Professor in memory of a fine surgeon. The annual Alvin J. Ingram, MD Memorial Lecture was initiated in memory of former Campbell Clinic Chief of Staff and Department Chairman Alvin J. Ingram, M.D., through a gift from members of his family, to honor his commitment to education. Dr. Ingram was a graduate of our residency program, and was a world authority on the treatment of polio.

The lecture series highlights achievements in surgeon education, and features a Keynote Address by a Distinguished Professor, followed by presentations from the Campbell Foundation graduating residents. In 2014, under the guidance of Course Director Derek M. Kelly, M.D., the Ingram Lecture was expanded considerably and included not only lectures by our Distinguished Professor, faculty and the residents, but also an Expert Panel and technical exhibits. The Ingram Lecture was open to the public, with continuing education credits available for physicians and other allied health professionals. An audience of more than 150 participated in the lecture.

2014 Alvin J. Ingram, MD Memorial Lecture • May 9, 2014

Distinguished Professor: Terrance D. Peabody, M.D.
Edwin W. Ryerson Professor and Chairman
Department of Orthopaedic Surgery
Northwestern University School of Medicine
Chicago, IL

Terrance D. Peabody, M.D.

2014 Distinguished Professor, Dr. Terrance Peabody, is a renowned expert in the surgical treatment of bone and soft tissue tumors, and he is also the Past President of the American Orthopaedic Association (AOA).

Dr. Peabody's lecture, "Orthopaedic Residency Education: Challenges and Opportunities" highlighted the changes affecting orthopaedic resident education programs. He described influences including work hour restrictions, technological change, outpatient surgery, "privatization" of patients, generational differences and surgeon adaptations. Dr. Peabody described the work underway at the national level to address these challenges, including discussion of simulations and alternative and innovative educational methods designed to capitalize on each program's unique advantages. He touched on changes related to competency-based education, and the development within the American Board of Orthopaedic Surgery (ABOS) to identify Top Ten Procedures, essential procedures and additional procedures. Dr. Peabody shared a vision of resident education in 2020 which may look substantially different than in prior years. The challenges and opportunities he presented elicited both excitement and some apprehension from the audience.

Another highlight of the 2014 Ingram Lecture was the presentation of the research of our graduating class of residents. Resident research at the Campbell Foundation is only possible through donor support. These financial gifts offset the costs of research, including supplies, testing equipment and support personnel. In addition, through a gift from the family of Dr. Hugh Smith, the Hugh Smith Research Award is presented each year to the best research project, judged by a panel from the Ingram Lecture. Dr. Hugh Smith, a former Campbell Clinic Chief of Staff, and one of the founders of the Campbell Foundation, believed strongly in the power of innovation to unlock solutions to challenging clinical programs. Dr. Smith recognized the significant role that research can play in developing new surgical techniques and implants that will lead to a better quality of life for patients, and his family wanted to formally celebrate and recognize the importance of ongoing research. The 2014 Hugh Smith Presentation Award was presented to Dr. Rob Murphy, for "Effect of Morbid Obesity on Complications of Femoral Fractures." Dr. Murphy's project provided new insights into the growing problem of obesity, and suggested further research into processes for chronic management of the condition.

At the close of the afternoon, Dr. Peabody heralded the Campbell Foundation's tradition of educational excellence, particularly in technical and surgical skill, along with the development of fine clinicians.

2015 Alvin J. Ingram, MD Memorial Lecture • May 22, 2015

Distinguished Professor: J. Lawrence Marsh, M.D.

Chairman, Professor
Residency Director, Carroll B. Larson Chair
Department of Orthopaedic Surgery
University of Iowa Hospitals & Clinics
Iowa City, Iowa


J. Lawrence Marsh, M.D.

J. Lawrence Marsh M.D., is the Chairman and tenured professor in the Department of Orthopedic Surgery at the University of Iowa Hospitals and Clinics. He holds the Carroll B. Larson Chair and serves as the Program Director of the Orthopedic Residency Training Program. He received his BA from Colgate University, his medical degree from Upstate Medical Center in Syracuse, New York, and trained in orthopedic surgery at Boston University. After the completion of his training, he served for two years as University Lecturer in orthopedic surgery at Oxford University in Oxford England.

Dr. Marsh's clinical practice is devoted to orthopedic trauma, adult reconstruction and he has developed techniques of minimally invasive articular fracture surgery. His research has focused on articular fractures and techniques of image analysis to assess the mechanical factors leading to post-traumatic osteoarthritis. He has also been instrumental in initiatives that have led to new requirements for laboratory-based surgical skills training for orthopedic residents, and his research in this area has led to new skills assessments and validated skills training techniques. His research has been funded by the NIH, OTA, Arthritis foundation, AO and by NBME. He and his co-authors were recipients of the 2011 OREF clinical research award for their work on Post-Traumatic Osteoarthritis.

Dr. Marsh also has a long-standing interest in orthopaedic education. He currently serves as the Chair of the Residency Review Committee for Orthopedic Surgery and is a member of the ACGME's Council of Review Committee Chairs. He has been instrumental in leading orthopaedic surgery into the next accreditation system and adoption of milestones. He is a Director for the American Board of Orthopedic Surgery and is the President Elect. He is a member of the National Board of Medical Examiners and is the President of the Mid-America Orthopedic Association and the American Orthopaedic Association.

Dr. Marsh will participate in both Mini Trauma Symposia, and his Keynote Address will be "Tipping Points in Surgical Education and Skills Training."

The Functional Movement Screen as a Predictor of Injury in Professional Basketball Players*

ABSTRACT

Background: The Functional Movement Screen (FMS) is designed to detect deficits and asymmetries in the movement patterns of athletes that predispose them to injury. This tool has been found to be predictive of injury in select populations, but has not been studied in professional basketball players. Our hypothesis was that injured players have lower FMS scores than non-injured players, and an FMS score of 14 is predictive of injury in this population.

Methods: Pre-season FMS testing was performed on all members of a single team in the National Basketball Association (NBA) over the course of four seasons. Injury was defined as a musculoskeletal condition that prevented an athlete from participating in practices or games for at least one week. The data was retrospectively analyzed to determine the ability of the FMS to accurately predict future injury over the course of a season.

Results: A total of 34 players met inclusion criteria, including 17 injured and 17 non-injured subjects. The mean FMS score for all subjects was 13.2 (min-max: 7-19; SD=2.6). Injured players did not have a significantly lower mean FMS score than non-injured players (p=0.16). A positive correlation existed between the hurdle test and injury (p=0.004), however, no other subscore of the FMS correlated with injury.

Conclusions: While the Functional Movement Screen is a valuable tool for identifying deficits and asymmetries of movement in some athletic activities, it is not predictive of injury in male professional basketball players.

Key Terms: Functional Movement Screen; injury prediction; professional basketball players

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INTRODUCTION

The incidence of injury in professional basketball players has been shown to be significantly higher than less competitive levels, with a rate of game-related injury twice as high as collegiate basketball players.[1] Injuries to professional athletes and subsequent time lost have important implications for both the team and the players' future careers. Increasing attention and research have focused on the prevention of injury in competitive athletes and methods to identify those at risk. The typical musculoskeletal portion of the pre-participation examination (PPE) focuses on isolated muscular flexibility and static stability testing of specific joints.

Recently, sports medicine specialists have shifted their focus to patterns of movement in order to identify deficiencies in balance, segmental range of motion and efficiency of specific movement patterns.[2-4] Movement screenings such as the Y-Balance Test, Box Drop Vertical Jump, and the Functional Movement Screen have been proposed as methods to identify at-risk individuals.[2,4-6] One of these tools, the Functional Movement Screen (FMS), has been shown to reliably predict injury in athletic and high-physical demand populations,[5,7,8] including professional football players.[9-11]

The FMS includes 7 screening tests designed to assess an individual's movement quality **(Table 1)**. Cook, Burton and Hoogenboom[2,3] defined a fundamental movement pattern as a basic movement utilized to test the interaction of strength, range of motion and flexibility. Deviations from normal movement patterns identify limitations in any or all of these areas. Such limitations could potentially place an individual at increased injury risk. A score of 1 to 3 is given based on the performance of the individual screening test, and a score of zero is given if the patient reports pain during the test;

*Accepted for publication in *Current Orthopaedic Practice*. Citation not yet available.

Tests	Description of Movement Pattern Tested
Deep Squat	Bilateral functional mobility of the hips, knees, and ankles
Hurdle Step	Single-leg stance stability and coordination between the hips and torso during a stepping motion
In-Line Lunge	Hip and ankle stability, quadriceps flexibility, and knee stability
Shoulder Mobility	Bilateral shoulder range of motion, scapular mobility, and thoracic spine extension
Active Straight Leg Raise	Active hamstring/gastroc-soleus flexibility while maintaining a stable pelvis and contralateral leg extension
Trunk Stability Push-up	Sagittal plane trunk stability during closed-chain upper extremity activity
Rotary Stability	Multi-plane trunk stability during upper and lower extremity motion

TABLE 1: Summary of individual tests comprising the FMA and movement patterns tested with each test.

the maximal test score is 21.[2,3] This test has previously been shown to demonstrate a high degree of interobserver and intraobserver reliability.[8,12]

A pre-season score of 14 or less has been shown to be predictive of subsequent injury in previous studies of male professional football players and female collegiate athletes.[7,10] Similarities exist in the type and location of injury seen in both professional and collegiate basketball and football players,[13-18] but the FMS test has not yet been studied in professional basketball players. The purpose of this study was to examine the relationship between preseason FMS scores and the likelihood of a player sustaining a subsequent injury in professional basketball to determine if the FMS score could be used as a predictor of injury. Our hypothesis was that an FMS score of 14 or less would be predictive of future injury in male professional basketball players.

MATERIALS AND METHODS

This retrospective study was approved by the University's Institutional Review Board (IRB). Subjects were members of a single National Basketball Association (NBA) team during 4 seasons from 2007-2011. Two Certified Athletic Trainers (ATCs), both certified FMS providers, conducted FMS testing on all players as part of a standard pre-participation screening protocol during training camps from 2007-2010.

Inclusion criteria for this study were players who completed each of the seven tests of the FMS with full documentation of results, and subsequently participated in at least 1 practice or 1 game. Players were excluded if they met any of the following criteria: 1) they were waived or traded during a season as their continued participation and injury status could no longer be monitored; 2) they averaged fewer than 10 minutes/game during a season; or 3) they played in fewer than 40 games during a season.

The FMS testing consisted of the seven tests of deep squat, hurdle step, in-line lunge, shoulder mobility, active straight leg raise, trunk stability push-up, and rotary stability. Each test was graded on an ordinal scale from one to three, as described by Cook et al.[2,7] A score of zero was given if the patient reported pain during the test. Additionally, three of the tests (push-up, shoulder mobility, and rotary stability) included clearing exams graded as positive or negative based on the presence of pain. Injury data were then recorded over the course of each season.

The team's head ATC tracked player injuries during the course of the 4 seasons. At the conclusion of the fourth season, a compilation of all injury data and FMS scores was reviewed. For the purposes of the study, an injury was defined as a traumatic or overuse musculoskeletal event resulting from basketball that led to time loss of at least 7 days from practice and/or games. Because the outcome measure was "injury in a season", players who were on the roster for multiple seasons were included as individuals for each season.

After exclusion criteria were applied, subjects were stratified into injured (INJ: n=17) and non-injured (NO-INJ: n=17) groups. To determine if a difference existed between groups in composite FMS scores, mean FMS scores of each group were compared using an independent t-test. Athletes were also divided into those having FMS scores of 14 or below and those having above 14 for nonparametric comparison. Each of the individual subscores of the FMS also was analyzed using nonparametric SPSS crosstabs program, Kendall's tau, and independent t-tests to determine if a significant difference existed between injured and non-injured groups. A Spearman's rho correlation was also used to evaluate the relationship between both total FMS score and injury, and each individual test score and injury. All statistical analyses were performed using IBM SPSS Statistics V. 20 for Mac and significance was considered at $p<0.05$.

Tests		Mean	Standard Deviation	Significance (p-value)
FMS Total Score	Non-Injured	12.6	2.7	0.16
	Injured	13.8	2.3	
Deep Squat	Non-Injured	1.6	0.61	0.37
	Injured	1.8	0.53	
Hurdle Step	Non-Injured	1.8	0.44	0.004
	Injured	2.2	0.44	
In-Line Lunge	Non-Injured	1.6	0.62	0.83
	Injured	1.6	0.93	
Shoulder Mobility	Non-Injured	2.5	0.8	0.64
	Injured	2.6	0.62	
Active Straight Leg Raise	Non-Injured	2	0.79	0.26
	Injured	2.3	0.69	
Trunk Stability Push-up	Non-Injured	1.8	0.75	0.52
	Injured	1.9	0.83	
Rotary Stability	Non-Injured	1.4	0.49	0.72
	Injured	1.3	0.47	

TABLE 2: Results of independent t-test of FMS scores for injured and non-injured players.

RESULTS

A total of 61 preseason FMS tests were conducted over the course of four NBA seasons from 2007-08 to 2010-11. Of these, 27 players failed to meet inclusion criteria, leaving a total of 34 players included in the final analysis.

The mean FMS score for all subjects was 13.2 (min-max: 7-19; SD=2.6). The INJ group mean was 13.8 (SD=2.3); the NOINJ group mean was 12.6 (SD=2.7). Each player who was injured had only one injury during the course of the season, no players were injured more than once. There was no significant difference between FMS means for injured and uninjured groups (p=0.164). Indeed, the injured group had a higher FMS mean score than the non-injured group **(Table 2)**. Of the seven tests that comprise the FMS, only the hurdle test score showed that a significantly higher score was predictive of injury (p=0.004) **(Table 2)**. Nonparametric measures were used to look at FMS individual scores, and there was only an association with injury for the hurdle test (Kendall's Tau C, p=0.0001) **(Table 3)**. When athletes were divided into two groups, one with cumulative FMS of 14 or less and the other with a total of more than 14, the noninjured group had 4 (23%) athletes with an FMS >14 and the injured group had 5 (29%) athletes with an FMS >14 **(Table 4)**. The FMS scores showed no correlation with minutes per game or total games played **(Figures 1,2)**. When data were analyzed separately for each season, no significant difference was seen in FMS scores between injured and non-injured groups.

Tests	Kendall's Tau-C	Significance (p-value)
Deep Squat	0.166	0.32
Hurdle Step	0.415	0.0001
In-Line Lunge	0.01	0.96
Shoulder Mobility	0.059	0.73
Active Straight Leg Raise	0.197	0.26
Trunk Stability Push-up	0.118	0.52
Rotary Stability	-0.059	0.71

TABLE 3: Nonparametric analysis of individual FMS test scores and their association with injury using Kendall's Tau-C.

	FMS SCORE	
	>14	≤14
Injured	5	12
Non-Injured	4	13

TABLE 4: Results of dichotomization of patients using a cut-point of 14 on FMS testing for nonparametric analysis.

DISCUSSION

The purpose of this study was to examine the relationship between preseason FMS scores and subsequent injury over the course of a season in professional basketball players. We hypothesized that an FMS score of 14 or less would be predictive of subsequent injury, as demonstrated in similar populations.[7,10] In this study, there was no significant difference between FMS scores in injured and non-injured players, and FMS score was not predictive of subsequent injury. However, average FMS scores for both injured and non-injured groups were under 14, which is lower than what has been previously reported in similar populations.[10,19] This is the first study that we are aware of that examines FMS exclusively in basketball players. It is not clear why this group of professional athletes scored so low on FMS testing, but reasons could include the low sample size. It may also be that many of the movement patterns that comprise the FMS are not movements that are commonly performed in basketball. For example, the hurdle step ex-

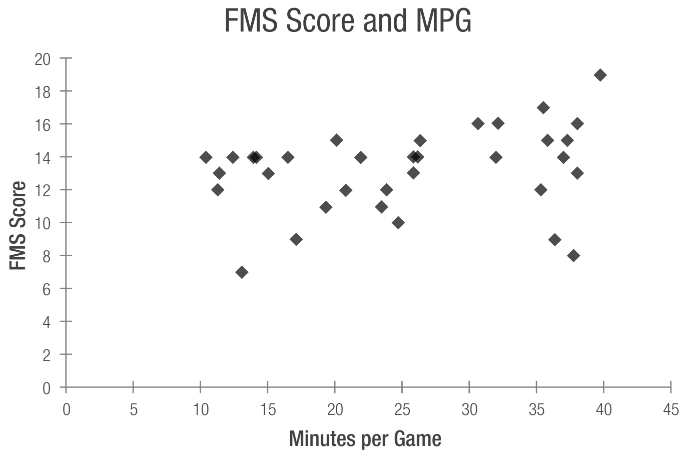

Figure 1: Relationship of FMS score to minutes played per game. There was no significant correlation between these variables (R = 0.274; P= 0.117)

amines a player's balance in single-leg stance and stride mechanics during a stepping motion. Though this provides information on an athlete's core strength and ability to stand on one leg, the movements in professional basketball are much more dynamic and involve jumping and cutting motions.

Nevertheless, one of the confusing findings of this study is that though only the hurdle test had a significant correlation with time lost due to injury, it was a positive correlation that was found. Of the 34 players, four scored a 3 on the hurdle test (completed test without difficulty), and all four of those players were injured. Conversely, four players scored a 1 (unable to complete test), and none of these players were injured. The remaining 26 players scored a 2 (able to complete test with compensation) with 13 injured and 13 noninjured, precluding any further differentiation. While the significance of the hurdle test as it pertains to subsequent injury is uncertain, we found no significant correlation between any of the other tests and future injury.

While it is counterintuitive that a higher score on one of the FMS domains may be predictive of injury, other authors have found similar positive correlations. For instance, in their study of 193 Division III athletes, Brumitt et al.[20] found that men who scored higher on the single-leg hop test and lower extremity functional test were three times more likely to experience a low back or lower extremity injury during their subsequent sports season. Conversely, women who scored lower on these tests were more likely to be injured. While injury is a multifactorial process, one explanation for these gender differences is that men may create higher forces during athletic activities, which places them at a higher risk of injury.

Kiesel et al.[10] also evaluated the ability of the FMS to predict injury in professional football players. They found that players with a score of 14 or less on the FMS demonstrated an 11-fold higher risk of injury and a 51% increased probability of incurring a serious injury during the season than those scoring 15 or higher; however, players were followed for only a single season. The types of injuries causing missed time have been shown to be similar in both professional basketball and professional football, with knee and ankle injuries being most common.[1,13,14,17] In these studies, ankle sprains were the most common injuries incurred, but knee injuries caused the most time lost.

Chorba et al.[7] in a similar study in female collegiate athletes participating in soccer, volleyball, and basketball, found that athletes scoring 14 or less incurred a 69% higher injury rate and a 4-fold increase in risk of injury. Additionally, a score of 15 or below had an injury rate 56% higher than those with higher scores, and a score of 13 or less resulted in an injury rate as high as of 81%. The types of injuries have been shown to be similar in frequency in both male and female professional basketball players, but a higher incidence of injury noted in women's professional basketball.[13]

Another use of the FMS score is to uncover deficiencies of movement and side-to-side asymmetries that can potentially predispose the athlete to later injury. This theoretically allows prophylactic targeted interventions to be performed. In a study of professional football

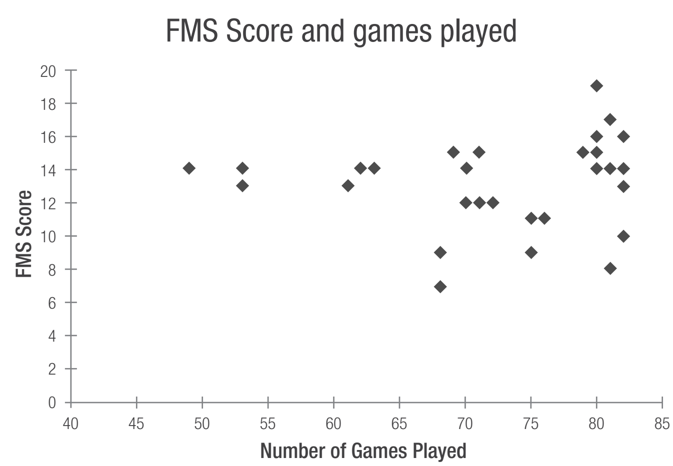

Figure 2: Relationship of FMS score to number of games played. There was no significant correlation between these variables (R = 0.101; P= 0.569).

players, Kiesel et al.9 found that both an FMS score of 14 or less and asymmetry on exam had an increased relative risk of injury, and the combination of these two factors was highly specific for predicting future injury. Peate et al.19 used FMS score as a screening exam in 433 firefighters, with a subsequent core strengthening program to address deficiencies. Injury results were then tallied over the course of a year. The total amount of time lost due to injury decreased by 62% and the total number of injuries decreased by 44% when compared to a historical control group. Similarly, Kiesel et al.11 evaluated the effects of a targeted off-season stretching and core strengthening program on FMS scores in professional football players. They found that players had an 11% average increase in FMS score and more players were free of right-left asymmetry after the program.

There were several limitations in the present study. First, it was a retrospective study, which does not allow for evaluation of interventions targeted at improving specific deficiencies or asymmetries. Also, there is no consensus definition of what constitutes an injury in the literature. Kiesel et al.[10] used 3 weeks as the minimal amount of time lost necessary to classify it as an "injury," while Chorba et al.[7] used the definition of any musculoskeletal condition that required medical attention. In the present study, we used 7 days of lost time in our injury definition to ensure that a player was truly injured, but also a short enough period of time to detect lesser injuries. Additionally, professional athletes are often biased against full disclosure of injuries for many reasons, and only injuries which were reported to the medical staff and resulted in time lost of 7 days were able to be identified. Finally, the overall FMS mean was below what has been previously reported for similar populations. It is not clear why FMS mean scores were so low for this population of professional basketball players. This finding could be related to the relatively small number of players meeting inclusion criteria, which also represents a limitation of this study. Since professional basketball teams have much smaller rosters than other professional sports, larger future studies with collaboration among several teams may increase the power to detect differences in future studies.

This study suggests the FMS is not predictive of future time lost due to injury in professional basketball players. Future areas of study include the prospective evaluation of FMS testing in large cohorts of athletes and subsequent interventions designed to correct these deficiencies.

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Cigarette Smoking Increases Complication Rate in Forefoot Surgery*

ABSTRACT

Background: Cigarette smoking is known to increase perioperative complication rates, but no study to date has examined its effect specifically in forefoot surgery. The purpose of this study was to determine if cigarette smoking increased complications after forefoot surgery.

Methods: The records of 602 patients who had forefoot surgery between 2008 and 2010, and for whom smoking status was known, were reviewed. Patients were categorized into three groups based on smoking status: active smoker, smoker in the past, or nonsmoker. Medical records were reviewed for occurrence of complications, including nonunion, delayed union, delayed wound healing, infection, and persistent pain.

Results: Active smokers were found to have a significantly higher complication rate (36.4%) after forefoot surgery than patients who previously (16.5%) or never (8.5%) smoked. Patients who continued to smoke in the perioperative period had the highest percentage of delayed union (3.0%), infection (9.1%), delayed wound healing (10.6%), and persistent pain (15.2%). Active cigarette smokers were 4.3 times more likely to have a complication than nonsmokers. Patients who smoked at any point in the past but quit prior to surgery were 1.9 times more likely than nonsmokers to incur a complication. The average time of smoking cessation for patients who had smoked at any point in the past but had quit prior to surgery was 17 years. For active smokers, those with a complication smoked an average of 18 cigarettes daily while those without a complication smoked 14 cigarettes daily.

Conclusions: Before forefoot surgery, surgeons should educate patients who smoke about their increased risk of complications and encourage smoking cessation.

Level of Evidence: Level III, retrospective comparative study

Key Words: Forefoot surgery; Smoking; Complications

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INTRODUCTION

The negative effects of cigarette smoking on overall health have been known since the 1960s, and recent literature has reported the specific effects on the musculoskeletal system and outcomes of orthopaedic procedures.[3,4,8,11,13,14,16,18,23,28] The 2011 National Health Interview Survey found that 19% of adults smoked cigarettes, with no significant change in prevalence from 2010.[3] Over $96 billion in direct medical expenses and $97 billion in lost annual productivity are attributed to cigarette smoking in the United States.[4] Nicotine, one of more than 4000 chemicals released during cigarette smoking, has addictive dopaminergic effects in the central nervous system.[13] Combined with carbon monoxide, this causes peripheral vasoconstriction, which reduces the amount of oxygen available to tissues and leads to microclotting.[16] This negative effect has been shown to be reversible.[11] Hydrogen cyanide, found in the volatile phase of cigarette smoke, interferes with cellular metabolism, and smoking negatively impacts the immune response through its effect on immunoglobulins and natural killer-cell activity.[8,14,23]

Animal studies have demonstrated the negative effect of nicotine on bone and skin healing,[6,7] and clinical studies have demonstrated the deleterious effects of cigarette smoking on outcomes in arthroplasty, spine surgery,[1,2,21] and a variety of other orthopaedic conditions and procedures, including fracture healing, hand and foot surgery, and ligament and cartilage repair. Slower healing has been reported in smokers than in non-smokers after transmetatarsal amputation, bunionectomy, and hindfoot fusion,[15,17,33] but no study to date has examined the effect of smoking on the complication rate after forefoot surgery.

Two meta-analyses in the non-orthopedic literature clearly indicate benefits of smoking cessation in reducing postoperative complications. Both Mills et al.[20] and Wong et al.[31] reported significant reductions in wound healing complications with at least 4 weeks of smoking cessation. Møller et al.[22] and Lindström et al.[19] also found a significant reduction in wound-related complications in patients who had total hip or knee replacement with a 6- to 8-week smoking cessation program before and/or after surgery. In 160 hindfoot fusions, Ishikawa et al. found that the nonunion rate dropped from 19% to 11% in those who quit smoking before surgery. A 2014 Cochrane Database Review30 concluded that smoking cessation interventions beginning 4 to 8 weeks before surgery could significantly reduce postoperative complications.

The purpose of our study was to determine the effect of smoking status on surgical outcomes in a large elective foot and ankle practice in order to provide practitioners with general numbers from which they be able to formulate strategies to better educate their smoking patients before surgery. We hypothesized that smokers would have a higher total complication rate than nonsmokers after surgery of the forefoot and that quitting smoking before surgery would lower the complication rate.

MATERIALS AND METHODS

This study was approved by our institution's Institutional Review Board before data collection began . All patients who had forefoot surgery for whom cigarette use could be determined from the medical record were included. A CPT code search for all forefoot operative procedures performed between 2008 and 2010 was used to compile a list of patients for a retrospective medical record review **(Table 1)**.

CPT Code	Procedure
28080	Excision interdigital neuroma, single, each
28112-28114	Excision of metatarsal head
28153	Resection, condyle(s), distal end of phalanx
28200-28210	Repair of tendon to foot
28226	Repair of tendon to foot
28226	Tenolysis of foot
28230-28234	Tenotomy of foot/toe
28270	Capsulotomy; MTP joint
28280	Syndactylization of toes
28285	Correction of hammertoe
28288	Partial exostectomy metatarsal head
28289	Hallux rigidus correction with cheilectomy
28290-28299	Hallux valgus correction
28306-28312	Metatarsal/phalangeal osteotomy
28313	Soft tissue reconstruction toe angular deformity
28315	Sesamoidectomy, first toe
28476	Percutaneous skeletal fixation of metatarsal fracture
28485	Open treatment of metatarsal fracture
28505-28525	Open treatment of toe fracture
28531	Open treatment of sesamoid fracture
28636	Percutaneous fixation of MTP joint dislocation
28645	Open treatment of MTP joint dislocation
28675	Open treatment of IP joint dislocation
28750-28760	Arthrodesis of great toe
28800-28825	Amputation of foot/toe

Table 1: CPT codes and procedures included.

All surgeries were done by three fellowship-trained orthopaedic foot and ankle surgeons. Medical records were reviewed to determine patient demographics, including age, sex, and presence of comorbidities. Comorbidities recorded were those that were known to have a negative impact on operative outcomes, including diabetes mellitus, rheumatoid arthritis, peripheral vascular disease, peripheral neuropathy, and chronic steroid use as detailed on the intake history and physical. All patients had palpable pulses in the operative foot before surgery or vascular consultation was obtained before any surgical intervention. Smoking status was determined from the intake history and classified as active smoker, smoker in the past, or nonsmoker as reported by the patient. Patients were classified into three groups based on chronology of cigarette smoking related to their forefoot procedure. Group I patients had no history of cigarette smoking. Group II included patients who previously smoked cigarettes but had stopped at some point before the date of surgery. Group III patients continued to smoke in the perioperative period. Medical records were then reviewed from the immediate post-operative visit through the latest follow-up visit. The length of follow-up was recorded for each patient.

Group	Males	Females	Avg. age	Avg. Follow-up
Group I (457) Non-smokers	84	373	52.6 years	15.3 months
Group II (79) Previous Smokers	21	58	62.4 years	18.4 months
Group III (66) Current Smokers	22	44	47.5 years	11.6 months
TOTAL (602)	127	475	53.1 years	15.2 months

Table 2: Demographics of the three patient groups.

Outcome measures were complications that occurred including nonunion, infection, delayed wound healing, delayed union, and persistent pain as detailed by the surgeon in the medical record. The presence of each complication was recorded to allow calculation of total complications and complication rate. Nonunion, delayed wound healing, and delayed union were considered to be present when the primary surgeon had documented each in the medical record during a follow-up visit. Infection was considered to be present when documented by the primary surgeon at follow-up and treated with antibiotics. Persistent pain was defined as pain significant enough to be reported by the patient as leaving him or her dissatisfied with the outcome at latest follow-up in the absence of any other complication. To account for patients who may have had more than one complication and to avoid artificial inflation of the complication rate, the complication rate was calculated as the number of patients with any complication divided by the total number of patients. A power analysis using a beta of 20% and a p-value of 0.05 was performed, as were a chi-square analysis and Fisher's exact test with a p-value of less than 0.05 indicating significance. A multiple logistic regression analysis was performed on the individual data at subject level with complications as the outcome and the smoking groups and medical comorbidities as explanatory variables Relative risk also was calculated.

RESULTS

The retrospective search of CPT codes identified 633 patients who had forefoot procedures between 2008 and 2010. Status of cigarette smoking could be determined from the medical records for 602 patients (95%); 21 patients did not answer the smoking questions on the intake history and were excluded from the study. The average age of the 475 females and 127 males was 53.1 years. Group I (non-smokers) contained 457 patients; group II (previous smokers), 79 patients; and group III (current smokers), 66 patients **(Table 2)**. Group II had a statistically higher percentage of patients with diabetes and peripheral neuropathy (p=0.046 and 0.0003, respectively); however, the percentages of patients with rheumatoid arthritis or reporting chronic steroid use were similar **(Table 3)**. The multiple logistic regression analysis demonstrated that medical comorbidities had no significant effect on complications when smoking is considered **(Table 5)**.

Power analysis confirmed adequate sample size to detect significance. The numbers of patients with any complication in each group were: group I, 39 (8.5%); group II, 13 (16.5%); and group III, 24 (36.4%). Delayed union, nonunion, infection, delayed wound healing, and persistent pain in the absence of any other complication were all significantly more frequent in group III **(Table 4)**. Chi square analysis showed a significant difference in total complication rate between groups (p=0.0001) in addition to a significant difference in each type of complication between groups. Compared to nonsmokers, patients who actively smoked in the perioperative period were 4.3 times more likely to have a complication after forefoot surgery. Patients who smoked at any point in the past but quit before surgery were 1.9 times more likely than nonsmokers to incur a complication. Compared to nonsmokers, the relative risk of active smokers to have each complication was 6.9 for delayed union, 6.9 for nonunion, 4.6 for infection, 9.7 for delayed wound healing, and 3.8 for persistent pain. The median duration of cessation prior to surgery for patients who had smoked at any point in the past but quit prior to surgery was 17 years. For active smokers, those with a complication smoked an average

		Group			P-value
		Group I Never	Group II Stopped	Group III Continued	
% Comorbidities	DM	8.3	16.5	6.1	0.0446
	Neuropathy	1.3	10.1	3.0	0.000326
	RA	8.5	11.4	4.6	0.3356
	Steroids	2.0	3.8	3.0	0.4655

Table 3: Co-morbidities in each patient group.

of 18 cigarettes daily while those without a complication smoked 14 cigarettes daily.

