Table of Contents

Letter from the Chairman

Letter from the Residency Director

2017 Kelly Society Visiting Professor

Kelly Day Agenda

PGY-5 Class

PGY-5 Bios, Manuscripts, and Abstracts
  Laura Bellaire, MD
  William Carpenter, MD
  Jimmy Daruwalla, MD
  Anuj Patel, MD
  Robert Runner, MD

PGY-3 Manuscripts

PGY 1-4 Residency Classes

Emory Orthopaedics Surgical Faculty

Kelly Day Visiting Professors

LETTER FROM THE INTERIM CHAIRMAN

Scott D. Boden, MD

We have a long tradition of outstanding leaders of our profession who have taken time from their personal and professional schedules to serve as the Kelly Day Visiting Professor. Dr. Vitale clearly ranks as a leader in Orthopaedics today, and I am particularly grateful to Dr. Vitale for being with us and enriching our educational program.

I also want to acknowledge the 15+ years of dedicated and unselfish service Dr. Jim Roberson has provided to the Department, and the tremendous growth and expansion that has taken place under his Chairmanship. We can all be proud of how the Department has changed and grown. We have seen the faculty more than double in size, including a stable, excellent group of full time Grady faculty. In addition to being among the most clinically busy services at Grady and the VA Hospital, the MSK service line has become a critically important component of Emory Healthcare with approximately 1 out of every 3.5 new patients to Emory entering through Orthopedics.

The blend of clinical efficiency, academic opportunities, and diverse patient care environments have resulted in the Emory Orthopaedic Residency and Fellowship training programs becoming increasingly among the most sought after in the country. In the coming years we will expand our fellowship offerings to include Upper Extremity, Trauma, and Pediatrics.

We are now also undergoing a major expansion of our basic/translational and clinical research team. Our Vice-Chair for Research, Hicham Drissi, PhD, and our Director of Clinical Research, Michael Gottschalk, MD, are leading those efforts with outstanding early successes.

Support and contributions from the alumni are increasingly needed to enhance the support for resident education and research, which are an integral component of these Department achievements. Thank you for your continued support.

With sincere appreciation for each of your efforts that contribute to Team MSK,

Scott

Scott D. Boden, MD
Kelly Day 2017 is a special event. It is the culmination of years of work by the residents, faculty and students within the Department of Orthopaedics.

The research projects and clinical case presentations contained in this year’s agenda reflect our core missions: to improve the quality of life of those with musculoskeletal disease and to improve the system through which we deliver such care.

It is an honor and privilege to host Dr. Mark Baratz as the 2017 Kelly Visiting Professor.

To say that Dr. Baratz is an innovator and thought leader is an understatement! I know we all look forward to the opportunity to spend time with and learn from Mark’s extensive experience with the care of the upper extremity. Welcome!
Dr. Michael G. Vitale is a leading New York Pediatric Spine Surgeon. He is the Ana Lucia Professor of Pediatric Orthopaedic Surgery at Columbia University Medical Center, Director of the Division of Pediatric Orthopaedic Surgery, and the Chief of the Pediatric Spine and Scoliosis Service at Morgan Stanley Children’s Hospital of New York – Presbyterian.

Dr. Vitale received his Masters of Public Health from Columbia University Joseph Mailman School of Public Health and his Doctor of Medicine from the College of Physicians and Surgeons of Columbia University, which was followed by a residency in Orthopaedic Surgery at Columbia-Presbyterian Medical Center and a one year fellowship at the Children’s Hospital of Los Angeles in University of Southern California.

Currently, he serves as the director of the Pediatric Orthopaedic Research Group, and has over 100 peer reviewed research publications in the field of pediatric orthopaedics, including a number of efforts leading national guidelines aimed at improving quality and safety of pediatric spine surgery. He has received numerous national awards from the Pediatric Orthopaedic Society of North America including the Arthur H. Huene Memorial Award, the Angela M Kuo Award Young Investigator Award, the Robert Hensinger Scientific Paper Award, as well as the Hansjorg Wyss Research Award, the Frank Stinchfield Research Award, the Rosamond Kane Award in Pediatric Orthopaedic Surgery, and the Harrison McLaughlin Award. Additionally, he is the recipient of the Castle Connolly’s Top Doctors award for 5 consecutive years and has been named in 50 Physicians in the US in the area of Scoliosis Care by Becker’s Spine Review.

Most recently, he has developed a career interest in the area of Quality Improvement, leading the research arm of the Pediatric Orthopaedic Society of North America’s Committee on Quality, Safety, and Value, serving as the Medical Director of New York Presbyterian’s Initiative to Make Care Better, and serving as the Chief Quality Officer of the Department of Orthopaedic Surgery at Columbia University Medical Center.

Dr. Vitale is an avid skier, marathon runner, and recreational triathlete. Most of all, he enjoys spending time with his wife and four sons.
2017 KELLY DAY AGENDA

Friday, June 9, 2017

7:00 AM  Registration & Breakfast

7:20 AM  Welcoming Remarks
James Roberson, MD
Robert P. Kelly Professor and Chair
Orthopaedics Department
Emory University School of Medicine

Welcoming Remarks
Hicham Drissi, Ph.D.
Orthopaedics Department
Emory University School of Medicine

Resident Research Presentation: Session I

7:30 AM  Assessment of Recovery From Geriatric Ankle Fracture Using The Life Space Mobility Assessment (LSA)
Briggs Ahearn, MD, PGY 3

7:40 AM  Radial To Axillary Nerve Transfers: A Multi Center Case Series
Charles Daly, MD - PGY 5 (Hand &Upper Extremity– Curtis National Hand Center)

7:50 AM  Tension Band Vs Acromial Plate Fixation: A Biomechanical Comparison Between The Locking Compression Plate And Tension Band Construct In The Fixation Of Type 3 Displaced Acromial Fracture After Reverse Total Shoulder Arthroplasty.
Jeff Konopka, MD - PGY 3

8:00 AM  Risk Factors For Manipulation Under Anesthesia And Lysis Of Adhesions Following Anterior Cruciate Ligament Reconstruction
Joel Huleatt, MD - PGY 5 (Sports Medicine– University of Connecticut)

8:10 AM  Discussion:
Dr. Mark Baratz and Emory Faculty

Upper Extremity Symposium I

8:30 AM  Forearm Trauma Case Presentation
Panel: Mark Baratz, MD Clifton Meals, MD Diane Payne, MD
Moderator: Mara Schenker, MD
Presenting: Adam Boissonneault, MD PGY 2
Basic Science Presentation I

9:00 AM  The Osteogenic Effects of Novel Small Molecule Inhibitors of Sclerostin
Steve Presciutti, MD
Associate Professor
Emory University Orthopaedic Surgery
Atlanta VA Medical Center

Break

9:30 AM  Break

Resident Research Presentation: Session II

9:40 AM  Outcomes Of Elmslie-Trillat Osteotomy For The Treatment Of Patellar Dislocations Using A Minimally Invasive Technique
Ian Gao, MD - PGY 3

9:50 AM  Risk Factors Associated With Delayed Discharge After Posterior Spinal Fusion For Neuromuscular Scoliosis
Tim Borden, MD – PGY 5 (Pediatric Orthopaedics – Boston Children’s Hospital)

10:00 AM  Can A Visiting Surgeon Program Coupled With Implant Donation And Local Surgeon Training Increase In-Country Surgical Capacity?
Sandi Hobson, MD – PGY 3

10:10 AM  Surgical Training Using A Novel And Inexpensive Durotomy Repair Model: A Randomized Control Trial
Eli Garrard, MD – PGY 5 (Spine Surgery – University of Wisconsin)

10:20 AM  Discussion - Dr. Mark Baratz and Emory Faculty

Alumni Presentation I

10:30 AM  Near Infrared Spectroscopy (NIRS) and Compartment Syndrome
Michael Shuler, MD
Alumni Class of 2007
Athens Orthopedic Clinic, Athens, GA
2017 Kelly Day Lecture

11:30 AM  Introduction of 2017 Kelly Visiting Professor
James Roberson, MD

2017 Kelly Visiting Professor
Mark Baratz, MD
Program Director, Orthopaedic Surgery Hand Fellowship,
Clinical Professor and Vice Chairman,
Department of Orthopaedics,
University of Pittsburgh Medical Center

12:00 PM  Lunch Presentation
Atlanta Gang Violence
Investigator Jason Somers, Atlanta Police Department
Targeted Enforcement Unit

Upper Extremity Symposium II

1:00 PM  Wrist Trauma Case Presentation
Panel: Mark Baratz, MD Gary McGillivary, MD Michael Shuler MD
Moderator: Clifton Meals, MD
Presenting: Dale Segal, MD PGY 2

Resident Research Presentation: Session III

1:30 PM  Predictors For Delayed Discharge After Total Joint Arthroplasty Of The Hip And Knee
Bryan Sirmon, MD - PGY 5 (Hand and Upper Extremity– The Philadelphia Hand Center)

1:40 PM  Outcomes Following Anterior Cruciate Ligament Reconstruction with Allograft—A
Comparison of Allograft Sterilization Methods and Source Tissue
Tim McCarthy, MD - PGY 3

1:50 PM  Association of a Modified Frailty Index with Postoperative Outcomes after Ankle
Fractures in Patients Aged 50 Years and Older
Rishin Kadakia, MD - PGY 3

2:00 PM  Discussion - Dr. Mark Baratz and Emory Faculty
Upper Extremity Symposium III

2:10 PM  Iatrogenic Elbow Challenges
Panel: Mark Baratz, MD Clifton Meals, MD Diane Payne, MD
Moderator: Michael Gottschalk, MD
Presenting: Jimmy Daruwalla, MD PGY 4

2:45 PM  Break

Basic Science Presentation II

3:00 PM  Immune-Dysregulation In A Rat Model Of Infected Femoral Segmental Bone Defect
Mara L. Schenker, MD
Assistant Professor
Emory University Orthopaedic Surgery
Grady Memorial Hospital

Alumni Presentation II

3:15 PM  Interscalene Catheter vs. Single shot for Total Shoulder Arthroplasty
Robert Rolf, MD
Alumni Class of 2007
Beacon Orthopaedics &Sports Medicine, Cincinnati, OH

3:30 PM  Things I Should Have Learned...
Michael D. Smith, MD
Alumni Class of 2015
Southlake Orthopaedics Sports Medicine & Spine Center, Birmingham, AL

3:45 PM  Introduction of Reunion Class of 2007 and The Future of the Kelly Society

4:00 PM  Closing Remarks
James Roberson, MD and Thomas Bradbury, MD

**CME credits will be issued in January 2018.
Please remember to provide your email address to receive your statement.
For more information, contact Sonya Williams at swill70@emory.edu**
### 2017 – 2018 Orthopaedic Chief Surgery Residents

**PGY-5**

<table>
<thead>
<tr>
<th>Name</th>
<th>Fellowship Match</th>
<th>Medical School</th>
<th>Hometown</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laura Bellaire, MD</td>
<td>Fellowship Match: University of Utah Salt Lake City, UT</td>
<td>Emory University, School of Medicine</td>
<td>Atlanta, GA</td>
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<tr>
<td></td>
<td>Pediatric Orthopaedic Surgery</td>
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<tr>
<td>William Carpenter, MD</td>
<td>Fellowship Match: NYU/Insall Scott Kelly Institute, New York, NY</td>
<td>University of TX-San Antonio</td>
<td>Waco, TX</td>
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<tr>
<td></td>
<td>Adult Reconstructive</td>
<td></td>
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<tr>
<td>Jimmy Daruwalla, MD</td>
<td>Fellowship Match: Curtis National Hand Center Baltimore, MD</td>
<td>Emory University, School of Medicine</td>
<td>Rockville, MD</td>
</tr>
<tr>
<td></td>
<td>Hand &amp; Upper Extremity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anuj Patel, MD</td>
<td>Fellowship Match: Massachusetts General Hospital &amp; Brigham and Women’s Hospital</td>
<td>University of South Alabama</td>
<td>Gadsen, AL</td>
</tr>
<tr>
<td>Administrative Chief</td>
<td>Spine Surgery</td>
<td></td>
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</tr>
<tr>
<td>Robert Runner, MD</td>
<td>Fellowship Match: Hoag Orthopaedic Institute</td>
<td>Emory University, School of Medicine</td>
<td>Atlanta, GA</td>
</tr>
<tr>
<td>Administrative Chief</td>
<td>Hand &amp; Upper Extremity</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Laura Bellaire, MD  PGY-5

Pediatric Orthopaedic Surgery Fellowship
The University of Utah
Salt Lake City, UT

EDUCATION:

Emory University School of Medicine –
Atlanta, GA
Doctor of Medicine, May 2012

Yale University, New Haven, CT
Bachelor of Arts, Cognitive Sciences, May 2008

COMPLETED PUBLICATIONS:

  - Completed literature review and wrote manuscript sections dedicated to optimization of a postoperative discharge pathway for pediatric patients with AIS having undergone spinal fusion
  - Performed chart review for 337 patients, calculated cumulative radiation exposure and correlated with injury mechanism, type and severity using electronic and paper medical records, performed statistical analysis
  - Wrote and edited the manuscript, prepared slides for podium presentation at the annual Southern Orthopaedic Association meeting in 2013
  - Edited the 4th ed. chapter on corticosteroid injections and added new sections describing viscosupplementation and the debate on the chondrotoxicity of local anesthetics

PENDING PUBLICATIONS:

- Skaggs D, Andras L, Fletcher N, Choi P, Bellaire L, Tolo V, “Don’t You Wish You Had Fused to the Pelvis the First Time: A Comparison of Reoperation Rate and Correction of Pelvic Obliquity.”
  - Podium presentation given at Scoliosis Research Society annual meeting on September 8, 2017
  - Discussed study design and criteria with principal investigator and co-investigators at multiple institutions
  - Performed chart review of over 200 patients and generated database for review
  - Publication pending in Spine (submitted 5/18/18)
- Bellaire L, Bowman C, Fletcher N, Bruce R, “Is early discharge possible following posterior spinal fusion for neuromuscular scoliosis?”
  - Completed chart review and radiographic analysis for ~200 patients treated with PSF for neuromuscular scoliosis of varying etiologies
  - Conducted statistical analysis and prepared manuscript for publication. Examined the impact of an accelerated discharge pathway on length of stay and patient outcomes.
  - Podium presentation at the 2017 EPOSNA meeting
  - Winner of the Kelly Society annual research award 2016
  - Finalizing manuscript edits prior to resubmission to J Spinal Deformity
- Fletcher N, Bellaire LL, Borden T, Bruce R, “Predictors of length of stay following posterior spinal fusion in neuromuscular scoliosis”
  - Completed retrospective chart review on over 200 neuromuscular scoliosis patients, evaluating for presence of comorbidities and intraoperative variables that potentially impact hospital length of stay
  - Manuscript in progress
  - Assisted in reviewing patient charts and gathering data for this study, which represents the largest series of lower extremity gunshot wounds that has been completed to date.
• Worked with department statistician to perform data analysis.
• Podium Presentation at the Georgia Orthopaedic Society annual meeting
• Accepted for publication in the Journal of Orthopaedic Trauma, pending edits.

PRESENTATIONS
• Bellaire L, Hiza E, Moore TJ, “Intra-articular Mycobacterium Tuberculosis Infection as the Initial Presentation of Systemic Tuberculosis.”
  – Completed chart reviews for the included patients.
  – Consulted Centers for Disease Control for discussion of manifestations and implications of extrapulmonary TB.
  – Prepared and presented scientific poster at the Southern Orthopaedics Association annual conference: July 18-21, 2012 in Greenbrier, WV.
• “Rotator cuff pathology and other causes of shoulder pain in the elderly population,” Wesley Woods Lecture Series, November 8, 2012.
  – Compiled demographic, epidemiologic, and market statistics related to the healthcare systems in Brazil, Russia, India, and China.
  – Researched healthcare infrastructure and policies with a focus on opportunities for partnerships with non-profit organizations, research, and protection of intellectual property and patents within those countries.
  – Composed and presented slide sets for the healthcare consulting group.

EXPERIENCE
• Quality, Compliance, & Ethics Committee, Grady Memorial Hospital (2014-2015)
  ▪ Served as a resident member, participated in lecture series and discussions
• Good Samaritan Health Center, Atlanta, GA (2009-2013)
  ▪ Volunteer: Worked alongside volunteer physicians to serve Atlanta’s underserved patient population.
  ▪ Assisted with Spanish-English translation.
• Himalayan Health Exchange, Himachal Pradesh, India (2011-2012)
  ▪ Volunteer: Spent 5 weeks in Northern India with a group of attending physicians, residents, and students.
  ▪ Provided medical care to patients in rural, high-altitude clinics, with focus on infections, traumatic injuries, and malnutrition.
  ▪ Prepared and presented lectures on assessing and treating lacerations and common extremity fractures.
• Grady Memorial Hospital International Clinic, Atlanta, GA (2009-2010)
  ▪ Completed primary care visits for Spanish-speaking patients.
  ▪ Assisted with routine vaccinations and lab work.
• Lazard Freres & Co., New York, NY (Summer 2008)
  ▪ Summer Intern: Analyst for leading investment bank. Researched alternative financings for healthcare and pharmaceutical companies.
• **IMS Health**, London, England (Summer 2007)
  - Research Intern for global health informatics company. Researched healthcare infrastructure trends in Brazil, Russia, India & China and implications for global health policy and biopharmaceutical manufacturers, with focus on strategies for improving access to healthcare.

• **Emory University Hospital ECHO Lab**, Atlanta, GA (Summer 2006)
  - Visiting student and research assistant with preceptor Dr. Randolph Martin (Professor of Medicine-Cardiology, Director of Noninvasive Cardiology).

**ACTIVITIES**

• Emory SOM Honor Council (2009-2013), Elected Member
  – Assisted in gathering written statements and interview summaries for honor code violation cases.
  – Presented relevant information to council chairs in preparation for hearings.

• Emory Orthopaedic Interest Group (2009-2013)
  – Attended splinting/casting clinics and helped organize resident and student-led lectures.

• Emory SOM Student Interviewer (2012-2013)
  – Interviewed SOM applicants and provided tours of campus and hospitals during interview days.

• Emory SOM Surgery Rotation Class Coordinator (2011-2012) and Surgery Sub-I Course Rep (2012-2013)
  – Gathered feedback from classmates and residents; communicated concerns and comments to rotation chair.
  – Designed presentations and pamphlets for orientation sessions for 2nd year students.

• Yale Alumni Schools Committee (2009-2013), Interviewer
  – Interview high school seniors in the Atlanta area and provide recommendations regarding admission to Yale’s undergraduate program.