DISCUSSION

Cigarette smoking has been shown to negatively impact outcomes of orthopaedic procedures, but its effect on forefoot surgery has not been reported. In our findings, active cigarette smokers were 4.3 times more likely to have a complication after forefoot surgery than nonsmokers, with a 36.4% total complication rate. Patients who continued to smoke in the perioperative period had the highest percentage of delayed union (3.0%), infection (9.1%), delayed wound healing (10.6%), and persistent pain (15.2%). It is unclear why group II had a slightly higher percentage of nonunion (2.5%) than group III (1.5%), but this may be related to the significantly higher percentage of patients with diabetes in group II.

In an effort to stratify patients by risk, a multiple logistic regression analysis was performed using complications as the outcome and medical comorbidities and smoking groups as the explanatory variables. As demonstrated in **Table 5**, medical comorbidities had no significant impact on complications when smoking was considered. Although our overall sample size was relatively large, a larger more focused study would need to be completed to examine the relationship between specific comorbidities and smoking on outcomes. For example, of the 602 patients included in the study, 66 identified as active smokers and only four patients in this group were diabetic. Although two of the four smokers with diabetes developed a complication, concluding that diabetic smokers have a 50% complication rate in forefoot surgery would be inaccurate as the study design was not powered to draw such conclusions.

Persistent pain was the most frequent complication in each group. Persistent pain was recorded as a complication only when it occurred in the absence of another complication. This eliminated any potential overlap with a patient who may have had pain due to a nonunion, delayed union, or wound problem. A significant increase in complication rate between groups remained even when persistent pain was removed from the calculation. Other studies have shown that smokers are more likely to have chronic back pain as well as persistent pain after lumbar spine surgery, but this has not been demonstrated with forefoot surgery.[9,10,12,29] While the etiology of this pain is unknown, it has been postulated that this amplified response to pain may be due to elevated levels of pro-inflammatory mediators seen in smokers.[26,32]

		Group			P-value
		Group I Never	Group II Stopped	Group III Continued	
% Complications	Delayed Union	0.4	2.5	3.0	0.0323
	Nonunion	0.2	2.5	1.5	0.0452
	Infection	2.0	1.3	9.1	0.3356
	Delayed Wound Healing	1.1	1.3	10.6	0.000247
	Persistant Pain	3.94	5.06	15.15	0.0025

Table 4: Complications in each patient group.

Medical records for group II were further reviewed to determine if a link could be made between the period of time between smoking cessation and surgery date and the risk of complications associated with surgery. The median period of time between smoking cessation and surgery date was 17 years. Six patients who stopped smoking at least 17 years before surgery had a complication while seven patients who stopped smoking less than 17 years before surgery had a complication. No direct correlation between duration of time between smoking cessation and surgery date could be drawn; a larger study would be needed to investigate this link. Similarly, group III was further analyzed to determine if a higher daily quantity of cigarette smoking increased the complication rate. Patients were asked to estimate how many cigarettes they smoked each day. Patients in group III who had a complication reported smoking an average of 18 cigarettes per day, while those without a complication reported using 14 per day. Although patients with a complication smoked more cigarettes than those without a complication, the difference is not significant and it is unclear how reliable a conclusion can be drawn because of reliance on patient self-reported tobacco use.

Other authors have studied the effect of cigarette smoking on complications after procedures in the hindfoot and ankle. Ishikawa et al.,[15] in a study of 160 patients undergoing hindfoot fusions, showed that smokers had a significantly higher rate of nonunion than nonsmokers.[22] The relative risk of nonunion was 2.7 times higher for smokers than nonsmokers in their study. They noted a trend towards a higher nonunion rate in patients who

Variable	Degrees of Freedom	Wald Chi Square	P-value
Smoking	2	34.9855	<0.0001
RA	1	0.52	0.4708
DM	1	0.8644	0.3525
Neuropathy	1	0.6141	0.4333
Steroid	1	2.1485	0.1427

Table 5: Multiple logistic regression analysis.

quit smoking before surgery, but this did not reach statistical significance. No significant difference was noted between smokers and nonsmokers with regards to infection or wound healing. Cobb et al.[5] found that the relative risk of nonunion was 3.75 times higher for smokers than nonsmokers in their study of 44 patients with ankle fusion. Nåsell et al.[25] reported the effect of smoking on complications in 906 operatively treated ankle fractures with 6-week follow-up. Multivariate analysis showed that smokers had six times higher odds of developing a deep infection than nonsmokers.

Although limited by its retrospective nature, our study does clearly show an increased risk of complications associated with cigarette smoking in patients with forefoot surgery. Smoking status could be determined from the medical records for 95% of the 633 patients; the exclusion of 21 patients who did not answer this question in the medical record could have introduced bias. The 11% of patients who identified themselves as smokers is lower than the 2011 Census data showing an average of 19% tobacco use in the US.[3] It is possible that some patients may not have accurately reported their cigarette smoking, which would bias the collected data. If patients who smoked small quantities identified themselves as nonsmokers, then group III would be over-represented by heavy cigarette smokers, which could overestimate the impact of cigarette smoking on the complication rate. If patients who actively smoked perioperatively identified themselves as nonsmokers, but consumed the same average daily quantity of cigarettes as those who correctly identified themselves as active smokers, then we may have underestimated the impact of cigarette smoking on the complication rate. Although nicotine serum testing would have increased the accuracy of the data, this was not possible because of the number of patients involved in the study, as well as its retrospective design.

Previous studies have demonstrated that cessation of cigarette smoking before elective orthopaedic surgery has a beneficial effect on reducing the postoperative complication rate. In a randomized trial of patients with hip and knee arthroplasty, 56 patients who underwent smoking cessation intervention 6 weeks preoperatively had a significantly lower complication rate (18%) than 52 patients in the control group (52%).[22] A randomized trial studying the effect of a smoking cessation program initiated during the acute hospitalization period for fracture surgery showed a complication rate of 20% in the cessation group compared to 38% in the control group.[24]

Our study demonstrates that smokers have a significantly higher complication rate after forefoot surgery than nonsmokers. Given the available evidence, every effort should be made by physicians to encourage smoking cessation. Although some surgeons believe that cessation counseling is best carried out by the patient's primary care practitioner, a study of 10,000 spine patients showed that when surgeons placed a "high priority" on smoking cessation compared to a "low priority", the quit rate increased from 19.5% to 35.6%.[27] The importance of surgeons' taking the time to encourage smoking cessation cannot be overemphasized. Possible methods to consider include referral to online resources (www.smokefree.gov), telephone hotlines (1-800-QUITNOW), and coordination with the patient's primary care practitioner for medical treatment. The surgeon may code tobacco use disorder in ICD-9 as code 305.1 and some insurance plans will reimburse for proper CPT coding. CPT code 99406 covers smoking cessation counseling of 3 to 10 minutes duration, while code 99407 covers more than 10 minutes of counseling. It is important for the practitioner to document the duration of counseling in addition to the resources provided.

Although numerous factors can affect outcomes of forefoot surgery, smoking is perhaps the most easily modified by the patient. This is the first study to examine the effects of cigarette smoking on complications after forefoot surgery. In our findings, active cigarette smokers were 4.3 times more likely to have a complication after forefoot surgery than nonsmokers, with a 36.4% total complication rate and persistent pain being the most frequently encountered complication. Before forefoot surgery surgeons should educate patients who smoke on the increased risk of complications and should support patients through smoking cessation. Larger studies are needed to determine what duration of smoking cessation is necessary for the complication rate to return to that of a non-smoker.

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Orthopaedic Foot and Ankle Surgeons' Approach to Elective Surgery in the Smoking Patient Population: A Survey Study

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ABSTRACT

Background: The current changes in healthcare by which physicians may be rewarded or penalized based on outcomes compared with a national average give surgeons a greater incentive to engage patients in practices that will improve results. Smoking cessation has been linked to significant improvements in surgical outcomes and the perioperative period may offer the greatest opportunity to achieve cessation. The purpose of this study was to assess the approach of orthopaedic foot and ankle surgeons to smoking patients with foot and ankle conditions.

Methods: An e-mail was sent to members of the American Orthopaedic Foot and Ankle Society (AOFAS) with an embedded link to a survey that allowed anonymous responses. Responses were collected during several time points in 2014. The survey questions yielded categorical answers that were either dichotomous or multiple choice.

Results: Out of 1,892 possible respondents, a total of 785 surgeons participated in the survey, yielding an overall response rate of 41.5%. Some questions had fewer responses dependent on answering yes or no to a previous question. Seven hundred and eight of 774 (91.5%) of surgeons report worse outcomes in smokers. Four hundred and thirty-seven of 724 (60.4%) foot and ankle surgeons counsel all smoking patients and 696 of 721 (96.5%) do so when planning surgery. Seven hundred and twenty-five of 750 (96.7%), use verbal advice to encourage smoking cessation. Less than 16% of respondents utilize handouts/other literature, supervised services or prescribe nicotine replacement or other pharmacologic options. Three hundred and ninety-nine of 750 (53.2%) refer to primary care physicians. Three hundred and twenty-one of 648 (49.5%) never check systemic nicotine levels preoperatively, 50 of 648 (7.7%) always check this parameter and 57 (8.8%) frequently check nicotine levels before proceeding with surgery. The remaining 34% did so only rarely or on occasion. Six hundred and sixteen of 778 (79.2%) would delay surgery based on tobacco use. Of 624 who responded to length of delay, 425 (68.1%) would wait four weeks or more.

Conclusions: Achieving smoking cessation is an important aspect in reducing perioperative complications and improving outcomes. Orthopaedic foot and ankle surgeons recognize this and most are likely to delay bony procedures at least 4 weeks to allow cessation. Foot and ankle surgeons almost universally counsel their smoking patients to quit before surgery, but many do not use other promising options (such as nicotine replacement and supervised cessation programs) to achieve this goal.

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Risk Factors for Surgical Release in Children with Clubfoot Treated by the Ponseti Method: Utility of Radiographic Assessment

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Acknowledgements: Lindsey Locke, MSN,; Shannon Kneirim, PT; Konstance Hines, PT; Lauren McGee, PT; Aristea Stocklein, PT; Jodie Beth Roberts, PT; Rachel Hess, CCLS; Crystal Soberg, CCLS; Cassie Nash, CCLS

ABSTRACT

Background: The Ponseti method has become the gold standard for treatment of congenital talipes equinovarus (CTEV). Despite the success of initial deformity correction with the Ponseti method, the deformity recurs in some feet and may require more extensive surgical intervention. The primary goals of our study were to identify factors that may predispose patients to failure of correction with the Ponseti method and to determine the role of clinical scoring and radiographs in predicting the need for surgical intervention.

Methods: Seventy-eight patients with CTEV presented to a single institute between January of 2010 and January of 2013 and were enrolled in the IRB-approved prospective study; 64 patients (97 feet) met inclusion and exclusion criteria. Database information included demographic data and treatment details; Dimeglio and Pirani scores and radiographic results at presentation, 6 months, and 12 months; and deformity recurrence and the need for more extensive surgical release.

Results : At an average follow-up of 32.4 months (range 18-60 months), 21 patients (33 feet, 34%) had required surgical release and represent the Ponseti failure (PF) cohort. These patients were compared to the cohort of 47 patients (64 feet) who did not require surgical correction for residual or recurrent clubfoot and who represent the successful Ponseti management (SPM) cohort. The differences between the Dimeglio and Pirani clinical scores in the two groups were statistically significantly different at all time points (presentation, 6 months and 12 months). Radiographically, anteroposterior and lateral talocalcaneal angles were significantly different at 6 months, but there were no statistically significant differences at 12 months. Risk factors found to correlate with surgical failure included higher presenting Dimeglio and Pirani scores, higher number of casts needed to correct the initial clubfoot deformity, and the need for repeat casting.

Conclusion: Children with CTEV who are at risk for failure of correction with the Ponseti method have significantly higher initial Pirani and Dimeglio scores, require more casts at initial treatment, and require more frequent recasting. Clinical scores at 6 months and AP talo-calcaneal radiographic angles at 6 months also correlate to failure. Radiographs are unnecessary for most children with CTEV <1 year old as they do not add diagnostic or prognostic value to clinical scores.

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Factors that Predict Instability in Pediatric Diaphyseal Both Bone Forearm Fractures

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ABSTRACT

Introduction: Diaphyseal forearm fractures are among the most common fractures in children. Significantly displaced or angulated fractures are treated with initial closed reduction and immobilization, with follow-up to determine if displacement occurs. The purpose of this study was to determine what factors upon initial presentation would predict failure of initial closed reduction and casting.

Methods: Radiographic and hospital records of skeletally immature patients that underwent closed reduction and casting of diaphyseal forearm fractures in the emergency department were evaluated. Demographic, time course, and radiographic data were evaluated at presentation and at varying time intervals until union was achieved. Univariate logistic regression analysis of these factors was performed to identify predictors of failure of initial closed reduction and immobilization as defined as requiring a repeat procedure.

Results: 188 patients meeting the inclusion criteria were identified and analyzed. 174 patients had adequate follow-up to union. The average patient age was 7.7 years old and 68% of patients were male. A total of 19 patients underwent a repeat procedure. Patients that underwent a repeat procedure had an average initial reduction time of 36.9 ± 22.2 minutes, whereas those patients who did not require additional procedures had an initial reduction time of 23.4 ± 11.8 minutes ($p<0.0103$). Odds of requiring repeat reduction were the greatest in those patients who presented with fractures translated greater than or equal to 50 % in any plane (odds ratio (OR)=10.1; confidence interval (CI) 95 3.1-33.1), age greater than 9 years (OR=4.1; CI 95 1.5-11.3), complete fracture of the radius (OR=9.1; CI 95 2.0-40.5), follow-up angulation of the radius greater than 15 degrees on lateral radiographs (OR=5.0; CI 95 1.3-18.6), follow-up angulation of the ulna greater than 10 degrees on anteroposterior (AP) radiographs (OR=8.7; CI 95 2.7-28.4), and follow-up translation of either bone greater than 50 % (OR=13.5; CI 95 4.5-40.2).

Conclusions: Patients requiring lengthy initial reductions are at an increased risk of having a repeat procedure than those with short initial reduction times. Age, initial translation, complete fractures of the radius, and residual translation on follow-up are highly predictive of patients having repeat procedures. These patients require carefully monitored follow-up and families should be counseled appropriately to their risk of repeat intervention.

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Predictors of Postoperative Pain and Narcotic Use After Primary Arthroscopic Rotator Cuff Repair

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ABSTRACT

Background: As more emphasis is placed on patient satisfaction as a driver of outcomes, reimbursement, and patient access, the ability to successfully predict which patients are at greater risk of pain management issues postoperatively gives the surgeon a chance to counsel patients on expectations preoperatively to potentially mitigate these issues. We hypothesized that specific patient characteristics might be predictive of pain and narcotic use after primary arthroscopic rotator cuff repair.

Methods: After IRB approval, primary rotator cuff repairs performed by a single surgeon over a 4-year period were identified. Patient-specific preoperative factors investigated included tobacco use, narcotic use, chronic pain syndromes, disability claims, mood disorders (depression/anxiety), worker's compensation claims, and obesity. Outcome measures included visual analog pain scores and narcotic usage.

Results: For the 65 repairs in the study, preoperative pain scores were weakly correlated ($r = 0.20$) with cumulative postoperative narcotic use. Significant predictors of increased pain scores at 12 weeks were preoperative narcotic use, chronic pain syndromes, and mood disorders. Tobacco use, obesity, and worker's compensation claims were not associated with higher pain scores. Cumulative narcotic usage at 12 weeks was significantly higher in patients with tobacco use, preoperative narcotic use, and mood disorders. There was no statistically significant increase in narcotic usage in chronic pain syndromes, worker's compensation claims, or obesity.

Conclusions: Preoperative narcotic use and mood disorders were most predictive of increased pain and narcotic usage after primary arthroscopic rotator cuff repair. Tobacco use was associated with significantly higher postoperative narcotic use but no statistically significant increase in pain scores. Chronic pain syndromes were associated with significantly higher pain scores but not significant increases in postoperative narcotic use.

Keywords: arthroscopic repair, rotator cuff, postoperative pain, postoperative narcotic use, predictors

Level of Evidence: Level II, retrospective prognostic study

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Optimal Baseplate Rotational Alignment for Locking-Screw Fixation in Reverse Total Shoulder Arthroplasty: A Three-Dimensional Computer-Aided Design Study*

ABSTRACT

Background: Baseplate loosening in reverse total shoulder arthroplasty (RTSA) remains a concern. Baseplate fixation is believed to be optimized by placing peripheral screws into the three pillars of densest scapular bone. Using a three-dimensional computer-aided design (3D CAD) program, we investigated the optimal rotational baseplate alignment to maximize peripheral locking screw purchase.

Methods: Seventy-three arthritic scapulae were reconstructed from computed tomography images and imported into a 3D CAD software program along with representations of an RTSA baseplate that uses 4 fixed-angle peripheral locking screws. The baseplate position was standardized and the baseplate was rotated to maximize individual and combined peripheral locking screw purchase in each of the three scapular pillars.

Results: The mean positions for optimal individual peripheral locking screw placement (referenced in internal rotation) were: 6 ± 2 degrees (mean ±SEM) for the coracoid pillar, 198 ± 2 degrees for the inferior pillar, and 295 ± 3 degrees for the scapular spine pillar. Of note, 78% (57/73) of the screws attempting to obtain purchase in the scapular spine pillar were unable to be placed without an in-out-in configuration. In contrast, 100% of coracoid and 99% of inferior pillar screws achieved full purchase. The position of combined maximal fixation was 11 ± 1 degrees.

Conclusions: These results suggest that approximately 11 degrees of internal rotation is the ideal baseplate position for maximal peripheral locking screw fixation in RTSA. In addition, these results highlight the difficulty in obtaining optimal purchase in the scapular spine.

Keywords: reverse total shoulder arthroplasty, baseplate, locking screws.

Level of Evidence: Basic science

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This study was funded through a research grant provided by Biomet, Incorporated.

None of the authors of any member of their family received any financial renumeration related to the subject of this article.

This was an IRB-exempt study.

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INTRODUCTION

Reverse total shoulder arthroplasty (RTSA) has emerged as a reliable treatment option for elderly patients with rotator cuff deficient glenohumeral arthritis and low-functional demands.[4,13] It does, however, have a higher complication rate than traditional shoulder arthroplasty.[3] Glenoid loosening or failure is frequent after RTSA,[2,4] especially in patients with rheumatoid arthritis, in whom a failure rate as high as 43% has been reported.[11] Optimimal screw placement is important to prevent glenoid component failure in this older, often osteoporotic population.[13] Screw and baseplate posi-

Screw length	<15 mm (In-Out-In)	20 mm	25 mm	30 mm	35 mm	Weighted Avg (mm)
Spine	61 (84%)	4 (6%)	0	0	8 (11%)	30.0
Coracoid	1 (1%)	6 (8%)	7 (10%)	21 (29%)	38 (52%)	31.3
Inferior	1 (1%)	3 (4%)	8 (11%)	27 (37%)	34 (47%)	31.0
* 5 baseplates have all three screws >15 mm, and 1 baseplate has a single screw for maximal fixation						

Table 1: Position of Combined Maximal Fixation Screw Lengths

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Screw length	<15 mm (In-Out-In)	20 mm	25 mm	30 mm	35 mm	Weighted Avg (mm)
Spine	57 (78%)	2 (3%)	0	0	14 (19%)	33.1
Coracoid	0	0	6 (8%)	22 (30%)	45 (62%)	32.7
Inferior	1 (1%)	0	3 (4%)	23 (32%)	46 (63%)	33.0
Note: The weighted average was calculated excluding In-Out-In screws						

Table 2: Maximal Screw Lengths Before Bicortical Glenoid Vault Perforation (Individual Corridors)

tioning is the primary surgeon-controlled means of influencing bony ingrowth onto the baseplate, which has been associated with preventing baseplate failure.[9]

Inferior placement of the baseplate has been shown to minimize scapular notching,[12] which has been associated with poorer outcomes.[8] Implantation of the glenoid component in inferior tilt has been suggested to reduce the frequency of biomechanical failure in RTSA by providing more uniform compressive forces and less micromotion at the baseplate-glenoid interface.[5] In a radiologic analysis of 12 cadaver scapulae, DiStefano et al. examined the optimal screw placement into the areas of thickest cortical bone (lateral aspect of suprascapular notch, scapular spine base, anterior/superior aspect of inferior pillar, and junction of the glenoid neck with the scapular spine), determining both the screw lengths and trajectories that resulted in optimal and safe fixation.[1] In a study of 12 scapulae, Parsons et al. demonstrated that baseplates rotated 20 degrees towards the scapular spine (external rotation) yielded shorter screw lengths than those positioned at 0 degrees of rotation

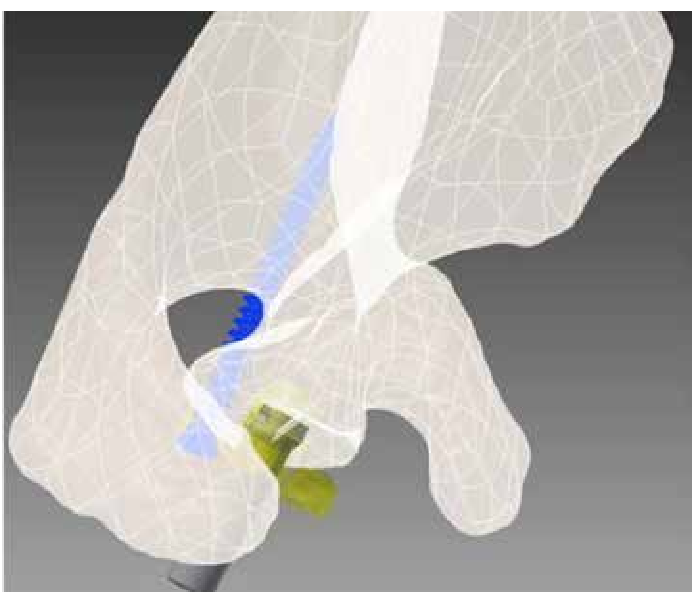

Figure 1: Axial projection demonstrating an "in-out-in" configuration of scapular spine baseplate screw

and 20 degrees towards the coracoid.[10] No study to date has examined the relationship between continuous sagittal baseplate rotation and maximal screw purchase. The purpose of our study was to determine the optimal rotation (referenced in internal rotation measured from the 12 o'clock position of the glenoid) of the RTSA baseplate with fixed-angle locking screws that obtains maximal screw purchase in the three bony pillars of the scapula (coracoid, scapular spine, and inferior).

MATERIALS AND METHODS

Seventy-three arthritic scapulae (43 left, 30 right) were scanned and reconstructed using three-dimensional computed tomography. Each scapula was then imported into AutoDesk Inventor Professional 2014 (Autodesk Inc., San Rafael, California, USA). Once in the program, a plane was generated using the most superior or inferior point of the glenoid rim and the most anterior and posterior points. The use of superior or inferior point was influenced by the default coordinate system in which the glenoids were scanned; the point chosen allowed for the best representation of the glenoid articular surface in the sagittal plane. On this de-

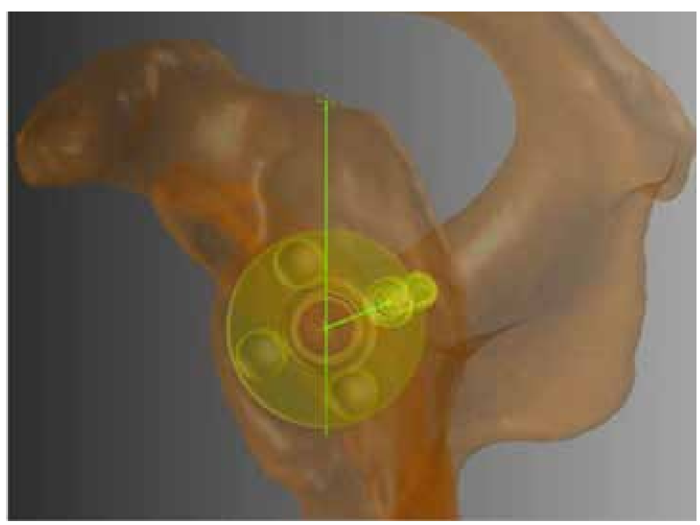

Figure 2: When referenced from the 12 o'clock position of the glenoid, baseplates were rotated to achieve maximal purchase in each bony pillar of the scapula

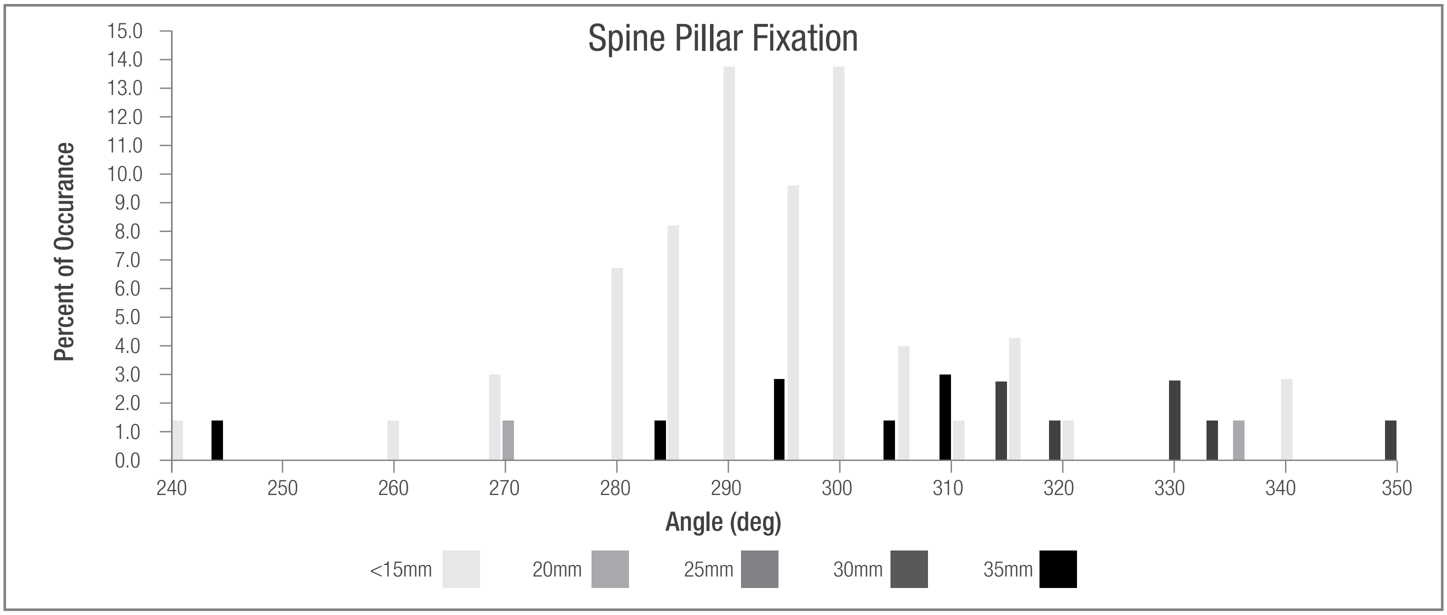

Figure 4: Screw lengths in spine pillar

fined glenoid sagittal plane, a line bisecting the glenoid was drawn from the most superior to the most inferior point. This was then converted into a 2-D object projecting out of the glenoid plane to aid in component placement. Three-dimensional representations of the RTSA 25-mm baseplate with fixed-angle peripheral locking screws were then imported into the AutoCad Inventor (Autodesk Inc., San Rafael, California, USA). A custom-made guide was constructed in AutoCad Inventor to ensure the mini-baseplate had a 10-degree inferior tilt with respect to the plane of the glenoid articular surface. This was done by constructing a cylinder with the same diameter as the central hole in the baseplate, protruding out of the center of a cube at a 10-degree tilt relative to vertical.

The scapula, along with the generated plane, mini baseplate, locking screws, and guide, was then imported into the assembly portion of AutoDesk Inventor. The square base of the guide was first constrained to translate only along the glenoid sagittal plane. It was additionally constrained to translate with the 2-D object passing through the midpoint of the cube with the cylinder tilted 10 degrees inferiorly. With this step complete, the guide was unable to rotate in any direction. The peripheral locking screws were constrained so that the threads aligned with the locking threads of the mini-baseplate. The mini-base plate was then constrained to rotate and translate along the guide cylinder.

An orthopaedic surgeon then verified the anatomical reference points and positioned the mini-baseplate within its defined constraints. The baseplate was positioned inferiorly to prevent notching and with 10 degrees of inferior tilt. The same orthopaedic surgeon rotated the mini-baseplate to position the screws in the spine, inferior, and coracoid pillars to achieve maximal screw purchase. Optimal screw placement was defined by achieving 1) maximal screw length, 2) far cortical fixation, and 3) placement in one of the three scapular pillars while avoiding neurovascular structures.7,11 Screws breach-

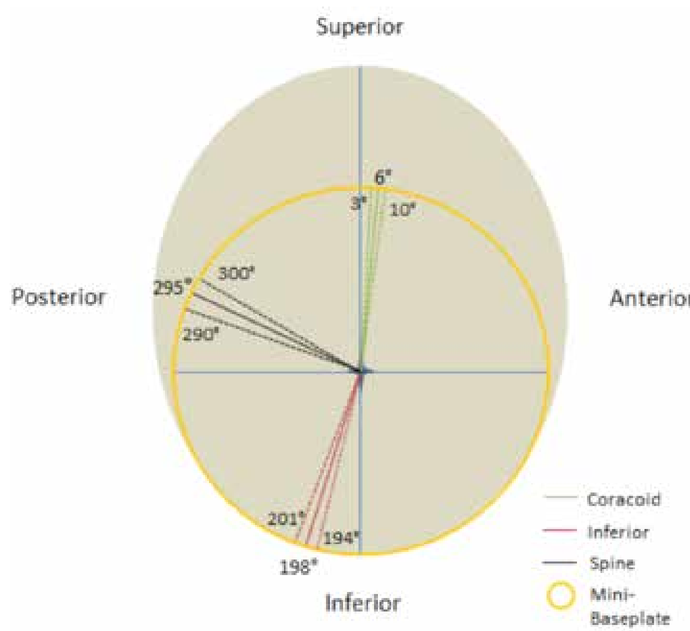

Figure 3: Confidence intervals of fixation rotations

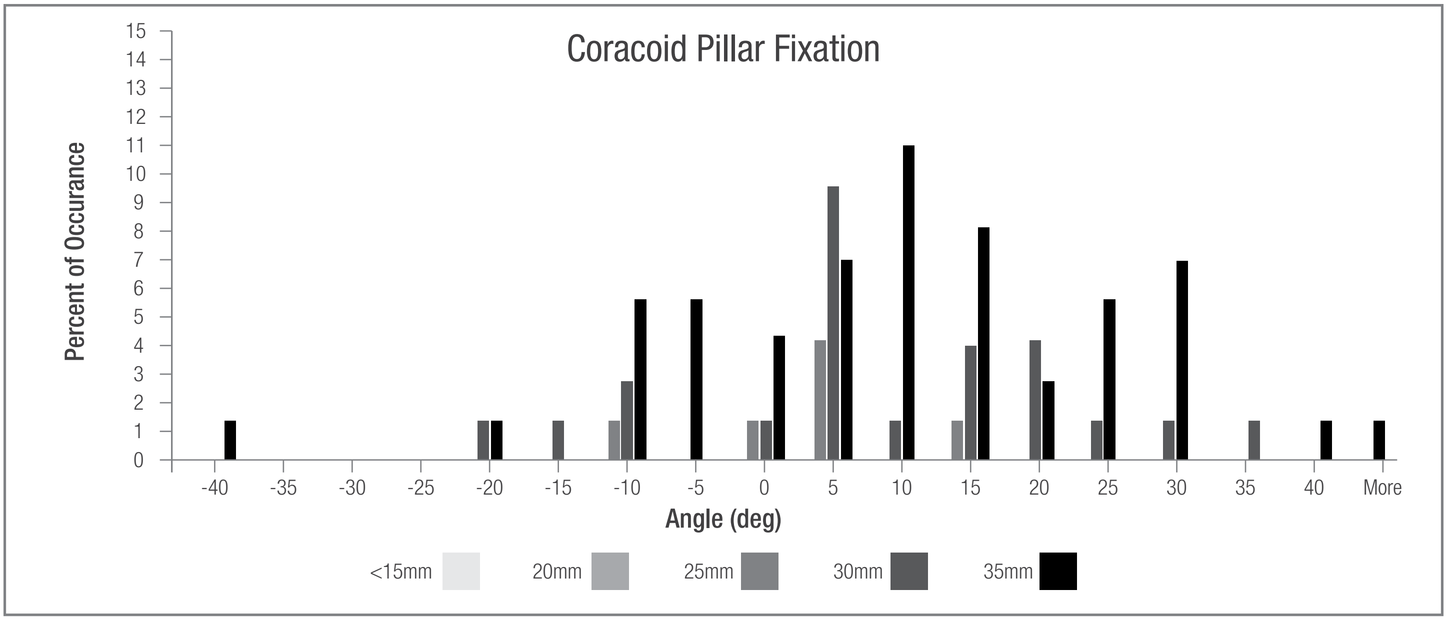

Figure 5: Screw lengths in coracoid pillar

ing cortical bone by more than 50% of their thread diameter before achieving purchase in their scapular pillars were designated as "in-out-in" screws **(Figure 1)**. In-out-in screws were then re-assessed to determine the maximal screw length prior to breaching cortical bone **(see Table 1)**. The angle formed by the most superior aspect of the glenoid rim, the geometric center of the mini-baseplate, and the geometric center of the screw-hole was projected onto the face of the mini-baseplate and measured to determine optimal baseplate rotation **(Figure 2)**. Screw lengths were recorded in each pillar.

RESULTS

The mean positions for optimal individual peripheral locking screw placement (referenced in degrees of internal rotation from the 12 o'clock position of the glenoid) were: 6 ± 2 degrees (mean ± SEM) for the coracoid pillar, 198 ± 2 degrees for the inferior pillar, and 295 ± 3 degrees for the scapular spine pillar **(Figure 3)**. Of note, 78% (57 of 73) of the screws attempting to obtain purchase in the scapular spine pillar could not be placed without an in-out-in configuration. In contrast, 100% of coracoid and 99% of inferior pillar screws achieved full purchase. The position of combined maximal fixation that allowed optimal fixed-angle locking screw purchase, typically in the coracoid and inferior pillars, was 11 ± 1 degrees **(Table 2)**. The average screw length in all three scapular pillars was approximately 33 mm for screws that avoided an in-out-in trajectory **(Table 2 and Figures 4, 5, and 6)**.

DISCUSSION

Baseplate positioning remains the primary surgeon-controlled means of increasing the stability of the baseplate-glenoid interface in RTSA, and it is important to maximize initial stability in the older, often osteoporotic patients in whom this procedure is most common. Longer screws have been shown to have greater pull-out strength in anterior cervical plating models,[6] suggesting that increasing initial stability with longer screws may decrease the frequency of baseplate failure. Newer baseplate designs incorporate porous metal designed for bony ingrowth; however, biomechanical stability is needed for this to occur.[14] Our study sought to define the optimal rotational alignment to allow for maximal screw purchase in the scapular pillars in a baseplate with mono-axial peripheral locking screws.

Our results suggest that approximately 11 degrees of internal rotation is the ideal baseplate rotational alignment for maximizing the length of fixed-angle peripheral locking screws in RTSA. The average length of screw in the position of maximal fixation (i.e. ideal rotation) was over 30 mm in all three scapular pillars. These results can guide the shoulder arthroplasty surgeon to place peripheral screws with the longest screws in the best possible bone. Interestingly, our results also highlight the difficulty of obtaining optimal purchase in the scapular spine: 78% of screws aiming for this pillar were placed in an "in-out-in" trajectory. It is arguable as to whether or not this "in-out-in" trajectory is acceptable, because it

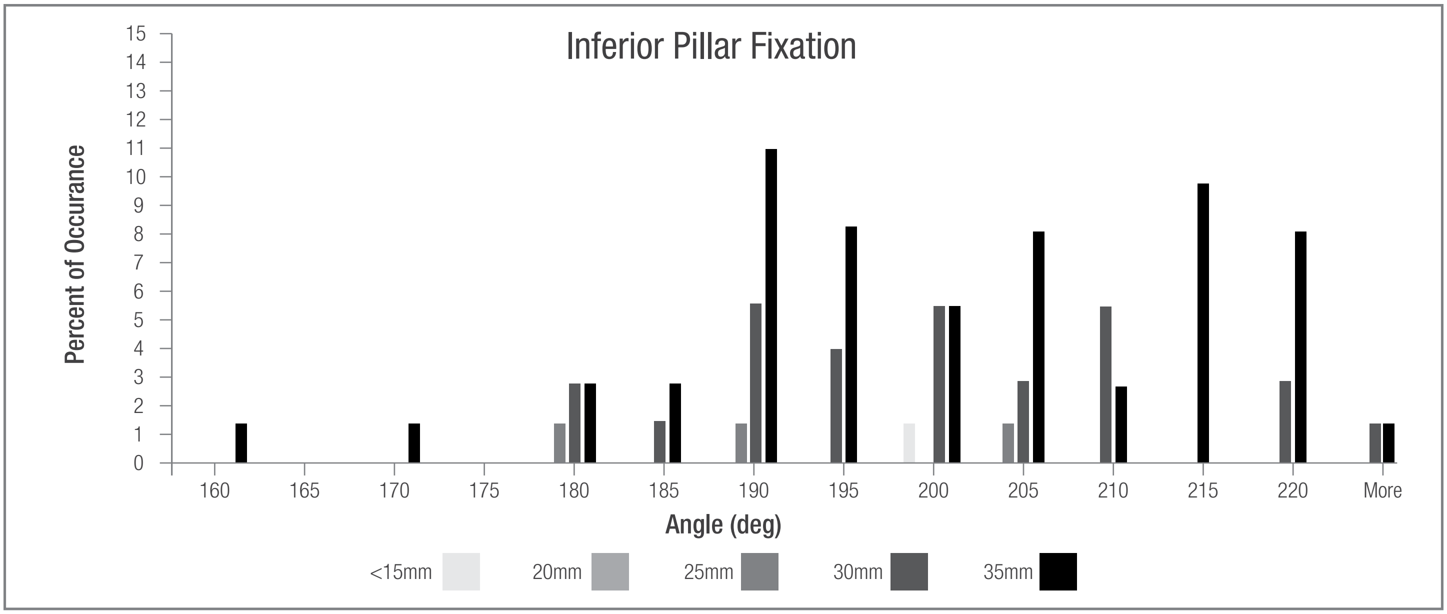

Figure 6: Screw lengths in inferior pillar

would potentially confer greater biomechanical stability (two additional cortices of purchase) at the expense of risking injury to the suprascapular nerve.

Our study has several weaknesses. First, we investigated a topic concerning biomechanical stability without the ability to directly test true measures of stability. However, longer screws have been shown to have better fixation. and we can infer that increasing baseplate screw length would increase the stability of the baseplate-glenoid interface. Further clinical study would be necessary to determine if using this optimal baseplate rotation would result in a clinically significant decrease in baseplate failure. Second, we did not precisely account for bone removed during the reaming process; however, we did estimate the amount of bone removed by reaming by placing the baseplate approximately 2 to 3 mm medial to the lateral aspect of the glenoid articular face.

CONCLUSION

Our results suggest that approximately 11 degrees of baseplate internal rotation from the 12 o'clock position offers maximal fixation with fixed-angle locking screws in RTSA. Future study will focus on a biomechanical model to test these results and a clinical study to investigate whether placing baseplates in this position results in use of longer screws and improved clinical outcomes.

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A Quantitative Analysis of Baseplate and Glenosphere Position on Deltoid Tension in Reverse Total Shoulder Arthroplasty*

ABSTRACT

Introduction: Optimizing deltoid tension is important to achieve maximal function after reverse total shoulder arthroplasty (RTSA), but the effects of baseplate and glenosphere positions on deltoid tension have not been quantified. We used a cadaver model to quantify deltoid elongation and elongation to failure under physiologic loads with three baseplate-glenosphere configurations with increasing inferior offset.

Material and Methods: The 24 cadaver shoulders were divided into 3 groups. The starting point for baseplate insertion in Group 1 was the center of the glenoid, with glenospheres placed in minimal inferior offset (0.5 mm). Groups 2 and 3 baseplates were placed 2 mm inferior to the center point and glenospheres in minimal (2.5 mm) offset (Group 2) or maximal (4.5 mm) offset (Group 3). Tensile testing was done to quantify deltoid elongation and evaluate failure.

Results: Deltoid elongation after loading decreased with increasing inferior offset of more than 2.5 mm. No significant difference in deltoid yield load was found among groups. The percent of elongation was decreased significantly between groups 2 and 3. Deltoid displacement at failure decreased from 33.3 mm for Group 2 to 17.3 mm for Group 3. Sixteen of the 24 specimens (67%) failed by anterior deltoid detachment from the acromion.

Conclusion: Increasing inferior offset in RTSA constructs appears to increase stretch forces on the deltoid, resulting in a diminished ability of the deltoid to further elongate under physiologic loads, most pronounced when the inferior offset exceeds 2.5 mm. This configuration also significantly decreases the yield displacement of the construct. [250 words]

Level of evidence: Basic Science Study, Biomechanics, Cadaver Model

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INTRODUCTION

Reverse total shoulder arthroplasty (RTSA) has revolutionized the treatment of rotator cuff-deficient shoulders, and its indications continue to expand to areas such as failed shoulder arthroplasty, revision arthroplasty, fracture sequelae, rheumatoid arthritis, instability and tumors.[4,6,20,21] Because of these expanding clinical applications, the number of RTSA performed in the United States has increased dramatically since 2004.[15] Successful outcomes ideally maximize range of motion and minimize instability and complications.[13] Central to that success is the nonanatomic biomechanics of the prosthesis and the effectiveness of the deltoid to restore shoulder function with a deficient rotator cuff.[3] Studies have shown that the deltoid generates over 50% of the force necessary to elevate the arm in the scapular plane and is the only muscle remaining in cuff-deficient shoulders to power abduction in the same plane.[29] Ackland et al. found that increased abductor moment arms for anterior, middle, and posterior regions of deltoid assist to overcome cuff deficiency in RTSA.[2]

RTSA constructs provide a stable and fixed fulcrum for elevation and increased resting length/tone of the deltoid.[3,19] Optimizing deltoid tension is important to achieve maximal function, and lengthening of the deltoid increases the patient's ability to forward elevate, likely by recreating the force-length relationship of the deltoid muscle.[14] Intraoperative determination of deltoid tension is difficult and mostly guided by surgical experience.[3] Inferior glenosphere placement also has been found to decrease scapular notching and improve forward elevation by lengthening the deltoid.[25] This has

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Figure 1: The starting point for baseplate insertion in Group 1 was the center of the glenoid, which was identified based on the measured midpoint between the superior/inferior and the anterior/posterior margins of the glenoid. Baseplates for Group 2 and 3 were placed 2mm inferior to the center of the glenoid.

prompted questions regarding the deltoid's ability to tolerate these increased stretch forces and may have implications for implant longevity. To date, no studies quantifying the effect of baseplate and glenosphere position on deltoid tension exist.

The primary objective of this study was to quantify deltoid elongation under physiologic loads for three different baseplate-glenosphere configurations with increasing inferior offset. The secondary objective was to quantify elongation to failure (yield displacement) and to record the mode of failure. We hypothesized that the increased deltoid tension caused by increasing the inferior offset more than 2.5 mm would result in a lessened ability of the deltoid to further elongate under physiologic loads.

MATERIALS AND METHODS

Specimen preparation

Twenty-four fresh-frozen cadaver shoulders were divided into 3 groups of 8. The specimens were acquired from the Medical Education and Research Institute (MERI), Memphis, TN. Specimens were stored at -20°C. Before component implantation, the supraspinatus and infraspinatus of each specimen were sectioned to approximate a rotator cuff-deficient shoulder. The subscapularis, teres minor, pectoralis major, latissimus dorsi, and deltoid tendons were left intact. This is consistent with specimen preparation in other cadaver studies involving reverse total shoulder arthroplasty.[1,2,11,12,14]

The components were implanted according to the manufacturer's specifications (Biomet Comprehensive Shoulder System, Warsaw, IN). A starting point for the humeral stem was made in the rotator cuff footprint and enlarged with a burr. Starting with the opening reamer (4 mm), reaming proceeded sequentially in 1-mm increments until solid cortical contact was felt in the intramedullary canal. The humeral cutting guide was applied flush with the humeral head and the version bar aligned with the forearm. Then, the humeral head was cut in 30 degrees of retroversion. Broaching then proceeded sequentially from the 4-mm broach to the same size as the reamed diameter. The corresponding humeral stem was then impacted into position.

In group 1, the starting point for baseplate insertion was the center of the glenoid, which was identified based on the measured midpoint between the superior/inferior and the anterior/posterior margins of the glenoid. Glenospheres were placed in minimal inferior offset (0.5 mm). Group 2 baseplates were placed 2 mm inferior to the center point and glenospheres were placed in minimal offset (2.5-mm total inferior offset) **(Figure 1)**. Group 3 baseplates were placed in the same inferior position with glenospheres placed in maximal inferior offset (4.5-mm total inferior offset). Using a template with a 10-degree inferior tilt built in, a guide pin was placed. The cannulated glenoid reamer was then used to plane the glenoid surface in 10 degrees of inferior tilt. The glenoid baseplate was inserted and impacted into posi-

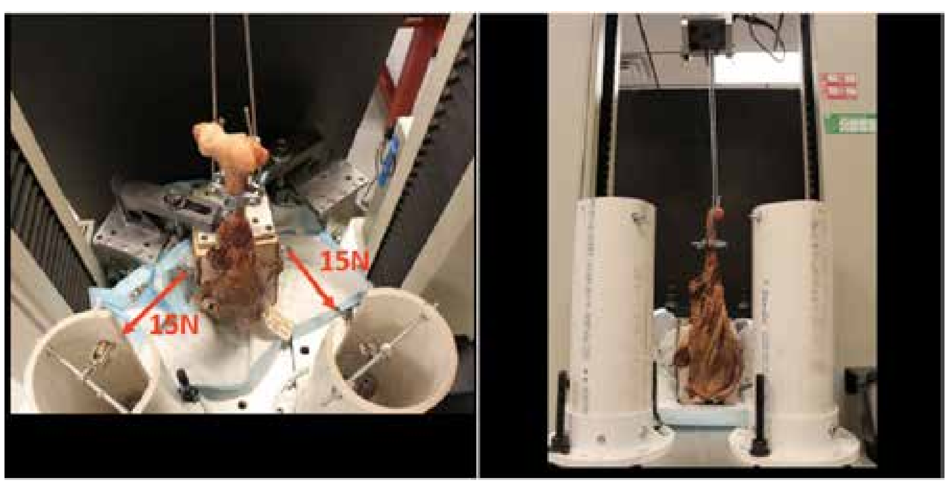

Figure 2: Test apparatus with shoulder specimen embedded in resin with pulley system arranged with constant physiologic loads.

tion based on the previously described groups. Using a depth gauge, the length of the 6.5-mm center screw was measured and the corresponding screw was placed. Four peripheral locking screws were then placed. All screws were placed in bicortical fashion for maximal fixation, with lengths varying by the size of the glenoid vault. A 36-mm glenosphere was impacted into position, again based on the parameters described for each group. A +0-mm polyethylene bearing surface was impacted into position in each specimen. After implantation, the glenohumeral joint was reduced and all specimens were surveyed visually to inspect their condition.

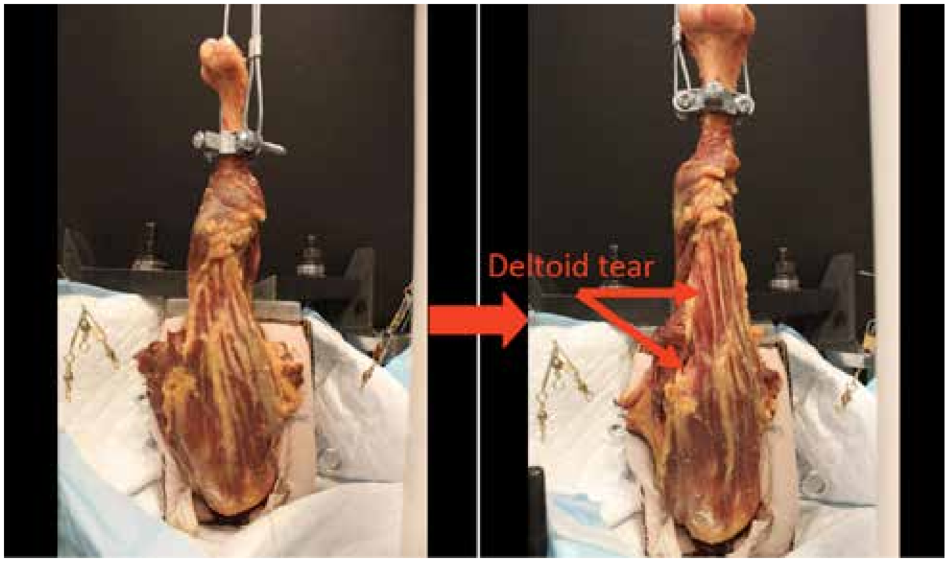

Figure 3: Specimen after load to failure showing anterior deltoid detachment.

Biomechanical testing

Tensile testing was done on all 24 specimens to quantify deltoid elongation and evaluate failure. To aid in gripping the specimen, the scapula was embedded in polyester resin. The scapula was oriented in the resin such that the shoulder was aligned in an anatomical "at rest" position when mounted to the actuator. Physiologic tension was placed on latissimus dorsi (15 N) and pectoralis major (15 N) tendons by way of pulleys and hanging weights **(Figure 2)**. This is consistent with specimen preparation in other studies of reverse shoulder arthroplasty.[1,2,11,12,24] Each specimen was placed into resting position, and the deltoid elongation was measured by pulling the humerus in tension to 30 N at a rate of 5 mm/min. The machine then maintained 30 N of tension for 5 minutes and recorded the elongation. Next, the specimen was pulled in tension at a rate of 10 mm/min until failure of the deltoid or RTSA components was observed.

Data analysis

The tensile load and displacement data recorded for each specimen were analyzed in TestWorks 4 (MTS 2004). The test method was configured to calculate the yield load, yield displacement, peak load, and peak displacement.

Statistical analysis was conducted to provide a comparison among treatment groups with respect to the deltoid elongation, percent of elongation, and yield load observed. A one-way analysis of variance (ANOVA) was performed to detect statistically significant differences among treatment groups. A post-hoc Neuman-Keul's comparison was conducted to perform discrete comparisons among treatment groups after the performed analysis of variance was found to be significant. Differences with $p<0.05$ were considered significant.

RESULTS

For all specimens, the average deltoid elongation was 1.1 mm (0.4 mm to 2.6 mm), with an average yield load to failure of 582.5 N (range 305.9 N to 848.3 N) and an average peak load of 864.1 N (range 431.2 N to 1747.7 N). No significant difference in deltoid yield load was found among groups ($p>0.05$).

Deltoid elongation after loading decreased with increasing inferior offset of more than 2.5 mm. The average deltoid elongation after loading was 1.3±0.7 mm for Group 1, 1.3±0.5 mm for Group 2, and 0.7±0.2 mm for Group 3 ($p=0.05$). The percent of elongation of the

	Yield Load	Yield Displacement	Deltoid Displacement	Percent Elongation (%)
Group 1	640 N	32.4 mm	1.3 mm	15
Group 2	498 N	33.3 mm	1.3 mm	20
Group 3	610 N	17.3 mm	0.7 mm	10
	P>0.05	P<0.007	P=0.05	P<0.007

Table 1: Significant changes in deltoid yield displacement and percent elongation occurred after inferior offset exceeded 2.5mm.

deltoid also was decreased significantly between groups 2 and 3 (20% vs. 10%, p=0.007). Deltoid displacement at failure (yield displacement) decreased from 33.3 mm for Group 2 to 17.3 mm for Group 3 (p=0.007).

Sixteen of the 24 specimens (67%) failed by anterior deltoid detachment from the acromion (Figure 3). Other modes of failure included deltoid tendon failure (16%), specimen pull-out of the polyester resin (8%), distal acromion fracture (4%), and humeral implant loosening (4%).

DISCUSSION

Intuitively, deltoid tension is increased by increasing inferior baseplate and/or glenosphere offset. RTSA takes advantage of this tension by increasing the deltoid moment arm, and an inferior baseplate position has been shown to increase the efficiency of the deltoid up to 30%.[2,5,7,12,13,20,21,26] While previous studies have shown inferior baseplate position and glenosphere tilt are protective against scapular notching with improved function, more uniform compressive forces with decreased shear force on the bone-baseplate interface, and greater range of motion before impingement,[9,10,22,25] the ability of the deltoid to accommodate lengthening has not been quantified.

Conceptually, the muscle tension-elongation relationship is set by Blick's curve, which suggests that lengthening of a muscle results in increased tension but at a certain tension, the muscle will no longer be able to lengthen.[23] Our study suggests that RTSA constructs with inferior offset of more than 2.5 mm diminish the ability of the deltoid to further elongate under physiologic loads. This was most pronounced between Groups 2 and 3 where total inferior offset of the constructs increased from 2.5 mm to 4.5 mm. When comparing these two groups, deltoid elongation under physiologic loading conditions decreased from 1.3 mm to 0.7 mm. While this represents merely a 0.6-mm difference in absolute terms, it reflects the diminished ability of the deltoid to tolerate increasing tension, effectively demonstrating Blick's curve. Further, increasing inferior offset significantly decreased the percent of elongation between these two groups. Most significantly, the deltoid yield displacement of 33.3 mm in Group 2 dropped to 17.3 mm in Group 3. This suggests a dramatic change in the ability of the deltoid to accommodate physiologic loads when inferior offset is increased from 2.5 mm to 4.5 mm. Essentially, at the tension generated with 4.5-mm of inferior offset, the deltoid can lengthen only an additional 17 mm before failing compared to an additional 33 mm when the RTSA construct is set at 2.5 mm of inferior offset.

Increased deltoid force may have clinical implications after RTSA, such as increased risk of deltoid attrition or acromial stress fracture.[12,18] Increased deltoid forces over a longer period may lead to deltoid-related pain and accelerate the decline in function that has been reported at mid-term follow-up.[8,12] In our study, the most common mode of deltoid failure in these non-pathologic specimens was detachment of the anterior deltoid from the acromion, which may lead to increased pain and functional loss.[2] In a recent case series of anterolateral deltoid ruptures following RTSA in a group who had previous open RTC repairs, all patients had significant declines in functional outcome after rupture.[29] Anterior deltoid insufficiency also has been linked to instability and is underestimated in revision surgery.[30] Postoperative fractures of the acromion and scapular spine are uncommon,[30] and our study's 4% rate of acromion fracture is similar to that of previous studies.[17,28] While this particular complication remains uncommon, function decreases significantly after fracture.[27]

As with other biomechanical and cadaver studies, recognized limitations exist. Mechanical actuators and static loads could not simulate active muscle contraction, proprioceptive control, and dynamically changing muscle lines of action.[13] Our cadaveric model with the scapula locked statically in resin was unable to account for the increased scapulothoracic motion and altered kinematics in RTSA.[16] Also, the specimens used in this study were not pathologic and may not precisely mimic the degenerative changes seen in most patients who have RTSA. Finally, while we used baseplate and glenosphere positions as surrogates for increased deltoid tension, those are not the only two factors involved in setting deltoid tension in RTSA. We speculate that any configuration that increases deltoid tension (including humeral-sided factors such as the size of the head cut or augmented humeral bearing trays) may well result in similar changes.

In conclusion, increasing inferior offset in RTSA constructs appears to increase stretch forces on the deltoid. This results in a progressively diminished ability of the deltoid to further elongate under physiologic loads and is most pronounced when the inferior offset exceeds 2.5 mm. This configuration also significantly decreases the yield displacement of the construct, suggesting that the deltoid may not tolerate this additional lengthening to the same extent as with other less-tensioned constructs; however, this potential disadvantage may be balanced by the ability to minimize scapular notching with inferiorly offset configurations.

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Statin-Associated Tendinopathy: A Report of Two Cases and Summary of the Literature

Clayton C. Bettin MD | Garnett A. Murphy MD

INTRODUCTION

Statins are commonly prescribed for their lipid lowering and cardioprotective properties and have been generally considered safe medications with minor side-effects. With increasing numbers of statin users, however, there have been increasing numbers of reports of musculoskeletal side-effects, including statin-associated tendinopathy. We report two cases of statin-associated tendinopathy and provide a summary of the literature on this topic in an effort to raise awareness among orthopaedists of this association and to educate patients accordingly.

CASE REPORTS

Case 1

A 51-year-old Caucasian male presented with a 5-month history of Achilles tendon swelling and pain. He denied any traumatic events and had not attempted any treatments before presenting for evaluation. Five months before noticing the swelling in his Achilles tendon he began taking atorvastatin for hyperlipidemia. A 2 cm X 2 cm area of intratendinous edema was noted approximately 5 cm from the insertion of the Achilles tendon **(Figure 1)**. No gaps in the tendon were palpable, and Thompson squeeze test demonstrated continuity of the Achilles tendon. Plantar flexion strength was 5/5 and calf circumference was symmetrical to the uninvolved extremity.

Figure 1: Intratendinous edema approximately 5 cm from the insertion of the Achilles tendon

After discussion with the patient's primary care practitioner, his statin therapy was discontinued and the patient was placed into a walking boot. Four weeks later, he reported significant improvement, had no pain with activity, and had no tenderness to palpation on examination. The patient was referred to physical therapy for eccentric strengthening exercises.

Figure 2: Enlarged, boggy, tibialis anterior tendon

Case 2

A 55-year-old Caucasian male presented with a chief complaint of anterior ankle swelling that had been present for one year. He denied any inciting traumatic event or any recent activity modifications. He noted that golfing was particular painful for him. Non-steroidal anti-inflammatory drugs (NSAIDs) had not relieved his symptoms. On further questioning, he reported starting pravastatin one year earlier. He denied any myalgias or history of taking any steroids or fluoroquinolones. His medical history was significant for hypertension, hyperlipidemia, and depression. and current medications included losartan, pravastatin, and paxil. The patient ambulated with an antalgic gait and had an enlarged, boggy, tibialis anterior tendon **(Figure 2)** with tenderness to palpation along the tendon course. No gaps

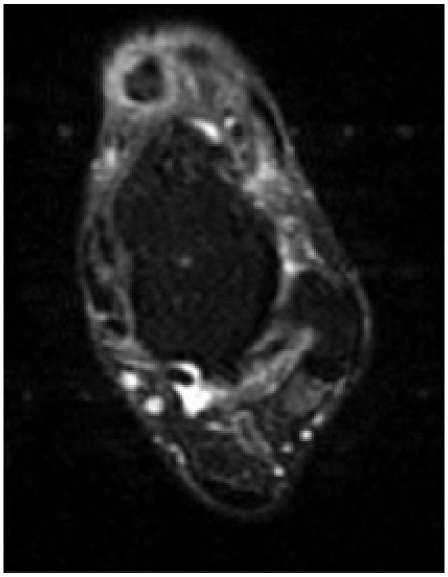

Figure 3: Axial T2-weighted MRI shows acute inflammatory process in tibialis anterior tendon.

were palpable in the tendon. Resisted ankle dorsiflexion was painful and showed 4/5 strength compared to 5/5 on the uninvolved extremity. MRI showed acute inflammatory process in the tibialis anterior tendon **(Figure 3)**, as well as structural changes within the tendon and mild tenosynovitis.

After discussion with the patient's primary care physician, pravastatin was discontinued and a course of methylprednisolone was begun. The patient was placed into a walking boot and formal physical therapy was begun. On repeat evaluation 3 weeks later, the patient noted improvement when wearing the walking boot, but complained of new pain along the medial cuneiform at the tibialis anterior tendon attachment. The insertion of the tibialis anterior tendon was injected with lidocaine, Marcaine, and Celestone. He reported only minimal improvement with the injection. After 6 months of conservative treatment, the patient had tenosynovectomy with debridement and repair of the tibialis anterior tendon **(Figure 4)**. Pathology evaluation of a specimen obtained at surgery found dense fibro-connective tissue with reactive changes and fibrin consistent with tendinitis **(Figure 5)**. The patient was kept non-weight bearing for 6 weeks, the first 4 weeks of which were in a walking boot. At 4 weeks after surgery, he reported no pain.

DISCUSSION

Statins (3-hydroxy-3-methylglutaryl-coenzyme A reductase inhibitors) are widely-prescribed drugs used to reduce low-density lipoprotein (LDL) cholesterol levels. In 2006 alone, Americans spent $16 billion on 157 million prescriptions for statin therapy.[8] The side-effect profile of statins is generally considered to be safe, and randomized trials have shown only slight increased risk of side-effects compared to placebo.[10] Musculoskeletal side-effects have been reported, but generally in only small percentages of patients. Myositis has been reported to occur in 0.5% of patients,[16] while vague muscle pain occurs in 2% to 11% of patients, which is the same as for a placebo.[9] Rhabdomyolysis, although serious, has not been reported in large trials in patients without other risk factors. A study of 252,460 patients on lipid-lowering agents found the incidence of admission for rhabdomyolysis to be 0.44 per 10,000 patient-years.[6]

No tendon complications associated with statin therapy were reported in 83,858 patients during the initial therapeutic trials for statin therapy.[15] The French literature began reporting statin-associated tendinopathy in 2000,[4] and by 2006 the FDA Adverse Drug Effects reporting database had 247 cases of statin-related tendon rupture reported.[15] Pfizer now includes reports of tendon rupture with its physician prescribing information.[14] Because the relationship between statins and tendinopathy may not be commonly known, the actual number of cases is likely underreported.

The literature contains primarily case reports of statin-associated tendinopathy in patients with no other risk factors for tendonitis or tendon rupture such as diabetes, hyperparathyroidism, chronic renal failure, and use of fluoroquinolones or anabolic steroids.[2-4, 13] The largest review published to date was of 96 spontaneous cases of statin-associated tendinitis (65%) or tendon rupture (35%) from the French Pharmacovigilance database from 1990-2005.[12] The authors reported that the incidence of tendinous side-effects was 2% (96 out of 4,597 side effects). The median age of those affected was 56 years, with a male to female ratio of 2.3:1. Twenty-eight percent of those affected had a medical condition also associated with tendon rupture (such as diabetes); however, none had a concomitant drug

Figure 4: Appearance of tibialis anterior tendon at time of debridement and repair.

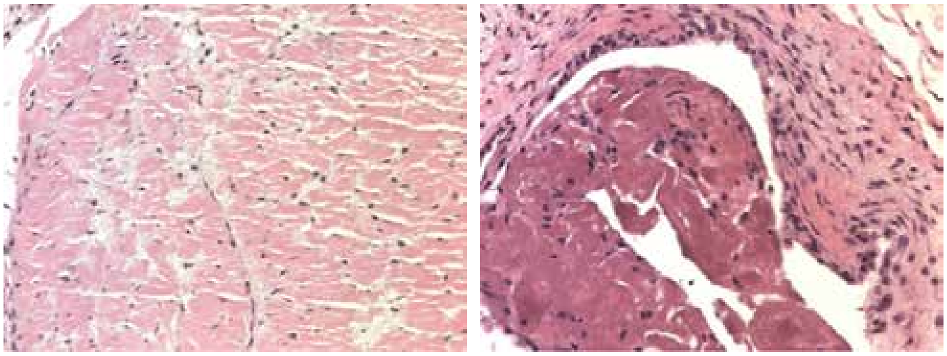

Figure 5: Pathology evaluation found early myxoid degeneration of tendinous fibroconnective tissue.

effect. The median time to onset was 243 days, and 59% of cases occurred during the first year of statin therapy. The most common tendon affected was the Achilles (52%), with 15% occurring in the quadriceps. Interestingly, 41% of cases occurred bilaterally. The median time to symptom resolution 23 days after discontinuing statin therapy, but 20% of patients had residual functional sequelae such as a limp or persistent pain. The authors concluded that the tendon disorders could be logically attributed to statin use because, "there was a temporal relationship between onset of tendinous signs and the initiation of statin therapy." In addition, all seven patients in whom statin therapy was reinitiated had recurrence of their tendon symptoms.