• Yale Women’s Leadership Initiative (2007-2009), Member, Participant in Mentorship program

• New Haven Reads (2006-2009), Volunteer tutor
Predictors of Hospital Length of Stay Following Neuromuscular Spinal Fusion
Nicholas D. Fletcher, MD, Laura L. Bellaire, MD, Eric Dilbone, MD, Laura Ward, Robert W. Bruce Jr. MD

**Background:** Patients with neuromuscular scoliosis (NMS) who undergo posterior spinal fusion (PSF) have historically stayed in the hospital for greater than one week after surgery. These patients' comorbidities, nutritional and respiratory compromise, and larger rapidly progressive curves put them at greater risk of complications and prolonged stay. Accelerated discharge (AD) protocols have the ability to reduce hospital length of stay without increasing complications, however a small subset of patients is not well suited to rapid mobilization and early discharge.

**Methods:** 197 patients with NMS underwent PSF between 2005 and 2013 by two surgeons. These patients were divided into quartiles based on their hospital length of stay (LOS), and their charts were retrospectively reviewed for preoperative, intraoperative, and postoperative factors that were associated with their LOS.

**Results:** Neuromuscular diagnosis, age at surgery, gender, and the need for tube feeds were not significant predictors of length of stay. Severely involved CP patients were more likely to have extended stays (p=0.02). Major coronal Cobb angle and pelvic obliquity were also significantly higher amongst those with extended stays (p=0.002, p=0.02). Patients with lengthier surgical times, higher numbers of levels fused, presence of a pulmonary complication, need for intraoperative and postoperative blood transfusion, and need for ICU admission were significantly more likely to fall into the extended LOS group (p<0.05).

**Conclusions:** Several variables have been identified as significant predictors of hospital LOS after PSF for NMS. Further study is needed to identify whether benefit exists to excluding such patients from an AD pathway and whether investing greater resources in optimizing these high risk patients preoperatively with further testing and medical interventions would be of value.

**Level of Evidence:** Therapeutic Level III
Introduction

There are multiple reasons why neuromuscular scoliosis (NMS) patients have historically required longer hospital stays after posterior spinal fusion (PSF) than their typically healthy adolescent idiopathic scoliosis (AIS) counterparts. NMS patients have higher rates of comorbidities including seizure disorder, mental retardation, reflux, and reactive airway disease. Many require tube feeds to maintain adequate levels of nutrition or tracheostomies to maintain adequate oxygenation. Those with more involved disease are unable to ambulate. Contractures and spasticity can make hygienic care difficult for their families and caregivers. All of these factors contribute to increased rates of intraoperative and postoperative complications including infection, wound dehiscence, pseudarthrosis, difficulty feeding, urinary tract infection, and respiratory failure. Historic literature cites complication rates as high as 60-70% amongst NMS patients. ¹⁻⁴

Historically, length of stay (LOS) amongst NMS patients has far exceeded LOS cited for AIS patients after PSF. A national database study completed in 2006 assessed 1570 NMS patients who underwent PSF and found mean LOS to be 9.2 days.⁵ Another national study completed ten years later in 2016 found that, over the course of the study period, which included 2154 NMS patients who underwent PSF, mean LOS declined from 9.1 to 6.7 days.⁶ Other smaller institutional studies in the past decade cite LOS’s ranging from 8 to 17 days, demonstrating that LOS varies considerably across regions and institutions.⁷⁻⁹

LOS at our institution is shorter than published averages, and an accelerated discharge (AD) pathway was implemented for NMS patients in 2008 which shortened stays further. Prior to 2008, LOS amongst patients with GMFCS 4 or 5 cerebral palsy (CP) averaged 4.9 days, and after 2008 it decreased to 4.0 days.¹⁰ In further assessing our NMS population, we found that the majority of patients stayed in the hospital for 3 to 6 days after surgery after implementing the AD pathway; however, a small number of outlier patients had very extended stays in excess of 20 days. These patients skewed our mean LOS. We hypothesized that a small subset of NMS patients were not as well-suited for rapid mobilization, early resumption of feeds and discontinuation of drains and catheters as the majority of other patients. By reviewing the charts of NMS patients who underwent PSF, we sought to identify variables that increased risk of extended LOS after surgery, so that these patients might be better optimized and counseled appropriately prior to surgery.

Methods

A retrospective chart review was performed for all patients with an underlying neuromuscular diagnosis who underwent posterior spinal fusion by one of two surgeons between the years of 2005 and 2013. This list totaled 233 patients. Patients undergoing revision surgery or placement or adjustment of growth-friendly instrumentation were excluded from this study. Patients who had anterior spinal procedures were also excluded. This left 197 patients who met inclusion criteria.

The patients included in this study encompassed a wide range of neuromuscular diagnoses including but not limited to cerebral palsy (CP), muscular dystrophy, genetic and chromosomal syndromes, spina bifida, Chiari malformations, syringomyelia, traumatic brain injury, spinal cord injury, spinal muscular atrophy, and Rett syndrome. We assessed patients’ preoperative demographics and comorbidities, as well as feeding and respiratory status. GMFCS level was determined by attending physician and documented in the patient’s preoperative note. Patients with CP were stratified into two groups: less severely involved patients with ambulatory capacity (GMFCS 1-3) and more severely involved patients who were largely unable to ambulate (GMFCS 4-5). Coronal and sagittal Cobb angles and pelvic obliquity were measured on each patient’s non-traction preoperative radiographs.

Next, we reviewed patients’ operative notes, anesthesia documentation, order summaries, and progress notes during their hospital stay to determine estimated blood loss (EBL), surgical time, number of levels fused, presence of intraoperative and postoperative complications, need for transfusion of blood products, need for and length of ICU admission, and hospital length of stay. We also reviewed their postoperative clinic notes for presence of complications and readmissions.

We then divided patients into one of three groups based on their LOS, with patients staying less than 3 days falling into the first quartile, patients staying 3-7 days in the middle two quartiles, and patients staying greater than 7 days falling into the fourth quartile. After stratifying patients into these 3 groups, we analyzed each group to assess for variables that were predictive of LOS group.
Results

Roughly half of the patients included in this study were female (56%), and mean age at the time of surgery was 13.2 years. Fifty-three percent of included patients required a feeding tube for nutrition. The majority were stable on room air and did not require supplemental oxygen or tracheostomy prior to surgery. The majority of CP patients were nonambulatory, with 84% rated as GMFCS 4 or 5. Average max coronal Cobb angle was 63 degrees prior to surgery, and mean pelvic obliquity was 17 degrees. Length of surgery and EBL, and postoperative variables are described in Table 2.

Table 1. Baseline patient characteristics

<table>
<thead>
<tr>
<th>Category</th>
<th>N (%) or Mean (Std)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age at time of surgery (years)</td>
<td>13.2 (3.2), (n=197)</td>
</tr>
<tr>
<td>Sex</td>
<td>Female 110/197 (56%)</td>
</tr>
<tr>
<td></td>
<td>Male 87/197 (44%)</td>
</tr>
<tr>
<td>Feeding status</td>
<td>Feeding tube 80/170 (53%)</td>
</tr>
<tr>
<td></td>
<td>PO 80/170 (47%)</td>
</tr>
<tr>
<td>Respiratory status</td>
<td>Room Air 185/197 (94%)</td>
</tr>
<tr>
<td></td>
<td>Supplemental O2 7/197 (4%)</td>
</tr>
<tr>
<td></td>
<td>Tracheostomy Dependent 5/197 (2%)</td>
</tr>
<tr>
<td>GMFCS (CP only)</td>
<td>1-3 22/136 (16%)</td>
</tr>
<tr>
<td></td>
<td>4-5 114/136 (84%)</td>
</tr>
<tr>
<td>Max Cobb angle (deg)</td>
<td>63.4 (18.3), (n=197)</td>
</tr>
<tr>
<td>Degree of pelvic obliquity (deg)</td>
<td>16.9 (14.6), (n=182)</td>
</tr>
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</table>

Table 2. Admission characteristics

<table>
<thead>
<tr>
<th>N (%) or Mean (Std)</th>
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</thead>
<tbody>
<tr>
<td>EBL</td>
</tr>
<tr>
<td>Length of surgery</td>
</tr>
<tr>
<td>Number levels fused</td>
</tr>
<tr>
<td>Pulmonary complications</td>
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<tr>
<td>Required ICU</td>
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<tr>
<td>Number of patients required blood transfusion intraop</td>
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<tr>
<td>Units transfused intraoperatively</td>
</tr>
<tr>
<td>Number of pts requiring blood transfusion postop</td>
</tr>
<tr>
<td>Units transfused postop</td>
</tr>
</tbody>
</table>

We found that patients had a median LOS of 4 days, and a mean LOS of 5.4 days. While the vast majority of patients are clustered with lengths of stay from 3-7 days, we found that several significant outliers existed. Of the 197 patients included in our analysis, 6 had stays in excess of 20 days, with the longest stay being 51 days (see Table 3).

Table 3. Distribution of hospital LOS

![Hospital LOS Distribution Chart]
Most demographic variables were not predictive of hospital LOS. Patients’ type of neuromuscular disease, gender, age at surgery, and dependence on tube feeds for nutrition were not predictive of ultimate LOS. Respiratory status, including the need for supplemental oxygen or tracheostomy prior to surgery, trended toward but did not meet statistical significance (p=0.08).

Several preoperative characteristics, however, did correlate. Patients with more involved CP (GMFCS 4-5) were significantly more likely to fall into the extended stay group, with 90% of CP patients requiring LOS >7 days being severely involved, as compared to 10% of those patients with LOS >7 days being GMFCS 1-3 (p=0.020). Maximum preoperative coronal Cobb angle was also predictive of LOS, with mean Cobb angle sequentially increasing by LOS group (p=0.002). Preoperative pelvic obliquity also increased sequentially, with a mean angle of 12 deg amongst those patients with LOS <3 days as compared to 21 deg amongst those with LOS >7 days (p=0.017).

### Table 4. Relationship between baseline demographics and LOS groups

<table>
<thead>
<tr>
<th></th>
<th>&lt;3 days</th>
<th>3-7 days</th>
<th>&gt;7 days</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age at surgery</td>
<td>13.3 (3.4), (n=56)</td>
<td>13.0 (2.9), (n=111)</td>
<td>13.7 (3.6), (n=30)</td>
<td>0.5642</td>
</tr>
<tr>
<td>Sex</td>
<td>Female 38/56 (68%)</td>
<td>58/111 (52%)</td>
<td>14/30 (47%)</td>
<td>0.0870</td>
</tr>
<tr>
<td></td>
<td>Male 18/56 (32%)</td>
<td>53/111 (48%)</td>
<td>16/30 (53%)</td>
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</tr>
<tr>
<td>Diagnosis Group</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
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<tr>
<td></td>
<td>32/56 (57%)</td>
<td>17/56 (30%)</td>
<td>1/111 (1%)</td>
<td>1/111 (1%)</td>
</tr>
<tr>
<td>GMFCS Level, cp only</td>
<td>1-3 10/30 (33%)</td>
<td>10/86 (12%)</td>
<td>2/20 (10%)</td>
<td>0.0002</td>
</tr>
<tr>
<td></td>
<td>4-5 20/30 (67%)</td>
<td>76/86 (88%)</td>
<td>18/20 (90%)</td>
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</tr>
<tr>
<td>Feeding tube</td>
<td>15/44 (34%)</td>
<td>50/100 (50%)</td>
<td>13/26 (50%)</td>
<td>0.1326</td>
</tr>
<tr>
<td>Respiratory status</td>
<td>RA 53/56 (95%)</td>
<td>107/111 (96%)</td>
<td>25/30 (83%)</td>
<td>0.0863</td>
</tr>
<tr>
<td></td>
<td>Supp O2 2/56 (4%)</td>
<td>2/111 (2%)</td>
<td>3/30 (10%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Trach 1/56 (2%)</td>
<td>2/111 (2%)</td>
<td>2/30 (7%)</td>
<td></td>
</tr>
<tr>
<td>Max Cobb angle</td>
<td>56.6 (16.9), (n=56)</td>
<td>65.3 (16.8), (n=111)</td>
<td>68.8 (15.6), (n=30)</td>
<td>0.0027</td>
</tr>
<tr>
<td>Degree pelvic obliquity</td>
<td>12.6 (14.1), (n=55)</td>
<td>18.0 (13.9), (n=86)</td>
<td>21.3 (16.4), (n=29)</td>
<td>0.0171</td>
</tr>
</tbody>
</table>

A number of intraoperative variables were found to correlate with LOS. Length of surgery was significantly longer in the prolonged LOS group, measuring an average of 1.5 hours longer amongst patients with extended stays than those with short stays (p<0.001). Number of levels fused was also significantly higher amongst the extended LOS group (p<0.001). Those patients who experienced pulmonary complications or required ICU admission were significantly more likely to fall into the extended LOS group. Estimated blood loss (EBL) during surgery trended higher but did not meet statistical significance (p=0.06).

### Table 5. Relationship between intraoperative and postoperative variables and LOS groups

<table>
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<tr>
<th></th>
<th>&lt;3 days</th>
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<th>&gt;7 days</th>
<th>p-value</th>
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<tr>
<td>Length of surgery</td>
<td>3.6 (1.2), (n=56)</td>
<td>4.5 (1.1), (n=111)</td>
<td>5.1 (1.6), (n=30)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>No. Levels Fused</td>
<td>12.9 (3.8), (n=55)</td>
<td>15.1 (2.0), (n=111)</td>
<td>15.3 (1.7), (n=30)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Intraop Complications</td>
<td>2/55 (4%)</td>
<td>2/111 (2%)</td>
<td>7/20 (35%)</td>
<td>0.0037</td>
</tr>
<tr>
<td>Pulmonary complication</td>
<td>1/56 (2%)</td>
<td>16/111 (14%)</td>
<td>12/30 (40%)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Required ICU</td>
<td>4/56 (7%)</td>
<td>3/26 (14%)</td>
<td>7/20 (35%)</td>
<td>0.0025</td>
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<tr>
<td>Time in ICU</td>
<td>0.8 (0.5), (n=8)</td>
<td>3.5 (1.7), (n=13)</td>
<td>3.2 (0.5), (n=6)</td>
<td>0.0250</td>
</tr>
<tr>
<td>Neurologic deficits</td>
<td>1/56 (2%)</td>
<td>4/111 (4%)</td>
<td>2/30 (7%)</td>
<td>0.4206</td>
</tr>
<tr>
<td>Infection, delayed healing</td>
<td>1/56 (2%)</td>
<td>1/111 (1%)</td>
<td>2/20 (10%)</td>
<td>0.1062</td>
</tr>
<tr>
<td>Required ABX</td>
<td>2/56 (4%)</td>
<td>9/102 (9%)</td>
<td>3/20 (15%)</td>
<td>0.2476</td>
</tr>
<tr>
<td>Required OR</td>
<td>0/56 (0%)</td>
<td>2/106 (2%)</td>
<td>5/20 (25%)</td>
<td>0.0719</td>
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<td>Decubitus ulcers</td>
<td>0/56 (0%)</td>
<td>1/111 (1%)</td>
<td>1/30 (3%)</td>
<td>0.3301</td>
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<tr>
<td>Cutout loosening malplacement</td>
<td>0/56 (0%)</td>
<td>2/94 (2%)</td>
<td>0/20 (0%)</td>
<td>1.0000</td>
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<td>Bleeding</td>
<td>0/55 (0%)</td>
<td>0/111 (0%)</td>
<td>1/25 (4%)</td>
<td>0.1309</td>
</tr>
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</table>
### Conclusions

Understanding the factors that prolong hospital stay amongst patients with NMS allows physicians to better counsel patients and their families prior to surgery. Patients with more involved CP and patients with more severe curves and pelvic obliquity are more likely to require extended stays. Greater numbers would be needed to determine whether type of neuromuscular diagnosis is also a risk factor. Recent literature cites mean length of stay for patients with spinal muscular atrophy after PSF as high as 17 days, suggesting that diagnosis may be an important factor, however greater study numbers would be needed to determine the significance of this variable.

This data begs the question of whether patients with multiple risk factors should be excluded from AD pathways. We have found that our AD pathway not only shortens LOS but also reduces some complications including pulmonary complications, which have historically been the most prominent complication following PSF for NMS. It is unclear whether delaying mobilization, resumption of feeds, and removal of drains and catheters would benefit these high risk patients. It is equally likely that their risk of prolonged stay and complications would be unchanged if excluded from an AD pathway. Again, further study is needed in this area.

Intraoperative and postoperative findings can also drive hospital stay. Length of surgery, numbers of levels fused, and the need for blood transfusions are all significantly linked to prolonged stays. Pulmonary complications and ICU admission are also significantly more common in the extended stay group. These factors should serve as red flags for those patients who require additional time and resources. Early vigilance and interventions may serve to minimize the complications that drive hospital LOS.

It would also be reasonable to consider whether high risk patients should undergo additional measures preoperatively to optimize them for surgery. For example, formal preoperative pulmonary function testing, respiratory treatments, and preoperative placement of feeding tubes may provide great benefit to a small subset of patients. These measures are not without cost to patients and healthcare centers, but may allow for fewer postoperative issues and improved outcomes. Limiting such interventions to those patients who stand to gain the greatest benefit will focus healthcare dollars and the efforts and time of patients’ families where they matter most.

<table>
<thead>
<tr>
<th></th>
<th>Intraop transfusion</th>
<th>Postop transfusion</th>
<th>Intraop transfusion units</th>
<th>Postop transfusion units</th>
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</thead>
<tbody>
<tr>
<td>Patients</td>
<td>2/55 (4%)</td>
<td>27/111 (24%)</td>
<td>1.0 (0.0), (n=2)</td>
<td>1.0 (0.0), (n=2)</td>
</tr>
<tr>
<td>Patients</td>
<td>2/55 (4%)</td>
<td>20/111 (18%)</td>
<td>1.4 (1.4), (n=27)</td>
<td>1.3 (0.7), (n=20)</td>
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<td>P-value</td>
<td>0.0037</td>
<td>0.0079</td>
<td>0.7800</td>
<td>0.4251</td>
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References:


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Atlanta Orthopaedic Society, Resident Member 2013 – Present
Georgia Orthopaedic Society, Resident Member 2016 - Present

Research Publications:


Research Projects:


Presentations:

Book Chapters:

Educational Videos
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PEER-REVIEWED PUBLICATIONS


PEER-REVIEWED PUBLICATIONS


PRESENTATIONS:


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Radial to Axillary Nerve Transfers: A Multi-Center Case Series
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David S. Ruch, M.D., Fraser J. Leversedge, M.D.

Abstract

Background
Loss of active shoulder abduction due to brachial plexus or isolated axillary nerve injury is associated with a severe functional deficit. The purpose of this multi-center study was to evaluate retrospectively the restoration of shoulder abduction after transfer of a branch of the radial nerve to the axillary nerve for patients after brachial plexus or axillary nerve injury.

Methods
Patients who underwent transfer of a branch of the radial nerve to the anterior branch of the axillary nerve in two institutions, either alone or in combination with other nerve transfers, between 2004 and 2014 were reviewed. A total of 27 patients with average follow-up of 21.8 months were included. Outcome measures included pre- and post-operative shoulder abduction and triceps strength, and active and passive shoulder ROM.

Results
The average pre- and post-operative shoulder abduction strength was 0.36 and 3.9 respectively, using the Medical Research Council grading system. Average pre-operative shoulder abduction was 12.4 degrees compared to 113.7 degrees post-operatively. Improvements of both average shoulder abduction strength and active shoulder abduction motion were statistically significant. Twenty-two of 27 (81.5%) achieved at least M3 strength, with 17 of 27 (62.9%) achieving M4 strength. No statistically significant differences were observed when subgroup analysis was performed for isolated nerve transfer versus multiple nerve transfer, mechanism of injury, injury level, branch of radial nerve transferred, or time from injury to surgery. A negative correlation was found comparing increasing age and both shoulder abduction strength and active shoulder abduction. No significant change in triceps strength was observed postoperatively. There were 4 patients who achieved no significant gain in shoulder abduction or deltoid strength and were deemed failures. No post-operative complications occurred.

Conclusions
Transfer of a branch of the radial nerve to the anterior branch of the axillary nerve was successful in improving shoulder abduction strength and active shoulder motion in the majority of the patients. The specific triceps nerve branch utilized for transfer did not influence the overall clinical outcomes.

Type of Study / Level of Evidence:
This is a retrospective case series representing a level IV study.

Keywords: nerve transfer, radial nerve, axillary nerve, deltoid, shoulder, brachial plexus injury

INTRODUCTION

Injuries to the axillary nerve or brachial plexus can result from penetrating trauma, traction injuries, shoulder dislocation, and as complications of shoulder surgery.\(^1,2\) The resulting lack of shoulder abduction secondary to nerve injury can result in a severe functional deficit for patients, making many activities of daily living difficult or impossible.\(^3,4\)

The reconstructive ladder for treating brachial plexus or axillary nerve injuries includes plexus exploration with neurorrhaphy, nerve grafting, nerve transfers, tendon transfers, and arthrodesis. Based on the restricted functional recovery with glenohumeral arthrodesis and previous reports of limited outcomes following tendon transfer reconstruction for a shoulder abduction deficit\(^5\), there has been increased...
interest in nerve grafting and nerve transfer procedures for shoulder reanimation. In 2011 Garg et al. performed a systematic analysis comparing the results of nerve transfers and nerve grafts in patients with traumatic upper plexus (C5-6 or C5-6-7) palsy. They showed more favorable outcomes in patients with nerve transfers compared to patients undergoing neurorrhaphy and nerve grafting. Successful restoration of deltoid strength and shoulder abduction has been reported in several small series, although worse results were associated with increasing time to surgery, increasing age, and obesity. The potential influences on clinical outcomes of the injury mechanism, the extent of plexus injury, the particular radial nerve branch donor, and the method of nerve repair are not well known.

The purpose of this study was to review our experience, across two institutions, in restoring active shoulder abduction by transferring a branch of the radial nerve to the axillary nerve. We report the largest series to date of patients undergoing radial to axillary nerve transfers for brachial plexus and axillary nerve injuries. We hypothesized that transfer of a branch of the radial nerve to the anterior branch of the axillary nerve would substantially improve shoulder function after brachial plexus or axillary nerve injury and would cause minimal donor related deficits.

METHODS
Following Institutional Review Board approval, the perioperative database for Current Procedural Terminology (CPT) codes related to surgeries involving radial to axillary nerve transfers between 2004 and 2014 was searched at two institutions. Patients were included if they had undergone transfer of a branch of the radial nerve to the axillary nerve, were over the age of 18, had a brachial plexus or axillary nerve injury with deltoid denervation as demonstrated by EMG, had no prior brachial plexus surgeries, had a minimum 6 months follow-up, and had a functioning radial nerve as demonstrated by M4 or 5 triceps strength preoperatively. Patients who had concomitant nerve transfers including spinal accessory nerve to suprascapular nerve or ulnar nerve fascicles to musculocutaneous nerve were included.

Patient charts were reviewed for demographic data including age, sex, date of injury, mechanism of injury, and time to surgery; clinical data including initial strength and abduction assessments; operative data including procedures performed and complications; and follow-up data including length of follow-up, final abduction strength and active shoulder abduction measurements. The treating surgeons performed all assessments. Strength was assessed according to the British Medical Research Council (MRC) grading scheme. Shoulder abduction was measured by the treating surgeon with a goniometer and was defined as the angle between the arm axis and the thoracolumbar spine. Validated functional outcomes instruments were not used consistently and were not included.

In brief, the surgery was completed via a posterior approach to the shoulder and brachium. At the surgeon’s discretion, the appropriate branch of the radial nerve to the triceps was divided distally and was transferred to the anterior branch of the axillary nerve, similar to the technique described by Leechavengvongs. Additional nerve transfers such as transfer of the spinal accessory nerve to the suprascapular nerve and selected ulnar nerve fascicle to the musculocutaneous nerve for C5-6 root injuries, were performed based on the patients’ injury pattern and functional deficits. A nerve stimulator was used to confirm the identity of the anterior branch of the axillary nerve. Neurorrhaphy was performed in end-to-end fashion with 7-0, 8-0, or 9-0 nylon and supplemented with fibrin glue (Tisseel, Baxter Inc, Deerfield, IL). Post-operatively a shoulder immobilizer was applied with initiation of pendulum exercises beginning at 10-14 days postoperatively. Physical therapy for shoulder mobilization was started when deemed appropriate by the attending surgeon.

There were five main outcomes of interest in this analysis: (1) pre- and post-operative shoulder abduction strength (MRC Grade); (2) pre- and post-operative active and passive range of shoulder abduction; (3) the
difference between pre- and post-operative shoulder abduction strength (MRC grade); (4) the difference between pre- and post-operative active range of shoulder abduction; (5) and the difference between pre- and postoperative triceps strength (MRC grade). The distributions for each of these outcomes were examined and, due to the non-normal shape and small sample size, the median, 25th percentile and 75th percentile were reported, also. Additionally, statistical analysis was performed for each of the outcomes analyses.

A Wilcoxon Signed Rank Test was used to examine the difference between the pre-operative and post-operative shoulder abduction strength, range of shoulder abduction motion, and triceps strength. The outcomes were examined by six covariates of interest: number of nerve transfers (single vs. multiple), injury level (plexus vs. nerve branch), injury type (surgery vs. trauma), time to surgery (≤6 months vs. >6 months), radial nerve branch (lateral vs. long vs. medial), age (≤40 years vs. 40 years). The outcomes were tested against number of nerve transfers, injury level, and injury type using a Wilcoxon Rank Sum Test. The Kruscal Wallace Test was employed to categorize differences in the outcome measures based on radial nerve branch utilized for transfer. Time to surgery and age group were examined both categorically using the Wilcoxon Rank Sum test and continuously using a Spearman correlation coefficient. This analysis was completed first including all of the patients and then again excluding the failures.

RESULTS

A total of 27 patients met the inclusion criteria for the study. Table 1 lists the demographics of the study population. Patient follow up averaged 21.8 months post-operatively. Four of the 27 patients did not have any noticeable recovery and were deemed failures.

The results demonstrated a statistically significant post-operative change in shoulder abduction strength (p <0.0001). (Table 2) The average post-operative shoulder abduction strength in those who showed any recovery was assessed as an MRC grade 3.9 (N = 23). Twenty-two of 27 patients obtained M3 or greater recovery of shoulder abduction strength. Of the 22 patients, 17 patients recovered to a meaningful M4 level of strength. No difference was found between pre- and post-operative triceps strength.

The results demonstrated a statistically significant post-operative change in range of shoulder abduction motion (p <0.0001). (Table 2) The average post-operative range of shoulder abduction in those who showed any recovery was 113.7 degrees (Range: 0–160 degrees, N = 23). The presence of concomitant nerve transfers (in addition to the radial nerve branch to axillary nerve transfer), the initial injury level (plexus vs. nerve branch), the injury type (surgery vs. trauma), the time to surgery (≤6 months vs. >6 months), and the age (≤40 years vs. >40 years) were not found to be related to the outcomes measured in this series. The radial nerve branch used was not associated with the outcomes but notably there were no differences in elbow extension strength post-operatively for any of the branches used in this cohort (Table 3).

The time interval from injury to surgery and the age of the patient at the time of surgery were examined both categorically and continuously. No results were found to be significant except for age which, when examined continuously, did demonstrate a difference in shoulder abduction strength change with a correlation coefficient of -0.3990 (p = 0.04) and difference in range of shoulder abduction change with a correlation coefficient of -0.4588 (p = 0.02) (Figures 1 and 2).

Failure was defined as no identified deltoid function or active shoulder abduction post-operatively. There were four failures in our series. (Table 4) When excluding the failures, the clinical results were similar except when examining mechanism of injury: the post-operative changes in shoulder abduction strength (p = 0.02) and in active shoulder range of motion (p = 0.01) were found to be statistically significant.
comparing those individuals experiencing injury as a result of trauma having more dramatic improvement in both strength and shoulder range of motion as compared to those individuals suffering iatrogenic injury.

**DISCUSSION**

In response to suboptimal outcomes of nerve grafting and prior nerve transfer techniques, 15,16 Witoonchart and Leechavengvongs published an anatomic feasibility study in 2003 investigating the potential transfer of the branch of the radial nerve to the long head of triceps to the anterior branch of the axillary nerve. 17 The authors found the diameter, number of axons, and the anatomic proximity of the nerve to the long head of the triceps to be acceptable for potential transfer to the anterior branch of the axillary nerve. In a follow up review of 15 patients with complete C5-6 avulsion injuries, 13 of 15 obtained M4 and 2 obtained M3 strength. 18 All patients had useful function of the deltoid with a mean shoulder abduction of 115 degrees and no reported failures. Bertelli reported 10 patients with radial to the axillary nerve transfers with an average active shoulder abduction of 92 degrees (range: 65-120 degrees). Only 3 of the 10 patients obtained M4 strength. 19 Based on the results of these studies, radial to axillary nerve transfers became an important option in the reconstructive ladder for brachial plexus and, particularly, axillary nerve injury. In a recent series with a nerve transfer cohort, 12 of 14 (86%) patients obtained M3 or greater deltoid strength. 20

Lee et al. recently reported a series of radial to axillary nerve transfers for isolated axillary nerve injuries. 21 In their retrospective series, the average MRC grade of deltoid muscle strength was 3.5 with a quarter of their patients not achieving anti-gravity strength. The authors expressed concern over the efficacy of the nerve transfers and determined that functional deltoid strength correlated negatively with the age of the patient, increasing time from injury to surgery, and the patient’s body mass index (BMI). Despite the information gleaned from these previous reports, there are numerous questions that remain unanswered regarding the functionality and morbidity of radial to axillary nerve transfers and its role in the reconstructive ladder for brachial plexus and axillary nerve injury.

Our retrospective study demonstrates the benefits of radial (triceps branch) to axillary nerve transfer in the setting of an axillary nerve or similar brachial plexus deficit, although complete functional recovery is not expected. Twenty-three of 27 patients achieved improvement in shoulder abduction strength and active range of motion. The 4 failures were present at various time-points during our review, thus they occurred irrespective of the level of experience of the treating surgeons. It is difficult to identify specific factors for the failures but trends were noted and correlated well with previous reports.

The average shoulder abduction strength (MRC grade 3.9) and active shoulder abduction range of motion (113.7 degrees) are similar to previously reported results with significant improvement from preoperative function (an average MRC shoulder abduction strength of 0.36 and shoulder abduction ROM of 12.4 degrees). Twenty-two of 27 (81.5%) achieved at least M3 strength, with 17 of 27 (62.9%) achieving M4 strength 13,14. There was no difference in shoulder abduction strength recovery between patients treated for brachial plexus or peripheral axillary nerve injuries.

The data were examined to determine other factors that might be attributed to success or failure of radial to axillary nerve transfers. When examined continuously, a negative correlation was found between age and post-operative shoulder abduction strength and active shoulder abduction motion. It has been widely reported that the patient’s age affects the outcome of nerve grafting procedures. Bonnard et al. demonstrated that there was a negative correlation between age and motor strength while Wehbe et al. reported better outcomes in patients younger than 25 years compared with older patients 15,16. Lee et al. supported these findings in nerve transfer patients with a 92% success rate in patients younger than 40
years old. Of the 4 failures in this study, 1 patient was 85 years of age and 2 of the remaining 3 were greater than 40 years of age. It is possible that age adversely influenced the outcomes of these patients.

In the present study, no correlation was found between functional outcomes and the time from injury to surgery (either ≤ 6 months or > 6 months from the time of injury). It is widely accepted that time to surgery will affect outcome after nerve repair, grafting, or transfer. Bonnard et al. demonstrated that a delay of 6 months resulted in a decrease in the number of successful outcomes following nerve grafting. Terzis et al. reported that patients with a denervation time of less than 4 months had improved shoulder function after nerve grafting. Because the donor nerve is closer to the target muscle, better motor recovery should be expected after delayed repair with a nerve transfer procedure when considering the time for nerve regeneration across a longer nerve graft segment. Although Bertelli did report success with nerve transfers performed in patients greater than 9 months from injury, Lee et al. noted a significant decrease in deltoid motor strength after 9 months with no patients obtaining useful recovery after 12 months. Although the results of our study did not show a correlation between the time from injury to surgery and functional outcomes, 3 of the 4 failures underwent surgery at an average of 10 months following injury.

A number of adjunctive methods have been investigated for the enhancement of nerve repair and may be applicable to nerve transfers to decrease failure and increase target muscle strength, considering the accepted mismatch between axon counts of the donor and recipient nerves. Tacrolimus (FK-506) has been proven experimentally to have a dose dependent positive neuroregenerative effect, yet immunosuppressive effects make it less than desirable for the long term treatment likely required for nerve regeneration and muscular recovery following nerve transfer. Similarly, electrical stimulation has been investigated for its positive neuroregenerative effects following nerve injury. Unlike Tacrolimus use, electrical stimulation decreases the time required for axons to traverse the injury site, however its effect has been shown to be temporary. Electrical stimulation is able to potentiate the effects of sex steroids and/or exercise on nerve regeneration. Investigations have demonstrated mixed results for direct electrical stimulation of denervated muscle: enhancing functional recovery in some studies while decreasing markers of muscle recovery in others. The severity of trauma or injury mechanism has been proposed as a factor influencing nerve recovery following injury and repair. No correlation was found between the injury type (trauma vs. surgery) and the functional outcomes after nerve transfer, a finding that has been supported previously. Despite the lack of statistical significance, all four of the failures in our study occurred as the result of traumatic injury.

In our study, there were no donor site complications and all patients maintained their pre-operative triceps strength, based on MRC grading only. Compared to tendon transfer surgery and nerve autograft reconstruction, radial to axillary nerve transfers appear to have less donor site morbidity and are able to be performed through a single incision. Furthermore, there was no difference in outcomes observed when comparing the particular branch of the radial nerve used for the transfer. Considering surgeon preferences, often patient anatomy will dictate the choice of the radial nerve branch donor. Three of the 4 failures in this study utilized the radial nerve branch to the long head of the triceps, however this was not determined to be statistically significant and we recognize that other variables most likely influenced ultimate outcomes in these cases.

The primary limitations of our study include its retrospective nature that weakens the analysis power. Also, despite being an accepted method of post-operative patient assessment for muscle recovery, manual muscle strength testing using the MRC grading system is a subjective measure and no objective validated outcomes scores were available for this study. Also, the strength testing did not consider the
physiologic aspect of fatigue on muscle function, possibly influenced by the amount of muscular reinnervation.

Our results support the benefits of radial to axillary nerve transfer in the treatment of selected brachial plexus and axillary nerve injuries. Our multi-surgeon, multi-institutional study demonstrated: (1) an average post-operative shoulder abduction strength of 3.9 and active shoulder abduction of 113.7; (2) no significant change in pre- and post-operative triceps strength following harvest of one of the three motor branches; (3) the radial nerve triceps branch used for transfer did not influence post-operative shoulder abduction or triceps strength; (4) increased age has a negative correlation with post-operative shoulder abduction strength recovery and active shoulder abduction. Ultimately, high quality randomized, controlled trials are necessary to further understand the role of the radial to axillary nerve transfer in reconstructing deltoid and shoulder function. Future research should continue to focus on the selection, repair and aftercare optimization of these patients to limit failures as well as improve identification of patient characteristics that influence patient outcomes.

REFERENCES:
Tables:
Table 1. Demographics of Study Population

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<th>Study Cohort (N=27)</th>
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</tr>
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<td>Female</td>
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<td>Single</td>
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<td>Nerve Branch Utilized</td>
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<td>Medial</td>
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<tr>
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<tr>
<td>Lateral</td>
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<td>Time to Surgery (Months)</td>
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<td>Length of Follow up (Months)</td>
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Results are reported as mean ± standard error
Table 2. Postoperative Change in muscle strength and shoulder abduction

<table>
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<td></td>
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<td></td>
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</tr>
<tr>
<td>Preoperative Deltoid Strength</td>
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<td>0 (0,0)</td>
</tr>
<tr>
<td>(MRC Grade)</td>
<td>&lt;0.0001</td>
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<td>4 (3,4)</td>
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<tr>
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<tr>
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<tr>
<td>Strength (MRC Grade)</td>
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<tr>
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<tr>
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<td>&lt;0.0001</td>
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<td>110 (85, 160)</td>
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<td>90 (60, 150)</td>
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<td>(degrees)</td>
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<tr>
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<td>5 (5,5)</td>
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<td>5 (5,5)</td>
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Table 3. Functional outcomes across radial nerve branch donors.