A retrospective EMR review13 found 93 cases of tendon rupture associated with statin exposure and compared these to 279 controls matched for age and sex.[1] Overall, no significant difference between cases and controls in the rates of statin use was found in their analysis. These results should be interpreted carefully because this was a single-site study with a small n-value and examined tendon rupture only. It did not include any cases of statin-associated tendinitis in its analysis. A subgroup analysis of the same data, though, showed statin exposure in the preceding 12 months was a significant risk factor for tendon rupture in women but not in men. This led the authors to conclude that statin-associated tendon rupture may be more "common" in men, but more "likely" in women.

An experimental study in rabbits with surgically repaired tendons that were randomized to atorvastatin exposure or placebo showed a significant difference in the construction of collagen on histological sections taken 6 weeks after surgical repair.[5] Proposed mechanisms to explain these musculoskeletal effects include the effect of statins on angiogenesis and tissue healing,[17] impaired cell membrane function,[11] and alteration of matrix metalloproteinase (MMP) activity.[15] The actual mechanism is likely multifactorial.

CONCLUSION

Statins have been shown to be beneficial in ways other than reducing LDL levels. The Heart Protection Study[7] demonstrated a 13% reduction in all-cause mortality, 24% reduction in major cardiovascular events, and 28% decrease in ischemic stroke with daily simvastatin compared to placebo. Given such a significant effect on overall morbidity and mortality, recommending against statin use to prevent musculoskeletal complications appears imprudent. It is important, however, for orthopaedists to recognize the association between statin use and tendinopathy given the prevalence of statin use and the frequency with which tendinopathy occurs in patients on statin therapy. The causes of tendinopathy are often multifactorial and, as seen in Case 2, cessation of statin therapy may not lead to improvement in the condition; however, given the minimal risk associated with a brief cessation of a statin drug, discontinuing the medication in a patient with a clinical history highly suggestive of statin-associated tendinopathy is warranted. Alternative lipid-lowering treatments may be considered as part of the treatment for statin-associated tendinopathy in coordination with the patient's primary care practitioner. Patients should be educated on the possible musculoskeletal side-effects associated with statin therapy and should be regularly monitored for these, especially in the first year of therapy.

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Is Gelsolin a Biomarker for Aseptic Loosening and Is it Linked to Hypersensitivity?

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ABSTRACT

Purpose: Current workup of a painful total knee arthroplasty (TKA) includes a battery of tests which may be inconclusive. No clinical test has been shown to be diagnostic for metal hypersensitivity. Gelsolin (GSN), an actin-regulatory protein, has been implicated in inflammatory reactions in asthmatic patients. GSN may be a marker for acute or chronic reactions at the surface of secretory cells whether in the bronchiole, or possibly in synovial tissue. Detection of increased levels of GSN in synovial fluid could differentiate between the diagnosis of aseptic loosening (low GSN) and hypersensitivity reaction (high GSN).

Methods: To determine if GSN levels are increased in the synovial fluid of patients who have a well-functioning TKA, seven cadaveric specimens with unilateral TKA were procured from the Memphis Education and Research Institute. Synovial fluid aspirated from both knees (native and TKA) was analyzed using ELISA for GSN levels and compared using a paired two-tailed student's t-test. TKAs were explanted after spiral CT scans for determination of wear patterns and loosening. Results were compared to synovial fluid recovered from seven consecutive revision TKA procedures for aseptic failure at the time of surgery using an independent one tailed student's t-test. Skin patch tests placed pre-operatively on the revision TKA patients were read 48 hours post-operatively while blood was drawn for a lymphocyte transformation test (LTT) to determine if any correlation between synovial GSN levels and patch test or LTT results exists.

Results: Average GSN levels for the cadaveric native and well-functioning TKA knees were 24,534±10,437ng/mL and 38,430±30,907ng/mL, respectively, showing no statistically significant difference ($p=0.314$). Average GSN level for patients undergoing revision TKA was 53,294±19,868ng/mL. Revision TKA patients had a significantly higher synovial GSN level than cadaveric well-functioning TKAs ($p=0.006$). Skin patch and LTT tests were available for 3 out of 7 patients. No positive patch tests occurred. The patient with the highest level of GSN at time of revision surgery showed high reactivity to nickel on LTT, while the two patients with the highest GSN levels were noted to have loose implants at time of revision surgery.

Conclusion: GSN levels from failed TKAs undergoing revision surgery were significantly higher than those found in well-functioning cadaveric TKAs. The highest levels of GSN occurred in association with metallosis; GSN may be a marker for the body reacting to metal debris

Significance: Understanding the role of GSN in metal hypersensitivity reactions may lead to better diagnosis and treatment of a painful TKA.

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The Use of Magnetic Resonance Imaging in the Evaluation of Spondylolysis

ABSTRACT

Background: In early studies, magnetic resonance imaging (MRI) had low sensitivity and positive predictive value in the evaluation of the pars interarticularis pathology; however, more recent reports have suggested an expanded role for MRI. The purpose of the present study was to evaluate the effectiveness of MRI in the diagnosis of pars and compare it to computed tomography (CT), which was used as the reference "gold standard" for the detection of fractures.

Methods: The radiographic and clinic data of 93 adolescents and young adults with a presumptive diagnosis of spondylolysis based upon history and clinic examination were reviewed. Only 26 patients who had MRI and CT images obtained within 30 days of each other were included. All images were reviewed by a fellowship-trained musculoskeletal radiologist and fellowship trained pediatric orthopedist.

Results: Overall, 39 individual pars lesions (stress reaction or fracture) were identified. MRI was effective in identifying 36 pars lesions. MRI identified 11 lesions in 9 patients with negative CT. Seven of these lesions were stress reactions (grade 1) while 4 were frank fractures. Three (3) pars injuries were noted on CT while the MRI was negative.

Conclusions: MRI is an effective method (92% sensitivity) for detecting pars injuries. It can detect stress reactions when a fracture is not visible on CT scan, allowing early treatment of these pre-lysis lesions. The 92% sensitivity of MRI is comparable to that of other diagnostic modalities such as bone scan, with the advantage of no radiation exposure. MRI should be strongly considered as the advanced imaging modality of choice in the evaluation of patients with suspected spondylolysis.

Level of evidence: Level III diagnostic study

Key words: spondylolysis, adolescents, diagnosis, MRI, CT

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Football-Related Concussion and Lower Extremity Injuries: Have Changes in the NFL/NCAA Had Any Effect on Younger Participants?

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Conflicts of Interest and Source of Funding: The authors declare no conflict of interest. None of the authors received financial support for this study.

ABSTRACT

Background: Recent concerns about head injuries and concussions have brought about changes in rules and tactics of football at the professional and collegiate levels, but it is unclear if these rule changes have had an effect on younger players.

Hypothesis/Purpose: The purpose of this study, based on the National Electronic Injury Surveillance System (NEISS) database, was to determine the number of emergency department (ED) visits at three time points (2006, 2009, 2012) with regards to football-related concussions and lower-extremity injuries. We hypothesized that recent changes in the rules at the professional and collegiate levels would result in a decrease in the number of concussions in youth football players and an increase in lower extremity injuries as tackling techniques shift to lower hits to avoid head trauma.

Study Design: Descriptive epidemiology study.

Methods: A stratified probability sample of U.S. hospitals providing emergency services in the NEISS was used for 2006, 2009, and 2012. Codes for all football-related injuries were analyzed for patients 6 years to 18 years of age .

Results: There were an estimated 351,408 football related ED visits in 2006; 338,278 in 2009; and 360,468 in 2012. The estimated numbers of ED visits for football-related concussions were 12,238 (3.4%), 16,768 (4.9%), and 27,933 (7.7%), respectively. The estimated numbers of ED visits for lower extremity football injuries were 91,184 (25.9%), 86,957 (25.7%), and 89,971 (24.9%), respectively.

Conclusion: ED visits for football-related concussions in pediatric patients have steadily increased between 2006 and 2012, while football-related lower extremity injuries have remained relatively constant.

Clinical Relevance: Recent changes in the rules and tactics of the game at the professional and collegiate levels appear to have had little effect on the frequency of concussions in younger players. An increased awareness of these injuries may have led to more frequent diagnosis and reporting of concussions in pediatric athletes, but the two-fold increase in concussions in 2012 compared to 2006 is a strong indication that these injuries remain a significant risk in this group of young athletes.

Keywords: pediatric, football, lower extremity injuries, concussion

What is known about the subject: Repeated concussions may increase an athlete's risk for chronic traumatic encephalopathy and mental health issues such as dementia, Parkinson's disease, and depression in later life. The frequency of concussion in professional and collegiate football players has been well documented, and a recent study found a comparable injury rate in football players aged 8 to 12 years

What this study adds to the existing knowledge: The increase in the frequency of ED visits for concussions in this age group, coupled with the relatively constant frequency of lower extremity injuries, suggests that, despite rule changes and increased awareness, concussions are still on rise in this sport and further interventions are needed to help reduce their occurrence.

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Atypical Neurologic Deficits Following Ponte Osteotomy and Posterior Spinal Fusion for Idiopathic Scoliosis

ABSTRACT

Background: New neurologic deficits after spine surgery are nearly 60% more frequent in children and adolescents than in adults. Spinal cord monitoring with somatosensory evoked potentials (SSEP) and motor evoked potentials (MEP) is used to decrease the risk and increase early detection of neurologic deficits; however, false-positive and false-negative changes can occur.

Results: In two adolescent patients who had Ponte-type osteotomies and posterior spinal fusion with instrumentation, the observed intraoperative neuromonitoring data did not correlate with the clinical examination postoperatively: one deficit was underestimated and the other was overestimated.

Conclusions: It is important for surgeons to realize that false-negative and false-positive results do occur with intraoperative neuromonitoring. In high-risk cases, such as those that involve osteotomies, the surgeon should not hesitate to use additional evaluation such as a wake-up test to supplement neuromonitoring.

Key Words: adolescent idiopathic scoliosis, posterior spinal fusion, complication, neurologic deficit

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INTRODUCTION

The risks of surgical correction of scoliosis include neurological injury, infection, ileus, pneumothorax, vision loss, dural tears, urinary complications, loss of lumbar lordosis, superior mesenteric artery syndrome, and pseudarthrosis [1,2]. Of these, the most serious and potentially catastrophic is neurologic deficit [3,4]. New neurologic deficits after spine surgery are nearly 60% more frequent in children and adolescents than in adults [5]. The reported rate of new neurologic deficits in adolescent scoliosis surgery range from 0.4% to 4.5% [3,5,6,7]. Careful preoperative planning, meticulous implant instrumentation, intraoperative spinal cord monitoring, and wake-up tests are all used to minimize the risk and increase early detection of neurologic deficits. Despite these efforts, neurologic deficits can still occur during the procedure. We describe two atypical neurologic deficits secondary to posterior spinal fusion for treatment of adolescent idiopathic scoliosis (AIS) in which the clinical examination postoperatively did not correlate with the observed intraoperative neuromonitoring data. Both cases were exempted from review by the involved institutional review boards.

Case 1

A 15-year-old African-American female had posterior spinal fusion with instrumentation to correct her scoliotic deformity consisting of an 85-degree right thoracolumbar main curve, a 55-degree upper thoracic curve, and a 48-degree left lumbar curve (**Figure 1**). She had no preoperative neurologic deficits. A T3-L5 posterior fusion with instrumentation and Ponte osteotomies at T10-11, T11-12, and T12-L1 was planned, using local bone autograft and allograft. Spinal cord monitoring with somatosensory evoked potentials (SSEP) and motor evoked potentials (MEP) was used during the entire

Figure 1: Case 1, preoperative anteroposterior (A) and lateral (B) radiographs.

procedure. After exposure of the spine and before creation of the osteotomies, pedicle screws were placed at T3-5 and L2-4 on the left side of the spine. A temporary distraction construct was placed across the concavity using two rods connected by a domino. Gradual distraction in 15-minute intervals was performed. All SSEP and MEP were normal. After the osteotomies were completed, Mersilene tape was placed at T9-11 and attached to the left-sided rod to translate the apex of the curve. No dural tear occurred, and no CSF was encountered during the osteotomies. Again, SSEP and MEP were normal after these maneuvers. Pedicle screws were placed on the left from T7-9 and on the right at T4-7, T11, and L3-5 (**Figure 2**). A screw was placed at T3 on the right, but decreased motor signals in the foot were reported so the screw was removed, and motor signals returned to baseline within a few minutes. Although there was no palpable breach, this screw was not replaced. Permanent rods were placed bilaterally, and final correction maneuvers were performed. Again, SSEP and MEP were equal to their initial baseline. All electromyogram testing of pedicle screws during their placement greater than 8 miliamperes. At the end of the procedure, the patient remained intubated for transfer to the pediatric ICU, but a wake-up test before departure from the operating room showed grossly intact ankle and toe plantar flexion and dorsiflexion without significant sensory deficits, but detailed neurological assessment at that time was difficult because of residual effects of anesthesia.

On physical examination, 5 hours postoperatively, the patient had stable vital signs and 5/5 strength bilaterally in her upper extremities and right lower extremity, with 2/2 sensation to light touch. Her left lower extremity, however, showed 3/5 strength in the extensor hallucis longus (EHL), tibialis anterior (TA), and gastroc-soleus complex (GSC) with intact sensation in the L4-S1 distribution. In light of the normal intraoperative SSEP and MEP and wake-up test examination, it was decided to re-examine the patient once she was less sedated. Repeat examination 12 hours postoperatively showed 4/5 strength of the left hip flexors, quadriceps, and GSC and 1/5 strength of the TA and EHL. She had intact sensation from L1-S1, but had dysesthesias on the plantar aspect of her left foot. CT scanning of the thoracic and lumbar spine to evaluate screw placement or possible graft migration into the canal showed no hematoma, fluid collections, malpositioned screws, or other etiology explaining the neurological changes. MRI was not obtained at that time because of concern that implant-related artifact would make interpretation of the study difficult, the results of the study would not change the plan to return to the operating room for removal of the rods, and this would further delay surgical intervention. Because of her abnormal, and worsening, neurologic examination, the patient was immediately taken back to the operating room for exploration and removal of rods. Baseline SSEP and MEP were normal in both upper extremities and the right lower extremity. Her left lower extremity showed intact MEP with decreased amplitude in the quadriceps and TA. Allograft and autograft material was meticulously removed, and the right-sided rod was removed with no change in potentials. The three Mersilene tapes and left-sided rod were then removed. Approximately one minute later, while still in the operating room, there was a 50% increase in MEP in the left

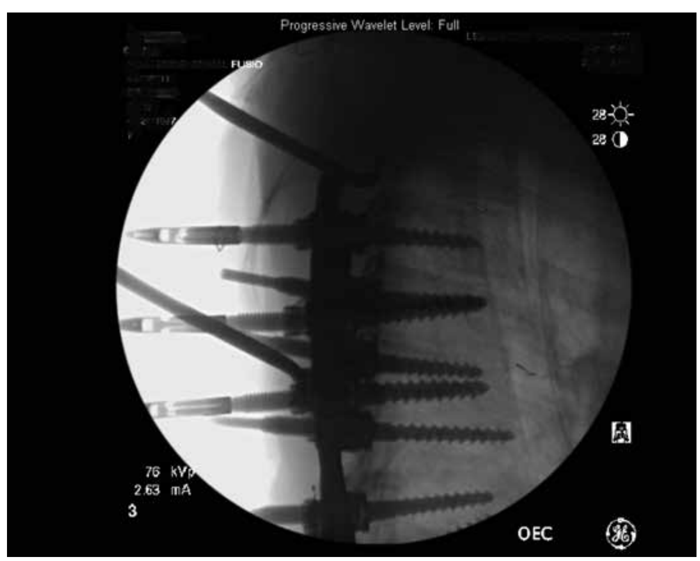

Figure 2: Case 1, After placement of permanent rods.

Time postop	EHL	TA	GSC	Hip flexors	Quadriceps	L4-S1 sensation
5 hours	3/5	3/5	3/5	–	–	–
12 hours	1/5	1/5	4/5	4/5	4/5	Dysesthesia plantar foot
2 days	1/5	1/5	4/5	4/5	4/5	Unchanged
4 days	0/5	0/5	2/5	4/5	4/5	Unchanged
5 days	0/5	0/5	2/5	3/5	4/5	Unchanged
10 days	1/5	0/5	3/5	4/5	4/5	Unchanged
24 days	2/5	1/5	4-/5	5/5	4+/5	Improving
26 days*	3/5	3/5	4/5	5/5	5/5	Mild dysesthesia
30 days**	3/5	2/5	4/5	5/5	5/5	Mild dysesthesia
2 & 7 weeks	4+/5	4+/5	4+/5	5/5	5/5	–

*Postop second surgery. **4 days after second surgery
EHL, extensor hallucis longus; TA, tibialis anterior; GSC, gastroc-soleus complex

Table 1: Case 1.

lower extremity. Following the procedure the patient returned to the ICU.

Two days after the initial surgical procedure, motor examination of the left lower extremity was unchanged, with 1/2 sensation to light touch in the L4-S1 distribution and dysesthesias in the plantar foot. Gabapentin was started the next day and titrated up to 400 mg twice a day. Strength of her left lower extremity continued to deteriorate (**Table 1**). Four days after surgery, MRI showed subtle edema-like signal within the central cord at T12 and right psoas major muscle, with no epidural impingement or abnormality within the lumbosacral plexus (**Figure 3**). A halo was applied with cervical traction starting at 4 lbs and gradually advanced over 2 weeks to 20 lbs. Repeat MRI 8 days after surgery ordered to evaluate the lumbosacral plexus showed no lumbosacral plexus abnormality or thecal/cauda equina impingement. At 10 days there was some improvement in left lower extremity strength and further improvement by 24 days (**Table 1**), but muscle strength was still not completely normal. Sensation to light touch was still diminished, but dysesthesias were reportedly "improving

Twenty-six days after her initial surgery, the patient returned to the OR for stage 2 T3-L5 posterior fusion using autograft and allograft, revision Ponte osteotomies at T10-11, T11-12, T12-L1, and extension of osteotomies to include T7-8, T8-9, T9-10. Again SSEP and MEP were unchanged from the beginning to the end of the re-instrumentation procedure, and muscle strengths were improved from preoperative values (**Table 1**). At discharge, 30 days from the original procedure and 4 days after the second procedure, strength was still diminished to the EHL and TA with intact sensation to light touch in the L3-S1 distribution and mild plantar dysesthesias (**Figure 4**). At time of this report, the patient had been seen twice for clinical follow-up at approximately 2 and 7 weeks after the final procedure. At both visits left lower extremity motor examination de-

Figure 3: Case 1, A and B, stage 2 of curve correction done 26 days after initial surgery.

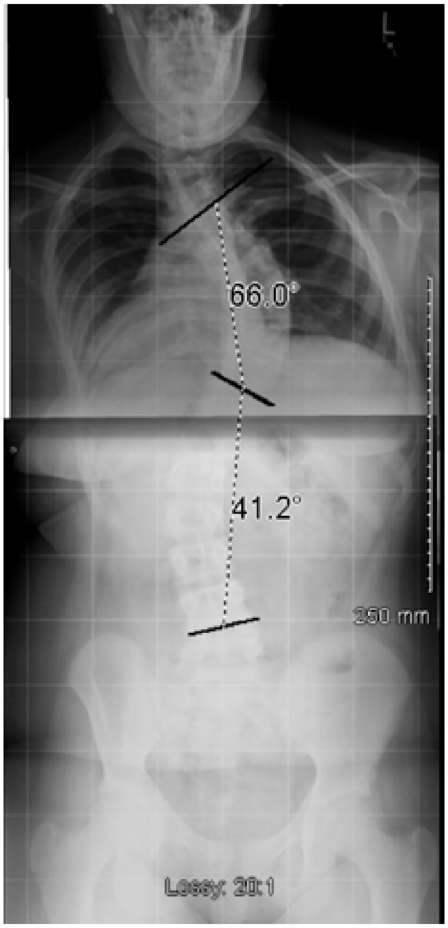

Figure 4: Case 2, A and B, preoperative radiographs.

termined strength to be 4+/5 in the GSC, EHL, and TA. Based on her clinical course as well as her CT and MRI, we believe the patient sustained a neurologic insult that resulted in a left-sided lumbar plexopathy, most likely from the degree of correction obtained.

Case 2

A 12 +6 year-old Caucasian female with a 69-degree right thoracic curve and a 52-degree left lumbar curve (**Figure 5**) was scheduled for posterior spinal fusion with instrumentation. Preoperative MRI of the spine did not show any spinal cord abnormalities. After induction of anesthesia, the patient had normal SSEP and MEPs. Through a standard subperiostal spine exposure, pedicle screws were placed at multiple levels from T3 to L3. There were no SSEP or MEP changes during or after pedicle screw insertion, and the lower thoracic and upper lumbar pedicle screws had normal impedance with EMG stimulation (> 8 miliamperes). Fluoroscopy also demonstrated proper position of the screws in both the anteroposterior and lateral planes.

Because of marked stiffness of the thoracic curve, as demonstrated on preoperative bending films, posterior (Ponte) osteotomies were planned at T6 through T10. A single-level osteotomy was completed at T10, and an osteotomy was begun at T9. After removal of the ligamentum flavum with the Kerrison rongeur, a dural tear was noted, and stimulated MEP revealed complete loss of the motor signals to the left lower extremity. Motor signals to the right lower extremity and bilateral upper extremities were unchanged from baseline. There were no SSEP changes. Intraoperative neurosurgical consultation was obtained, and T9 laminectomy revealed an approximately 5 mm X 5 mm tear of the posterolateral dura. There was no visible cord injury under microscopic examination. The dural tear was repaired with a collagen graft sutured in place posteriorly and laterally, augmented with fibrin glue. A deep dural drain was placed by the neurosurgical team.

Motor signals remained at baseline in the right lower and bilateral upper extremities, but absent in the left lower extremity. The decision was then made not to place any rods or attempt any correction maneuvers because of the uncertain neurologic picture. All the planned pedicle screws had been placed, and these were deemed to be in acceptable position. None of these implants were removed, and no additional screws were placed. The wound was irrigated and closed in layers with a superficial drain placed above the fascia.

When she awoke from anesthesia in the operating room, the patient was able to dorsiflex and plantar flex her right foot at the ankle and move her toes up and down, but she had no motor function at the left ankle or foot. Upon further evaluation in the recovery room an hour later, she had 3/5 strength at the level of the left hip flexor and left quadriceps, and 2/5 at the left ankle dorsiflexors, EHL, and GSC. Sensation was again grossly intact to light touch throughout both lower extremities and was subjectively equal.

Figure 5: Case 2, CT scan (A) and MRI (B) obtained immediately after surgery.

Immediate MRI was somewhat difficult to interpret because of implant-related artifact, but no visible cord injury, edema, or hematoma was identified (**Figure 6**). CT scanning demonstrated good positioning of the implants. There were no breaches of the pedicle screws into the canal at any level.

Over the next 48 hours, the patient was placed on flat bedrest. Motor function in the left lower extremity gradually improved, with complete resolution of her motor deficit by postoperative day 6. Her Foley catheter was discontinued 3 days after surgery, and she was able to void spontaneously; however, she reported feeling urgency and having some difficulty with mild urinary retention. Six days after surgery, her intradural drain was removed. She was placed into a thoracic-lumbar-sacral orthosis (TLSO) to prevent rapid decompensation of the curve, and she was progressively mobilized with physical therapy. She was discharged 10 days after her first procedure with normal motor and sensory examinations of both extremities.

At 2 weeks after surgery, she had no complaints of weakness or sensory changes in the lower extremities, but did complain of some urgency with urination, to the point where she struggled to make it to the bathroom in time. She denied any perineal numbness or bowel incontinence. She stated that her urination urgency was somewhat improved since leaving the hospital.

The patient returned to the operating room 6 weeks after the initial surgery for placement of definitive instrumentation to prevent severe decompensation of her curve. Despite a normal neurological examination before surgery, after induction of total intravenous anesthesia, the patient continued to have extremely low motor baselines to the left lower extremity with normal motor baselines to the right lower and bilateral upper extremities. Because she had a full and complete recovery clinically prior to induction of anesthesa, it was elected to continue with surgery. Dissection was then again performed down to the spine, and the previously placed screws were examined. Rods were placed on the left and right sides and fixed to the fixation points, and derotation and correction of the scoliosis were performed. Following decortication and bone grafting, the wound was closed in layers with a superficial drain placed above the fascia. Her motor and sensory baselines were unchanged at the end of surgery, with continued decreased signal to the left lower extremity. When she woke from anesthesia, she was able to actively dorsiflex and plantarflex both ankles and all toes on both feet. She had 5/5 strength at all levels of both lower extremities on motor examination in the recovery room.

At her 6-week follow-up, the patient was doing well with no complaints of weakness, numbness, or tingling. She did continue to complain of some urgency with urination, but this was steadily improving.

Figure 6: Case 2, A and B, Complete of scoliosis correction 6 weeks after initial surgery.

DISCUSSION

Neurologic deficit is one of the most concerning complications of elective spine surgery for surgeons, patients, and parents [3]. Neurological deficits following scoliosis surgery can result from direct injury by instrumentation, from stretch during distraction, or from vascular compromise. New neurologic deficits are uncommon after surgical treatment of AIS, with reported frequencies ranging from 0.4% to 4.5% [5,8]. Deficits range from nerve root to spinal cord involvement leading to para-/quadriplegia and may result in complete or incomplete recovery. In both of our patients intraoperative spinal cord monitoring consisting of SSEP, MEP and EMG was used. In the first case, during the patient's initial surgery, SSEP, MEP, and EMG neuromonitoring signals were normal at the conclusion of the procedure. There was a transient decrease in right lower extremity MEP. In the second case, neuromonitoring showed loss of all MEP in the left lower extremity after a dural tear that persisted despite dural repair. In the secondary procedure for definitive fixation, neuromonitoring showed abnormal readings despite normal pre- and postoperative motor examinations. These findings highlight the limitations of neuromonitoring at detecting neurologic deficits. In case one, neuromonitoring readings gave false negative results. In case two, the neurologic deficit was not as severe as indicated by the neuromonitoring signal change during the first procedure, while the second procedure demonstrated a false positive reading. In a prospective evaluation of neuromonitoring in corrective surgery for AIS, the sensitivity and specificity of SSEP and MEP combined approached 100% [9]. Hamilton et al [5] reviewed the Scoliosis Research Society Morbidity and Mortality data from 2004-2007 and found the sensitivity and specificity of combined SSEP and MEP intraoperative monitoring for new neural deficits to be 43% and 98%, respectively. It is important to emphasize that the reported sensitivity and specificity of combined neuromonitoring vary in the literature and that false negatives can occur. The sensitivity and specificity reports must also be reviewed in light of the authors' definitions of true positive, false positive, true negative, and false negative. In the report of Kundnani et al [9], 4 of 13 patients with substantial signal alert did not show reversal after systematic intervention. Of those 4, 2 had no postoperative neurologic deficit despite persistent abnormal signals at the conclusion of the case. Similarly, Noonan et al [7] reported a false positive rate of 4.5% when evaluating neuromonitoring changes in AIS surgery. Half of these false positives had signal changes that persisted through the conclusion of the case. Additionally, two-thirds of their true positives had signals return to baseline before the conclusion of the case. Thus the authors recommended a wake-up test for all cases in which monitoring changes occur because neurologic deficits can be seen postoperatively despite signal return to baseline.

Surgery in both of our patients included osteotmies. The review by Reames et al [10] of the Scoliosis Research Society Morbidity and Mortality database from 2004 to 2007 showed a 2% rate of new neurodeficit with osteotomies in pediatric scoliosis surgery, which was significantly higher than cases not including osteotomies. An analysis of morbidity and mortality in pediatric spinal surgery by Fu et al [11] showed that patients with osteotomies were more than twice as likely to suffer a new neurodeficit than patients without osteotomies10. MacEwen et al [12] were the first to report the findings of the SRS Morbidity and Mortality Committee based on data from 1965-1971. They concluded that certain procedures, including spinal osteotomy, increased the risk of neurological injury. The use of osteotomies in both of our cases placed the patients at an increased risk of complications. It is important to thoroughly explain this to patients and their parents preoperatively.

It also is important for surgeons to realize that false negative and false positive results do occur with intraoperative neuromonitoring. In high-risk cases, the surgeon should not hesitate to use additional evaluation such as a wake-up test to supplement neuromonitoring. Furthermore, surgeons must recognize that neuromonitoring data are retrospective and alert that an insult, albeit at times reversible, has already occurred. Fu et al [11] showed that neuromonitoring did not appear to reduce the overall new neurodeficit rate: monitored patients had higher rates of new neurodeficits than non-monitored patients. Thus, it is imperative to recognize high-risk cases preoperatively, such as those in which osteotomies will be performed, and plan accordingly.

In both cases, the patients received a full posterior approach to the spine followed by at least one posteriorly based spinal osteotomy without the placement of rods. Therefore, both patients required supplemental, temporary spinal stabilization. Case one had a larger pre-operative curve, a more significant severe neurological deficit with a longer period of neurological recovery, and more levels of spinal destabilization as the result of osteotomoies. Therefore, it was deemed safer in case one to provide temporary stabilization with halo gravity traction and prolonged hospital admission while allowing for discharge in case two with stabilization provided by TLSO brace.

By approximately 2 months postoperatively, both patients had significant return of motor function. This is consistent with reports of partial or complete resolution of over 90% of nerve root or spinal cord deficits [5,6]. These two patients developed atypical neurologic deficits after posterior spinal fusion and instrumentation with Ponte-type osteotomies for AIS. Neuromonitoring in both cases gave a false indication of the severity of the neurodeficit, overestimating one and underestimating the other. The addition of a wake-up test to SSEP and MEP may help clarify the situation and guide surgical decisions.

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Patient-Specific Targeting Guides Compared to Traditional Instrumentation for Glenoid Component Placement in Shoulder Arthroplasty: A Multi-surgeon Study in 70 Arthritic Cadaver Specimens*

ABSTRACT

Hypothesis and/or Background: The purpose of this study was to compare the accuracy of patient-specific guides for total shoulder arthroplasty (TSA) to traditional instrumentation in arthritic cadaver shoulders. We hypothesized that the patient-specific guides would place components more accurately than standard instrumentation.

Materials and Methods: Seventy cadaver shoulders with radiographically-confirmed arthritis were randomized in equal groups to 5 surgeons of varying experience levels who were not involved in development of the patient-specific guidance system. Specimens were then randomized to patient-specific guides based off of computed tomography (CT) scanning, standard instrumentation and anatomic TSA, or reverse TSA. Variances in version and/or inclination of more than 10 degrees and more than 4 mm in starting point were considered indications of significant component malposition.

Results: TSA glenoid components placed with patient-specific guides averaged 5 degrees of deviation from the intended position in version and 3 degrees in inclination; those with standard instrumentation averaged 8 degrees of deviation in version and 7 degrees in inclination. These differences were significant for version ($p=0.04$) and inclination ($p=0.01$). Multivariate ANOVA analysis to compare the overall accuracy for the entire cohort (TSA and RTSA) revealed patient-specific guides to be significantly more accurate ($p=0.01$) for the combined vectors of version and inclination. Patient-specific guides also had fewer instances of significant component malposition than standard instrumentation.

Conclusion: Patient-specific targeting guides were more accurate and had fewer instances of component malposition than traditional instrumentation for glenoid component placement in this multi-surgeon cadaver study of arthritic shoulders. Long-term clinical studies are needed to determine if these improvements produce improved functional outcomes.