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<td>0 (0, 0)</td>
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<tr>
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<td>110 (60, 160)</td>
<td>90 (0, 160)</td>
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<td>(degrees)</td>
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<td>5 (5, 5)</td>
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<td>(MRC Grade)</td>
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Table 4: Demographics of Failures

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<tr>
<td>Female</td>
<td>1 (25%)</td>
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<tr>
<td>Side</td>
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<tr>
<td>Right</td>
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<tr>
<td>Left</td>
<td>2 (50%)</td>
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<tr>
<td>Mechanism</td>
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<tr>
<td>Trauma</td>
<td>4 (100%)</td>
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<tr>
<td>Surgery</td>
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<tr>
<td>Injury</td>
<td></td>
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<tr>
<td>Plexus</td>
<td>2 (50%)</td>
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<tr>
<td>Nerve</td>
<td>2 (50%)</td>
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<tr>
<td>Nerve Transfers Performed</td>
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<tr>
<td>Single</td>
<td>2 (50%)</td>
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<tr>
<td>Multiple</td>
<td>2 (50%)</td>
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<tr>
<td>Nerve Branch Utilized</td>
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<td>Medial</td>
<td>1 (25%)</td>
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<tr>
<td>Long</td>
<td>3 (75%)</td>
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<tr>
<td>Lateral</td>
<td>0 (0%)</td>
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<tr>
<td>Time to Surgery (Months)</td>
<td>8.0 ± 3.2</td>
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<tr>
<td>Length of Follow up (Months)</td>
<td>14.0 ± 22.5</td>
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Figure 1: The average change in deltoid strength as a function of age. The correlation coefficient of -0.39 was found to be significant. (p = 0.04).
Figure 2: The average change in range of motion (ROM) as a function of age. The correlation coefficient of -0.46 was found to be significant. \( p = 0.02 \).
Figure 3: The average change in deltoid strength as a function of time to surgery. The correlation coefficients of -0.03, was not found to be significant. (p > 0.05).
Figure 4: The average change in range of motion (ROM) as a function of time to surgery. The correlation coefficients of -0.08 respectively was not found to be significant. (p > 0.05).
Jimmy Daruwalla, MD  PGY-5

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PUBLICATIONS/ PRESENTATIONS

Current Projects/Grants
Garrard EC, Braly B, Simpson A, Heller JG. “A retrospective radiographic review of fusion rates at 3 months for one and two level anterior cervical diskectomy and fusion with and without recombinant Bone Morphogenetic Protein-2.” Preparing manuscript.
Garrard EC, Gottschalk MB, Yoon ST. “Surgical training using a novel and inexpensive durotomy repair model.” Emory University Research Seed Grant: $3,000.00.
Garrard EC, Rhee J, Stephens B. “Surgical treatment of de novo C5 palsies affecting the deltoid.” Submitted to CSRS, AAOS meetings.
Shi WJ, Schell A, Garrard E, Rhee JM. “Increased adjacent segment motion after ACDF: How is it distributed in the cervical spine?”
Surgical Training Using A Novel And Inexpensive Durotomy Repair Model.
Eli Garrard, MD, Michael Gottschalk, MD, S. Tim Yoon, MD

INTRODUCTION
The incidence of dural tears or incidental durotomies (ID) during spine surgery has been reported as low as 2.7% to as high as 10.6%[1,2,3]. Postoperative complications after ID include durocutaneous fistula, pseudomeningocele, arachnoiditis and need for reoperation if the ID is missed during the index procedure. Du et al. found that prior spine surgery, laminectomy and older age where significant independent risk factors for ID[1]. In another review of intraoperative durotomies, Yoshihara et al. found that older age, female gender, increased Elixhauser comorbidity score and high hospital caseload were significant risk factors[2]. This study also reported that when comparing patients with and without ID during the index procedure, those with ID had significantly higher overall in-hospital complications, higher in-hospital mortality rate, longer hospital stays, increased total hospital charges and a lower percentage of patients discharged home[2].

With the ever-increasing burden for post-graduate residents and fellows to acquire surgical skills in the setting of restricted duty hours[4,5], the interest and need for developing cost-effective instructional and skill-building models for use outside of the operative room (OR) has grown. Several authors have already demonstrated the benefits of such models[6,7]. Expensive commercial ID models exist but require significant investment by residency and fellowship programs with significant recurring costs to replenish the used portions of the model.

Given the limited exposure that residents and fellows have to repairing ID intraoperatively given the technical nature of the repair, the authors of this paper initially set out to build a novel dural repair model that most closely resemble the complexity of the dural repair intraoperatively. Furthermore, the authors wished to build the model using commonly acquired and inexpensive items that most residents and fellows would be able to obtain at his or her training facility and at a local hardware and convenience stores.

METHODS
Twelve orthopaedic residents postgraduate year (PGY) 1 to 5 from a single orthopaedic residency program that had previously never used the novel dural repair model were asked to simulate a primary repair of a 10mm incidental durotomy using the dural repair model. Residents who were post-graduate year 1 or 2 were considered juniors whereas residents who were post-graduate year 4 and 5 were considered chiefs. The residents were provided with one 6” DeBakey atraumatic tissue forceps, one 5.5” Tungsten Carbide Castro-Viejo needle holder, one 6-0 polypropylene monofilament suture, two #11 protected disposable scalpels and one novel dural repair model. Figure 3.2.

The residents were briefly instructed on the use of the instruments and common dural repair technique. The residents then used the ruler on the #11 protected disposable scalpel to measure 10mm. Using the second provided #11 protected disposable scalpel, the residents created a 10mm incidental durotomy in the novel dural repair model. Once the durotomy was created, a timer was started.

The residents had as much time as he or she needed to repair the durotomy and were not allowed to start over for any reason. Figure 3. After repair of the durotomy was completed, the time expired (second’s) and quantity of water (grams) leaked was recorded. Each resident was tested consecutively in the same
sitting for a total of three times with time given in between trials to refill the model and adjust the dural repair model with fresh surface area to create the incidental durotomy.

RESULTS
Twelve residents completed three attempts at the durotomy repair model. No resident was excluded from the results. There were three residents each from the post-graduate years one, two, four and five. Table 1, 2.

Attempt 1
The mean time to complete the first attempt by all 12 residents was 378 seconds and ranged from 133 seconds to 570 seconds. Chart 1. The mean volume of water leaked during the first attempt was 330 mL and ranged from 122 mL to 493 mL. Chart 2.

The mean time for juniors to complete the first attempt was 476 seconds and ranged from 240 seconds to 570 seconds. The mean time for chiefs to complete the first attempt was 280 seconds and ranged from 133 seconds to 360 seconds. Chart 1. There was a statistically significant difference between the time that it took the juniors and chiefs to complete the first attempt (ρ <0.03).

The mean volume of water leaked during the first attempt by the juniors was 409 mL and ranged from 306 mL to 493 mL. The mean volume of water leaked during the repair by the chiefs was 250 mL and ranged from 122 mL to 316 mL. Chart 2. There was a statistically significant difference between the volume of water leaked during the repair with the juniors and chiefs during the first attempt (ρ <0.008).

Attempt 2
The mean time to complete the second attempt by all 12 residents was 288 seconds and ranged from 144 seconds to 465 seconds. Chart 1. The mean volume of water leaked during the first attempt was 227 mL and ranged from 92 mL to 442 mL. Chart 2.

The mean time for juniors to complete the second attempt was 339 seconds and ranged from 186 seconds to 465 seconds. The mean time for chiefs to complete the second attempt was 236 seconds and ranged from 144 seconds to 345 seconds. Chart 1. There was a statistically significant difference between the time that it took the juniors and chiefs to complete the second attempt (ρ <0.04).

The mean volume of water leaked during the second attempt by the juniors was 262 mL and ranged from 98 mL to 442 mL. The mean volume of water leaked during the second attempt by the chiefs was 192 mL and ranged from 92 mL to 264 mL. Chart 2. There was no statistically significant difference between the volume of water leaked during the repair with the juniors and chiefs during the second attempt (ρ <0.25).

Attempt 3
The mean time to complete the third attempt by all 12 residents was 255 seconds and ranged from 85 seconds to 657 seconds. Chart 1. The mean volume of water leaked during the first attempt was 242 mL and ranged from 113 mL to 515 mL. Chart 2.

The mean time for juniors to complete the third attempt was 365 seconds and ranged from 186 seconds to 657 seconds. The mean time for chiefs to complete the third attempt was 144 seconds and ranged from 85 seconds to 210 seconds. Chart 1. There was a statistically significant difference between the time that it took the juniors and chiefs to complete the third attempt (ρ <0.039).

The mean volume of water leaked during the third attempt by the juniors was 329 mL and ranged from 183 mL to 463 mL. The mean volume of water leaked during the third attempt by the chiefs was 156 mL and ranged from 113 mL to 235 mL. Chart 2. There was no statistically significant difference between the volume of water leaked during the repair with the juniors and chiefs during the second attempt (ρ <0.57).
Percent Improvement between Attempt 1 and 2
The mean percent improvement in time between the first attempt and the second attempt by all residents was 21% and ranged from -8% to 52%. Chart 3. There was a statistically significant difference between the first and second attempts by the twelve residents (p <0.004).
The mean percent improvement in volume leaked between the first attempt and the second attempt for all residents was 29% and ranged from -1% to 77%. Chart 4. There was a statistically significant difference between the first and second attempts by the twelve residents (p <0.006).

Percent Improvement between Attempt 2 and 3
The mean percent improvement in time between the second attempt and the third attempt was 15% and ranged from -56% to 54%. Chart 3. There was no statistically significant difference between the second and third attempts by the twelve residents (p <0.3).
The mean percent improvement in volume leaked between the second attempt and the third attempt was -22% and ranged from -164% to 50%. Chart 4. There was no statistically significant difference in volume leaked between the second and third attempts by the twelve residents (p<0.65).

Percent Improvement Overall
The mean percent improvement overall in time between the first attempt and the third attempt was 35% and ranged from -15% to 70%. Chart 3. There was a statistically significant difference in time between the first and third attempts by the twelve resident (p<0.0008).
The mean percent improvement overall in volume leaked between the first attempt and the third attempt was 27% and ranged from -17% to 59%. Chart 4. There was a statistically significant difference in volume leaked between the first and third attempts by the twelve resident (p<0.004).

DISCUSSION
Many tasks performed by fellows, residents and medical students in the operating room require prior repetitive practice outside of the OR such as suturing and knot tying. Unfortunately, many complex situations in the OR cannot be realistically recreated outside of the OR to allow for repetitive practicing and the development of fine motor skills. In these situations, the residents and fellows are left to develop these often complex and challenging skills during the limited opportunities available while in his or her residency or fellowship.

Although there are multiple sub-specialties in both orthopaedic and neurological surgery, during spine surgery, primary repair of the dura unites these two fields and requires the development of unique skills by residents and fellows. Orthopaedic spine and neurological surgery residents and fellows must hone these complex and crucial skills allowing him or her to eventually operate independently and successfully around the spine. The authors of this paper recognized the complexity of primarily repairing the dura coupled with the limited availability of residents and fellows to practice this procedure. This “perfect storm” of deficient training could theoretically lead to graduating orthopaedic and neurosurgical residents and fellows having practiced this critical portion of the procedure in the event of a durotomy only a few times during his or her five to seven years of training.

This novel and inexpensive incidental durotomy model was able to show that residents are able to adapt very quickly to unique and complex situation with an overall mean improvement in time to closure of 35.5% (p<0.0003) and an overall mean improvement in volume of water leaked of 30.7% (p<0.002). It is quite fascinating to think that with only three attempts at closing the incidental durotomy using this model, the residents involved in this study were able to improve their time and volume leaked by roughly
one-third. One can assume that this trend towards improvement would continue but eventually plateau
the more attempts the residents made as these fine-motor skills are developed and refined.
Although there was no significant difference in the percent improvement between the junior and chief
residents, there was a significant difference in the time and quantity of water leaked during the first
attempt when comparing the junior and chiefs, (p<0.03 and p<0.008, respectively). There was also a
significant difference between the junior and chief residents in the time that it took to close the durotomy
during the second and third attempts, (p<0.04 and p<0.039, respectively). One can conclude that the chief
residents by this point in their training had developed overlapping fine motor skills during his or her extra
years in the OR so that even though repairing the dura on this model was novel, he or she was able to
adapt more quickly to this situation compared to the junior residents.

Although durotomies are a somewhat rare event intraoperatively, multiple fine motor skills are needed
to complete this repair given the delicacy of the procedure. Our model, using the novel biological
membrane, recreates this unique situation by allowing residents to quickly develop skills necessary to
handle the delicate and complex situation. By using instruments similarly used in the operative theater to
repair the dura, residents were faced with learning a complex new task that is pertinent to their education
as residents.

Training with a cost-effective durotomy repair model significantly improved the ability of orthopaedic
residents to properly close incidental durotomies. Training with a durotomy repair model may be a useful
adjunct in orthopaedic and neurosurgical resident spine education. No matter how realistic a surgical
model or simulator is made; the authors realize that there is no substitute for real-life surgical experience.
Further directions for this project include testing the model on attending and fellowship-trained
orthopaedic spine surgeons as well as on orthopaedic spine fellows to compare the times and volume of
fluid leaked by verifying the realistic nature of the model using surgeons repairing the dura in vivo.
REFERENCES


4. Asch DA, Bilimoria KY, Desai SV. Resident Duty Hours and Medical Education Policy — Raising the Evidence Bar. NEJM Published online April 5, 2017.


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Table 2.

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Chart 1.

Average Time (s) per Run

- **All**
- **Juniors**
- **Seniors**

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Chart 2.

Average Weight (g) per Run

- All
- Juniors
- Seniors

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<td>Juniors</td>
<td>329.5</td>
<td>226.8</td>
<td>242.4</td>
</tr>
<tr>
<td>Seniors</td>
<td>409.2</td>
<td>249.8</td>
<td>329.0</td>
</tr>
<tr>
<td></td>
<td>261.8</td>
<td>191.7</td>
<td>155.8</td>
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</tbody>
</table>
Chart 3.

Percent (%) Improvement in Time Between Runs

<table>
<thead>
<tr>
<th>Runs</th>
<th>All</th>
<th>Juniors</th>
<th>Seniors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>20.8</td>
<td>27.2</td>
<td>14.5</td>
</tr>
<tr>
<td>2-3</td>
<td>14.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-3</td>
<td>36.2</td>
<td>35.0</td>
<td>24.3</td>
</tr>
<tr>
<td>1-3</td>
<td>35.0</td>
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</tr>
<tr>
<td>1-3</td>
<td>45.8</td>
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</table>

Percent (%) Change
Chart 4.

Percent (%) Improvement in Weight Between Runs

<table>
<thead>
<tr>
<th>Runs</th>
<th>All</th>
<th>Juniors</th>
<th>Seniors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>29.3</td>
<td>34.9</td>
<td>23.7</td>
</tr>
<tr>
<td>2-3</td>
<td>-21.6</td>
<td>10.1</td>
<td>-53.4</td>
</tr>
<tr>
<td>1-3</td>
<td>27.2</td>
<td>21.4</td>
<td>33.0</td>
</tr>
</tbody>
</table>

- All
- Juniors
- Seniors
Anuj Patel, MD  PGY-5

Spine Surgery Fellowship
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Alpert Medical School at Brown University
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Atlanta Orthopaedic Society, Resident Member 2013-present
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HONORS AND LEADERSHIP:
Residency Interviewing and Selection Committee 2013-2017

PEER-REVIEWED PUBLICATIONS


SUBMITTED PUBLICATION FOR PEER REVIEW
NON-PEER REVIEWED PUBLICATIONS

BOOK CHAPTERS


PODIUM PRESENTATIONS


Huleatt JB, Bruce BG, Spetrini D, Green A. (2010, April 29). Obesity: Is It A Risk Factor and Outcome Predictor for Total Shoulder Replacement? The Alpert Medical School of Brown University Community Health Research Presentation Ceremony; Providence, RI.

POSTER PRESENTATIONS
Huleatt JB, Bruce BG, Spetrini D, Green A. (2010, April 29). Obesity: Is It A Risk Factor and Outcome Predictor for Total Shoulder Replacement? The Alpert Medical School of Brown University Community Health Research Presentation Day; Providence, RI.

Huleatt JB, Yue L. (2006, August 3). The Role of TRPM7-mediated Calcium Signaling in Cardiac Fibrogenesis. The 2006 Summer Research Fellowship Program Poster Presentation, UConn Health Center; Farmington, CT.
Risk Factors For Manipulation Under Anesthesia And Lysis Of Adhesions Following Anterior Cruciate Ligament Reconstruction
Joel Huleatt, MD, Michael Gottschalk, MD, Kelsey Fraser, MA, Allison Boden, BS, Poonam Dalwadi, BS, Matthew Pombo, MD, Kyle Hammond, MD Study Coordinators: Patricia Bush Ed.D

Introduction:
The anterior cruciate ligament (ACL) is a structure in the knee that limits anterior translation and internal rotation of the knee joint and allows an athlete to better participate in sports that require cutting maneuvers. When the ACL is injured leading to loss of knee stability, reconstruction of the ligament (ACLR) can restore knee stability and allow return to sports. In the United States, ACLR was performed 134,421 times in 2006, up 37% per capita from 1994, with a 924% increased rate in patients less than 15 years of age (Buller 2015). Despite advancements in surgical techniques and rehabilitation protocols, approximately 5.4% of patients develop arthrofibrosis that requires another procedure involving manipulation under anesthesia (MUA) and/or lysis of adhesions (LOA) of the knee in order to regain functional knee range of motion (Hettrich 2013, Freedman 2013). Previous studies have reported on possible risk factors associated with developing arthrofibrosis, including female sex (Csintalan et al. 2014, Sanders et al. 2015, Nwachukwu et al. 2011), the adolescent age group (Hettrich et al. 2013, Wasserstein et al. 2013, Nwachukwu et al. 2011), patients who were operated on more than 4 weeks out from the original injury date (Sanders et al. 2015, Shelbourne et al. 1991, Mayr 2004), and having associated knee pathology requiring concomitant procedures at the time of the ACLR (Austin 1993, Mook 2009, Werner 2015).

To date, there have been no published studies comparing the prevalence of arthrofibrosis after ACLR in patients enrolled in a government sponsored healthcare program compared to patients with private insurance. In the United States, 77% of ACLR cases were compensated by private insurance, and 14% through Medicare, Medicaid, or other government payments in 2007, trending up from 5% in 1996 (Buller 2015). The primary goal of this study is to investigate if government sponsored healthcare patients are more likely to undergo subsequent procedures to address arthrofibrosis following ACLR. We hypothesize that there is a higher risk of MUA/LOA in these patients secondary to decreased access and participation in pre-and post-operative rehabilitation that would help prevent the development of arthrofibrosis. The secondary goal of this study is to report on other factors including patient age, sex, mechanism of injury, delay in surgery, primary versus revision ACLR, graft type, concomitant procedures, complications requiring irrigation and debridement of the surgical site, and compliance with prescribed physical therapy that may influence the risk of undergoing MUA/LOA for arthrofibrosis. Additionally, we were interested if there was any association between undergoing MUA/LOA and subsequent ACLR failure requiring revision reconstruction.

Methods:
After IRB approval, a retrospective cohort study was performed by patient chart review. Inclusion criteria were patients of any age who underwent ACLR between May 1, 2006 and April 30, 2016 at a single academic institution by six orthopaedic surgeons fellowship trained in sports medicine. Exclusion criteria were patients who either did not have the details of their ACLR documented in the current electronic medical record (EMR) system, or did not have multiple post-operative follow up visits documented. The patient charts were queried from an EMR database with the CPT code for ACL Reconstruction (29888), Manipulation under Anesthesia (27570) and Lysis of Adhesions (29884). To allow for adequate time to pass for possible secondary surgery, all patients’ electronic medical records were to be reviewed at a...
minimum of 6 months after the date of ACLR. Demographic information at the time of surgery was collected including age, sex, ethnicity, and insurance status. Details of the injury, surgical technique, clinical course, and any subsequent procedures were garnered from operative and clinical notes, including date and mechanism of injury, history of previous ACLR, date of surgery, operative procedures performed, graft type, complications, physical therapy compliance, failure of ACLR, diagnosis of arthrofibrosis, and subsequent performance of MUA and/or LOA.