Level of Evidence: Basic Science Study

Keywords: total shoulder arthroplasty; patient-specific targeting guides; standard guides; cadaver study; component placement

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Running title: Patient-specific targeting guide for TSA

INTRODUCTION

Accurate glenoid component placement is an important technical goal in shoulder arthroplasty. Multiple biomechanical studies have identified glenoid malposition in either version or inclination to be detrimental to component fixation and stability.[15,21-23,26,28] Malpositioned components have clinically significant implications for function and implant longevity; including potential alterations in impingement-free range of motion and stability.[4,5,10,13,31] Current methods to address glenoid wear patterns and

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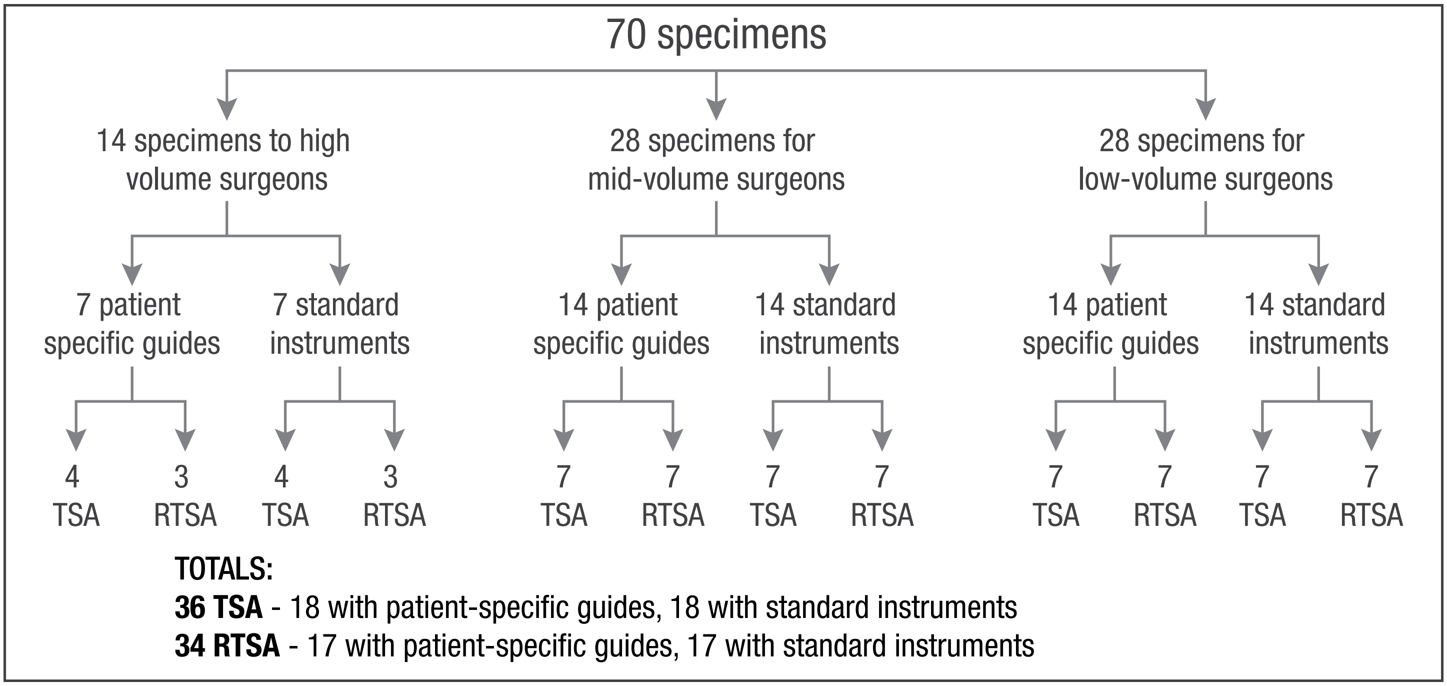

Figure 1:. Specimen allocation by surgeon experience, arthroplasty type, and surgical technique. For the mid- and low-volume groups, one surgeon was assigned 3 TDS and 4 RTSA per specimen group, while the other surgeon was assigned 4 TSA and 3 RTSA.

then place components accurately often are inadequate and can result in aseptic loosening.[7,9,13]

Multiple methods of attempting to correct glenoid wear have been described, including eccentric glenoid reaming, bone grafting, and augmented components.[12,16,24,25] Intra-operative navigation systems to guide component placement have been developed,[1,20,27,30] and 3-dimensional computed tomography (CT) has been investigated as a pre-operative planning and templating tool.[7,14,19] Finally, CT scans also have been used to create patient-specific guides to improve glenoid component placement in some studies[11,17,29]; however, there have been no adequately powered studies to compare the accuracy of these guides with standard preparation techniques. The purpose of this study was to compare the accuracy of glenoid component placement with patient-specific targeting guides and traditional instrumentation using an arthritic cadaver model. We hypothesized that patient-specific guides would place components more accurately and with fewer significant instances of component malposition than standard instrumentation.

This study was supported by Biomet, for whom all authors are consultants.

METHODS AND MATERIALS

In order to conduct this randomized controlled trial, we conducted a pre-study power analysis. Sample-size calculations were implemented in nQuery Advisor 7.0 software (Statistical Solutions, Boston, MA) using a 1:1 ratio of patient-specific guides to traditional instrumentation. The primary objective of this study was to determine differences between patient-specific guides and traditional instrumentation in absolute version of glenoid components relative to the intended neutral version. With a planned two-sided t-test with alpha of 0.05 and beta of 80% for difference in mean degrees of absolute version, a sample size of 66 shoulders to detect a statistically significant difference between preparation techniques was recommended. In order to have similar sample sizes among 5 surgeons, a study size of 70 shoulders was chosen. All 70 specimens had pre-test radiographic analysis for confirmation of glenohumeral arthritis, typically by identification of an inferior humeral head osteophyte. Specimens were then randomized by random number generator to the use of patient-specific targeting guides (Signature, Biomet, Inc, Warsaw, IN) or standard glenoid preparation (Comprehensive, Biomet, Inc, Warsaw, IN) and anatomic total shoulder arthroplasty (TSA) or reverse total shoulder arthroplasty (RTSA).

The Signature glenoid pre-operative planning techniques were used to formulate a plan for each cadaver. Specimens were placed supine in the scanner with the arm externally rotated (palm up). A General Electric (GE, Fairfield, CT) LightSpeed 64 CT scanner was used for all scans. CT scans were obtained in accordance with the Signature glenoid CT scanning protocol using soft-tissue algorithms and 0.625 mm x 0.625 mm slices at 120kVp. Two-dimensional DICOM images were segmented and used to create a 3D representation of the cadaver scapulae; 3D reconstructions were done with ORS Visual (Objects Research Systems, Montreal, QC), which converted the 2D DICOM images to a 3D .stl file. These files were converted to .IGES files with Geomagic Studio (Geomagic). All scapular planning was performed in NX 7.5 (Siemens, Washington, DC).

The Signature planning technique uses 3D CT imaging to plan implantation in neutral version based on the methods of Friedman et al.[6] This method essentially aligns the implant version by aiming towards the medial border of the scapula and is defined as anatomic version. Glenoid inclination was pre-operatively planned in neutral inclination based on the methods of Churchill et al.[2] and De Wilde et al.[3] Using these methods to measure anatomic inclination, an average of each author's results (8 degrees inclined from the anatomic axis projecting perpendicular to the medial border of the scapula) was defined as neutral inclination. The starting point for guide-pin placement also was defined by the Signature planning techniques. Anatomic TSA implants were placed in the center of the glenoid, which was determined through anterior-posterior and inferior-superior measurements of the glenoid. RTSA baseplate components were planned for placement in the anterior-posterior center of the glenoid, but were positioned slightly inferior such that the inferior aspect of the baseplate was flush with the inferior glenoid rim.

All shoulders had pre- and post-implantation CT scans for guide creation, evaluation of glenoid morphology, and evaluation of glenoid component placement. Patient-specific guides were created using 3-dimensional segmentation and derivation of CT data. TSA guides were created to place components in anatomic version and inclination with a center starting point. RTSA guides were created to place components in anatomic version and 10 degrees of inferior inclination with an inferior starting point referenced off of the inferior aspect of the glenoid.

Five orthopaedic surgeons with various levels of experience in shoulder arthroplasty who were not involved with the design of the patient-specific guide system were recruited to participate in the study. There was one high-volume surgeon (>100 shoulder arthroplasties per year), two medium-volume surgeons (30 to 50 per year), and two low-volume surgeons (<10 per year). Each surgeon performed a total of 14 arthroplasties in the study: 7 with traditional glenoid preparation and 7 with patient-specific guides **(Figure 1)**. TSA components (18 standard, 18 patient-specific guides) were used in 36 specimens, and RTSA components (17 standard, 17 patient-specific guides) were used in 34. In the medium and low volume groups, one surgeon performed 3 TSA and 4 RTSA, while the other implanted 4 TSA and 3 RTSA. Assignment to TSA or RTSA and patient-specific guide or traditional instrumentation was randomized using SAS version 9.2 (SAS, Cary, NC).

For all specimens, a deltopectoral exposure and humeral head cut in 30 degrees of retroversion and 45 degrees of inclination were used. For specimens designated to receive TSA or RTSA components using traditional instrumentation, the surgeon identified the starting point and/or glenoid size using a standard templating guide. The starting point for RTSA baseplate placement was identified using the standard guide such that the inferior aspect of the baseplate was flush with the inferior glenoid rim (typically approximately 2 mm inferior to the glenoid center). After guide-pin placement, correction of glenoid wear patterns with eccentric reaming was done at the discretion of each surgeon. Glenoid preparation and component implantation were otherwise carried out consistent with the manufacturer's specifications. As the use of cement was unlikely to affect glenoid component position or accuracy of placement, implants were placed without cement. TSA components were intended to be placed in anatomic version and inclination with a center starting point, while RTSA components were intended to be placed in anatomic version and 10 degrees of inferior tilt with an inferior starting point.

For specimens designated to receive components using patient-specific guides, the soft tissues on the anterior aspect of the glenoid (capsule and labrum) were first resected from the 1 o'clock position to the 5 o'clock position (right shoulders) or the 11 o'clock to 7 o'clock position (left shoulders). After adequate dissection to bone, the patient-specific targeting guides were applied, referencing off of the debrided anterior aspect of the glenoid. When firm contact was achieved without shift of the guide, the guide pin was placed. For TSA, a guide pin trajectory in neutral version and inclination was used; an alternate guide pin trajectory in 10 degrees of inferior tilt and neutral version was used in specimens receiving reverse total shoulder implants **(Figure 2)**. After guide-

Anatomic TSA	Version (Degrees)	Standard Deviation (Version)	Inclination (Degrees)	Standard Deviation (Inclination)	Starting Point (mm)	Standard Deviation (Starting Point)
Custom	5	4.8	3	4.3	2	1
Standard	8	8.2	7	7.9	3	2
p-value	p=0.04	p=0.09	p=0.01	p=0.04	p=0.20	p=0.38
RTSA						
Custom	6	7.0	4	4.6	2	1
Standard	6	7.4	5	6.3	2	1
p-value	p=0.87	p=0.77	p=0.16	p=0.22	p=0.27	p=0.76
TSA + RTSA						
Custom	5	4.5	3	2.8	2	1
Standard	7	5.5	6	4.3	3	1
p-value	p=0.17	p=0.26	p=0.004	p=0.01	p=0.09	p=0.45

Table 1: TSA components placed with patient specific targeting guides were significantly more accurate in version and inclination than standard instrumentation. However, there were no statistically significant differences for RTSA components.

pin placement, the glenoid was reamed flat in version and in anatomic inclination (TSA) or in 10 degrees of inferior tilt (RTSA). Glenoid preparation and component implantation were carried out as described above. All specimens were immediately taken for post-implantation CT scans and the deltopectoral exposure was left open. Humeral components were not placed so as to not cause metal artifact that could distort the CT scans.

After post-implantation CT scanning, deviations from intended component position in version, inclination, and starting point were determined using an automated algorithm. Post-implantation reconstructions of the scapula and components were created through standard segmentation techniques performed by technicians not involved with the implantation procedures. The automated script performed a best-fit alignment of the post-operative scapular reconstruction to the pre-operative scapular reconstruction, as well as a best-fit alignment to the postoperative implant reconstruction in 3D space. Deviations in version from the intended neutral position and/or inclination of more than 10 degrees from neutral (TSA) or 10 degrees inferior from neutral (RTSA) were considered indicative of significant component malposition.[11,17] Similarly, deviation of more than 4 mm in the starting point from the intended center point of the glenoid (TSA) or inferior starting point referenced off the inferior glenoid rim (RTSA) were also considered to be significantly malpositioned. (Figure 3).

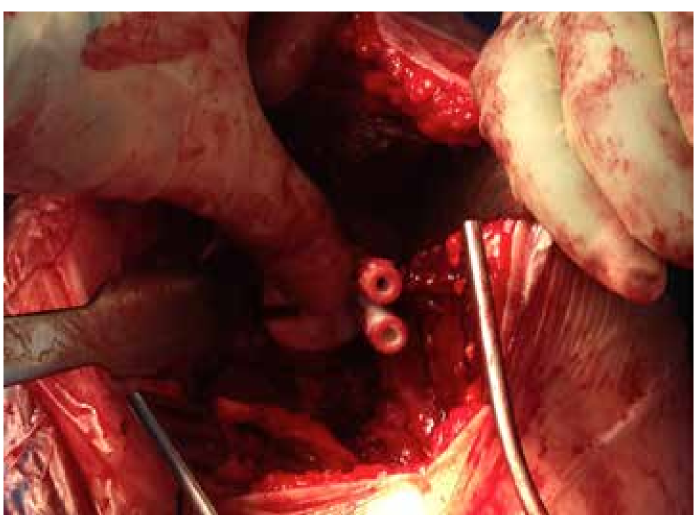

Figure 2: Application of the patient-specific targeting guide with TSA (top) and RTSA (bottom) guide-pin trajectories.

T-tests were used to detect differences in version, inclination, and starting point between patient-specific guides and standard instrumentation. Standard deviations (SD) were calculated and differences between groups were identified using folded F-tests. Analysis of component malposition in version, inclination, and starting point was performed using Fischer's exact test. Multivariate analysis of variance (MANOVA) was performed to compare the combined version and inclination vectors of standard instrumentation and patient-specific guides. Differences with $p<0.05$ were considered statistically significant.

RESULTS

The average deviation from the intended anatomic placement in version for TSA components placed with patient-specific guides was 5 degrees (SD 4.8), while implants placed with traditional instrumentation averaged 8 degrees (SD 8.2) of deviation. The average deviations from intended anatomic inclination for these components

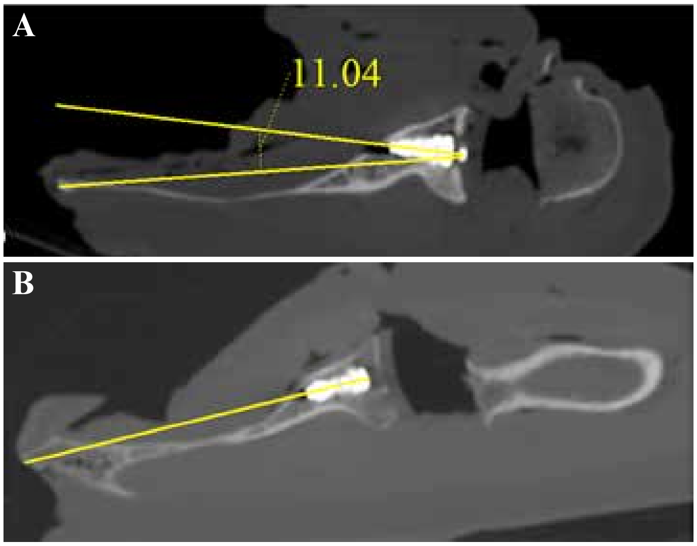

Figure 3: Post-implantation CT scans demonstrating component with 11 degrees of malposition in version using traditional instrumentation **(A)** and anatomic component placement (0 degrees of deviation) using a patient-specific targeting guide **(B)**.

were 3 degrees (SD 4.3) for patient-specific guides and 7 degrees (SD 7.9) for standard instrumentation. These differences in anatomic TSA component placement were statistically significant in version (p=0.04) and inclination (p=0.01). Deviations from the intended starting point were 2 mm for the patient-specific guides group and 3 mm for the standard group (p=0.20). The difference in standard deviation between patient-specific guides and standard preparation was statistically significant in inclination, but not in version or starting point **(Table 1)**.

RTSA components placed with patient-specific guides averaged 6 degrees (SD 7.0) of deviation from anatomic version and 4 degrees (SD 4.3) from the intended inclination (10 degrees inferior tilt), while RTSA components placed with standard instrumentation averaged 6 degrees (SD 7.4) of deviation in version and 5 degrees (SD 6.3) in inclination. The average deviation from the intended starting point was 2 mm for both the patient-specific guides and standard instrumentation. None of these differences was statistically significant **(Table 1)**.

When the TSA and RTSA groups were combined, the average deviation from intended version for patient-specific guides was 5 degrees (SD 4.5) and 3 degrees (SD 2.8) for inclination. Standard instrumentation resulted in an average of 7 degrees (SD 5.5) of deviation in version and 6 degrees (SD 4.3) in inclination. Patient-specific guides averaged 2 mm of deviation from the intended starting point and standard instrumentation averaged 3mm of deviation. The differences in version and starting point between patient-specific guides and standard instrumentation did not reach statistical signficance (p=0.17, p=0.09), but the difference in inclination was statistically significant (p=0.004, **Table 1**). Multivariate analysis of variance (MANOVA) to compare the combined vectors of version and inclination revealed a statistically significant difference in overall component accuracy favoring patient-specific guides (p=0.01).

Analysis of malpositioned components (more than 10 degrees of deviation in version and/or inclination, more than 4 mm in starting point) in the combined TSA and RTSA group revealed 6 instances of malposition for patient-specific guides and 23 for traditional instrumentation (p=0.001, **Table 2**). Eleven implants were malpositioned in version (4 patient-specific guides, 7 standard instrumentation, p=0.51).

The analysis of malpositioned components in version was stratified by the degree of pre-implantation glenoid wear. Eighteen of the 70 glenoids exhibited more than 10 degrees of glenoid retroversion (average 14 degrees). Components placed with patient-specific guides averaged 6 degrees of deviation, while traditional instrumentation averaged 11 degrees (p=0.14). In these shoulders, use of patient-specific guides resulted in 3 instances of component malposition in version (3/10), while traditional instrumentation resulted in 5 malpositioned implants (5/8) (p=0.34, **Table 3**). There were no significant differences between patient-specific guides and traditional instrumentation regarding deviations in starting point or inclination in this subset of glenoids with more severe retroversion.

In contrast, for the remaining 52 shoulders with less than 10 degrees of glenoid wear, average deviation in component version was 5 degrees for patient-specific guides and 6 degrees for standard instrumentation (p=0.47). There was one instance of component malposition using patient-specific guides and two with standard instrumentation (p=1.0).

Accuracy in component version, inclination, and starting point and instances of significant malposition also were stratified relative to surgeon experience in shoulder arthroplasty. There were no consistent trends

TSA + RTSA	Version	Inclination	Starting point	Total
Custom	4	0	2	6
Standard	7	8	8	23
p-value	p=0.51	p=0.004	p=0.31	p=0.001

Table 2: In the overall cohort, and particularly in inclination, there were significantly more instances of component malposition using traditional instrumentation than patient specific targeting guides.

TSA + RTSA	Version	Malpositioned Components (%)
Custom	6	3 (30%)
Standard	11	5 (63%)
p-value	p=0.14	p=0.34

Table 3: In glenoids with pre-implantation deformity of 10 degrees or more, components placed with patient specific targeting guides demonstrated less deviation in version with slightly fewer instances of component malposition. However, these differences did not reach statistical significance with the numbers available.

or statistically significant differences between surgeons of different volume levels according to the use of patient-specific guides or standard instrumentation.

DISCUSSION

The results of this multi-surgeon cadaver study comparing the accuracy of patient-specific targeting guides to traditional instrumentation in shoulder arthroplasty suggest that patient-specific guides place implants more accurately in version and inclination than standard techniques. This is particularly true of TSA components, where differences in version and inclination were individually statistically significant. While differences in these variables between the patient-specific and traditional groups were not individually significant for RTSA, MANOVA analysis of the accuracy in version and inclination demonstrated a statistically significant advantage favoring patient-specific targeting guides in the study overall. Further, standard deviations were narrower for components placed with patient-specific guides, though these differences only reached statistical significance regarding inclination. Patient-specific targeting guides also resulted in significantly fewer malpositioned components than traditional instrumentation. Taken together, these data suggest that patient-specific guides are not only more accurate than standard techniques, but also can prevent significant component malposition. Patient-specific guides also may be more accurate in placing implants in a targeted version in shoulders with more preoperative glenoid retroversion. However, while the 5-degree difference in accuracy and the 33% fewer instances of significant component malposition favored patient-specific guides in this subset, these differences did not reach statistical significance with the numbers available. Although we believe that these differences are clinically significant in preventing component malposition, adequately powered cadaver and clinical studies of glenoids with increased preoperative retroversion are necessary to confirm this supposition.

Other authors have studied the use of patient-specific instrumentation in shoulder arthroplasty. Iannotti et al.[17] used 3 dimensional planning software to create 9 patient specific bone models to improve guide pin positioning by surgeons of varying experience levels. In these pathologic bone models, the 3-D surgical planning and reusable positioning tool both improved guide pin placement over standard instrumentation. These results using bone models are similar to our findings in an arthritic cadaver model. Suero et al.[29] reported their results using a patient-specific jig based off of CT scanning in 7 shoulders. They concluded that the patient-specific jig was a reliable guide for both TSA and RTSA placement. In a larger clinical study, Hendel et al.[11] compared the use of patient-specific guides to traditional instrumentation in 31 shoulders undergoing anatomic TSA using a randomized model. They found an overall average of approximately 7 degrees of deviation in version using traditional instrumentation versus 4 degrees in the patient-specific group. Further, there was a statistically significant advantage to patient-specific guides regarding inclination and medial-lateral offset. As in this study, the advantage of patient-specific guides was more pronounced in shoulders with higher preoperative glenoid retroversion. In these shoulders, Hendel et al found a statistically significant difference in version favoring the patient-specific guides. These clinical findings closely follow the results we found in our model. However, our studies differ in that the work of Hendel et al. involved only experienced surgeons familiar with the glenoid targeting system and was exclusive to anatomic total shoulder arthroplasty. In contrast, this study involved surgeons of varying experience levels who were unfamiliar with the guidance system and included both anatomic TSA as well as RTSA.

Advantages of this study include its randomized, adequately-powered design, which lends credence to the statistical analysis. Also, the use of multiple surgeons of differing experience levels who were not on the design team of the patient-specific guidance system allowed us to analyze that variable referable to the use of patient-specific guides. We found no advantage to surgeon experience in narrowing the differences in component accuracy or the number of malpositioned components. Rather, patient-specific guides appeared to be equally helpful for surgeons of all levels in these specimens. Finally, the use of shoulders with radiographically documented arthritic changes closely simulated the clinical setting.

As with all cadaver models, however, this study can only approximate the clinical scenario, not replicate it. The presumed long-term advantage of targeting guides is that correct component position will result in improved implant longevity. Clearly, this cannot be proven with a cadaver model, only with long-term clinical studies; however, the biomechanical and clinical consequences of component malposition in shoulder arthroplasty are well-known.[4,5,10,13,15,21-23,26,28,31] The inaccuracy of traditional instrumentation also has been reported, particularly with severe pre-operative glenoid erosion, suggesting the need for more accurate methods of glenoid component placement.[8,9,18]

CONCLUSION

In summary, we found patient-specific targeting guides to be more accurate with fewer instances of significant component malposition than traditional instrumentation in placing shoulder arthroplasty components. This suggests that patient-specific targeting guides are a promising tool to improve component position in shoulder arthroplasty, but the results of this cadaver study must be confirmed by highly powered, long-term clinical trials.

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Distal Femur Replacement for Acute Distal Femur Fractures in Elderly Patients

ABSTRACT

Objectives: To evaluate outcomes and complications utilizing cemented modular distal femoral replacement in elderly patients with distal femoral fractures.

Design: Retrospective chart review, case series.

Setting: Level 1 trauma center, tertiary referral hospital

Patients/Participants: Eighteen patients over 60 years of age (average age 77 years) who had cemented distal femoral replacement for distal femoral fractures (comminuted, intraarticular, osteoporotic, arthritic) between 2005 and 2013. Patients with prior knee surgery were excluded.

Intervention: Cemented modular distal femoral replacement.

Main Outcome Measures: Implant status, complications, Knee Society Score, Musculoskeletal Tumor Society (MSTS) score, and Western Ontario and McMaster Osteoarthritis Index (WOMAC).

Results: All patients were extremely or very satisfied with their outcomes. For patients with functional outcome data, knee score averaged 85.7 with a functional score of 35, MSTS score averaged 19.2, and WOMAC score averaged 23.1 at an average follow-up for 2.3 years. Range of motion was 1 to 99 degrees. Implant related complications occurred in two patients (11%); one required revision to total femoral replacement because of periprosthetic fracture and one had a deep infection that required exchange of the components. No patient had aseptic loosening or patellar maltracking. There were no perioperative deaths or late amputations.

Conclusions: Cemented modular distal femoral replacement is a viable treatment option in elderly patients that enables immediate full weightbearing with most patients returning to preoperative functional status.

Level of evidence: Level IV, case series

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A Mechanical and Histologic Comparative Study of the Effect of Saline, Steroid, Autologous Blood, and Platelet-Rich Plasma on Collagenase-Induced Achilles Tendinopathy in a Rat Model*

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ABSTRACT

Background: Reported results from clinical studies of platelet-rich plasma (PRP), autologous blood (AB), and steroids in the treatment of tendinopathy have varied considerably and direct comparisons of these treatment methods are lacking.

Methods: After the use of collagenase to induce an achilles tendinopathy, 160 Sprague-Dawley rats were divided into four treatment groups (injections with AB, PRP, steroid, and phosphate buffered saline) and an untreated control group. Load to failure testing was performed on 85 specimens harvested at 14 days, and histological analysis was done at days 3, 7, and 14 after injection (75 specimens).

Results: Tendon strength was found to be decreased in three of the four treatment groups as compared to controls. The AB group appeared to have an increase in strength that approached but did not attain statistical significance. At days 3 and 7, there were no significant histological differences between any of the observational categories, including controls. At day 14, structure of fibers adjacent to the induced tendinopathy site demonstrated significantly more order than control tendons.

Discussion: We found no significant difference in tendon strength among treatment groups, although the AB group had the greatest load-to-failure value. The PBS and PRP groups had statistically lower load-to-failure values. Only the structure of the tendon adjacent to the collagenase injection site showed a statistical difference between the AB and the control and saline groups. Further studies are needed to evaluate the response, safety, and efficacy of this intervention prior to use on human subjects.

Keywords: Achilles tendon; autologous blood; platelet-rich plasma; rat model; saline; steroid

Conflicts of Interest and Source of Funding: This study was supported by a grant from the American Foundation for Surgery of the Hand.

Acknowledgement: The authors gratefully acknowledge the assistance of David Komatsu, PhD, in the pilot project and histological aspects of the project.

INTRODUCTION

Tendinopathy is a frequent source of pain and disability in individuals of all ages and activity levels. Initial treatment is almost always conservative with activity modification, but a variety of other methods have been used including parenteral medications and injections. Corticosteroid injection has historically been used for the treatment of various tendinopathies, although some argue that anti-inflammatory medications are ineffective because tendinopathy actually may not be an inflammatory process. More recent treatments of tendinopathy include autologous blood (AB) and platelet-rich plasma (PRP) injections, both termed "regenerative" substances because they contain high concentrations of growth factors needed for healing.[1] Although there have been a number of clinical trials involving the use of these substances, there are few studies investigating their effects on the actual strength and structure of the tendon.[2,3] The purposes of this study were

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* Accepted to *Current Orthopaedic Practice*. Citation not yet available.

Figure 1: Harvested Achilles tendon.

to quantitatively and qualitatively analyze the effect of three different treatments on a collagenase induced tendinopathy in an animal model.

Using a rat model of collagenase induced Achilles tendinopathy, we compared mechanical strength and histological findings after AB and PRP injections to those after injection of steroid and phosphate buffered saline and in untreated control animals. This animal model is commonly used to evaluate healing in response to various treatments.[4,5,6] We hypothesized that AB and PRP would be more effective in the treatment of tendinopathy than corticosteroid.

MATERIALS AND METHODS

Animal experiments were performed in accordance with relevant national and international guidelines and were approved by the authors' Institutional Animal Care and Use Committee (IACUC). A total of 160 3-month old Sprague-Dawley rats were used to test the hypothesis that both AB and PRP injections would result in superior mechanical strength and histological findings as compared to steroid injections and untreated controls following the aforementioned collagenase induced Achilles tendinopathy model. At the age of three months, the animals are considered skeletally mature. All injections were done with 30 gauge needles mounted on 0.5 ml syringes after light general anaesthesia was induced in an isoflurane chamber. Each rat weighed approximately 250 g, and an oral 780 microliter dose of children's Tylenol (32 mg/ml) was calculated from a recommended administration of 100mg/kg and given for post-injection discomfort.

After sterile preparation with Betadine and alcohol, Sigma C 1639 histolyticum collagenase type 1-S (Sigma-Aldrich, St. Louis, Missouri; lot number 090m8609V, 10mg/ml) was injected percutaneously with a 30 gauge needle around the Achilles tendon, 1.0 cm proximal to its insertion. This collagenase is specific for type 1 collagen. The collagenase injection volume was 30 microliters, a previously reported experimental dose in other studies.[7] No animals were observed to exhibit signs of pain requiring additional pain medication. The rats were randomized into 5 groups and on the third day after collagenase injection, 4 groups were injected with phosphate buffered saline (PBS), corticosteroid, AB, or PRP using the same induction protocol; the 5th group served as controls and received no further injections. One donor rat was exsanguinated and served as the source for the PRP and AB. The PRP was then

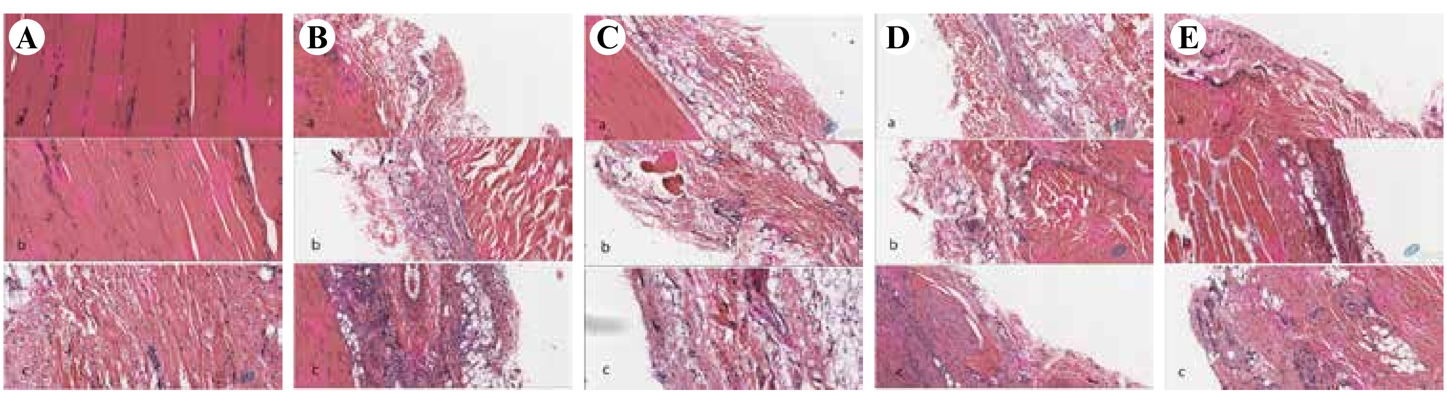

Figure 2: Representative histological slides. **A**, Intratendinous fiber alignment: normal (a), intermediate (b), severely disorganized (c). **B**, Surface reaction: mild (a), moderate (b), marked (c). **C**, Adjacent fiber alignment: normal (a), intermediate (b), severely disorganized (c). **D**, Adjacent tendon cellularity: mild (a), moderate (b), marked (c). **E**, Surface collagen deposition: scant (a), moderate (b), dense (c).

prepared by whole blood centrifugation at 160xg for 20 minutes, plasma centrifugation at 400xg for 15 minutes, and subsequent removal of the platelet poor plasma to obtain a platelet concentration 3 times that of whole blood. The white blood cell concentration of the PRP was not assessed. The steroid injection consisted of 0.2 mg of Depo-Medrol (methylprednisolone) and saline. All injections were 30 microliter volumes. These concentrations are similar to other studies evaluating tendinopathy healing in animal models.[8]

Animals were then sacrificed by CO2 inhalation and bilateral pneumothorax: five animals per group at day 3 (25 animals), 5 animals per group at day 7 (25 animals), and the remaining animals at day 14 (110 animals). Our time points of 3, 7, and 14 days were modeled after a similar study, which concluded that by day 14 after collagenase injection, the quantity of inflammatory cells had returned to pre-injury values.[4] Treated and untreated Achilles tendon specimens were carefully dissected to include the proximal calf muscles and distal calcaneal attachments **(Figure 1)**. Specimens for histological analysis were placed in ice cold 10% formalin, and those for mechanical testing were placed in saline soaked gauze and then stored and shipped for analysis at -20 degrees C.