The insurance status of each patient was categorized as either private insurance (including commercial insurance and worker’s compensation), government sponsored healthcare program (Medicaid, Medicare and Tricare), or no insurance. Each patient’s EMR chart was manually assessed for his or her insurance status at the time of ACL reconstruction.

Statistical analysis of the data was performed using JMP Pro Software. Categorical variables were compared using a Chi Square or Fischer exact test with a P Value set at 0.05. For continuous variables that were parametric (e.g. normal distribution) a student t test was used. Nonparametric variables were assessed using a Mann Whitney U or Kruskal Wallis Test. A linear and multivariate logistic analysis was performed. As this is a retrospective chart review we did an A Priori sample analysis and determined we would need 30 patients with government sponsored healthcare to see a moderate effect size for requiring repeat surgery when compared to patients with private insurance.

Results:

There were a total of 2424 ACLRs identified that met the inclusion criteria, which were performed by six orthopaedic surgeons with a sports medicine fellowship training at a single academic institution in the 10 year time period from May 1, 2006 to April 30, 2016 [Table 1]. The average time of chart review was 56.7 (7.6 -124.0) months following ACLR. The average age of the patient at the time of ACLR was 27 (range, 8-66) years old, 42% were female, 91% had private insurance, 8% were enrolled in a government sponsored healthcare program, and 1% had no insurance. The ACL was injured by a noncontact mechanism in 83%, and there was a median of 52 (range, 1 -16189) days between injury and ACLR. Of the ACLR procedures, 13.9% were a revision, 50% were isolated ACLR, 28% of cases were ACLR plus meniscectomy, 6% were ACLR plus meniscal repair, 1% were ACLR plus single other ligament complex (MCL, PCL, or LCL/PLC) reconstruction, and 10% involved multiple concomitant procedures. Graft types used included 34% tibialis anterior allograft, 26% quadriceps tendon autograft, 15% hamstring autograft, 15% bone-patellar tendon-bone autograft, 4% bone-patellar tendon-bone allograft, 4% hamstring allograft, and 1% or less of other graft types. Post-operative hematomas requiring evacuation occurred in 1.1%, infection requiring irrigation and debridement in 0.7%, and graft failure in 7.3%. Documented physical therapy noncompliance was 1.8%. The highest volume ACLR surgeon performed 67% of the cases, the lowest volume ACLR surgeon less than 1%, and the other four surgeons between 2%-17%.

There were 108 (4.5%) ACLRs that subsequently had MUA and/or LOA procedures performed for arthrofibrosis at an average of 5.5 months after ACLR. The payer mix for these patients was 88% private insurance, 11% government sponsored healthcare, and 1% with no insurance. The calculated relative risk was 1.44 (p = 0.2222) for being enrolled in government sponsored healthcare and undergoing MUA/LOA after ACLR. The average age of these patients was 22 years old at time of ACLR and 54% were female. The median number of days between injury and ACLR surgery was 39 days, and 4.6% of the cases were revision ACLR. Following ACLR, 3.7% underwent evacuation of hematoma and 3.7% underwent irrigation and debridement for infection prior to MUA/LOA. Only 2.8% had documented physical therapy noncompliance, and 2.8% ultimately had graft failure requiring subsequent revision ACLR.

Of the risk factors analyzed for association with MUA/LOA following ACLR [Table 2], statistically significant increased relative risk was found for infection (5.45), hematoma requiring evacuation (3.55), ACLR plus meniscal repair (2.83), use of quadriceps tendon autograft (2.68), age of less than 18 years (2.39), ACLR plus multiple procedures (1.69), contact injury (1.62), female sex (1.60), and surgery within
28 days of injury (1.53). Statistically significant decreased relative risk was found for revision ACLR (0.30), age of greater than 25 years (0.34), and use of tibialis anterior allograft (0.36). Although the risk for ACLR graft failure was decreased by almost 200% after MUA/LOA (risk ratio, 0.37), this was not found to be statistically significant (p=0.0848) [Table 3].

Discussion:

The current published literature has not addressed whether being enrolled in government sponsored healthcare was associated with a higher MUA/LOA rate following ACLR. We hypothesized that this would put patients at increased risk, as numerous studies have reported decreased access to care for this patient population, and from our own experience we have noticed that it is often more difficult for these patients to access physical therapy. The results of this study do not fully support our primary hypothesis, as the relative risk for undergoing MUA/LOA after ACLR was 1.44 for patients enrolled in government sponsored healthcare, with the 95% confidence interval including no difference in risk. There may be a number of explanations for this. It is of course possible that insurance status has no significant bearing on the development of arthrofibrosis. Alternatively, it is possible that patients with government sponsored healthcare did have significantly higher rates of arthrofibrosis, but that either the patients and/or the surgeons had less motivation to have a MUA/LOA performed. It is also possible that those most affected by therapy or health care access difficulties were screened out prior to surgery. For example, if Medicaid patients were less compliant with "pre-hab" physical therapy and went on to develop arthrofibrosis pre-operatively, this may have prevented them from having an ACLR performed. Even though the Medicaid patients included in this study may have had access and affordability difficulties with physical therapy, the process of getting signed up for and going through ACL reconstruction surgery, and then attending multiple post-operative follow up visits where therapy compliance was being encouraged and monitored, may have helped make insurance status less of a factor. In fact, the rate of documented physical therapy noncompliance in this study was unexpectedly low (1.8%), and it was not found to be a statistically significant risk factor for undergoing MUA/LOA. Thirdly, patients who did not attend physical therapy may have not attended follow up visits with their surgeon either, and therefore may have been excluded from this study. A fourth explanation for the findings may be that including Tricare and Medicare patients in the “government sponsored healthcare” group may have masked a difference that exists between strictly Medicaid patients and patients with standard private health insurance.

The incidence of arthrofibrosis after ACLR that persists despite prescribed physical therapy and is treated with MUA or LOA has been reported in the previous published literature to vary due to a number of reasons, one important factor being concomitant procedures. For isolated ACLR, Freedman et al reported a 5.4% incidence of MUA or LOA in a 2003 meta-analysis including 1804 ACLRs (Freedman et al 2013). In 2015 Werner et al reported a much lower 0.5% incidence of MUA and 0.3% incidence of LOA within 6 months after isolated ACLR in a national sample of 48,631 patients. The incidence of MUA increased to 1.8%, 4.1%, and 8.0% with concomitant collateral ligament reconstruction, concomitant PCL reconstruction, and combined ACL, PCL and collateral ligament reconstruction respectively (Werner 2015). Austin reported at 10% incidence of arthrofibrosis after ACLR and meniscal repair (Austin 1993). The present study demonstrated a similar trend, with a 3.7% rate of MUA/LOA after isolated arthroscopic ACLR in 1208 patients increasing to 5.2% after ACLR performed with concomitant procedures in 1216 patients. More specifically, we found rates of MUA/LOA to be 7.1% after ACLR plus multiple concomitant procedures, 8.7% after ACLR plus single concomitant ligament repair/reconstruction, and 11.3% after ACLR plus meniscal repair.

Other risk factors associated with developing arthrofibrosis that have been previously published include female sex (Csintalan et al. 2014, Sanders et al. 2015, Nwachukwu et al. 2011), the adolescent age group (Hettrich et al. 2013, Wasserstein et al. 2013, Nwachukwu et al. 2011), patients who were operated
on more than 4 weeks out from the original injury date (Sanders et al. 2015, Shelbourne et al. 1991, Mayr 2004), and having associated knee pathology requiring concomitant procedures at the time of the ACLR (Austin 1993, Mook 2009, Werner 2015). Our study had concordant findings for some of these factors, such as increased risk for females, patients less than 18 at time of surgery, and patients who had meniscal repairs or multiple concomitant procedures at the time of ACLR. On the other hand, in discord with some of the prior literature, our study found that patients undergoing ACLR within 4 weeks of injury had a higher rate of MUA/LOA, and patients undergoing revision ACLR had a lower rate of MUA/LOA. Other interesting findings of this study were significantly higher rates of MUA/LOA in patients who had sustained contact injuries, in those who had a hematoma evacuation or infection debrided surgically after ACLR, and in those who received a quadriceps tendon autograft reconstruction. BPTB autograft use also had an increased RR of 1.42 for undergoing MUA/LOA, although this was not found to be significant, while the use of tibialis anterior allografts had a significantly lower risk. These findings, coupled with the finding that patients who underwent MUA/LOA had close to a 200% reduction in the risk of graft failure (albeit not statistically significant), suggest that potentially larger autografts may incur a higher rate of arthrofibrosis but also protect against graft failure.

An important strength of the present study is the number of arthroscopic ACLR cases examined with careful review of each patient's medical record. A total of 2424 ACLRs were included and reviewed for postoperative MUA/LOA with a minimum follow up period 7.6 months and average follow up period of 56.7 months. This retrospective study does have a number of limitations: (1) There may have been a sampling bias due to (A) accuracy of billing codes by physicians, and (B) changes in medical record systems during the study period that likely resulted in not all ACLRs performed by the designated surgeons being documented in the current EMR, and thus not included in the study. However, all patient charts that were identified through the procedure code query of the database were reviewed for accuracy and the cases were omitted if they either failed to meet the inclusion criteria or met the exclusion criteria. (2) Our study includes only patients that underwent ACLR by sports medicine fellowship trained surgeons at a single academic institution in a large metropolitan area, 1634 being performed by the highest ACLR volume surgeon, and there was no standardized indication for pursuing a MUA or LOA after ACLR. Therefore, the results of this study may be highly dependent on the included surgeons' preferences, and may not be generalizable to practice patterns throughout the United States. (3) Although the time to MUA/LOA after ACLR in our study was on average 5.5 months, and our average follow up was 56.7 months, we may be missing a small number of subsequent procedures by including patients with a follow up as short as 7.6 months. (4) Another reason this study may have underestimated the true rate of MUA/LOA is that patients who developed arthrofibrosis may have sought follow up and underwent MUA/LOA with a provider outside of our academic institution without our knowledge. (5) And lastly, some of the data required subjective interpretation, such as whether patients were noncompliant with physical therapy based on follow-up clinic notes, or what the date or mechanism of injury was when these were described in the medical record in imprecise terms. However, if there was insufficient information upon which to base a rational judgement or estimation, a blank was left in the data collection.

Conclusion:

Whether patients have private insurance or government sponsored health care as the payer for ACLR, this is likely not an important risk factor for undergoing a subsequent MUA or LOA for arthrofibrosis. Many other factors likely play a more significant role, including surgical complications of the ACLR, graft type, delay between injury and ACLR, primary vs revision ACLR, age, sex, and injury mechanism. Undergoing MUA or LOA is not associated with an increased rate of graft failure, and on the contrary appears to be associated with a lower risk and re-rupture.
References/Bibliography


TABLE 1 Study Characteristics of ACLR (N = 2424)

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, mean (range), years</td>
<td>27.2 (8 - 66)</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>1020 42.1%</td>
</tr>
<tr>
<td>Male</td>
<td>1404 57.9%</td>
</tr>
<tr>
<td>Ethnicity</td>
<td></td>
</tr>
<tr>
<td>Caucasian</td>
<td>1850 76.3%</td>
</tr>
<tr>
<td>African American</td>
<td>441 18.2%</td>
</tr>
<tr>
<td>Hispanic</td>
<td>19 0.8%</td>
</tr>
<tr>
<td>Asian</td>
<td>89 3.7%</td>
</tr>
<tr>
<td>Native American</td>
<td>5 0.2%</td>
</tr>
<tr>
<td>Middle Eastern</td>
<td>9 0.4%</td>
</tr>
<tr>
<td>Other</td>
<td>10 0.4%</td>
</tr>
<tr>
<td>Payer</td>
<td></td>
</tr>
<tr>
<td>Private Insurance</td>
<td>2216 91.4%</td>
</tr>
<tr>
<td>Government Sponsored</td>
<td>194 8.0%</td>
</tr>
<tr>
<td>No Insurance</td>
<td>14 0.6%</td>
</tr>
<tr>
<td>Injury</td>
<td></td>
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<tr>
<td>Contact Injury</td>
<td>360 14.9%</td>
</tr>
<tr>
<td>Noncontact Injury</td>
<td>2023 83.5%</td>
</tr>
<tr>
<td>Delay to Surgery, median (range), days</td>
<td>52 (1 - 16,189)</td>
</tr>
<tr>
<td>Surgery</td>
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<tr>
<td>Revision ACLR</td>
<td>336 13.9%</td>
</tr>
<tr>
<td>Graft Type</td>
<td></td>
</tr>
<tr>
<td>Tibialis Anterior Allograft</td>
<td>822 33.9%</td>
</tr>
<tr>
<td>Quadriceps Tendon Autograft</td>
<td>623 25.7%</td>
</tr>
<tr>
<td>BPTB Autograft</td>
<td>352 14.5%</td>
</tr>
<tr>
<td>Hamstring Autograft</td>
<td>369 15.2%</td>
</tr>
<tr>
<td>BPTB Allograft</td>
<td>90 3.7%</td>
</tr>
<tr>
<td>Hamstring Allograft</td>
<td>88 3.6%</td>
</tr>
<tr>
<td>Concomitant Procedures</td>
<td></td>
</tr>
<tr>
<td>None (Isolated ACLR)</td>
<td>1208 49.8%</td>
</tr>
<tr>
<td>ACLR + meniscectomy</td>
<td>671 27.7%</td>
</tr>
<tr>
<td>ACLR + meniscal repair</td>
<td>150 6.2%</td>
</tr>
<tr>
<td>ACLR + MCL, PCL, or LCL/PLC repair/reconstruction</td>
<td>23 0.9%</td>
</tr>
<tr>
<td>ACLR + multiple procedures</td>
<td>241 9.9%</td>
</tr>
<tr>
<td>Physical therapy noncompliance</td>
<td>43 1.8%</td>
</tr>
<tr>
<td>Complications</td>
<td></td>
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<tr>
<td>Arthrofibrosis treated with MUA and/or LOA</td>
<td>108 4.5%</td>
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<tr>
<td>Hematoma</td>
<td>26 1.1%</td>
</tr>
<tr>
<td>Infection</td>
<td>17 0.7%</td>
</tr>
<tr>
<td>Graft Failure</td>
<td>176 7.3%</td>
</tr>
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</table>

Values are expressed as n followed by % out of total ACLR (n/2424) unless otherwise indicated. ACLR, anterior cruciate ligament reconstruction; BPTB, bone-patellar tendon-bone; MCL, medial collateral ligament; PCL, posterior cruciate ligament; LCL, lateral collateral ligament; PLC, posterolateral corner; MUA, manipulation under anesthesia; LOA, lysis of adhesions.
TABLE 2 Risk Factors for MUA and/or LOA after ACLR

<table>
<thead>
<tr>
<th>Risk Factor</th>
<th>Rate of MUA/LOA</th>
<th>RR</th>
<th>95% CI</th>
<th>P Value</th>
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<td>Demographics</td>
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<tr>
<td>Age &lt; 18 years</td>
<td>8.0%</td>
<td>2.39</td>
<td>1.65 - 3.46</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Age 18 – 25 years</td>
<td>5.1%</td>
<td>1.24</td>
<td>0.84 - 1.82</td>
<td>0.2846</td>
</tr>
<tr>
<td>Age &gt; 25 years</td>
<td>2.2%</td>
<td>0.34</td>
<td>0.22 - 0.53</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Female</td>
<td>5.7%</td>
<td>1.00</td>
<td>1.10 - 2.31</td>
<td>0.0131</td>
</tr>
<tr>
<td>Payer</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Private Insurance</td>
<td>4.3%</td>
<td>0.69</td>
<td>0.39 - 1.20</td>
<td>0.1885</td>
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<tr>
<td>Government Sponsored</td>
<td>6.2%</td>
<td>1.44</td>
<td>0.80 - 2.57</td>
<td>0.2222</td>
</tr>
<tr>
<td>No Insurance</td>
<td>7.1%</td>
<td>1.61</td>
<td>0.24 - 10.7</td>
<td>0.6234</td>
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<tr>
<td>Contact Injury</td>
<td>6.7%</td>
<td>1.02</td>
<td>1.05 - 2.52</td>
<td>0.0307</td>
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<tr>
<td>Surgical Factors</td>
<td></td>
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<tr>
<td>Surgery within 28 days</td>
<td>6.1%</td>
<td>1.53</td>
<td>1.03 - 2.28</td>
<td>0.0339</td>
</tr>
<tr>
<td>Revision ACLR</td>
<td>1.5%</td>
<td>0.36</td>
<td>0.12 - 0.73</td>
<td>0.0083</td>
</tr>
<tr>
<td>Graft Type</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tibialis Anterior Allograft</td>
<td>2.1%</td>
<td>0.36</td>
<td>0.22 - 0.61</td>
<td>0.0001</td>
</tr>
<tr>
<td>Quadriceps Tendon Autograft</td>
<td>8.3%</td>
<td>2.08</td>
<td>1.86 - 3.87</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>BPTB Autograft</td>
<td>6.0%</td>
<td>1.42</td>
<td>0.89 - 2.26</td>
<td>0.1370</td>
</tr>
<tr>
<td>hamstring autograft</td>
<td>3.3%</td>
<td>0.70</td>
<td>0.39 - 1.26</td>
<td>0.2287</td>
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<tr>
<td>Concomitant Procedures</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>None (Isolated ACLR)</td>
<td>3.7%</td>
<td>0.72</td>
<td>0.49 - 1.05</td>
<td>0.0840</td>
</tr>
<tr>
<td>ACLR + meniscectomy</td>
<td>3.3%</td>
<td>0.67</td>
<td>0.42 - 1.06</td>
<td>0.0858</td>
</tr>
<tr>
<td>ACLR + meniscal repair</td>
<td>11.3%</td>
<td>2.83</td>
<td>1.73 - 4.63</td>
<td>&lt;0.0001</td>
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<tr>
<td>ACLR + MCL, PCL, or PLC repair/reconstruction</td>
<td>8.7%</td>
<td>1.97</td>
<td>0.52 - 7.50</td>
<td>0.3205</td>
</tr>
<tr>
<td>Physical therapy noncompliance</td>
<td>9.3%</td>
<td>2.13</td>
<td>0.82 - 5.52</td>
<td>0.1196</td>
</tr>
<tr>
<td>Complications</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hematoma</td>
<td>15.4%</td>
<td>3.55</td>
<td>1.41 - 8.91</td>
<td>0.0070</td>
</tr>
<tr>
<td>Infection</td>
<td>23.5%</td>
<td>5.45</td>
<td>2.26 - 13.1</td>
<td>0.0002</td>
</tr>
<tr>
<td>Graft Failure</td>
<td>1.7%</td>
<td>0.36</td>
<td>0.12 - 1.14</td>
<td>0.0824</td>
</tr>
</tbody>
</table>

The rate, relative risk (RR), 95% confidence interval (CI), and significance level are reported for each risk factor’s association with the performance of manipulation under anesthesia (MUA) and/or lysis of adhesions (LOA) for athrofibrosis following ACLR (anterior cruciate ligament reconstruction). BPTB, bone-patellar tendon-bone; MCL, medial collateral ligament; PCL, posterior cruciate ligament; LCL, lateral collateral ligament; PLC, posterolateral corner.