Biomechanical analysis was performed on 17 specimens from each group of animals whose tendons were harvested at the 14 day time point (85 specimens). The

Score/Category	1	2	3
Intratendinous Fiber Alignment	Normal	Intermediate	Disorganized
Tendon Surface Reaction	Mild	Moderate	Marked
Adjacent Tendon Fiber Alignment	Normal	Intermediate	Disorganized
Adjacent Tendon Cellularity	Mild	Moderate	Marked
Surface Collagen Deposition	Scant	Intermediate	Dense

Table 1: Histological grading scale and description

		Cell Count ǂ	Fiber Alignment	Surface reaction	Adjacent tendon fiber alignment	Adjacent tendon cellularity	Surface collagen deposition
DAY 3	C	119.24	1.82	1.98	2.09	1.75	2.08
	PBS	91.80	2.30	2.18	2.43	1.75	2.15
	STER	123.07	2.16	1.82	2.05	1.45	2.07
	PRP	118.11	1.83	2.33	1.98	1.93	2.04
	AB	132.53	1.85	2.28	2.19	1.47	2.03
DAY 7	C	123.81	1.83	1.92	2.08	1.61	1.83
	PBS	113.73	2.38	2.05	2.25	1.78	2.05
	STER	111.72	1.71	2.08	1.94	1.50	2.23
	PRP	120.72	2.00	1.81	2.34	1.44	2.25
	AB	139.52	1.93	1.93	2.00	1.73	2.23
DAY 14	C	110.07	1.70	1.85	2.28	1.90	2.08
	PBS	103.89	1.81	2.17	2.21	2.02	1.81
	STER	121.71	1.83	1.82	1.92	1.60	1.84
	PRP	123.40	1.67	1.70	2.03	1.56	2.13
	AB	118.95	1.67	1.93	1.54*	1.58	2.07

C = control, PBS = phosphate buffered saline, STER = steroid, PRP = platelet-rich plasma, AB = autologous blood.
ǂ Cell count = average number of cells observed on high-power (20X) view.
*Statistical significance (lower than control or PBS injected)

Table 2: Grading Characteristics, Histological Samples (Means)

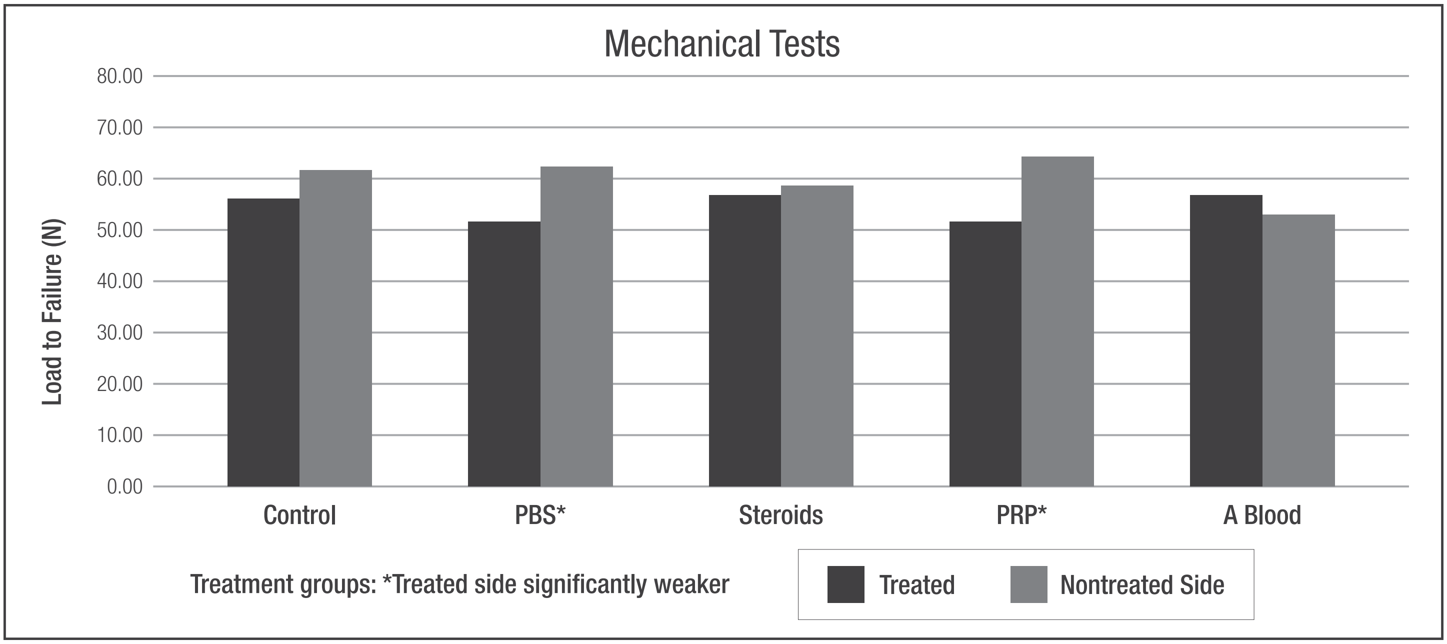

Figure 3: Average load-to-failure, treated vs. untreated tendons

specimens were thawed and secured to a loading machine (Instron Model 1122) using clamps with gauze wrapped around the free ends to decrease tendon slippage. Preconditioning of the samples after slack removal was performed with 5 consecutive cycles of 5 percent clamp to clamp displacement. 25 seconds of stress relaxation was allowed, and then the tendons were loaded to failure at a rate of 10 millimeters per minute. The maximal load in Newtons (N) on the tendon prior to failure was recorded. Both the injected (I) and non-injected limbs (UI) were subjected to the same mechanical testing.

Histological analysis was performed on 5 animals in each of the 5 study groups at days 3, 7, and 14 days after injection (75 animals). Standard hematoxylin and eosin (H&E) staining and slide preparation was perfomed, and the slides were digitized. A portion of the sample on the slide considered to represent the overall histological features of each specimen was selected by a researcher not directly involved in the study. These specimens were then graded by the study group consisting of one orthopaedic attending and three orthopaedic residents; all were blinded to the treatment groups. Both intratendinous and tendon surface characterizations included cell counts, fiber alignment, and collagen deposition at various points within and on the surface of the tendon at 20x magnification **(Table 1 and Figure 2).** Variability was controlled by preparing a document displaying the observational categories with a histological example of each possible rating. This information was available to the four raters throughout the rating process in an effort to establish uniformity in the process.

Unpaired, two tailed student's t tests were used to compare means for both the mechanical and histological data. A post hoc ANOVA analysis and Tukey's honest significant difference test were also performed to compare results between and within treatment groups for the histological data. Fleiss' Kappa was used to calculate interobserver reliability between the raters at all time points for the histological data.

RESULTS

Mechanical

The loads to failure (N) averaged 57.3 for the control group, 51.9 for the PBS group, 56.2 for the steroid group, 46.7 for the PRP group, and 60.1 for the whole blood group. When compared to untreated tendons, results were significant only for the PBS (p=0.028) and PRP (p=0.012) groups, as depicted in **Figure 3**. Interestingly, the only group that appeared to have an increase in tendon strength was the AB group; this result approached, but did not attain, statistical significance.

Histological

Histological data were organized by day sacrificed and subdivided by treatment group, with mean results shown in **Table 2**. Each group's grading characteristics were then compared to the other groups by day sacrificed. At days 3 and 7, there were no significant differ-

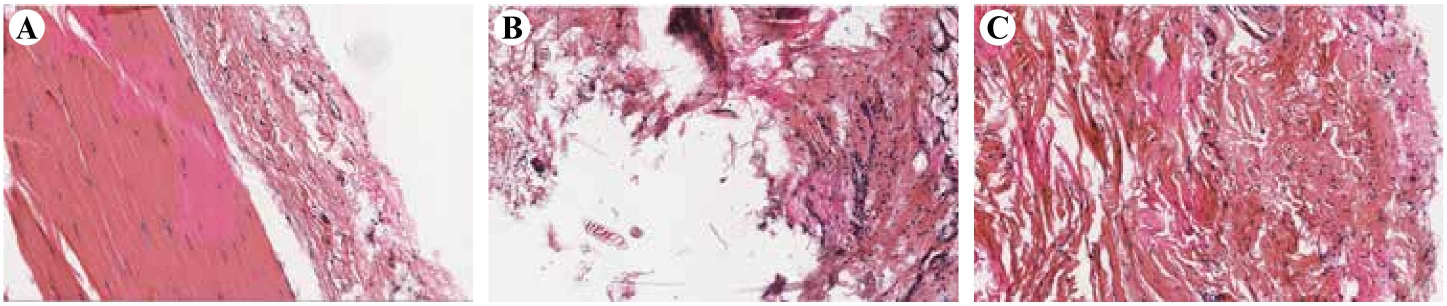

Figure 4: At day 14, AB group **(A)** demonstrated more ordered adjacent fiber alignment than control **(B)** and PBS **(C)** groups.

ences within or between the experimental and control groups. However, the animals sacrificed on day 14 who were treated with AB had near normal surface tendon alignment as compared to those animals treated with saline or control (p=0.031 and 0.043, respectively). These differences in adjacent tendon fiber alignment reached statistical significance. The AB group clearly demonstrated more improvement and order in fiber alignment than the saline and control groups **(Figure 4)**, but there were no significant differences observed on comparison of AB to steroid or to PRP. With the exception of adjacent fiber tendon alignment in the AB group to saline and control, the other groups' differences in histological grading characteristics did not obtain statistical significance.

DISCUSSION

Chronic tendon disorders are a common cause of pain and activity limitation in patients of all ages and activity levels. A number of interventions have been used in the treatment of these disorders, ranging stepwise from exercise protocols to surgery. Our study aims to evaluate the effect of three different treatments on an induced tendinopathy in an animal model in an effort to advance understanding of this controversial topic.

This study compared the results of three treatments for the treatment of achilles tendinopathy in an animal model. Autologous blood injection appeared to improve tendon strength and promote a more substantial histological response, while PRP and steroid treament seemed to weaken tendons while not producing a significant histological improvement.

Category	N*	*K*
Fiber alignment	93	0.36
Surface reaction	183	0.30
Surface - adjacent tendon fiber alignment	134	0.23
Surface - adjacent tendon cellularity	136	0.08
Surface - collagen deposition	197	0.10
*n = number of samples for which we had complete data from all four observers.		

Table 3: Interobserver reliability

Clinical studies using an ultrasound-guided technique with autologous blood have suggested improved results in patellar tendinosis,[9] medial epicondylitis,[10] and lateral epicondylitis.[11,12,13] Results of 60 patients randomized to either steroid or AB were found to favor AB in Nirshl scores, grip strength, and limb function at 8 weeks.[12] When PRP was compared to steroid injections, Peerbooms et al. found over 70% improvement in pain and DASH scores compared to about 50% in the steroid group.[14] Mishra et al. reported 60% success in PRP-injected patients compared to 16% with bupivacaine,[15] and Creaney et al reported a success rate of 66% with PRP compared to 72% with AB for refractory tennis elbow despite twice as many conversions to surgery in the AB group.[2] In contrast, Thanasas et al. found better results in refractory tennis elbow when patients were treated with PRP rather than AB.[3] Wolf et al. found neither AB nor steroid more beneficial at 6-month follow-up than placebo saline in a randomized prospective multicenter study involving 28 patients with lateral epicondylitis.[16] Similarly, de Jonge et al found no difference between PRP and saline in Achilles tendinopathy patients (59% satisfaction both groups) and similar degrees of tendon structure improvement.[17]

The variations in clinical outcomes are not surprising. Both patient and tendinopathy variability make intervention outcomes confusing. Moreover, well-performed studies with all treatment interventions, including suitable controls, have not been performed. Patient stratification according to age, disease duration, severity, vocational and avocational levels, activity, comorbid factors, and coping mechanisms greatly complicates comparative studies. Additionally, the traditional definition of tendinopathy being strictly an inflammatory process has been recently challenged. Current literature describes two independent physiologic processes and their interventions: inhibition of inflammation by steroids and other anti-inflammatory treatments, and promotion of healing through increased concentration of growth factors.[1] Thus, animal experimentation to evaluate the response to various treatments may help guide treatment.

The rat Achilles tendon has been used as a model for studies of AB and PRP.[18,19,20,5,6] While often used in literature, this tendinopathy model has the advantage of wide acceptance and ease of dissection and treatment administration. However, continued use of this model may provide a standardized baseline across studies with different treatments for future comparison. Findings from animal studies, however, also have been equivocal as to the effect of these substances on tendon strength and structure, and we found no comprehensive study directly comparing injections with the different substances (AB, PRP, PBS, and steroid).

There were several shortcomings in the study methods. Although each animal was injected by the same person in the same general area, the specific injection site was not known. The intent was to inject the collagenase around the Achilles tendon, but the specific site of injection was variable, the extent and duration of tendon exposure to the collagenase was not known, and the potential for and investigation of any tendon trauma induced by the 30-gauge needle was unknown. While other studies have used similar doses of collagenase,[8] this dose may have been too low to induce a true tendinopathy. However, the fact that the control animals continued to have histological evidence of tendinopathy at day 14 reveals that the AB treatment did have an effect on restoring the tendon to pre-tendinopathy structure. For the histological ratings, interobserver reliability was only slight to fair in all categories **(Table 3)**. Additionally, the Achilles tendon in a small animal model is structurally different from tendons in the human hand.[21]

We believe our results indicate that AB injection may be a more effective treatment to improve tendon strength and structure following tendinopathy than other injectates tested. Continued basic science research and large, randomized clinical studies are needed to further evaluate this potentially beneficial treatment.

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Development of Fluorescent Arthroscopy for Early Detection of OA and Cartilage Injury

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STRUCTURED ABSTRACT

Background: Osteoarthritis (OA) is the most common form of joint inflammation and leads to a progression of articular cartilage degeneration and loss of joint function. Unfortunately, there is no method for detection and evaluation of this condition in the early stages when pharmacological and biological intervention could be most effective. To identify early stages of cartilage degeneration, we have developed a fluorescent method for investigation of early changes in the cartilage matrix that can be used in vivo in small animals and translationally in larger joints through the development of fluorescent arthroscopy.

Methods: We have used fluorescent monoclonal antibody to type II collagen to identify damaged articular cartilage using IVIS optical scanners in vivo in the post-traumatic osteoarthritic model of knee overload in mice. Additionally, we have adapted near-infrared fluorescent endoscopes for arthroscopic purposes, to examine damaged articular cartilage from the pig knee.

Results: Our results shown that the antibody-targeted fluorescent probe can detect early damage on the articular surface of cartilage in the post-traumatically injured mouse knee and the amount of fluorescent probe can be quantitatively measured in vivo. In parallel, the fluorescent antibody can be shown to localize to cartilage injuries in the knees of domestic pigs using a fluorescent endoscope adapted for arthroscopic use.

Conclusion: A fluorescent antibody reagent that binds selectively to exposed type II collagen in damaged articular cartilage can be shown to detect early changes in a mouse model of post-traumatic osteoarthritis. In addition, a fluorescent endoscope visualized articular cartilage damage in the pig knee with ICG-labeled antibody, offering a promising potential for fluorescent arthroscopy in clinical

Clinical relevance: This technique offers promise for its translation for clinical diagnosis and applied research for cartilage resurfacing.

Keywords: Osteoarthritis, Cartilage degeneration, Type II collagen antibody, Fluorescence imaging, Fluorescent arthroscopy

INTRODUCTION

Osteoarthritis (OA) is the most common form of joint inflammation in the US and is an increasingly large burden on the American healthcare system1. Approximately 27 million Americans have been diagnosed with this condition. The economic burden increased by 46% between 1990 and 2010 and is anticipated to continue to increase in both absolute and relative terms[2,3]. It is also a major contributor to back pain that is the most prevalent and costly musculoskeletal problem in all developed nations. OA develops as a result of a combination of genetics, aging, trauma, obesity and possibly other as yet unidentified metabolic abnormalities[4]. In younger individuals trauma from accidents, sports injuries, or repetitive stress injuries may lead to the development of premature joint degeneration (post-traumatic osteo-

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arthritis; PTOA)[5]. This is particularly true for knee injuries. Although the problem involves the entire joint and is multifactorial, OA is considered to be primarily an abnormality of cartilage by most experts[6,7]. It begins at the superficial layer and gradually involves deeper layers of the articular cartilage eventually exposing subchondral bone[8,9]. Although cartilage is avascular and is not directly innervated, pain is a significant component of the process and most current therapies are directed primarily at relieving pain[10]. Early detection and treatment of this condition could delay the progression of the disease through the use of physical therapy, bracing, correction of mechanical abnormalities and joint protection. Such measures would relieve the personal and financial burden to some extent[3,7]. Unfortunately, there are currently no established pharmacologic approaches to preventing progression. One obstacle for the development of such therapies is the lack of adequate diagnostic tools for efficiently detecting early stages of cartilage damage and establishing a rate of progression that can be used in the evaluation of experimental approaches[11,12]. To some extent it may be advantageous to use OA animal models for sequentially monitoring disease progression[5,13]. However, the use of OA animal models is also limited by a lack of nondestructive measurement tools. The most widely used approach to diagnosis, is through determination of cartilage thinning as measured in weight-bearing radiographs of the knee[14,15]. This approach suffers from both a lack of sensitivity and specificity. Magnetic Resonance (MR) imaging is useful and is both more sensitive and specific when high field strength scanners and advanced imaging protocols are employed. It is expensive and studies of its use in prognostic longitudinal studies of outcomes are lacking probably due to the expense and the availability of such advanced protocols[16,17].

We have developed an alternative to x-ray imaging based on an understanding of the pathophysiology of the disease process. Joint cartilage consists primarily of type II collagen (CII) and proteoglycans. The collagen provides structural integrity and the proteoglycans contribute to elasticity and compressibility primarily through their ability to trap water[18.] In the earliest stages of OA there is degradation and loss of the glycoproteins and proteoglycans on the surface of the cartilage that exposes the underlying CII fibrils[18,19]. As the lesion enlarges, more CII is exposed. In a previous study, we reported on the development of highly specific monoclonal antibodies (Mab) that can bind to the exposed CII (MabCII), but do not bind to other types of collagen and do not bind to normal cartilage[20,21]. These MabCII can be directly attached to fluorescent molecules or to liposomes that have incorporated fluorescent or other labels. We have shown that these antibodies bind to early osteoarthritic knee cartilage in an animal model of spontaneous osteoarthritis that develops in Dunkin Hartley guinea pigs. The binding can be detected by measuring fluorescence of an associated probe and can be quantitatively correlated with disease progression as measured by the histopathological score[22]. We now report the diagnostic efficacy of these antibodies in a mouse model of post-traumatic osteoarthritis (PTOA). Using mice has several advantages over the use of guinea pigs as described in our early experiments. Mice are less expensive to obtain and maintain, there are more and better-characterized reagents for analysis and their genetic background is more easily manipulated. Mechanical loading of the mouse knee has been described by others[23,24,25]. This model uses repetitive stress on the knee three times weekly. The mice show an initial lesion after two-weeks that progresses over a 5-week interval to advanced OA[23,24]. We believe that this model provides a valuable resource to researchers for investigating arthritic progression since it is reproducible, involves only external manipulation, and can be varied both in the intensity of the loading, its frequency, and its duration to achieve the desired endpoint. For our preliminary studies in vivo, we have injected fluorescent MabCII antibodies to identify early OA using an IVIS imaging system to localize these antibodies in the knee joint. This system allows non-invasive scanning of whole mouse knees[22]. It functions well because the shallow depth of the involved knee joints allows light to penetrate the joint and be externally detected. However, for larger joints that would be more equivalent to those of human patients, the light would not be sufficient to be easily detected using current technology.

In addition to the use of the mouse animal model, we were also interested in other approaches that might be applicable to human subjects[23,24]. Arthroscopy is a common procedure for visualization, diagnosis, and treatment of intraarticular cartilage injuries. With the aid of a miniature camera linked to the arthroscope, the surgeon can not only visualize the inside of the joint and examine the bones, cartilage, and ligaments of the knee but also image the observed structures for permanently storing data regarding the lesions detected[17]. However, conventional arthroscopy cannot visualize the molecular or structural changes that are present in articular cartilages and is limited in its ability to establish and quantify the early stages of OA[26]. In this study, we develop the experimental groundwork that will serve as a foundation for the development of fluorescent arthroscopy for approaching the question of what constitutes a detectable lesion and to what extent can endogenous mechanisms repair lesions. Thus, for these studies, we have utilized near-infrared fluorescent endoscopes adapted for arthroscopic purposes and the FDA approved near infrared dye Indocyanine Green (ICG) in the joint space of a pig knee to diagnose proteolytically damaged articular cartilage.

MATERIALS AND METHODS

Preparation and Characterization of Fluorescent Antibodies to Type II collagen

We have described the generation and characterization of the MabCII used in this experiment previously[27]. Briefly, mice were immunized with CII, splenocytes harvested and fused with SP2/0 cells. When clonally diluted antibody producing cells were expanded an immunoassay was performed to assess specificity. We were able to identify an antibody that had strong immuno-reactivity with native CII. Further characterization of this antibody established that it recognized an epitope on CII within the CB11 region that consisted of peptide amino acids 124-290[27]. We grew the antibody producing cells in culture and purified the antibody they produced by affinity chromatography on Protein A Sepharose. Purified antibody was then coupled with a fluorescent dye (Perkin Elmer Xenolight CF680 or ICG from AAT Bioquest Inc, CA) according to the manufacturers recommended protocol. Briefly, the purified MabCII dissolved in phosphate-buffered saline (PBS) and concentrated in a Microcon 50 k molecular weight cut-off concentrator (Amicon, Bedford, MA). The MabCII concentration was set to 1mg/mL by volume adjustment with PBS containing 0.1M sodium bicarbonate. The Xenolight CF680 (0.1 uM) or ICG (2mg/ml) in DMSO was added to MabCII solution. After the reaction mixture was incubated at room temperature for 1 hour, the fluorescently labeled MabCII was isolated using the Microcon (Amicon, Bedford, MA) or Sephadex G-25 column (Amersham Pharmacia AB, Uppsala, Sweden). The details of antibody coupling with fluorescent dye and the characterization of the resulting compound is described in Cho et. al.[22]. MabCII is of the isotype IgG2A and for isotype control experiments we used an antibody (MabCont) of the same subclass from R&D Systems (Mouse IgG2A Isotype Control, Clone 20102, Minneapolis, MN).

Animal Model

Mice with mechanical loading to induce PTOA: The C57BL/6 male mice were obtained from the Jackson Laboratory (Bar Harbor, Maine, USA). Animals were kept in a housing facility for a 1-2 week acclimation period before experimentation was begun. All procedures, in this study, were performed according to approved protocols and experimental procedures of IACUC at the University of Tennessee Center for the Health Sciences. Mice were used when their body weight was approximately 20g. The left knee joint of each mouse received 40 cycles of compressive loading at 9 N, three times weekly over a period of two weeks[24]. The load was administered with a static offset load of 2N to maintain contact between the specimen and the load cell. During mechanical loading, mice were continuously anesthetized using 2% isoflurane. After loading, the mouse was allowed normal cage activity and any abnormal behavior, weight loss or a diminished food intake, was monitored. At intervals after loading we injected fluorescent MabCII for detection of OA lesions in the damaged cartilage. In some experiments the fluorogenic enzyme substrate MMPSense (Perkin Elmer, Hopkinton, MA) for measurement of the matrix metalloproteinases that are responsible for degradation of the cartilage matrix components28. Both fluorescent probes were quantified by the IVIS imaging system at 18-24 hours after their injection.

Quantification of fluorescence and comparison with histologic evaluation: After the last loading interval, mice were injected retro-orbitally with 80ul of solution containing 40ul XenoLight CF680 (Perkin Elmer, Hopkinton, MA) conjugated to MabCII or the control antibody (MabCont) plus 40ul of MMPSense750. At 24 hours after the injection of the labeled probe, the mice were anesthetized, depilated and scanned using the IVIS imaging system (IVIS® Lumina XR System, Perkin Elmer, Hopkinton, MA) with a mid-high range filter set (excitation 675nm, emission 720 nm) and the fluorescence remaining in each knee joint was quantified using Living Image 4.0 software to calculate the region of interest (ROI). Emission fluorescence was graphed as radiant efficiency (photons/sec/cm2/str)/(μW/cm2). To yield a standardized ROI for measurement of the knee fluorescence, the same area of capture was used

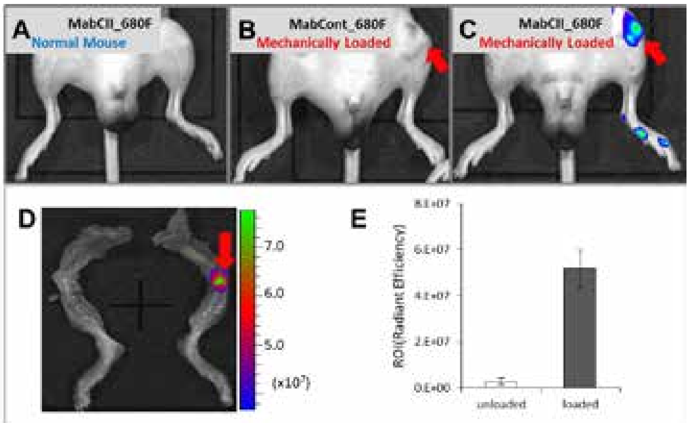

Figure 1: Fluorescent MabCII localizes specifically to mechanically loaded joints. Mice were injected retro-orbitally with either fluorescently labeled or control antibody and were subjected to in vivo optical imaging 24 hours later. No activity was detected in normal mice (A). Mice where one knee was mechanically loaded at 9N three times a week for 2 weeks and who received fluorescent control antibody (MabCont) also failed to show localization of the label (B) Only mice who were both mechanically loaded and received labeled MabCII demonstrated localization of the label (C). To confirm that the localization was specific to the knee joint, the hind limbs were removed and dissected free of skin and connective tissue and then re-scanned (D) For quantification, the ratio of fluorescence (radiant efficiency) emitted from the unloaded contralateral knee vs. the loaded knee is calculated (E).

for each mouse. After IVIS imaging, the mice were euthanized, and their hind limbs removed and the knees were dissected free of skin and surrounding connective tissue. The femoral, tibial, and patella portions were reimaged separately by IVIS. The knees were then fixed in 10% formalin solution, decalcified with Decalcifying Solution (Thermo Fisher Scientific, MA), embedded in paraffin, and sectioned. The histological sections were stained with H&E and analyzed by an observer who was unaware of the IVIS results.

Detection of early OA by fluorescent arthroscopy: The knee joints used in this investigation were obtained from 3-4 month old domestic pigs. All tissues were taken from healthy pigs that were freshly euthanized for other experiments according to approved protocols and experimental procedures at the University of Tennessee Health Sciences Center. Knee joints from pigs ranging from 30 to 50 kg were carefully dissected free of skin and connective tissue to enable visualization of the medial and lateral femoral condyles. In order to expose the CII, a surgical scalpel (Bard-Parker) was then used to introduce a lesion on the articular cartilage surface by lightly scraping. Then 100 µL of MabCII conjugated with Indocyanine Green (ICG) was then added to the joint space, mixed with the residual synovial fluid and was allowed to incubate for 10 minutes at 37 °C. After incubation, the cartilage surfaces were washed thoroughly with saline in order to flush out unbound MabCII-ICG. Using a Novadaq Pinpoint Fluorescence Imaging system (Ontario, Canada) with a laparoscopic camera, the joint was then visualized with white light, and the area of cartilage damage was brought into view. The laparoscope was then set to a specific near-infrared mode for detection of fluorescence, followed by a subtractive mode analysis used for detecting contrast when viewing ICG.

SOURCE OF FUNDING

This work supported with resources and the use of facilities at the Veterans Affairs Medical Center (VAMC) at Memphis TN USA. This research was supported by a VA Merit Review award from Department of Veterans Affairs, an R21 from National Institutes of Health (AR060408) and Maturational Funds from UTRF (Karen A. Hasty, PI)

RESULTS

With the PTOA model in mice, the knees of mice that have been repetitively mechanically loaded showed distinct localization of the fluorescent antibodies to the loaded knee and ankle while the contralateral side did not show any significant amounts of fluorescence **(Figure 1)**. The MabCII antibodies appeared to specifically localize to the damaged knee cartilage as determined by analysis of the isolated joint components **(Figure 1C)**. In all of the experiments control antibodies that had been similarly labeled and injected did not localize in mechanically loaded knees or ankles **(Figure 1B)**. Normal mice injected with the fluorescent MabCII antibody did not show any fluorescent localization in the knee joints. Quantitative measurements made by optical scanning of the fluorescent antibody in the loaded knees showed a twenty-fold increase in fluorescence over that seen in the contralateral control knees.

Histopathological analyses confirmed that the superficial layer of the articular knee cartilage of the tibia was roughened **(Figure 2)** compared to the contralateral knee and had lost Safranin O staining (data not shown). It is unclear if this was due to direct contact and abrasion by the opposing femoral cartilage or whether it was a manifestation of degenerative changes initiated within the cartilage that resulted in proteolysis of the extra-

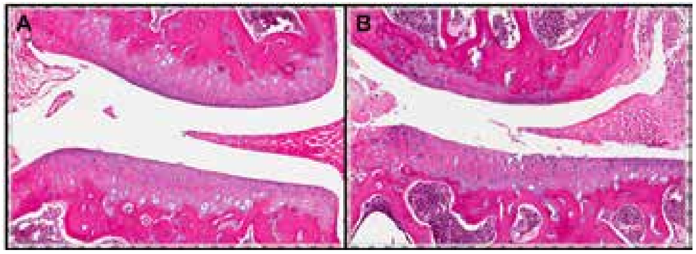

Figure 2: Histopathology of control and mechanically loaded knees. In order to confirm that intermittent loading of the knee joints resulted in histologic changes consistent with OA, we obtained knees from mice after they had been loaded for two weeks. Knees were harvested, dissected free of connective tissue, fixed and decalcified as described in Methods. After imbedding knees were sectioned and stained with hematoxylin and eosin. A frontal section of the medial condyle in the knee that was not loaded showed a normal cartilage surface (A) whereas the loaded knee showed a roughened articular surface with early fissuring consistent with the development of OA (B). Magnification for figures A and B is 10X.

cellular matrix components. To investigate the level of matrix metalloproteinases that were present at this time, mechanically loaded mice were simultaneously injected with both fluorescent antibodies to type II collagen labeled with XenoLight 680 as well as the fluorogenic substrate MMPSense that reads at a wavelength of 750. Both types of fluorescent labels co-localized in the mechanically loaded knee joint, but were not observed in the contralateral control knee **(Figure 3)**. This confirms that activated matrix metalloproteinases are present in the mechanically loaded knee joints and supports that these enzymes contribute to the unmasking of the type II collagen epitope.

While the PTOA mouse model offers many advantages for studies of genes and pharmacological interventions that might influence the development of OA, studies of cartilage re-surfacing and tissue engineering require larger joints that allow surgical manipulation. Therefore, we have re-purposed a fluoroscopic endoscope to utilize the fluorescent probes that we are using in the mouse model to a more clinically equivalent model in the domestic pig knee. In this model, we have used a surgically induced abrasion with a scalpel to inflict a direct injury on the surface of the tibial plateau. As shown **(Figure 4)**, the ICG labeled MabCII antibodies binds to the abrasion and can be visualized by the fluorescent endoscope. We have also used the fluorescent endoscope to visualize fluorescently labeled stem cells (data not shown) indicating that this approach may be useful for future studies of cartilage replacement using the domestic pig knee as a translational model for clinically focused applications.