TABLE 3 MUA and/or LOA as a risk factor for ACLR graft failure

<table>
<thead>
<tr>
<th>Risk Factor</th>
<th>RR</th>
<th>95% CI</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MUA and/or LOA</td>
<td>0.37</td>
<td>0.12 - 1.15</td>
<td>0.0848</td>
</tr>
</tbody>
</table>

The relative risk (RR), 95% confidence interval, and significance level are reported for the association of manipulation under anesthesia (MUA) and/or lysis of adhesions (LOA) with subsequent ACLR (anterior cruciate ligament reconstruction) graft failure.
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University of South Alabama College of Medicine, Mobile, FL
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AOA Emerging Leaders Forum  2015
3rd Place Kelly Day Resident Research Award – Emory University  2014
Emory University GME Committee Member  2014-2017
Program Evaluation Committee Member  2012-2017
Residency Interviewing and Selection Committee  2012-2017

PEER-REVIEWED PUBLICATIONS:
ABSTRACT

Background:
Total joint arthroplasty (TJA) is one of the most common orthopaedic procedures performed today and comprises a significant portion of US healthcare expenditures, particularly in the elderly. With the recent push towards value-based health care, predicting delays in discharge is crucial. Postoperative hypotension, a common side effect of total joint arthroplasty, has been shown to be a risk factor for delayed physical therapy and thus delayed discharge after various surgeries in multiple surgical specialties. While other risk factors for prolonged hospital stay have been identified in patients receiving total joint arthroplasty, postoperative hypotension has been underreported in the orthopaedic literature. This study explores postoperative hypotension along with other potentially modifiable risk factors such as opioid use and laboratory anomalies and their association with prolonged hospitalization after total joint arthroplasty. We hypothesized that the number of acute postoperative hypotensive events after TJA is correlated with increased hospital length of stay.

Methods:
This retrospective cohort study identified 2561 primary total hip and total knee arthroplasty cases at a single institution between June 2012 and August 2014. A comparison of cases with a hospital length of stay less than two days to those with a hospital length of stay two days or greater was performed. Our institution uses an accelerated physical therapy program, which often times may be interrupted by patient hypotension. As such, an analysis of postoperative hypotension along with other potentially modifiable risk factors such as opioid use and laboratory anomalies and their association with prolonged hospitalization after total joint arthroplasty was performed between the two cohorts. A multivariate logistic regression model was built to identify independent risk factors for delayed hospital discharge after total joint arthroplasty.

Results:
28.5% (732/2651) of all patients had a length of stay of less than 2 days following total joint arthroplasty. The number of postoperative hypotensive events in the acute postoperative period (POD 0 and 1), defined as a systolic blood pressure less than 90 mmHg or a diastolic blood pressure less than 60 mmHg, was associated with an increased length of stay (p<0.0001). Patients with a higher Charlson Comorbidity Index, along with females, African Americans, the elderly, and patients who were not married, were more likely to have an increased postoperative length of stay (p<0.0001 for each variable). When compared to non-Caucasians, Caucasians were more likely to have a postoperative hospital length of stay less than 2 days (p<0.0001). Patients who stayed more than 2 days used a higher Oral Morphine Equivalent dose in the first two days, then those who stayed less than 2 days, 127 mg versus 106 mg, respectively (p=0.01).

Conclusions:
As the financial landscape of US health care is rapidly evolving, identifying means of decreasing hospital length of stay without compromising care after total joint arthroplasty could have a significant financial impact. As outpatient total joint arthroplasty has become more popular, it is important to identify factors that may improve patient safety while reducing any potential burden from readmissions.
INTRODUCTION

Total joint arthroplasty (TJA), including both knee and hip arthroplasty, is the most frequently performed inpatient surgery in the United States, with roughly 2.2 million TJA operations in 2012 alone. The current annual national healthcare expenditure for these operations is approximately 20 billion dollars, and this amount has been increasing annually. One of the major drivers of the cost associated with TJA is the hospital length of stay (LOS) after the procedure. Studies examining large cohorts of patients have estimated the LOS after total knee and total hip arthroplasty to be roughly 3.5 and 3.7 days, respectively. As the financial landscape of healthcare is set to undergo significant changes, efforts aimed at decreasing LOS after TJA is one potential target to help contain and potentially decrease healthcare costs associated with these procedures.

Multiple authors have analyzed factors associated with increased length of stay in the hospital after TJA. While certain patient characteristics, such as age, body mass index (BMI), various comorbidities, race, income, and insurance status have been correlated with LOS after TJA, less attention has been focused on how potentially modifiable risk factors, such as opioid use, aberrant vital signs, or laboratory values may affect LOS.

In particular, postoperative hypotension has been linked to increased LOS in other surgical fields. While there are published clinical protocols that stress the importance of fluid management to minimize risk of postoperative hypotension after TJA, postoperative hypotension remains underreported in the orthopaedic literature. In this study, we analyzed inpatient hospital records for individuals undergoing primary total hip or total knee arthroplasty at a single institution. We sought to identify independent modifiable risk factors for delayed discharge that have been previously underrepresented in the literature, particularly opioid use, postoperative laboratory abnormalities, and the frequency of hypotensive events. Our primary outcome measure was postoperative hypotensive events. We hypothesized that, similar to other surgical specialties, the number of acute postoperative hypotensive events after TJA is correlated to patient LOS. We also examined patient characteristics, such as demographic information, comorbidities, and insurance status, to confirm if an independent link between these variables and LOS exists.

Methods

Participants

After Institutional Review Board approval, we identified all patients undergoing primary total hip or knee replacement between June 2012 and August 2014, by one of four surgeons at our institution. Each of the four surgeons is fellowship-trained and works in the same orthopaedic specialty hospital. None of the 2,561 patients identified by the above criteria died during their post-operative hospital stay, and none were subsequently excluded from our analysis.

Variables of Interest

Our model examined predictors of length of stay and included patient demographics, comorbidities, inpatient opioid medication use, postoperative hypotension, and abnormal laboratory values.

To assess comorbidities, the Charlson Comorbidity Index (CCI) was computed for each patient using International Classification of Diseases (ICD) categories. The CCI score values the presence of 19 medical conditions and has a total range of 0 to 37. An index score greater than 2 has been correlated to an annual mortality rate of greater than 50%. Opioids were converted to oral morphine equivalents (OME) for comparison. The number of postoperative hypotensive events, defined as a systolic blood pressure less than 90 mmHg or a diastolic blood pressure less than 60 mmHg for any single reading, was recorded as a continuous variable for each postoperative day.
Given the lack of universal consensus on laboratory threshold values, we determined abnormal values for laboratory results as the default threshold values embedded as clinical support tools in our institution's electronic medical record system (Cerner Systems). The specific cutoffs used for each laboratory value can be seen in Appendix 1. The presence of either an abnormal high or abnormal low value was determined for each post-operative day by retrospective review of all lab results for each patient during their hospitalization. Abnormal values for specific lab results were thus coded as categorical variables, either ‘abnormal high’ or ‘abnormal low’, for each post-operative day.

In an effort to preserve the fidelity of our model, we attempted to remove very rare abnormal lab values from our analysis. To accomplish this, if an abnormal value appeared in at least 5% of our sample, which we deemed a conservative threshold, that specific laboratory result was included in our analysis. The presence of low Calcium, high Creatinine, low Hemoglobin, and low Sodium values were the only laboratory results to occur at a frequency above this threshold, and thus were included in the model. A baseline characterization for all patients in our sample can be seen in Table 1.

Outcomes
The primary outcome measure of interest was hospital length of stay (LOS), defined categorically as days. Each night spent in the hospital after surgery was considered an increase in LOS of one day. For example, a patient discharged on the day following surgery spent one night in the hospital and thus had a LOS of 1. Due to lack of available, reliably accurate data on the exact time of discharge during each day, efforts were not made to distinguish if a patient was discharged in the morning or the evening on a particular postoperative day. Given that 28.6%, (732/2561), of all patients had a LOS of less than 2 days, and that a LOS of exactly 2 days was the most common LOS duration, we chose to compare patients with a LOS of less than 2 days to those with a LOS of 2 days or greater, to identify differences in patients who are able to leave the hospital before the median LOS to all others.

Statistical Analysis
Statistical analysis was performed using the R: A language and environment for statistical computing (R Foundation for Statistical Computing, http://www.R-project.org). Student t tests were performed for continuous data and χ² or Fisher exact tests were performed for categorical data, as appropriate. Univariate and multivariate logistic regression was performed to identify independent risk factors for prolonged hospital length of stay. All data has been presented as aggregated data for all patients undergoing either primary total hip or total knee arthroplasty procedure in our model. All values are presented as mean with standard deviation (SD) or 95% confidence intervals (CI). Two-tailed p values <0.05 were considered statistically significant.

Results
The average age of patients undergoing primary total joint arthroplasty in our cohort was 62.6 (SD 11.6) years, and 56.4% were women. Both the median and mode for LOS was 2 days, and 63.9% of patients were discharged before postoperative day 3 (POD 3). The mean LOS for all patients was 2.2 days (SD: 1.2, Range: 0,9) (Table 2).

Univariate Logistic Regression
Univariable analysis comparing patients with a prolonged LOS to those with a LOS of 2 days or less isolated numerous significant predictors for length of stay (Table 3). Specifically, increased CCI score (OR, 1.77 [CI, 1.54, 2.03]), male sex (OR, 2.13 [CI, 1.75, 2.59]), non-Caucasian race (OR, 2.09 [CI, 1.68, 2.61]), single marital status (OR, 1.98 [CI, 1.63, 2.41]), increased age
(OR, 1.40 [CI, 1.30, 1.51]), Medicaid insurance (OR, 4.55 [CI, 2.20, 9.42]), Medicare insurance (OR, 3.31 [CI, 2.59, 4.23]), the number of hypotensive events on POD 0 and 1 (OR, 1.35 [CI, 1.20, 1.53]), OME on POD 0 and 1 (OR, 1.11 [CI 1.10, 1.13]), and the presence of abnormally high glucose (OR, 1.36 [CI, 1.13, 1.62]) or low hemoglobin (OR, 4.64 [CI 3.84, 5.60]) on POD 0 and 1, were all significantly associated with increased LOS.

**Multivariate Logistic Regression**

Multivariable logistic regression analysis comparing patients with a prolonged LOS to those with a LOS of 2 days or less identified significant independent risk factors for prolonged LOS (Table 4). With all other variables constant, for every five additional hypotensive readings during POD 0 and 1, there was a 20% increased odds of a hospital LOS of greater than 2 days. Similarly, for every 10 mg increase in OME use during POD 0 and 1, there was a 14% increased odds of a LOS greater than 2 days. Regarding non-modifiable risk factors for prolonged LOS, for every unit increase in CCI score and for every 10 year increase in age, there was a 36% and 64% increase in odds of a LOS greater than 2 days, respectively. The strongest association between any risk factor and LOS in our model was that of low hemoglobin; patients with low hemoglobin values on POD 0 or 1 had a 2.7 times odds of a LOS greater than 2 days than those without abnormal hemoglobin values on those days. When controlling for the effect of other variables in our model, the effect of Medicare and Medicaid insurance on LOS was no longer statistically significant.

**Postoperative Hypotension**

In addition to the findings above, a subgroup analysis was performed to further describe the relationship between postoperative hypotension and LOS after TJA.

The number of hypotensive events during POD 0 and 1 for patients with a LOS less than 2 was compared with that of patients with a LOS greater or equal to 2, using four quartiles. Quartile 1 (Q1) included patients with 0 or 1 hypotensive events during POD 0 and 1. Q2 contained patients with 2 or 3 hypotensive events, Q3 with 4, 5, or 6 hypotensive events, and Q4 with greater than 6 hypotensive events during this time period.

This sub-group analysis revealed that patients in Q3 and Q4 were significantly more likely to have a LOS of 2 days or more (Q3: OR 1.45 [CI 1.15, 1.82], Q4: OR 1.74 [CI 1.36, 2.22]). Similarly, patients in Q1 were not more likely to have a LOS of 2 days or more (Table 5).

**DISCUSSION**

Our patients had a mean LOS of 2.2 days—lower than published estimates, which have reported a mean LOS of over 3 days for TJA.1-6 The shorter LOS observed in our patients may be due partly to each surgeon’s fellowship training, as well as the fact that TJA comprised the majority of their surgical case load during the study period. In addition, each surgeon worked in the same orthopaedic specific hospital that employs an early, aggressive physical therapy protocol and uniformly defined clinical pathways.

In this setting, our results confirm several previously identified risk factors for increased hospital LOS after TJA. Specifically, increased CCI score, male sex, non-Caucasian race, single marital status, and increased age were all independently associated with increased hospital LOS in our model (Table 4). Of note, when studied in isolation, both Medicaid and Medicare insurance holders had an increased LOS compared to private insurance holders; however, when adjusted for all other variables, these associations regarding insurance status and LOS were no longer statistically significant (Table 3 and 4).

Most importantly, our results confirm additional and more modifiable risk factors for increased hospital LOS after TJA. Specifically, increased postoperative hypotensive events and opioid use during the day of

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64
surgery (POD 0) and postoperative day 1 (POD 1) were both independent risk factors for increased hospital LOS. This data thus supports future research into initiatives aimed to reduce early postoperative hypotension and opioid use in patients undergoing TJA.

Our results also confirm that several laboratory values are independently associated with increased LOS, and protocols to correct these aberrant laboratory values could also prove valuable to reduce LOS after TJA. Specifically, as low postoperative Hemoglobin had the highest correlation with increased LOS of any risk factor, research to determine an appropriate postoperative hemoglobin threshold for transfusion and a subsequent postoperative TJA transfusion protocol to optimize patient outcomes and LOS may substantially reduce average hospital LOS for patients undergoing TJA.

While more work needs to be done to determine appropriate protocols for reducing the impact of modifiable risk factors and potentially decreasing postoperative LOS, properly identifying modifiable targets as a first step is imperative. In attempting to do so, this study has several strengths. This study has a large sample size of over 2,500 patients giving it considerable power to detect the relative impact of various risk factors. Additionally, unlike national health databases with data aggregated from numerous facilities with varied protocols and surgeon’s with heterogeneous case loads, our patients were all treated by surgeons performing greater than 400 TJA procedures each year, at the same institution with the same protocols. Thus, more standardized data such as vital signs, laboratory values, and medication use can be gleaned and examined across our sample.

Our study also has some limitations; including its retrospective nature and that all patient information was derived from medical records. As such, not all variables of interest, such as the presence of orthostatic hypotension or time of first postoperative physical therapy session, were recorded uniformly and thus were not included in our model. Our study also employs a conservative threshold to define hypotension as any reading with a systolic pressure of 90 mmHg or less or a diastolic pressure of 60 mmHg or less, as defined previously in the literature.\textsuperscript{26,27} It is possible that values above this threshold may also be abnormal on the continuum of postoperative blood pressure, especially in the setting of a patient with known hypertension, a common comorbidity in elderly patients undergoing TJA. Future studies should examine individual postoperative hypotension readings as a continuous variable and adjust for preoperative values and operative variables to determine the most appropriate threshold to be classified as abnormal in this clinical setting. Lastly, laboratory values were coded as abnormal low, normal, or abnormal high as described above. The categorical presence of abnormal low or high values was thus ascertained and included in our model; however, our model does not consider the magnitude of laboratory derangements. As this study was intended to be an initial examination to identify potentially modifiable risk factors for prolonged hospital LOS, we deemed our handling of laboratory values as appropriate; however, future work should explore each abnormal value and its magnitude in addition to its direction, to further guide initiatives aimed at reducing aberrant values and potentially reducing hospital LOS.

Conclusion
As the financial landscape of US health care is rapidly evolving, identifying means of decreasing hospital length of stay without compromising care after total joint arthroplasty could have a significant financial impact. This study demonstrates that increased opioid use, hypotensive events, and abnormal Calcium, Hemoglobin, Creatinine, and Glucose values in the acute postoperative period are all independently associated with a longer hospital LOS after TJA. It is important to identify these and other potentially modifiable factors that may improve patient safety while reducing any potential burden from readmissions.
# Table 1. Risk Factor Analysis

<table>
<thead>
<tr>
<th>Class</th>
<th>mean ± sd [min, max] freq/total(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>62.6 ± 11.6 [16.0, 94.0]</td>
</tr>
<tr>
<td>OME (mg); first 2 days</td>
<td>190.6 ± 140.0 [0, 2623]</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>1445/2561 (56.4%)</td>
</tr>
<tr>
<td>Male</td>
<td>1116/2561 (43.6%)</td>
</tr>
<tr>
<td>Race</td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>1900/2561 (74.2%)</td>
</tr>
<tr>
<td>Non-White</td>
<td>661/2561 (25.8%)</td>
</tr>
<tr>
<td>Marital status</td>
<td></td>
</tr>
<tr>
<td>Married</td>
<td>1697/2561 (66.3%)</td>
</tr>
<tr>
<td>Not Married</td>
<td>864/2561 (33.7%)</td>
</tr>
<tr>
<td>CCI score</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1703/2561 (66.5%)</td>
</tr>
<tr>
<td>1</td>
<td>561/2561 (21.9%)</td>
</tr>
<tr>
<td>2</td>
<td>185/2561 (7.2%)</td>
</tr>
<tr>
<td>3</td>
<td>77/2561 (3.0%)</td>
</tr>
<tr>
<td>4</td>
<td>22/2561 (0.9%)</td>
</tr>
<tr>
<td>5</td>
<td>9/2561 (0.4%)</td>
</tr>
<tr>
<td>6</td>
<td>2/2561 (0.1%)</td>
</tr>
<tr>
<td>7</td>
<td>1/2561 (0.0%)</td>
</tr>
<tr>
<td>8</td>
<td>1/2561 (0.0%)</td>
</tr>
<tr>
<td>Pre-op Diagnosis</td>
<td></td>
</tr>
<tr>
<td>Osteoarthritis</td>
<td>2311/2557 (90.4%)</td>
</tr>
<tr>
<td>Other</td>
<td>246/2557 (9.6%)</td>
</tr>
<tr>
<td>Insurance</td>
<td></td>
</tr>
<tr>
<td>HMO / Managed Care</td>
<td>884/2552 (34.6%)</td>
</tr>
<tr>
<td>Medicaid</td>
<td>69/2552 (2.7%)</td>
</tr>
<tr>
<td>Medicare</td>
<td>1172/2552 (45.9%)</td>
</tr>
<tr>
<td>Other</td>
<td>427/2552 (16.7%)</td>
</tr>
<tr>
<td>Calcium – Low</td>
<td>1156/2561 (45.1%)</td>
</tr>
<tr>
<td>Creatinine – High</td>
<td>1803/2561 (70.4%)</td>
</tr>
<tr>
<td>Glucose – High</td>
<td>1414/2561 (55.2%)</td>
</tr>
<tr>
<td>Hemoglobin – Low</td>
<td>1872/2561 (73.1%)</td>
</tr>
<tr>
<td>Sodium – Low</td>
<td>1109/2561 (43.3%)</td>
</tr>
</tbody>
</table>
### Table 2. Hospital Length of Stay (LOS)

<table>
<thead>
<tr>
<th>LOS (days), continuous measure</th>
<th>2 ± 1 [0 , 9]</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOS (days), ordinal measure</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1/2561 (0.0%)</td>
</tr>
<tr>
<td>1</td>
<td>731/2561 (28.5%)</td>
</tr>
<tr>
<td>2</td>
<td>954/2561 (37.3%)</td>
</tr>
<tr>
<td>3</td>
<td>603/2561 (23.5%)</td>
</tr>
<tr>
<td>4</td>
<td>156/2561 (6.1%)</td>
</tr>
<tr>
<td>5</td>
<td>63/2561 (2.5%)</td>
</tr>
<tr>
<td>6</td>
<td>23/2561 (0.9%)</td>
</tr>
<tr>
<td>7</td>
<td>23/2561 (0.9%)</td>
</tr>
<tr>
<td>8</td>
<td>2/2561 (0.1%)</td>
</tr>
<tr>
<td>9</td>
<td>5/2561 (0.2%)</td>
</tr>
<tr>
<td>LOS (days), categorical measure</td>
<td></td>
</tr>
<tr>
<td>≥ 2 days</td>
<td>1829/2561 (71.4%)</td>
</tr>
<tr>
<td>&lt; 2 days</td>
<td>732/2561 (28.6%)</td>
</tr>
</tbody>
</table>

### Table 3. Univariable Logistic Regression for Predictors of Delayed Discharge; <2 days vs ≥2 days

<table>
<thead>
<tr>
<th>Predictor</th>
<th>OR (95% CI)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypertensive events</td>
<td>4.08 (4.29)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>CCI Score</td>
<td>0.08 (0.86)</td>
<td>0.01</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>1.76 (1.56, 2.05)</td>
<td>0.01</td>
</tr>
<tr>
<td>Race</td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>4.72 (4.72, 4.72)</td>
<td>0.01</td>
</tr>
<tr>
<td>Non-White</td>
<td>0.47 (0.38, 0.59)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Marital status</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Married</td>
<td>0.39 (0.39, 0.39)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Not Married</td>
<td>1.41 (1.41, 1.41)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Age</td>
<td>1.00 (1.00, 1.00)</td>
<td>0.01</td>
</tr>
<tr>
<td>CME (mg)*</td>
<td>216.49 (151.59)</td>
<td>0.01</td>
</tr>
<tr>
<td>Pre-op Diagnosis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Osteoarthritis</td>
<td>1.03 (0.77, 1.38)</td>
<td>0.83</td>
</tr>
<tr>
<td>Other</td>
<td>1.00 (1.00, 1.00)</td>
<td>0.01</td>
</tr>
<tr>
<td>Insurance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HMO/Managed Care</td>
<td>1.10 (0.87, 1.39)</td>
<td>0.01</td>
</tr>
<tr>
<td>Medicare</td>
<td>4.50 (2.26, 9.42)</td>
<td>0.01</td>
</tr>
<tr>
<td>Medicaid</td>
<td>3.31 (2.59, 4.23)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Other</td>
<td>1.00 (1.00, 1.00)</td>
<td>0.01</td>
</tr>
<tr>
<td>Low Calcium</td>
<td>1.15 (0.97, 1.37)</td>
<td>0.11</td>
</tr>
<tr>
<td>High Creatinine</td>
<td>0.85 (0.70, 1.03)</td>
<td>0.10</td>
</tr>
<tr>
<td>High Glucose</td>
<td>1.36 (1.14, 1.62)</td>
<td>0.08</td>
</tr>
<tr>
<td>Low Hemoglobin</td>
<td>4.64 (3.54, 5.66)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Low Sodium</td>
<td>1.08 (0.98, 1.29)</td>
<td>0.41</td>
</tr>
</tbody>
</table>

* variables presented as mean ± sd
Table 4

**Multivariable Logistic Regression for Predictors of Delayed Discharge**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>SE</th>
<th>95% CI</th>
<th>OR</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-4.13</td>
<td></td>
<td>(1.02, 1.40)</td>
<td>1.20</td>
<td>0.03</td>
</tr>
<tr>
<td>Hypotensive events on POD 0 &amp; 1</td>
<td>0.04</td>
<td>0.02</td>
<td>(1.01, 1.40)</td>
<td>1.20</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>(Per 5 additional hypotensive events)</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>CCI score (per 1 unit increase)</td>
<td>0.30</td>
<td>0.08</td>
<td>(1.15, 1.59)</td>
<td>1.36</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Sex (Female vs Male)</td>
<td>-0.33</td>
<td>0.13</td>
<td>(0.56, 0.93)</td>
<td>0.72</td>
<td>0.01</td>
</tr>
<tr>
<td>Race (White vs Non-White)</td>
<td>-0.58</td>
<td>0.14</td>
<td>(0.43, 0.74)</td>
<td>0.56</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Age (per 10 year increase)</td>
<td>0.05</td>
<td>0.01</td>
<td>(1.42, 1.88)</td>
<td>1.64</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Marital status (married vs not married)</td>
<td>-0.38</td>
<td>0.13</td>
<td>(0.53, 0.88)</td>
<td>0.68</td>
<td>&lt;0.01</td>
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<tr>
<td>OME (mg) (per 10 mg increase)</td>
<td>0.01</td>
<td>0.00</td>
<td>(1.12, 1.16)</td>
<td>1.14</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Pre-op DX (osteoarthritis vs. other)</td>
<td>0.00</td>
<td>0.02</td>
<td>(0.66, 1.51)</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Insurance</td>
<td>-0.19</td>
<td>0.15</td>
<td>(0.62, 1.11)</td>
<td>0.83</td>
<td>&lt;0.01</td>
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<tr>
<td>HMO/Managed Care v. Other</td>
<td>0.71</td>
<td>0.44</td>
<td>(0.87, 4.78)</td>
<td>2.04</td>
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<tr>
<td>Medicaid v. Other</td>
<td>0.35</td>
<td>0.18</td>
<td>(1.00, 2.02)</td>
<td>1.43</td>
<td></td>
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<tr>
<td>Medicare v. Other</td>
<td>0.26</td>
<td>0.14</td>
<td>(0.98, 1.70)</td>
<td>1.29</td>
<td>0.07</td>
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<tr>
<td>Low Calcium</td>
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<td>0.20</td>
<td>(0.25, 0.54)</td>
<td>0.37</td>
<td>&lt;0.01</td>
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<tr>
<td>High Creatinine</td>
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<td>0.15</td>
<td>(1.39, 2.55)</td>
<td>1.88</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>High Glucose</td>
<td>0.99</td>
<td>0.13</td>
<td>(2.06, 3.49)</td>
<td>2.70</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Low Hemoglobin</td>
<td>-0.07</td>
<td>0.14</td>
<td>(0.71, 1.22)</td>
<td>0.93</td>
<td>0.60</td>
</tr>
</tbody>
</table>

*CCS as a continuous variable

Table 5

**Hypotensive Events Days 0-1, by quartile vs. LOS**

<table>
<thead>
<tr>
<th>Hypotensive Events (Days 0-1)</th>
<th>LOS ≤ 2 days</th>
<th>LOS &gt; 2 days</th>
<th>OR (95% CI)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1: &gt;6</td>
<td>417/1829 (22.8%)</td>
<td>122/732 (16.7%)</td>
<td>1.74 (1.36, 2.23)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Q3: &gt;3 - ≤ 6</td>
<td>422/1829 (23.5%)</td>
<td>151/732 (20.6%)</td>
<td>1.45 (1.15, 1.82)</td>
<td></td>
</tr>
<tr>
<td>Q2: &gt;1 - ≤ 3</td>
<td>391/1829 (21.4%)</td>
<td>158/732 (21.6%)</td>
<td>1.56 (0.99, 1.59)</td>
<td></td>
</tr>
<tr>
<td>Q1: ≤ 1</td>
<td>592/1829 (32.4%)</td>
<td>301/732 (41.1%)</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>
### APPENDIX 1. Laboratory Reference Ranges

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Low*</th>
<th>High*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albumin</td>
<td>3.5</td>
<td>5</td>
</tr>
<tr>
<td>Alkaline Phosphatase</td>
<td>38</td>
<td>126</td>
</tr>
<tr>
<td>Anion Gap</td>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td>Osmolality, Calculated</td>
<td>261</td>
<td>280</td>
</tr>
<tr>
<td>Bilirubin, Total</td>
<td>0.2</td>
<td>1.3</td>
</tr>
<tr>
<td>Calcium, Total</td>
<td>8.4</td>
<td>10.5</td>
</tr>
<tr>
<td>Chloride</td>
<td>98</td>
<td>107</td>
</tr>
<tr>
<td>Carbon Dioxide</td>
<td>22</td>
<td>30</td>
</tr>
<tr>
<td>Creatinine</td>
<td>0.66</td>
<td>1.25</td>
</tr>
<tr>
<td>Glucose</td>
<td>74</td>
<td>106</td>
</tr>
<tr>
<td>Potassium</td>
<td>3.5</td>
<td>5.1</td>
</tr>
<tr>
<td>Protein, Total</td>
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<td>8.2</td>
</tr>
<tr>
<td>Aspartate Aminotransferase</td>
<td>15</td>
<td>46</td>
</tr>
<tr>
<td>Alanine Aminotransferase</td>
<td>21</td>
<td>72</td>
</tr>
<tr>
<td>Sodium</td>
<td>137</td>
<td>145</td>
</tr>
<tr>
<td>Blood Urea Nitrogen</td>
<td>9</td>
<td>20</td>
</tr>
<tr>
<td>Hemoglobin</td>
<td>11.4</td>
<td>16.1</td>
</tr>
<tr>
<td>Hematocrit</td>
<td>33.3</td>
<td>46.5</td>
</tr>
</tbody>
</table>

* to be classified as low or high, value must be below or above cut-off
REFERENCES


2. in Health, United States, 2014: With Special Feature on Adults Aged 55-64 (Hyattsville (MD), 2015).


Assessment of Recovery From Geriatric Ankle Fracture Using The Life Space Mobility Assessment (LSA)

Briggs Ahearn, MD, Claire Mueller, Stephanie Boden, Danielle Mignemi, Shae Tenenbaum, Jason Bariteau, MD

Abstract:

Introduction: Ankle fractures are the third most common type of fracture seen in the elderly population. Current outcome measures do not accurately assess true mobility in the geriatric population. In this study, we utilize the Life Space Assessment (LSA), a novel medical assessment survey which focuses specifically on how a patient moves within his/her environment following a medical event, to assess mobility in geriatric ankle fracture patients. This tool has not been previously utilized in orthopedic patients. We postulated that the LSA would provide improved assessment of these patients and help identify key differences in operative and non-operatively treated patients.

Methods: This study was designed as a prospective observational study in which all geriatric patients age 65 and older with an ankle fracture were followed for one year. Non-operative or operative treatment was determined by the attending physician on a patient specific basis. The LSA was administered at predetermined intervals post injury. SF-36 and VAS scores were also collected as standard of care data within this practice. Survey scores were tallied and standard means were determined and analyzed for significance.

Results: 26 patients met inclusion criteria and 20 were enrolled. 11 underwent surgery while 9 were treated non-operatively. Regardless of treatment, the pre-injury LSA score was 86.7. This significantly dropped to 20.6 at 6 weeks and recovered to 73.6 at 12 months. In the surgical cohort, the LSA scores preinjury were 91.4 and improved to 87.6 after 1 year. The non-op group recorded 80.88 pre-injury and only improved to 59.5 at 1 year (p = 0.0070). For the VAS, surgical patients reported pain of 2.2 and 1.40 at 6 and 12 months. Non-op patients recorded pain of 2.30 and 2.4 at 6 and 12 months. For SF-36 physical score, surgical patients recorded 57.6 and 70.9 at 6 and 12 months while non-op patients scored 53.2 and 60.1.

Conclusion: The LSA was effective in assessing recovery in geriatric ankle fracture patients. The survey highlights a severe deficit in mobility for the first 6 months of recovery regardless of treatment. Operative patients ultimately returned to their baseline LSA while non-operative patients continued to have lower mobility at one year. This was also corroborated by the SF-36 physical scores. Additionally, the operative group had less pain at 12 months compared to the non-operative group.

Introduction: Ankle fractures are the third most common type of fracture seen in the elderly patient population, second only to hip and distal radius fractures. It is estimated that annually, one out of every three elderly patient experiences a fall, and twenty percent of these falls result in serious injury such as a fracture.
Recent work has shown that operative intervention of geriatric ankle fractures yields less morbidity and mortality as compared to conservative treatment, suggesting that the improved early mobility after an operative intervention may play a protective role. However, current outcome measures do not specifically assess mobility and have a floor and ceiling effect that makes their use limited in this particular patient population.

In this study, we utilized the Life Space Assessment (LSA) to evaluate a cohort of geriatric ankle fracture patients. The LSA is a validated and novel medical assessment survey recently refined at the University of Alabama at Birmingham that focuses specifically on how a patient functions within his/her environment (i.e. "life space") following a medical event. The survey assesses where and how often patients travel within their environment and any assistance needed to accomplish that task during the 4 weeks leading up to the assessment. Mobility, in terms of life-space, can be visualized as a pattern of areas defined by distance extending from the location where a person sleeps (Figure 1). The LSA permits assessment of the full range of mobility, ranging from mobility dependent on assistance from another person and limited to the room where a person sleeps to daily, independent travel out of the person’s town. Life space mobility sub-scores are obtained for 5 separate life space levels by multiplying the life space level by frequency and independence. The sub-scores then are summed across all levels to obtain the composite score. Scores range from 0-120, with higher scores indicating greater mobility. A sample of a completed LSA can be seen in Figure 2. Previous authors have effectively used this measure to demonstrate a correlation between or change in the life space of elderly patients following general non-operative and operative hospitalizations, gynecological surgery, and mental illness such as depression. This assessment, however, has never been applied to the field of Orthopaedics. Although many functional and physical performance assessments determine what patients are able to do, the LSA reveals what patients actually do and whether assistance is needed.

It is well understood throughout the Orthopaedic literature that maintaining mobility following an injury or surgery leads to improved functional outcomes and reduces risk of medical complications. This is especially true in the elderly population. This patient group tends to have a more medical co-morbidities and lower baseline physical function compared to younger patients. Therefore, it is important for clinicians to understand just how profound of an impact a relatively common injury such as an ankle fracture can have in this geriatric population. Thus, in an attempt to eliminate the floor and ceiling effect of other commonly used physical functioning assessments, we chose to study the mobility of this cohort throughout recovery using the LSA.

The purpose of this study was to assess the LSA’s effectiveness in measuring post-injury mobility in geriatric patients with ankle fractures in order to better understand the impact that this injury can have on this particular population. Secondly, we attempted to identify any key differences between patients treated non-operatively and with open reduction and internal fixation in an effort to assess recovery based on treatment modality. We postulated that the LSA would provide a more accurate assessment of mobility in geriatric ankle fracture patients and demonstrate that this injury is severely limiting in this population. Additionally, we hypothesized that operatively managed ankle fractures would demonstrate improved mobility throughout recovery compared to non-operative fractures.

Methods:

This study was designed as a prospective observational study in which all willing geriatric patients age 65 and older with any type of ankle fracture were targeted. Patients of a single surgeon clinic who met the
inclusion criteria were invited to participate in the study when they presented for their initial injury visit. Those individuals who indicated a willingness to participate were given information about the risks and benefits of participation, the purpose of the study, and were informed that participation in the study was strictly voluntary. Non-operative or operative treatment options were determined by the attending physician on a patient specific basis. The LSA was administered at the initial visit as a measure of pre-injury status and also at 6 weeks, 3 months, 6 months and 12 months post injury/surgery. The SF-36 and VAS surveys were administered at 6 months and 12 months solely as a standard of care in this practice. Survey scores for all three were tallied and standard means were determined for each time point. Statistical analyses as outlined below were performed to determine significance.

Statistical Analysis:

Unadjusted means and standard deviations of all surveys collected at each time point were calculated. Additionally, due to the small sample sizes, medians and IQRs were calculated for each survey and time point. The results of the Life Space survey were examined by treatment and time period using a repeated measures linear means model. Using these models, adjusted means and 95% confidence intervals were calculated for each time period. In addition to the previous analysis, the results of the Life Space survey were compared to the results of the VAS and SF-36 Mental and Physical scores. All surveys were examined across treatment and the 6 month and 12-month time periods using a repeated measures linear means model for the 6 month and 12-month time periods. All analyses were completed using Statistical Analysis Software (SAS) v9.4 (Cary, NC) at an alpha level of 0.05.

Results:

We identified 26 patients who met inclusion criteria and 20 were enrolled in the study over a 2.5-year period. 5 participants were male and 15 were female (p = 1.0). 11 patients underwent surgery while 9 were treated non-operatively. The average age of the entire cohort was 74.8 years. The average age of the non-operative group was 74.2 and the surgical group was 75.4 years (p = 0.6969). These results can be seen in Table 1.

Table 2 outlines the unadjusted descriptive statistics for each survey over time. Regardless of treatment, the LSA score for the cohort was 86.7 preinjury. This declined to 20.7 at 6 weeks post injury and gradually rose to 73.6 at 12 months. The surgical LSA group scored 91.4 pre-injury and 19.2 at 6 weeks, which improved to 87.6 after 1 year. The non-op LSA group recorded 80.88 pre-injury, 22.3 for 6 weeks, and only improved to 59.5 at 1 year. For the VAS survey, surgical patients reported pain of 2.2 and 1.4 at 6 and 12 months respectively. Non-op VAS patients recorded pain of 2.3 and 2.4 at 6 and 12 months respectively. For SF-36 physical score, surgical patients recorded 57.6 and 70.9 at 6 and 12 months, while non-op patients scored 53.2 and 60.1. SF-36 mental scores for the surgical group were 60.6 and 77.8 at 6 and 12 months, while non-op patients recorded 76.9 and 86.50.