DISCUSSION

Detection and monitoring of early lesions of OA has proven to be challenging in both patients and in animal models. The methods described in these studies demonstrate that it is possible to detect even early lesions using a monoclonal antibody to CII coupled to a fluorescent probe. Thus we have developed a method for quantitatively evaluating OA in vivo, using a fluorescent-tagged monoclonal antibody to CII that is exposed in damaged cartilage. CII is almost unique to cartilage tissue but is unavailable for binding to antibody in the normal articular cartilage[20, 21]. We have developed and tested this method in animal models of traumatic joint injury, utilizing the mouse models of destabilization of the medial meniscus (DMM), traumatic mechanical loading of the knee and spontaneous OA in guinea pigs[22]. The comparability of the findings to histopathological analysis confirmed the validity of the observations. It is likely that this approach succeeds because epitopes on CII are masked in normal undamaged cartilage but are unmasked as a result of the mechanical trauma applied to the joint[20]. This unmasking could be related to the release of proteins that cleave proteoglycans/glycoproteins and expose the underlying CII[18, 29]. It is also possible that mechanical stress results in non-enzymatic physical disruption of the cartilage surface or to a combination of factors[29, 30]. We have previously shown in in-vitro anal-

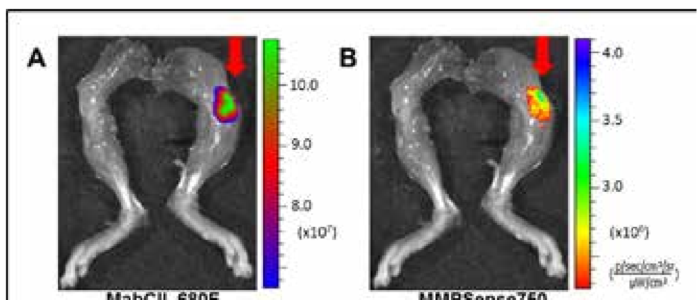

Figure 3: Mechanically loaded mouse knees show increased matrix metalloproteinase activity that co-localizes with MabCII. Mice were mechanically loaded for two weeks and then injected with MabCII and MMPSense retro-orbitally. The mice were euthanized 24 hours later and optical imaging of the skinned carcasses was performed to determine where the dye localized. The 680 Xenofluor dye that had been coupled to MabCII can be seen in the loaded left knee, but not in the right knee that was not loaded (A) When the same mouse was re-analyzed using a different filter set, the MMPSense fluorogenic product co-localized in the same area (B).

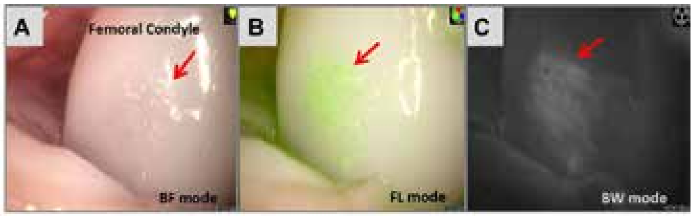

Figure 4: Fluorescent arthroscopy of fluorescent MabCII localizing to damaged cartilage in the pig knee. Pig knees were obtained from 3 month-old domestic pigs (see Methods) and the surface of the cartilage damaged with a light abrasion using a scalpel blade. The fluorescent MabCII was then incubated in the synovial cavity. After washing with PBS, the knee cartilage was visualized with a fluorescent endoscope using bright field mode (A), fluorescent mode (B), or under bright field mode but with subtractive software rendition of localized fluorescent signal (C). The red arrows indicate the abraded area.

yses that proteolytic digestion of intact cartilage with trypsin exposes CII[22]. Thus the action of enzymes alone could account for our findings. The co-localization of MMPSense fluorogenic product confirms that active MMPs are present in the area identified by the antiCII probe. According to the manufacturer, "MMPSense is a matrix metalloproteinase (MMP) activatable agent that is optically silent upon injection and produces fluorescent signal after cleavage by disease related MMP's. Activation can occur by a broad range of MMP's including MMP 2, 3, 7, 9, 12, and 13." The precise source for cartilage degrading enzymes is beyond the scope of the present experiments but is most likely the superficial layer of chondrocytes[28].

The animal model we used is representative of PTOA. The impact injury to articular cartilage triggers OA likely through a mechanism involving chondrocyte death and matrix degradation. PTOA is indistinguishable from degenerative OA in its late stages, and is manifested by progressive loss of cartilage, pain, inflammation, and loss of joint function. Despite the morbidity associated with PTOA, the ability to diagnose and treat this disorder is limited, contributing to the development of disability in affected individuals[5]. While our data establishes that our antibody binds to damaged and osteoarthritic cartilage using in vivo imaging system (IVIS) technology, technical limitations prevent the use of IVIS in larger animals and humans. We are confident that the techniques we have described will be applicable to human degenerative OA but this assumption remains to be established.

One obstacle for developing a preventive therapy for OA is the lack of good tools for effective evaluation of initial cartilage injury and disease progression31. At early stages, the effects of therapeutic drugs or biologics are most likely to be effective. However, traditional approaches for evaluation of PTOA have significant limitations. Radiography is the historical standard for OA diagnosis, although this approach is more effective for detection of bone-related changes at end-stages without direct cartilaginous imaging[32]. Magnetic resonance imaging (MRI) improves the ability to evaluate cartilage, but standard MRI lacks the resolution to discern cartilage trauma and early changes in cartilaginous matrix that precede macroscopic erosions[14]. Arthroscopy is considered the clinical standard for cartilage assessment, but this approach is limited to surface inspection and tactile probing, which falls short of laboratory standards of histopathology, metabolic studies and biomechanics[17, 26]. Such repeated histological assessment is time-consuming, expensive, traumatic to native tissue, and does not lend itself to clinical application. Development of modalities to more thoroughly assess cartilage injury and molecular changes in cartilage matrix could serve diagnostic needs as well as foster development of future clinical treatments. Showing feasibility of a fluorescent arthroscopic method, utilizing advancements in optical imaging technology, would accelerate translation of this method into clinical use. Advancements in fluorescent and optical imaging allow the capacity to monitor tissue responses to therapeutic intervention over-time or could be used for evaluation of engineered cartilage implants or recruitment of cartilage stem cells **(Figure 5)**. Analogous advances in optical imaging are currently under investigation to aid in

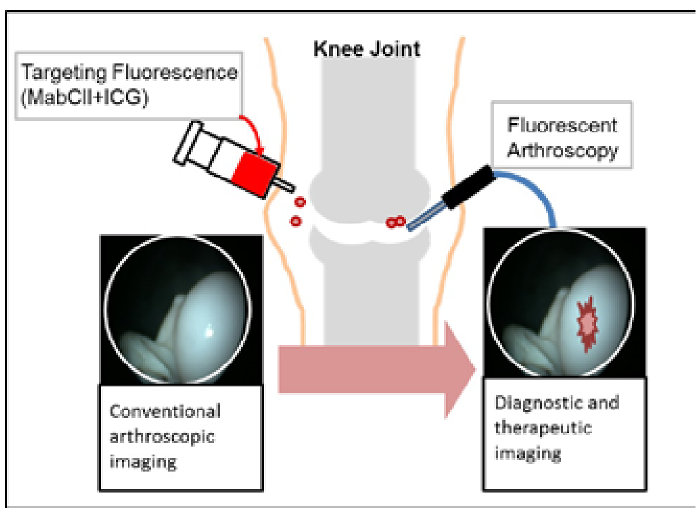

Figure 5: Schematic diagram of fluorescent arthroscopy proposed for diagnostic and therapeutic imaging of cartilage injury and osteoarthritis staging and for reparative strategies.

the diagnosis and resection of gastrointestinal, urologic, and brain disease disorders, with recent FDA approval of such methodology for treatment of bladder cancer[33, 34]. Such approaches couple traditional white light endoscopic analysis of affected organs with drug delivery of fluorescent agents. In the context of cancer diagnosis and treatment, these fluorescent agents are preferentially metabolized by tumor cells compared to normal tissue, and emit signals that can be detected by a blue light endoscope, to monitor tumor response to therapy or to aid in tumor resection[35, 36]. Analogous approaches for the diagnosis and treatment of damaged cartilage, coupling traditional white light arthroscopy with fluorescent visualization at other ends of the spectrum, have yet to be developed. The sensitivity and specificity of the fluorescent antibody that we have developed provides a potential new tool for diagnosis of cartilage injury and early OA, when used in conjunction with white light and fluorescent arthroscopy.

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A Novel Technique for Partial Transphyseal Anterior Cruciate Ligament Reconstruction in the Skeletally Immature: Surgical Technique and Review of Outcomes

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ABSTRACT

With increased sports participation, increasing numbers of anterior cruciate ligament (ACL) ruptures are seen in the skeletally immature. Growth disturbances after pediatric ACL reconstruction are more likely to occur at the femoral physis, thus, partial transphyseal techniques may be a better surgical option in this population. We report the outcomes of our novel technique; an arthroscopic assisted ACL reconstruction using quadruple looped hamstring graft with a synthetic graft extender and a distal femoral physeal sparing technique. This procedure was performed in 17 patients with open physes between years 2007 and 2012. All patients had knee stability restored with no incidence of growth disturbance at an average of 2.0 years follow-up in this case series.

INTRODUCTION

With increased sports participation, increasing numbers of ACL ruptures in the skeletally immature are seen now than in the past. Returning to an active lifestyle with an ACL deficient knee can result in repeated episodes of instability, meniscal tears, and progressive damage to articular cartilage. The management of anterior cruciate ligament injuries in the skeletally immature population is the subject of ongoing research and has attracted considerable interest in the literature.[1-4]

Treatment options for the acute ACL tear in this patient population can be divided into non-operative and operative management. Historically, surgical management has been avoided until the patient reaches skeletal maturity due to risk of physeal damage resulting in premature closure, angular deformity, and leg-length discrepancy. Conservative management consists of activity modification, bracing, and rehabilitation. Long term results of non-operative management are disappointing. McCarroll et al[5] reported that 37 of 38 patients treated conservatively for ACL rupture developed instability symptoms and 27 had evidence of meniscal injury after 4.2 years of follow-up. Aichroth et al[6] noted that 30% of the 33 patients initially treated non-operatively required surgical stabilization due to intolerable instability, while all reported significant activity reduction and decreased functional scores. Delaying surgical repair for 6-12 months for the patient to reach skeletal maturity has been attempted with mixed results.[7-8] Pursuing non-operative management requires extensive counseling for the patient and parents regarding requirements of activity modification, long term sequelae of an ACL deficient knee, and the significant risks posed with further injury from instability. Difficulties in patient adherence to this less active lifestyle and advances in surgical technique have led to most authors recommending operative treatment.

Reconstruction techniques have been developed to minimize the potential risk of growth disturbance and can be categorized by the method of

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Figure 1: Graft Measurements

handling the distal femoral and proximal tibial physes: physeal-sparing, complete transphyseal, and partial transphyseal techniques. Physeal sparing techniques reconstruct the ACL without damage to either the tibial or femoral physis. This can be accomplished through a combination of intra-articular and extra-articular reconstruction[9-10] or with an all-epiphyseal technique.[11-12] Results are similar to other published techniques data with overall good/satisfactory outcomes and few reports of growth disturbance. These procedures, though, are technically demanding and require intra-operative fluoroscopy or even intraoperative CT for precise tunnel placement.[11]

Transphyseal techniques place tibial and/or femoral bone tunnels by transphyseal drilling, and can be either partial (tibial only) or complete (femoral and tibial). There are numerous studies that document excellent outcomes for transphyseal reconstruction utilizing a variety of grafts and fixation techniques.[6, 13-22] However, a survey of the Herodicus Society physicians in 2002 reported 15 cases of growth disturbances after ACL reconstruction in skeletally immature patients, eight of which were directly related to surgical error with the transphyseal technique.[23] Physeal drilling can be made safer with bone tunnels oriented centrally and perpendicular to the physis,[24] allowing only soft tissue graft to span the drill hole across the physis,[25] and using small drill sizes.[26]

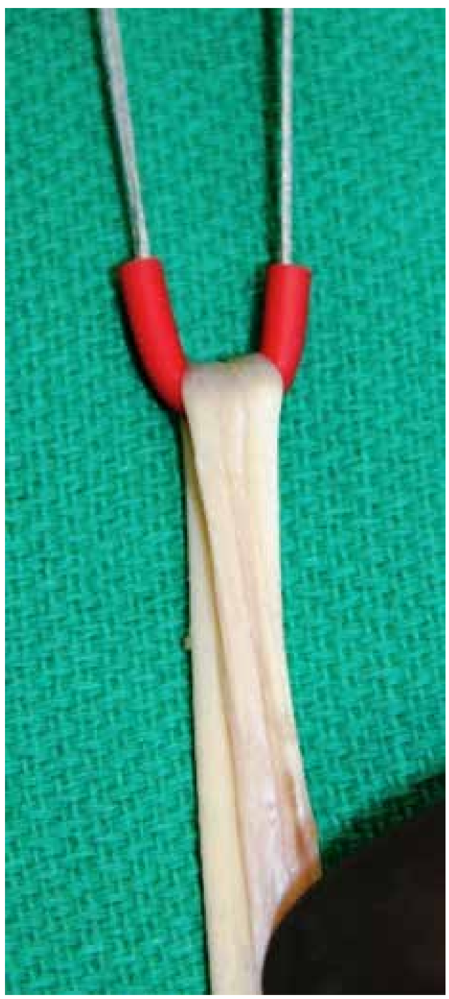

Figure 2: Graft with Synthetic Extender

Given that growth disturbances after ACL reconstruction in the skeletally immature predominantly occur at the femoral physis,[23] physeal sparing tunnel placement is technically demanding with a small margin of error,[12] partial transphyseal techniques may be a better surgical option. Partial transphyseal techniques drill a standard transphyseal tibial tunnel but avoid the more problematic distal femoral physis by using an over-the-top position. Biomechanical research has shown that both over-the-top fixation and transphyseal reconstruction closely restore intact knee kinematics.[27] The earliest published study of partial transphyseal reconstruction is from Lipscomb et al[28] in 1986, and involved an open full medial arthrotomy that was supplemented by additional extra-articular reconstruction. There appear to be only three studies published on arthroscopic partial transphyseal reconstruction. Andrews et al[29] reported on eight patients who underwent ACL reconstruction with fascia lata or Achilles tendon allograft centrally placed across the tibial physis and in an over-the-top position on the femur. Lo et al[30] described five ACL reconstructions using either hamstring tendons or quadriceps patellar tendon spanning the tibial physis and in an over-the-top position on the femur. At an average of 4.8 to 7.4 years of follow-up respectively, there were no failures or cases of growth disturbance. Bisson et al[31] passed semitendinosus/gracilis graft through the tibial physis and over-the-top of femur in nine patients and had two graft failures and no physeal injuries or growth deformities.

Our study presents a novel surgical method of arthroscopic assisted ACL reconstruction using quadruple looped hamstring graft with graft extender and a distal femoral physeal sparing technique. It is the largest study of an arthroscopic partial transphyseal technique to date.

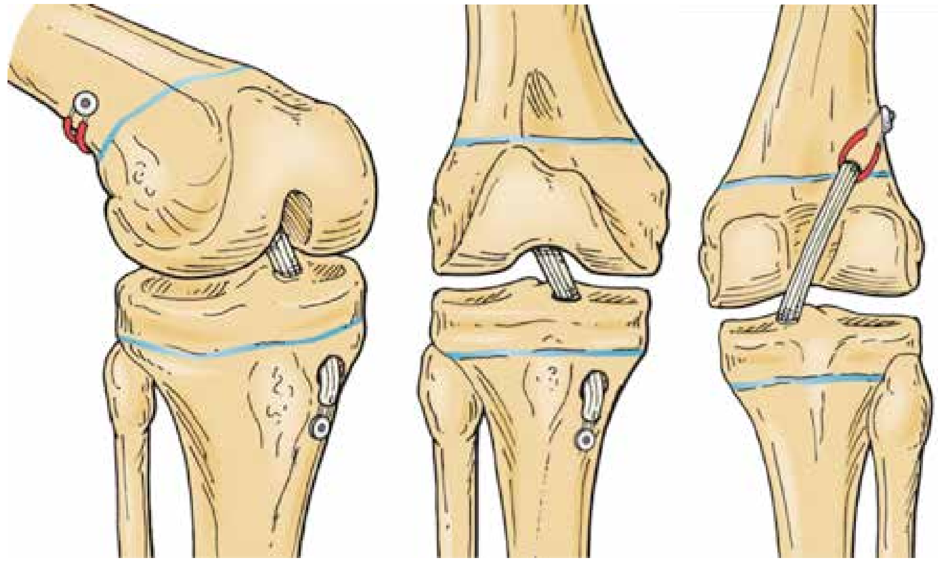

Figure 4: Graft in final position

METHODS

This study was approved by the University of Tennessee Health Science Center Institutional Review Board. All patients whom underwent the studied procedure at our institution between years 2007 and 2012 with a minimum of six month follow-up were included in this case series. All cases were performed by two sports fellowship trained orthopaedic surgeons. A medical record review was performed on all patients to collect information including injury mechanism, associated injuries, time to surgery, rehabilitation protocol, length of follow up, incidence of growth disturbance/deformity, and ability to return to pre-injury activity level. All patients were invited to return for repeat physical examination, KT-1000 measurement, scanogram, and to complete a Lysholm knee scale and International Knee Documentation Committee (IKDC) score.

SURGICAL TECHNIQUE

All patients' guardians signed informed consent prior to the operation after understanding the risks and benefits of operative and non-operative management. After general anesthesia was induced, a Lachman's and pivot shift test were performed to confirm clinical instability of the knee. A diagnostic arthroscopy was then performed under pneumatic tourniquet, and repair of any additional pathology encountered was performed as necessary. The gracilis and semitendinosus were recovered through a 3cm longitudinal incision placed 6cm below the anteromedial tibial plateau. Dissection was carried down to the sartorial fascia which was elevated off of the superficial medial collateral ligament in an inverted-L fashion. The hamstring tendons were identified and a right-angle clamp was used to separate the gracilis from the semitendinosis. A sharp #15 blade was used to peel the semitendinosis and gracilis off of the sartorious at their insertion point. A clamp was placed on the end of the gracilis tendon and a whipstitch was placed using a #2 Ethibond suture. The adhesions from the gracilis were cleared and a tendon stripper was used to perform the extraction. The semitendinosis was similarly stitched and removed. The sartorial fascia was repaired. The tendons were then taken to the back-table and prepared into the graft. A whipstitch was placed into the opposite ends of the tendons with a #2 Ethibond suture **(Figure 1)**.

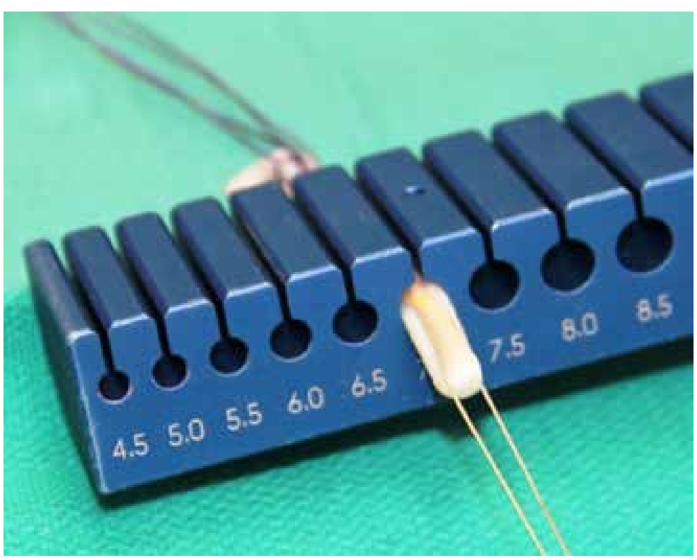

Figure 3: Sizing of Graft

The tendons were then folded over a #12 French red rubber catheter that had been cut to 3cm in length. A braided non-absorbable tape suture was fed through the red rubber catheter to act as a graft extender **(Figure 2)**.

The quadruple looped hamstring graft was trimmed

Figure 5: Scanogram and AP Lower X-Rays

and sized as necessary **(Figure 3)** and set aside under a moistened towel. A motorized shaver was used to remove the remnant ACL and tissue from the intercondylar notch posterolaterally taking care to protect the PCL. A tibial guide was set at a 65 degree angle and placed off of the medial eminence and at the level of the posterior portion of the anterior horn of the lateral mensiscus, just in front of the PCL insertion. A guide pin was placed and a trans-tibial, transphyseal tunnel was drilled and reamed up to 7.5mm. The arthroscope was then placed into the medial portal. A #11 blade an incision in the distal lateral thigh was made down to the fascial layer. The fascia was incsed and the iliotibial band was noted. The posterior aspect of the ilitibial band was palpated and, just anterior to this, a longitudinal incision was made with a #15 blade. A periosteal elevator was used to elevate soft tissue taking care to avoid the growth plate of the distal femur. An arthroscopic gaff was passed through the lateral portal around the lateral femoral condyle, being careful not to loop around the PCL in the intercondylar notch. The gaff was visualized on the lateral aspect of the distal femur in the area of the previous incision and a #5 Fiberwire suture was passed through the end of the gaff and back into the joint under direct visualization. This was then passed out through the tibial tunnel for graft passage. The graft was retrieved from the back table and passed using the suture-shuttle through the tibial tunnel and in the over-the-top position around the back portion of the lateral femoral condyle and out to the lateral cortex. Under direct fluoroscopic visualization, an entry point for a 6.5mm screw was placed on the distal femur proximal to the growth plate and subsequently a 25mm length screw with a non-spiked washer was placed. The suture that had been previously placed through the red rubber catheter was then tied over the 6.5mm screw post. On the tibial side another 25mm length 6.5mm screw was placed distal to the tibial growth plate with a non-spiked washer. The graft was tensioned with the leg in extension to avoid overtightening due to the over-the-top position and subsequently tied over the post. A Lachman's was performed to assess stability. The arthroscope was reintroduced to confirm appropriate graft placement followed by wound closure. An artistic rendition of the graft in position at the completion of the procedure is shown in **Figure 4**.

Postoperatively patients were placed into a hinged knee brace locked in extension and made non weight bearing on the involved extremity. Physical therapy began one week post-op. At four weeks the knee brace was unlocked from 0-90degrees. Weight bearing was advanced to partial weight bearing at 6 weeks when the patient's brace was unlocked completely. At 8 weeks the patients were allowed full weight bearing. At four months patients were placed into a custom-fitted functional ACL brace and allowed to begin jogging and open-chain exercises. Biodex dynamometer testing was obtained at nine month follow-up and patients were released to full activity at that time.

RESULTS

17 patients underwent the studied procedure between 2007 and 2012, all with greater than six month follow-up, and were included in the study. Patient ages ranged from 7.7-14.9 years with an average age of 12.4

years and all patients were male. All patients had open tibial and femoral physes on initial radiographs and magnetic resonance imaging. 10/17 (59%) of patients had an associated meniscal tear, 2/17 (12%) had an MCL tear, and 1/17 (6%) had a partial PCL tear. All injuries occurred during sporting activity with a twisting mechanism. 8/17 occurred during football, 3/17 with basketball, 2/17 with soccer, 3/17 while playing at recess, and one from falling off a 4-wheeler. The average time to surgery from date of injury was 78 days (range 17-184 days). Of the 10 patients with a concomitant meniscal tear, 6 underwent repair and 4 had partial meniscectomy. Length of follow-up ranged from 9 months to 6.4 years with an average of 2.0 years. At latest follow-up all patients were able to return to sporting events, all had a stable Lachman's test with a firm endpoint. 14/17 (82%) patients regained full range of motion while 3/17 (18%) lost an average of 7 degrees of motion (range 5-10 degrees). 9/17 (53%) of patients returned to complete KT-1000 measurements, Lysholm and IKDC scores, scanogram and AP radiographs of the lower extremities **(Figure 5)**. The difference in KT-1000 measurements for these patients at 20lb and 30lb were 0.9mm and 1.0mm respectively. The average limb length discrepancy on scanogram was 2.2mm with an average angular difference of 1.7degrees on AP Lowers radiographs. Neither of these were significant. The average Lysholm knee and IKDC scores were 91.5 (range 64-100) and 92.7 (range 63.2-100), respectively.

DISCUSSION

With increased sports participation, increasing numbers of injuries are being seen in the skeletally immature population. In 2011 there were over four million athletes under the age of 14 treated for sports related injuries[32]. This represents a significant increase in pediatric sports injuries likely related to increased year round training, single sport focus, and less free play. When a child incurs a tear to the ACL, parents are left choosing between operative and non-operative management. Conservative treatment with a brace, rehab, and activity modification is associated with a 71% incidence in new meniscal injuries by four years after the date of injury[33]. Operative techniques in this population differ from adults in how the surgeon deals with the open physes about the knee. Complete physeal sparing procedures can be technically difficult and rely heavily on intraoperative imaging. Transphyseal procedures, although standard in the skeletally mature population, do introduce concern for iatrogenic growth disturbance. Steps can be taken to minimize this risk to the physis, although the risk cannot be eliminated completely. Partial transphyseal procedures can avoid the distal femoral physis which has been shown to be more susceptible to injury and more likely to lead to growth disturbance than the tibial physis[23]. As a standard tibial tunnel lies in the approximate midline of the anatomic axis compared to the standard offset femoral tunnel, a growth disturbance would only produce length irregularity for a tibial physeal injury compared to both length and angular deformity from injury to the femoral physis.

Andrews et al reported a partial transphyseal technique with a centrally placed tibial tunnel across the physis and over-the-top femoral fixation of a fascia lata or Achilles tendon allograft in eight patients with a mean age of 13 years and an average of 4.8 year follow-up[29]. They showed no significant difference in scanogram limb length at latest follow-up. On KT-1000 arthrometer testing, five patients had less than 3mm of displacement when compared to the contralateral limb. Three patients had between 3-5mm of displacement. They gave final overall ratings of excellent in six patients, one

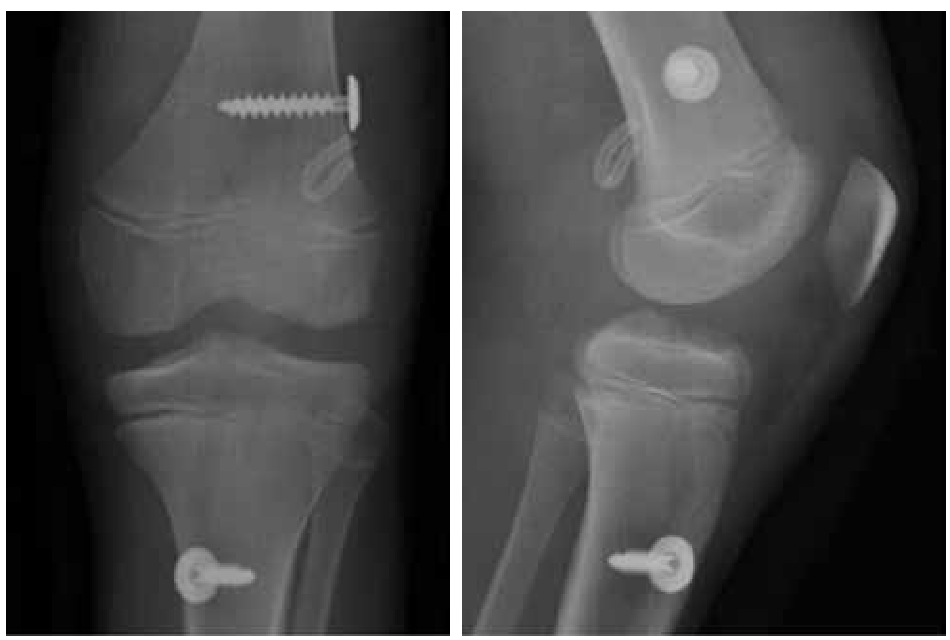

Figure 6: Post-Op AP/Lateral Xray

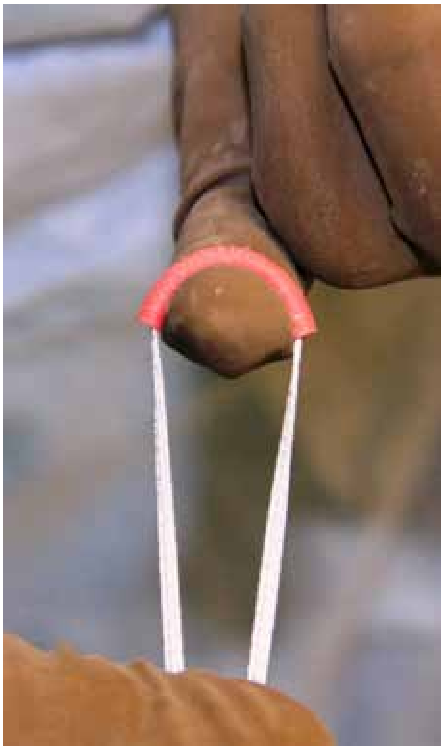

Figure 7: Synthetic Graft Extender

good, and one fair. The authors concluded that this procedure appeared to have merit in skeletally immature athletes who did not wish to modify athletic activities or whom were already undergoing surgery for associated meniscal pathology.

Lo et al reported on a partial transphyseal technique in five patients with an average age of 12.9 and follow-up of 7.4 years[30]. Three patients had hamstring graft while two had quadriceps patellar tendon, all fixed with a central tibial transphyseal tunnel and in a femoral over-the-top position. Scanogram showed no significant limb length discrepancy. Four patients were given a grade A and one a grade C on IKDC evaluation form. The patient with a grade C had sustained a subsequent patellar dislocation with osteochondral fracture. The authors concluded that this technique did not seem to adversely affect outcome or future growth.

Bisson et al reported on nine male patients whom underwent partial transphyseal reconstruction using semitendinosus and gracilis grafts passed through the tibial physis and over-the-top of the femoral condyles with an average follow-up of 3.3 years[31]. They reported a 22% graft failure rate although note that the seven patients with functional grafts had excellent results with a mean Lysholm score of 99 and a mean maximum KT-1000 difference of 2.8mm. No patient had a clinically significant leg-length discrepancy, angular deformity, or radiographic evidence of physeal injury.

In our study of 17 patients, stability was restored in all patients using a quadruple looped hamstring autograft with synthetic graft extender **(Figure 7)**. Given that the length of hamstrings in the skeletally immature patient is significantly less than an adult, the synthetic graft extender provides additional overall length to the graft while allowing the hamstrings to be quadruple looped for additional strength. It also delivers the strongest portion of the graft, the quadruple looped hamstring, into the functional zone of the knee. The graft extender is comprised of a #12 French red rubber catheter trimmed to 3cm in length and fed over a braided non-absorbable tape suture. The rubber catheter protects the graft from suture cut-out in the same way that a piece of rubber protects the fragile bark of a leaning tree from a tensioned corrective guy-wire. All patients were able to return to sporting activity at latest follow-up.

In the 9 patients who returned for additional testing and imaging studies, no significant limb length or angular deformity was detected on scanogram or AP lower extremity radiographs. KT-1000 arthrometer testing showed an average AP displacement at 20lb and 30lb of 0.9mm and 1.0mm, respectively. The average Lysholm knee score was 91.5 (range 64-100) and IKDC score was 92.7 (range 63.2-100). Almost all Lysholm and IKDC scores were above 90 except one patient who scored 64 and 63.2 on each test, respectively, at 4.3 years after his procedure. He reported a new injury while playing basketball several months prior to latest follow-up as well as significant mechanical symptoms with activity. An MRI was obtained and a new medial meniscal tear was identified. He underwent arthroscopic partial meniscectomy and has returned to full activity without complaints at most recent follow-up.

Our technique successfully restored stability in all 17 skeletally immature patients with ACL injury with no failures and no significant limb length discrepancy or angular deformity. This partial transphyseal technique avoids the distal femoral physis and is an option for ACL reconstruction in the skeletally immature population. Many studies have shown success with physeal sparing procedures as well as complete transphyseal techniques. As Vavken and Murray showed in a retrospective review of 47 studies, choosing surgical intervention over conservative treatment is likely more important than which technique is used34.

CONCLUSION

Arthroscopic assisted ACL reconstruction using quadruple looped hamstring graft with a synthetic graft extender and distal femoral physeal sparing technique restored knee stability in all cases with no incidence of growth disturbance at an average 2.0 years follow-up.

This technique is an option for the skeletally immature population at risk for growth disturbance during ACL reconstruction.

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Campbell Foundation Achievements

Jack R. Blair

Chairman, Board of Trustees
Campbell Foundation

It is hard to believe, but I have worked in the healthcare industry for forty years, and the orthopaedic industry for the last thirty. In that time, I have enjoyed a front row view of remarkable innovations as the result of research. I have seen advancements in materials and design that have led to total joints that can be implanted in an outpatient setting and are expected to last three decades or more in an active patient. I've seen the application of minimally invasive surgical techniques from sports medicine to all facets of orthopaedics - from orthopaedic trauma to total joints to spine surgery. Throughout my career, I have worked alongside dedicated and imaginative surgeons and engineers who worked diligently to solve the clinical problem at hand and to imagine a better solution. Usually, they have done so in a way that is more cost efficient, which benefits our entire healthcare system.

This innovative pathway begins with the clinical problem. Researchers work to examine and quantify the problem and to illuminate possible solutions to test and explore. I've seen this scientific research method applied repeatedly and observed the formation of not only novel implants and treatments, but entire companies and businesses which emerge from the innovation. Deliberate and applied clinical research is highly effective, and must be a key element of any academic clinical practice.

Nearly 70 years ago, Dr. Willis Campbell's original, hand-selected partners established the Campbell Foundation to uphold the legacy of excellence that he established. Donor support through the Foundation has enabled the Clinic and its partners to conduct the research necessary to bring about many of the treatments that benefit us today. This new journal represents a sample of the breadth of clinical research being conducted by our orthopaedic residents in training and the Campbell Clinic medical staff.

I hope you have enjoyed this issue of the Campbell Orthopaedic Journal which reflects the results of our efforts to expand and focus our research output. Our work is designed to address real-world, clinical problems. It is our intention to quickly share our findings with the world, in order to implement our results for the immediate benefit of patients. Due to the dual effects of an aging, more active patient population and a less-healthy, more obese population, demand for orthopaedic treatments and solutions will increase dramatically. Only through research and innovation will we be able to provide enhanced quality of life for patients everywhere.

Ongoing donor support is needed to sustain our momentum, and expand our impact. I hope you have seen the potential of the work in these pages and will join us in our efforts to expand this research. I invite you to visit the Campbell Foundation website today (campbell-foundation.org), and please give generously to help more people.

2015 Graduating Orthopaedic Residents

MICHAEL G. AZZAM, M.D.
Hometown: St. Louis, MO

Undergraduate Institution - St. Louis University, B.A. Psychology, Biology Minor, Certificate in Business Administration

Medical School - St. Louis University School of Medicine, St. Louis, MO

Dr. Azzam follows in the medical footsteps of his father who is a pediatric anesthesiologist and his uncle who is a neurosurgeon. He chose to pursue a career in medicine because he enjoys taking care of people and never having the same day twice. He was fascinated by anatomy in medical school and the potential of orthopaedic surgery to improve patients' quality of life.

Plans After Campbell - Sports Medicine Fellowship at the Andrews Sports Medicine Institute (ASMI), Birmingham, AL

Dr. Azzam extends thanks to all of the faculty and staff for their guidance and expertise and to his fellow residents, he states, "*It wouldn't have been the same journey without you.*"

CLAYTON C. BETTIN, M.D.
Hometown: Columbus, OH

Undergraduate Institution - The Ohio State University, B.S. Biological Engineering, Minor, Biomedical Engineering

Medical School - The Ohio State University College of Medicine and Public Health, Columbus, OH

Dr. Bettin is the first in his family to pursue medicine as a career, and his wife, Kristen, is a pediatrician and Assistant Professor at Le Bonheur Children's Hospital. Dr. Bettin and his wife have two children, Alyssa, age 2 and Sawyer, 4 months.

Dr. Bettin chose a career in medicine because of his desire to make a difference improving the health of others, and he chose orthopaedics due to the ability to positively impact quality of life more than any other specialty.

Plans After Campbell - Foot & Ankle Fellowship, University of Utah, Department of Orthopaedic Surgery, Salt Lake City, UT. Following Fellowship, Dr. Bettin will join the staff of Campbell Clinic Orthopaedics as a Foot & Ankle surgeon.

Dr. Bettin is grateful to all of the staff for their guidance, and he looks forward to joining them as a partner. He added, *"A special thank you to my wife, Kristen, for tolerating me the past five years and for being a wonderful mother to our two children."*

2015 Graduating Orthopaedic Residents

MICHAEL A. HAMES, M.D.
Hometown: Ft. Worth, TX

Undergraduate Institution -
Texas A & M University, B.S. Biomedical Science, Minor, Business Administration

Medical School - University of Texas Medical Branch, Galveston, TX

Dr. Hames and his wife, Christal, are in residency simultaneously - he in orthopaedic surgery and she in general surgery. Dr. Hames' grandfather was a dentist. Dr. & Dr. Hames are proud parents of son Grayson Michael, who they say is 16 months going on 18 years.

Mike stated that he has always enjoyed helping others and was interested in understanding how the body works and so medicine seemed like a great way to combine both interests. He selected orthopaedics because the variety of surgeries and patients is always interesting. He says that being able to improve someone's life by taking away their pain or increasing their mobility was very appealing to him.

Plans After Campbell - Foot & Ankle Fellowship, Foundation for Orthopaedic, Athletic, Reconstructive Research, University of Texas-Houston, Houston, TX. Following Fellowship, Dr. Hames will be joining an orthopaedic group in Wichita Falls in North Texas, specializing as a Foot & Ankle surgeon.

Dr. Hames wishes to thank the many people who have so graciously aided him in getting to this point. He thanks the faculty for the many hours spent showing him the way, and says he leaves Campbell prepared and knowing he has stood in the footsteps of giants. Dr. Hames also extends his gratitude to the staff and employees for their unending assistance and constant smiles on their faces. He stated that the Clinic truly is a fun and great place to work and learn and He adds to his wife, "*Your patience knows no bounds. Thank you for seeing me through this and thank you for the greatest gift- our son.*" Dr. Hames further stated, "*To my fellow residents (of all years) - you've made the tough times bearable and the good times better. You've made me better. I'll truly miss the comradery.*" And to the Clinic staff and employees, "*The Clinic truly is a fun and great place to work and learn and y'all are such a big part of that.*"

DAVID J. HEINSCH, M.D.
Hometown: Dover, DE

Undergraduate Institution -
University of Notre Dame, B.S. in Biology and History

Medical School - Medical College of Georgia, Augusta, GA

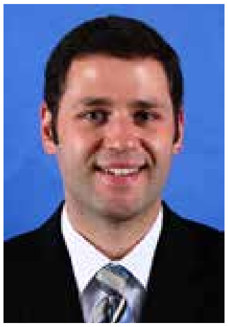
Dr. Heinsch is the first physician in his family, however his sister is a pediatric occupational therapist and his wife, Stephanie, is a Emergency Room Physician Assistant. Dave and Stephanie have two children, Jacob, 19 months, and baby #2 due in late September, 2015.

Dr. Heinsch chose to pursue a career in medicine because it combines discovery, knowledge, skill and empathy in one field. He states it is a social profession that provides unique challenges and rewards on a daily basis. Dr. Heinsch was drawn by the diversity of problems, and the reward of helping people. Being active is important to Dave, and therefore he enjoys helping people get back to activity, thus a love of orthopaedics. He finds that orthopaedic patients have goals that involve regaining function and this makes them motivated who will be demanding of themselves and their providers. While the goals of patients can change over a lifetime, he feels that, as an orthopaedic surgeon, he can help them meet those goals - whether they are a return to athletics or providing mobility and independence through a pain-free knee, hip or foot.

Plans After Campbell - Foot & Ankle Fellowship, University of Pennsylvania, Philadelphia, PA. Following Fellowship, Dr. Heinsch will practice in Atlanta, GA.

Dr. Heinsch wishes to thank the faculty for their patience and trust. He understands that teaching residents takes away from productivity and adds extra stress at times, but he appreciates their collective efforts to enhance the residents' education. He adds, "*Thank you to the Campbell Foundation staff for their continued support and assistance. Thank you to the Campbell Clinic and Surgery Center staff for their support, the friendly tips, and their assistance in patient care. Thank you to my fellow residents for sharing this time in our careers and lives; and for supporting each other with tough cases, call switches, baby showers, birthday parties, and friendship.*"

2015 Graduating Orthopaedic Residents



JEFFREY I. KUTSIKOVICH, M.D.
Hometown: Mayfield, OH

Undergraduate Institution - Case Western Reserve University, B.A. Biology and Economics

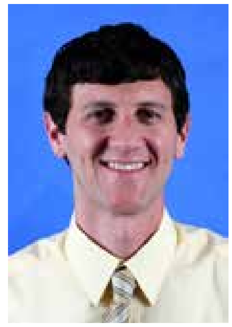
Medical School - The Ohio State University College of Medicine and Public Health

With Dr. Kutsikovich's choice of medicine as a career, he is following the footsteps of his older brother, Gary Kutsikovich, who is a neurologist. Dr. Kutsikovich met his wife, Annie, an attorney, while in college at Case Western, and together they have a daughter, Evelyn May, who was born in September, 2014.

Dr. Kutsikovich pursued medicine because he was always interested in the anatomy and physiology of the human body. The field of orthopaedics emerged because he wanted to help improve patients' function and quality of life.

Plans After Campbell - Orthopaedic Hand Surgery Fellowship, Indiana Hand to Shoulder Center in Indianapolis, IN.

Dr. Kutsikovich wishes to thank all the faculty at the Campbell Clinic for the world class education in orthopaedics. He adds, *"I would also specifically like to thank the hand surgery faculty including Dr. Calandruccio, Dr. Jobe, Dr. Cannon, and Dr. Mauck, for all their support."*



TROY A. ROBERSON, M.D.
Hometown - Rossville, IN

Undergraduate Institution - Purdue University, B.S. in General Health Sciences with a Biology Minor

Medical School - Indiana University School of Medicine, Indianapolis, IN

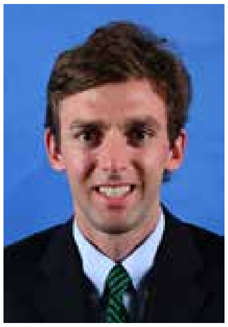
Dr. Roberson is the first in his family to pursue medicine as a career, and his wife, Lindsay, is a Veterinary Technician, but currently enjoying her role as a stay-at-home mom. He and Lindsay have two children, Olivia, age 5 and Ethan, age 1.

Dr. Robertson chose to pursue a career in after he decided he wanted to be an orthopaedic surgeon. The road through medical training has been pointing toward fulfilling this goal. His choice of orthopaedics came from firsthand observation of the impact an orthopaedic surgeon can have on a patient's life. His choice has been confirmed multiple times over as he has witnessed the influence and has continued to learn about how to most effectively execute this impact.

Plans After Campbell - Sports Medicine Fellowship, Steadman Hawkins Clinic of the Carolinas, Greenville, SC.

Dr. Roberson expressed thanks to the Campbell Clinic staff for their time and knowledge in providing him the foundation to launch a successful career. He added, *"I feel very blessed to be a part of this tradition and to say I was 'Campbell trained.' Thank you also to the unsung heroes of the program who maintain the excellence of the clinic and program. Mostly of all, thank you to my wife Lindsay who was there when I made the decision to pursue Orthopaedics and who has been my constant support ever since."*

2015 Graduating Orthopaedic Residents



BYRON F. STEPHENS, M.D.
Hometown: Hendersonville, TN

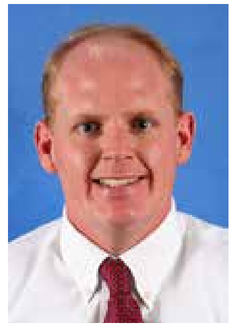
Undergraduate Institution -
Vanderbilt University College of Arts & Science, B.S. Biological Sciences

Medical School - University of Tennessee Health Science Center College of Medicine, Memphis, TN

Dr. Stephens is the first in his family to become a physician, and his wife, Sara, is an operating room nurse at Le Bonheur Children's Hospital. He took an EMT course in college during the process of getting his firefighter's license. He loved the EMT course and decided to pursue medicine. Notably, his EMT text was published by the AAOS during Dr. Canale's year as Academy President. Dr. Stephens chose orthopaedics because he was attracted to the ability to have an immediate and tangible impact on patients' lives and mobility. He also loved that outcomes in orthopaedics are generally good and that our patients are generally healthy and happy.

Plans After Campbell - Spine Fellowship, Emory University, Atlanta, GA. Following Fellowship, Dr. Stephens will join the staff of Campbell Clinic Orthopaedics as a Spine surgeon.

Dr. Stephens would like to thank Drs. Williams, Camillo and Gardocki for encouraging him to pursue a spine fellowship and for their educational efforts along the way. He also expressed that Dr. Throckmorton and Dr. Kelly deserve recognition and thanks for their tireless efforts to improve the residency program and support research endeavors. He wishes to also thank Dr. Heck for having and excellent and organized curriculum and taking the time to teach residents in a one-on-one, Socratic format. He also thanks Drs. Perez, Rudloff, and Weinlein for educating and challenging the residents to be better surgeons during the foundation of their training at the MED. He adds, "*Finally, I'd like to thank Drs. Canale, Beaty and Azar for their leadership that has made the Campbell Clinic a premier institution and orthopaedic training program. It is truly an honor to have trained here.*"



JONATHAN W. WRIGHT, M.D.
Hometown: Florence, AL

Undergraduate Institution -
University of Alabama, B.S. Biology, Minor, General Business

Medical School - University of Alabama School of Medicine, Birmingham, AL

Dr. Wright is the first in his family to pursue a career as a physician. He and his wife, Katherine, are the proud parents of a daughter, Margaret Katherine.

Dr. Wright wanted to pursue a career in medicine as a child, and he chose orthopaedics in order to have the opportunity to assist patients in returning to activities they enjoy and even just basic ambulation.

Plans After Campbell - Dr. Wright will begin a practice in General Orthopaedics in his hometown of Florence, AL, following graduation.

Dr. Wright wants to thank the staff and Education Committee for giving him the opportunity to train at such a well known institution. He adds, "*I want to thank all of the residents that I have worked with for their hard work and help making the last 5 years an extremely enjoyable time in my life.*"

2015 Orthopaedic Fellows

ANTHONY M. HOLLINS, M.D.
Sports Medicine Fellow
Hometown: La Jolla, CA

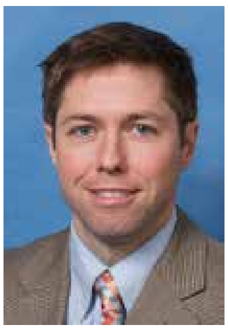
Undergraduate Institution - Washington University, B.A. Biology

Medical School - University of Tennessee Health Science Center, College of Medicine, Memphis, TN

Orthopaedic Surgery Residency - Campbell Foundation, Memphis, TN

Dr. Hollins is the first in his family to pursue a career in medicine. He elected to pursue orthopaedics because of his desire to help people have a better quality of life.

Plans After Campbell: Still in development.



KEVIN J. MCCARTHY, M.D.
Foot & Ankle Fellow
Hometown: St. Louis, MO

Undergraduate Institution - Emory University, B.S. Biology, Minor, Russian Language

Medical School - Saint Louis University School of Medicine, St. Louis, MO

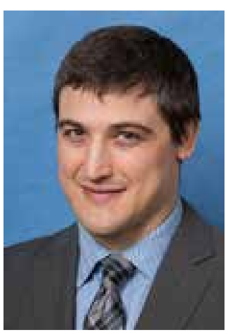
Orthopaedic Surgery Residency - University of Kansas Medical Center, Kansas City, KS

Dr. McCarthy is the first in his family to become a physician, and his wife, Jenna, whom he met while in med school, is a Pediatric Nurse Practitioner. Dr. McCarthy and his wife have two children, Colin, age 3 and William, age 1.

Dr. McCarthy chose a career in medicine because of his desire to do something that would continue to be challenging and prevent him from being bored. He chose orthopaedics because he feels that - more than any other field of medicine - orthopaedic surgeons make people better! And, he added, because it's fun!

Plans After Campbell: Dr. McCarthy will begin practice in Belleville, IL.

Dr. McCarthy stated, "*I would like to thank the faculty for being excellent mentors.*"



MICHAEL LUCIUS POMERANTZ , M.D.
Hand Fellow
Hometown: Santa Cruz, CA

Undergraduate Institution - University of California, San Diego, B.S, Biology, B.A. Psychology

Medical School - Albany Medical College, Albany, NY

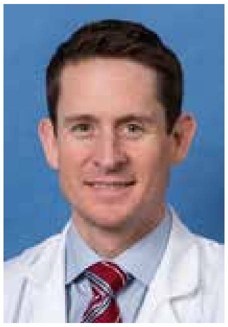
Orthopaedic Surgery Residency - University of California San Diego, San Diego, CA

Dr. Pomerantz is the first in his family to pursue a career as a physician, and his wife, Arisa, is a Procedural/Cosmetic Dermatologist. He chose to pursue a career in medicine because it is an honored occupation that continues to change, but will always afford the opportunity to directly help others through the combination of art and science. He chose orthopaedics because he felt for his personality, orthopaedics is the best combination of art and science that has a definite and drastic impact on a person's well being. He enjoys using his hands and fun tools to help someone regain function.

Plans After Campbell: Dr. Pomerantz plans to return to San Diego, CA, join a large orthopaedic group and to stay in medical education by working with the University in a voluntary capacity.

Dr. Pomerantz is honored to have been a part of such an extraordinary institution. He has learned so much and has gained the tools that will carry him in his career. He adds, "*The faculty I worked with are amazing people, the staff exemplify "Southern Hospitality," and the residents I have been fortunate to work with have been bright, hardworking and fun to have around. I hope that I have been able to help them grow as orthopaedic surgeons as much as they helped me. A special thanks to Dr. Calandruccio for everything including being so hospitable to my family, Dr. Jobe for building the micro table and taking me out to the lake, Dr. Cole for his time and patience, Dr. Mauck for his kind words and advice, and Dr. Cannon for his knowledge and pragmatism.*"

2015 Orthopaedic Fellows



JOHN D. ROATEN, M.D.
Hometown: Corpus Christi, TX

Undergraduate Institution - Hardin Simmons University, B.S. Biology

Medical School - University of Texas Medical Branch at Galveston, TX

Orthopaedic Surgery Residency - Texas Tech University, Lubbock, TX

Dr. Roaten joins other healthcare providers in his family including an uncle who is in Family Medicine at U.T. Southwestern, and his wife, Shelley, who is a Registered Dietician. From early on, he loved learning the sciences and developed an interest in anatomy and physiology. Medicine was the best fit for his interests and desire to have an impact on his community. Dr. Roaten selected orthopaedics to have a direct impact on a person's life by fixing their injuries. He loves to operate and orthopaedics provided the best fit for his interests.

Plans After Campbell: Dr. Roaten will specialize in pediatric orthopaedics when he joins the staff at Cook Children's Hospital in Fort Worth, TX.

Dr. Roaten would like to thank the Campbell Clinic Foundation for the opportunity to be a part of its first rate program, and he would like to thank all the pediatric orthopaedic staff for teaching me the tools to be successful in the field of pediatrics and for being great mentors and friends. He adds, "*I am grateful to Dr. Jeff Sawyer for taking an interest in me and for giving me the opportunity to help further my career. I had a very meaningful and learning experience as a Campbell Clinic Fellow and will always be grateful for my time in Memphis.*"

KONSTANTINOS M. TRIANTAFILLOU, M.D.
Hometown: Silver Spring, MD

Undergraduate Institution - Georgetown University, B.A. Government

Medical School - Georgetown University School of Medicine, Washington, D.C.

Orthopaedic Surgery Residency - Georgetown University Hospital, Washington, D.C.

Dr. Triantafillou is the first physician in his family, and his wife, Carrie, is a Nurse.

He chose to pursue a career in medicine because it gives him the opportunity to couple his interest in human physiology with the desire to apply it in real time to those who need it. Dr. Triantafillou feels it is a true honor to be in a field where one is entrusted with someone's life at their most vulnerable moment. He said he chose orthopaedics because of the saws, screws and drills.

Plans After Campbell: Dr. Triantafillou will join an orthopaedic practice in Austin, TX, focusing on orthopaedic trauma.

Dr. Triantafillou stated, "*Thank you for the opportunity to be part of a great organization that has been at the forefront of Orthopaedic Surgery. The faculty and residents have been a pleasure to work with. I hope that I can contribute to the Campbell name by continuing the legacy of excellence in patient care, education and innovation.*"

Current Orthopaedic Residents

INTERNS

Austin R. Davidson, M.D.
Undergraduate: Lipscomb University
Medical School: University of Tennessee Health Science Center College of Medicine

Steven M. DelBello, M.D.
Undergraduate: Rhodes College
Medical School: University of Texas Medical Center, Houston

Donald B. Franklin, M.D.
Undergraduate: Samford University
Medical School: University of Tennessee Health Science Center College of Medicine

Clay G. Nelson, M.D.
Undergraduate: University of North Carolina
Medical School: Eastern Virginia Medical School

Mims G. Oschsner, M.D.
Undergraduate: University of Georgia
Medical School: Mercer University School of Medicine

Colin W. Swigler, M.D.
Undergraduate: Florida State University
Medical School: Florida State College of Medicine

Kirk M. Thompson, M.D.
Undergraduate: Rose-Hulman Institute of Technology
Medical School: Southern Illinois University School of Medicine

Jordan D. Walters, M.D.
Undergraduate: Furman University
Medical School: Wake Forest School of Medicine

CLINICAL YEAR 2

Thomas R. Acott, M.D.
Undergraduate: University of Illinois at Urbana-Champaign
Medical School: St. Louis University School of Medicine

D. Christopher Carver, M.D.
Undergraduate: East Tennessee State University
Medical School: East Tennessee State University College of Medicine

Justin D. Hallock, M.D.
Undergraduate: Birmingham Southern College
Medical School: University of Tennessee Health Science Center College of Medicine

Travis W. Littleton, M.D.
Undergraduate: Lipscomb University
Medical School: University of Tennessee Health Science Center College of Medicine

Timothy M. Lonergan, M.D.
Undergraduate: Saint Louis University
Medical School: Saint Louis University College of Medicine

Erin M. Meehan, M.D.
Undergraduate: Clemson University
Medical School: Mercer University School of Medicine

A. Ryves Moore, M.D.
Undergraduate: University of Mississippi
Medical School: University of Mississippi Medical Center - School of Medicine

Daniel B. Wells, M.D.
Undergraduate: University of Georgia
Medical School: Mercer University School of Medicine

Current Orthopaedic Residents

CLINICAL YEAR 3

Eric N. Bowman, M.D., M.P.H.
Undergraduate: Texas A & M University
Masters: The Ohio State University
Medical School: The University of Cincinnati College of Medicine

John J. Feldman, M.D.
Undergraduate: Denison University
Medical School: West Virginia University School of Medicine

Christopher M. Hopkins, M.D.
Undergraduate: University of Texas
Medical School: University of Texas Medical Branch - Galveston School of Medicine

Nicholas B. Jew, M.D.
Undergraduate: University of Mississippi
Medical School: University of Mississippi Medical Center - School of Medicine

Megan N. Mayer, M.D.
Undergraduate: Webster University
Medical School: University of Missouri- Kansas City College of Medicine

Arturo D. Villarreal, M.D.
Undergraduate: Texas State University- San Marcos
Medical School: University of Texas Medical Branch - Galveston

William J. Weller, M.D.
Undergraduate: Illinois College
Medical School: Rush Medical College

Andrew J. Wodowski, M.D.
Undergraduate: University of Tennessee
Medical School: University of Tennessee Health Science Center College of Medicine

CLINICAL YEAR 4

Kaku Barkoh, M.D.
Undergraduate: Texas A & M University
Medical School: University of Texas Southwestern Medical School

Collin C. Bills, M.D.
Undergraduate: Harding University
Medical School: East Tennessee State University Quillen College of Medicine

Tyler J. Brolin, M.D.
Undergraduate: Concordia College
Medical School: University of North Dakota School of Medicine

Sean P. Calloway, M.D.
Undergraduate: University of Notre Dame
Medical School: Indiana University School of Medicine

Marcus C. Ford, M.D.
Undergraduate: University of Kansas
Medical School: University of Texas Health Science Center -San Antonio

John W. Harkess, M.D.
Undergraduate: University of Virginia
Medical School: University of Tennessee Health Science Center College of Medicine

Ryan P. Mulligan, M.D.
Undergraduate: Texas A & M University
Medical School: Texas A & M Health Science Center College of Medicine

Matthew G. Stewart, M.D.
Undergraduate: Auburn University
Medical School: Medical College of Georgia

Campbell Club In Memoriam

Alfons Altenberg, MD
Lewis D. Anderson, MD
Robin Arena, MD
Bordon Backynski, MD
Tory Bagwell, MD
James Barnett, MD
Robert Basist, MD
Henry Beck, MD
Reginald V. Bennett, MD
Dan R. Bigelow, MD
Thomas H. Blake, Sr., MD
W. Griffin Bland, MD
Michael Bluhm, MD
Harrison O. Bourkard, MD
Harold B. Boyd, MD
Hanes H. Brindley, Sr., MD
Robert G. Brashear, MD
Charles E. Brighton, MD
Louis P. Britt, MD
Joseph C. Burd, MD
John G. Caden, MD
Rocco A. Calandruccio, MD
Willis C. Campbell, MD
Dan Carlisle, MD
Peter G. Carnesale, MD
Charles A. Carraway, MD
Tom Phillip Coker, MD
Romulo E. Colindres, MD
Harry Collins, MD
Francis V. Costello, MD
P. Thurman Crawford, MD
A. Hoyt Crenshaw, Sr., MD
Henry I. Cross, MD
Jere M. Disney, MD
Daniel B. Eck, MD
Thomas S. Eddleman, MD
Allen S. Edmonson, MD
E.W. Ewart, MD
W. McDaniel Ewing, MD
Edward L. Farrar, MD
M. Craig Farrell, MD
Bryan Fleming, MD
Dale E. Fox, MD
Kermit W. Fox, MD

Isaac L. George, MD
Gary Giles, MD
A. Lee Gordon, III, MD
Harry R. Gossling, MD
John T. Gray, MD
Basil Griffin, MD
Herbert Alfred Hamel, MD
Joe Frank Hamilton, Jr., MD
Joe Frank Hamilton, Sr., MD
Richard M. Harkness, MD
Benjamin L. Hawkins, MD
David N. Hawkins, MD
C. Leon Hay, MD
Don Henard, MD
Edward D. Henderson, MD
George B. Higley, Sr., MD
Kenneth C. Hill, MD
John T. Hocker, MD
Frank C. Hodges, MD
John M. Hundley, MD
Alvin J. Ingram, MD
E.R. 'Rickey' Innis, MD
Otis E. James, Jr., MD
Leland H. Johnson, Jr., MD
David S. Johnston, MD
Orville N. Jones, MD
Dan Klinar, MD
Robert A. Knight, MD
F. E. Linder, MD
Stanley Lipinski, MD
John F. Lovejoy, MD
Harry A. Luscher, MD
Athey R. Lutz, MD
Michael Lynch, MD
H. B. Macey, MD
Paul H. Martin, MD
Juan A. Mayne, MD
James M. McBride, MD
Frank O. McGhee, MD
C. C. McReynolds, MD
I. S. McReynolds, MD
Walter C. Metz, MD
Lee W. Milford, MD
T. Rothrock Miller, MD

Alfred F. Miller, MD
William L. Minear, MD
J. M. Mitchell, MD
Joseph Mitchell, MD
J. M. Mitchner, MD
Wayne S. Montgomery, MD
Larry B. Morrison, MD
John T. Murphy, MD
Vernon Nickel, MD
Arthur Osborne, MD
W. Martin Payne, MD
Samuel B. Prevo, MD
George D. Purvis, MD
R. Beverly Ray, MD
Thomas A. Richardson, MD
S. L. Robbins, MD
R. C. Robertson, MD
R. C. Rountree, MD
Fred P. Sage, MD
Stanley Schwartz, MD
T. David Sisk, MD
W. H. Sisler, MD
Donald Slocum, MD
Hugh Smith, MD
J. Spencer Speed, MD
William B. Stanton, MD
Marcus J. Stewart, MD
Bruce Stivers, MD
Mario M. Stone, MD
Henry Thomas Stratton, MD
Ernest J. Tarnow, MD
Robert E. Tooms, MD
Phillip C. Trout, MD
Fredrico Van Domselaar, MD
Isaac L. Van Zandt, MD
John A. Vann, MD
R. H. Walker, Jr., MD
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Thomas L. Waring, MD
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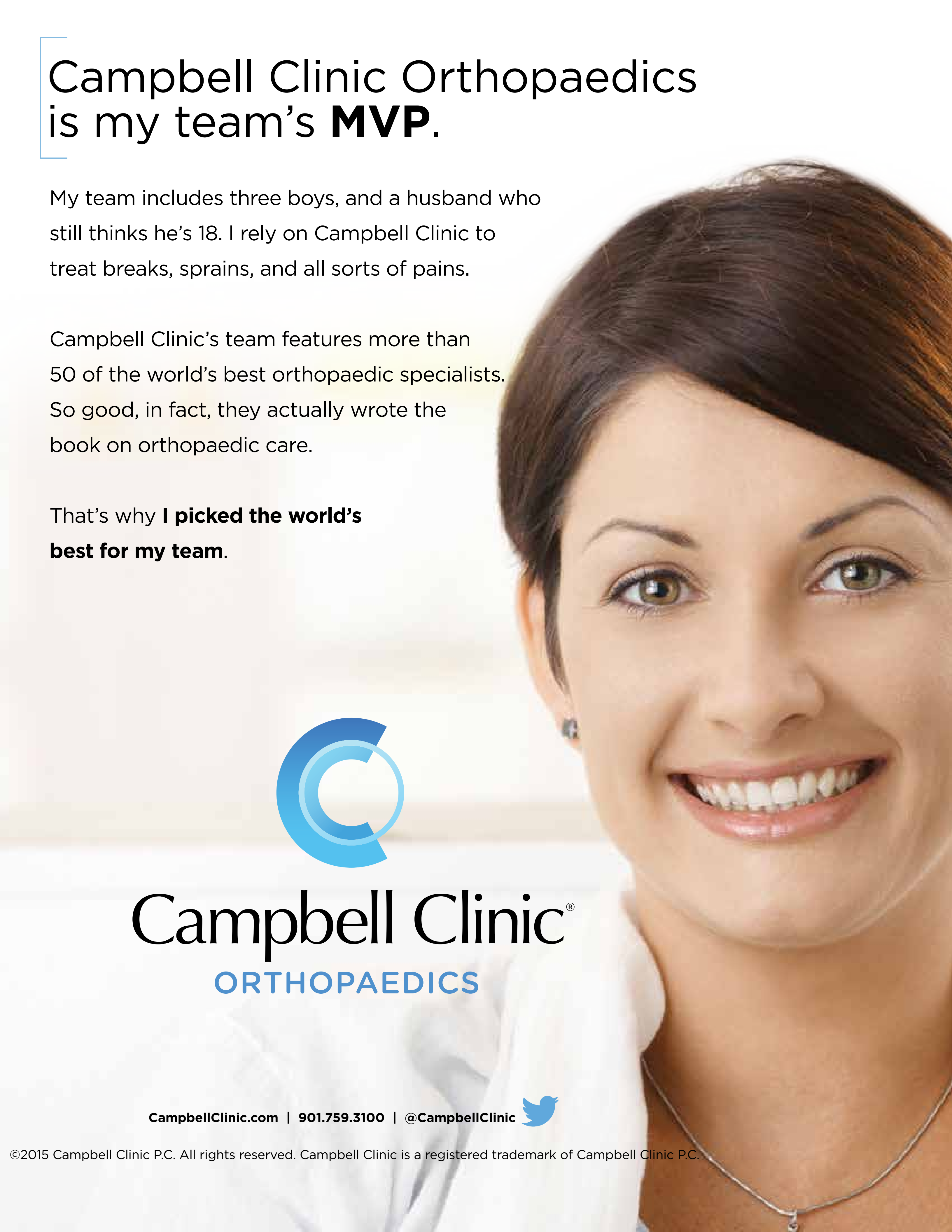
Frederick C. Workman, MD
B. T. Wright, MD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is my team's MVP.
My team includes three boys, and a husband who still thinks he's 18. I rely on Campbell Clinic to treat breaks, sprains, and all sorts of pains.
Campbell Clinic's team features more than 50 of the world's best orthopaedic specialists. So good, in fact, they actually wrote the book on orthopaedic care.
That's why I picked the world's best for my team.
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on Emerging Technology

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It includes premier surgical technique videos, animations, presentations and related science utilizing emerging technology and techniques.

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References:

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