Table 3 demonstrates the adjusted descriptive statistics solely for the LSA in a comparison of operative and non-operative treatment using a 95% confidence level. This was performed in an effort to dampen the effect of outliers in a smaller sample size. The results of this table are graphically plotted in Figure 3. The adjusted LSA means for the non-operative group were 78.7 pre-injury, 22.3 at 6 weeks, and rose to 67.6 at 12 months. The operative group recorded LSA means of 91.4 pre-injury, 19.1 at 6 weeks, and improved to 86.7 at 12 months. A statistical comparison of survey outcomes based treatment yielded a p-value of 0.0070.
Lastly, adjusted descriptive statistics for all surveys at 6 months and 12 months using a 95% confidence interval can be seen in table 4. The P-values for the results of the LSA, VAS, SF-36 Mental, and SF-36 Physical were found to be 0.1405, 0.8358, 0.8987, and 0.7351 respectively. None of the results were found to be statistically significant as there was no single p-value < 0.05.

Discussion:

Ankle fractures represent a very common medical problem facing the geriatric population, and the incidence is on the rise. Limited mobility, multiple medical comorbidities, poor bone quality, and frequent falls all contribute to the high incidence of ankle fractures in this unique patient population. Despite the common nature of geriatric ankle fractures, the true impact of this injury on mobility is underreported and underappreciated. This study aimed to highlight the effectiveness of the Life Space Assessment in quantifying the mobility of geriatric ankle fracture patients throughout recovery.

This study was successful in highlighting the LSA’s ability to quantify changes in mobility in geriatric ankle fracture patients in the year following injury. Regardless of treatment regimen, patients saw a rapid decline in life space scores following injury and this persisted through the 6-week assessment. The average pre-injury LSA score of the group regardless of treatment was 86.7 which is generally consistent with Level 5 life space functioning with little to no limitations. However, following injury, the group as a whole averaged 20.7 at 6 weeks which is consistent with Level 1-2 life space. These patients demonstrated severe limitations, needed maximum assistance and rarely left the home. In fact, many patients seldom left their room on a regular basis and only left the house to make their clinic appointment. At 1 year, the group averaged a life space score of 73.6 which was a deficit of 13.1 points from the pre-injury state. This loss can be equated to a constriction of independent movement by one life space zone, such as from within one’s town to within one’s neighborhood.

As previously mentioned, prior authors have looked at the utility of the LSA to evaluate geriatric patients following medical and surgical hospital admissions as well as following elective urogynecological and non-elective gynecological oncology procedures. Stewart et al. found a 23-point decline in life space score following non-elective gynecological oncology surgery; however, this returned to baseline at 6 months and was maintained out to 1 year. Additionally, Brown et al. retrospectively evaluated life space mobility after hospitalization for prior medical and surgical admissions. Patients who were hospitalized for various major surgeries were found to have a life space score decline of 23 points; however, this returned to baseline at 1 year. Comparatively, in our study, we found an average life space score drop of 66 points following injury or surgery at the 6-week mark. Unlike patients in these two studies, geriatric ankle fracture patients treated surgically were still significantly limited at 6 months but ultimately recovered to near baseline by 1 year. This highlights the significant level of impairment seen throughout recovery with this injury.

When assessing recovery based on treatment regimen using the LSA, this study found that operative patients nearly returned to their baseline score, while non-operative patients continued to have lower mobility at 12 months (P=0.0070). In fact, operatively managed geriatric ankle fractures performed better on all 3 surveys compared to non-operative patients. In looking at the adjusted means for the LSA in Table 3, the life space score deficit between pre-injury and 12-month in the non-operative group was 11.1 while the operative group was only 4.7. This outcome difference equates to an approximate loss of 1 life space level in the non-operative group at 12 months compared to the surgical group. Regardless of treatment,
patients appeared to be significantly limited in mobility for the first 3 months; however, surgical patients’ recovery ultimately surpassed that of non-op patients between 6 months and 12 months. In concordance with prior studies looking at generalized outcomes of operative ankle fractures in elderly patients, this study demonstrated satisfactory subjective outcomes at 12 months.\(^6\) It is important, however, to acknowledge that several caveats exist when making this conclusion. Despite being statistically significant, we did not attempt to match these treatment cohorts and control for confounding variables. The non-operative group has lower pre-injury LSA scores and this could speak to the fact that these patients were less mobile and or more ill than the surgically selected patients. Therefore, the benefit of operative intervention on improved mobility is strictly an observational conclusion.

The results of the VAS mirrored those of the LSA. Surgical patients reported pain of 2.2 and 1.4 at 6 and 12 months while non-op patients recorded pain of 2.3 and 2.4, indicating mild improvement of pain in the surgically managed patients compared to no improvement in pain in non-operatively managed patients. This coincides with the results of the LSA in that surgical patients’ pain improved more so than non-op patients’ pain between 6 months and 12 months, and ultimately surgical patients demonstrated less overall pain at the 12-month mark. As patients in the non-operative group demonstrated higher residual pain after 12 months, in addition to lower LSA scores, there may be an association between the higher residual pain and decreased mobility in this patient group. However, it is important to note that we did not collect pre-injury VAS scores as this wasn’t the standard of care in this clinic. Therefore, it is difficult to determine the significance of these pain levels as well as their clinical significance.

The SF-36 physical and mental scores both improved between 6 months and 12 months overall and in both treatment groups. The surgical patients recorded scores of 57.6 and 70.9 at 6 and 12 months, while non-op patients scored 53.2 and 60.1. SF-36 mental scores for the surgical group were 60.6 and 77.8 at 6 and 12 months, while non-op patients recorded 76.9 and 86.50. The SF-36 physical survey was satisfactory in being able to capture the improvement in function throughout recovery. Additionally, it demonstrated the improved functioning with surgical patients over non-operative patients, as seen with the LSA. Therefore, we were unable to conclude that the LSA was superior to the SF-36 physical survey in assessing physical functioning following an ankle fracture in the geriatric population. However, keep in mind that the SF-36 score is a comprehensive measure of overall physical functioning. The LSA, on the other hand, not only demonstrates true mobility but also ties in how frequent and the degree of assistance required.

It documents what patients actually do, not what they can do.

Although there was a trend toward improved scores in the LSA, VAS, and SF-36 physical scores at 6 months and 12 months in operatively managed patients, there was no statistical significance when comparing adjusted means of each survey at 6 months and 12 months (Table 4). The P-value was 0.1405 for the LSA, which was lower than the other 3 surveys. One could generalize that the results of the LSA seen with this study are less likely to occur by random chance given a lower P-value, albeit this is still not statistically significant.

Despite being an observational conclusion, the improved results of operatively managed geriatric ankle fractures highlighted in this study are consistent with most of what is seen in the current literature. For example, Koval et al\(^14\text{-}17\) and Bariteau et al\(^9\) both utilized Medicare databases and determined the 1 year mortality of operative geriatric ankle fractures to be 6.7% and 9.1% at 1 year while non-operative fractures showed a mortality of 9.2% and 21.5%. Based on this study, one can deduce that the LSA has effectively demonstrated improved mobility at the 12-month time point in this patient population that undergoes surgery. Thus, an extrapolation can be made that the improved mobility seen in the operative group may be directly related to a lower mortality rate.
This study has several limitations. It is limited by its relatively small number of participants (n = 20) and thus is inherently underpowered. Additionally, while the LSA is a great modality for assessing functional recovery following an injury such as an ankle fracture, the scores can be affected by multiple variables (i.e. changes in health around the time of injury, depression, etc.) which this study did not control for. Lastly, a high level of patient attrition was noted throughout the course of data collection over 1 year, especially in the LSA group at 6 months and 12 months.

There are several strengths of this study. The research is prospective and longitudinal with 1 year follow up. The LSA may be a better measure of functional status in the elderly than other measures because it documents a patient’s true mobility and participation in society over time and space. This allows us to appreciate not only what patients can do, but what they are actually doing\textsuperscript{11}. This study is inherently a pilot study for the field of Orthopaedics in which data may be able to help power or frame future studies.

**Conclusion:**

Ankle fractures in the elderly population represent a complex problem given the common nature of the injury and the wide variability in treatment. The severity of this injury on the generalized mobility in the elderly is often underappreciated; thus, patient’s expectations are commonly inaccurate. The ideal treatment must be approached on a patient specific basis taking into account various factors such as medical comorbidities, fracture pattern, and overall functionality. Based on this study, the LSA was able to elucidate a significant decline in mobility in this patient population throughout the 12-month recovery. Additionally, the LSA captured the improvement in subjective recovery at 12 months when these fractures are treated operatively compared to non-operatively. This was simultaneously corroborated by the results of the SF-36 physical survey. Additionally, operatively managed patients demonstrated less pain at 12 months compared to non-operative patients. It is important for the treating surgeon to take all of the above into account when deciding the best way to manage an elderly patient with an ankle fracture. Based on our results, patients should be counseled accordingly especially regarding the magnitude of mobility impairment within 6 months of injury/surgery. Furthermore, it appears that unless patient specific risks preclude intervention, operative treatment of geriatric ankle fractures can lead to improved functional mobility and less pain at 12 months, and ultimately a lower mortality rate. Further investigations are needed to determine the optimal treatment paradigm for geriatric ankle fracture patients as it relates to improved functionality and lower mortality rates.
Figure 1: Conceptual model showing life-space levels as a series of concentric areas radiating from the room where a person sleeps with average survey scores and standard deviations for each level.
Figure 2: Example of scoring of the Life-Space Assessment. The subject traveled to all levels (levels 1–4) except for out of town (level 5); traveled daily to levels 1 and 2, and traveled 1 to 3 times each week to levels 3 and 4; uses a cane at all times and requires assistance with driving.9
Table 1. Descriptive Statistics

<table>
<thead>
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<th></th>
<th>Overall</th>
<th>Non-op Treatment</th>
<th>ORIF Treatment</th>
<th>p-value</th>
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<td><strong>Gender</strong></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Male</td>
<td>5/20 (25%)</td>
<td>2/9 (22%)</td>
<td>3/11 (27%)</td>
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<td>Female</td>
<td>15/20 (75%)</td>
<td>7/9 (78%)</td>
<td>8/11 (73%)</td>
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</tr>
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<td><strong>Age</strong></td>
<td>74.8 (6.2), (n=19)</td>
<td>74.2 (7.3), (n=9)</td>
<td>75.4 (5.4), (n=10)</td>
<td>0.6969</td>
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</table>

Table 2. Unadjusted Descriptive Statistics for Surveys Over Time

<table>
<thead>
<tr>
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<th>Non-op Treatment</th>
<th>ORIF Treatment</th>
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</thead>
<tbody>
<tr>
<td><strong>LS</strong></td>
<td></td>
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</tr>
<tr>
<td>Baseline</td>
<td>18</td>
<td>86.7 (28.1)</td>
<td>91.4 (21.2)</td>
</tr>
<tr>
<td>6 Week</td>
<td>19</td>
<td>20.7 (24.5)</td>
<td>19.2 (14.7)</td>
</tr>
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<td>3 Months</td>
<td>15</td>
<td>37.0 (34.4)</td>
<td>25.9 (25.3)</td>
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<tr>
<td>6 Months</td>
<td>10</td>
<td>49.8 (38.3)</td>
<td>55.9 (43.7)</td>
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<td>12 Months</td>
<td>10</td>
<td>73.6 (38.3)</td>
<td>67.6 (33.5)</td>
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<td><strong>VAS</strong></td>
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<td></td>
</tr>
<tr>
<td>6 Months</td>
<td>9</td>
<td>2.2 (2.8)</td>
<td>2.2 (2.6)</td>
</tr>
<tr>
<td>12 Months</td>
<td>10</td>
<td>1.9 (2.1)</td>
<td>1.4 (1.9)</td>
</tr>
<tr>
<td><strong>SF 36 Mental</strong></td>
<td></td>
<td></td>
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<tr>
<td>6 Months</td>
<td>8</td>
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<td>60.6 (28.2)</td>
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<td>12 Months</td>
<td>9</td>
<td>81.9 (21.5)</td>
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<td>57.6 (21.2)</td>
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<td>9</td>
<td>82.6 (16.4)</td>
<td>70.9 (15.9)</td>
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Table 3. Adjusted Descriptive Statistics for LS Total Over Time

<table>
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<tr>
<th></th>
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<th>ORIF Treatment</th>
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<tr>
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Table 4. Adjusted Descriptive Statistics for All surveys at 6 months and 12 months

<table>
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<td>12 Months</td>
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<td>12 months</td>
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Figure 3. Adjusted Means of LS Total Scores by Time and Treatment, p-value=0.0070
REFERENCES


Abstract

Purpose:
To examine clinical outcomes of tibial tubercle osteotomy (TTO) utilizing an Elmslie-Trillat osteotomy performed alone or in combination with medial patellofemoral ligament (MPFL) reconstruction using a minimally invasive technique involving <3 cm incisions and <4 cm osteotomies for the treatment of recurrent patellar dislocation.

Methods:
Over a 12-year period (2004 to 2016), a single surgeon performed 64 consecutive Elmslie-Trillat osteotomies using a minimally invasive technique. Patients with recurrent patellar subluxation or dislocation, failure of nonoperative management, tibial tubercle–trochlear groove (TT-TG) distance >15 mm, and a closed tibial apophysis were included. Preoperative International Knee Documentation Committee (IKDC) scores were obtained at the time of initial evaluation, and postoperatively a retrospective chart review as well as prospective data collection from patients were used to obtain postoperative IKDC scores, information about repeat dislocation/subluxation after surgery, as well as need for further surgery.

Results:
64 patients with mean age of 23.5 ± 7.8 years underwent consecutive TTO. 36 underwent TTO only, and 28 underwent TTO with MPFL reconstruction. 55 patients (86% follow-up) were contacted postoperatively at a mean follow-up of 4.0 ± 2.9 years. Mean preoperative IKDC score was 47.0 ± 12.3 compared to mean postoperative IKDC score of 74.5 ± 15.9 (p < 0.0001). 3 patients had recurrent dislocation, and 5 had recurrent subluxation. 9 patients underwent subsequent surgery.

Conclusion:
A minimally invasive approach for TTO using smaller incisions and smaller osteotomies can achieve good clinical outcomes, similar to those attained using a more traditional open approach.

Level of Evidence:
Level IV, case series
Introduction

Patellar instability leading to patellar dislocation is common and accounts for 2-3% of all knee injuries, and its highest incidence is found among young active patients. With a recurrent dislocation rate between 15-44% and a 33% overall frequency of symptoms following a first-time dislocation, patellar instability can have a significant negative impact on knee function and quality of life. Treatment of patellar instability starts with conservative management, consisting of bracing and physical therapy with early range of motion and quadriceps strengthening. However, surgical intervention is indicated in the setting of recurrent patellar instability when conservative management has failed.

Important anatomic factors associated with recurrent patellar instability include: patella alta, trochlear dysplasia, excessive lateral patellar tilt, and increased tibial tubercle – trochlear groove (TT-TG) distance. Surgical treatment of patellar instability seeks to stabilize the patella by restoring normal patellofemoral kinematics. The medial patellofemoral ligament (MPFL) has been shown to be an important restraint to lateral patellar displacement from 0 to 30° of knee flexion, and studies have shown that the MPFL is injured during all lateral patellar dislocations. As a result, MPFL reconstruction has become popular to address patellar instability. However, when the TT-TG distance is greater than 15 mm, MPFL reconstruction alone is unable to restore patellofemoral kinematics. In these cases of significantly increased TT-TG distance (>15 mm), tibial tubercle osteotomy (TTO) is indicated to correct the TT-TG distance by re-aligning the distal bony attachment of the patella. It can be performed alone or in combination with proximal soft tissue procedures such as MPFL reconstruction to treat recurrent patellar dislocation.

Multiple techniques for tibial tubercle osteotomy have been described, such as the Hauser osteotomy, Maquet osteotomy, Elmslie-Trillat osteotomy, and Fulkerson osteotomy. These distal re-alignment procedures performed alone or in combination with proximal soft tissue procedures have been shown to have good clinical outcomes in the management of recurrent patellar dislocation.

Currently, the most frequently used tibial tubercle osteotomies are the Fulkerson osteotomy and Elmslie-Trillat osteotomy. The standard approach to both of these techniques requires large incisions (>8 cm in length) and large osteotomies (>7 cm in length). In this study, a minimally invasive approach was utilized for tibial tubercle osteotomy involving a longitudinal skin incision of approximately 3 cm in length and an Elmslie-Trillat osteotomy approximately 4 cm in length to medialize the tibial tubercle. The purpose of this study was to examine the outcomes of tibial tubercle osteotomy performed for the treatment of patellar instability using this minimally invasive technique, and it was hypothesized that this technique could achieve good clinical outcomes, as determined by the following outcome measures: recurrent dislocation/subluxation rates, need for further surgery, and postoperative subjective knee function scores.

Methods

This retrospective review of prospectively collected data received institutional review board approval, and informed consent was obtained from all participants prior to participation. From 2004 to 2016, the senior author performed 64 consecutive tibial tubercle osteotomies (64 knees on 64 patients) using a minimally invasive Elmslie-Trillat osteotomy technique as described below. From these 64 patients, 55 were able to be contacted for full follow-up at the time of data collection for this study. The 9 patients who were unable to be contacted had either moved out of the area or had a change in contact information. All patients were identified from a prospective database that categorized patients by surgical procedure. Inclusion criteria were: recurrent patellar subluxation or dislocation, failure of nonoperative
management, TT-TG distance >15 mm on MRI, and a closed tibial apophysis. Exclusion criteria were: revision surgeries, the treatment of patellofemoral pain, and concurrent cruciate ligament or meniscal injury.

Preoperatively, International Knee Documentation Committee (IKDC) scores and TT-TG distances were obtained prospectively at the time of initial patient evaluation. Operative data was collected through retrospective review of the medical record. Patients underwent one of two procedures: TTO only or TTO combined with MPFL reconstruction. In this study, the indication to perform MPFL reconstruction in addition to TTO was if the patient had fixed lateral tracking of the patella or reproducible dislocation/subluxation of the patella during intra-operative examination after the TTO had been performed. Other proximal procedures such as lateral release or medial reefing were not performed during any of the procedures.

Postoperatively, patients were contacted by the study team via phone or email to obtain their current IKDC scores at the time of data collection for this study, obtain information about any repeat dislocation or subluxation after surgery, and obtain their need for further surgery. The need for subsequent surgery was also acquired from a retrospective review of the medical record.

Statistical analysis was performed using JMP Pro 12 (Cary, NC). Standard descriptive statistics were used to present demographic and operative data. Parametric continuous data was analyzed using Student t-tests, while nonparametric data was analyzed with Mann Whitney-U and Kruskal-Wallis testing when appropriate. When categorical data was analyzed with a frequency greater than 10, a χ² test was used. When frequency was less than 10, Fischer Exact test was used. Two-tailed p values <0.05 were considered statistically significant.

TTO Surgical Technique:

Patients were positioned supine on the operating table. General anesthesia and regional nerve block anesthesia (femoral or adductor canal nerve block) were used. An examination of the knee including assessment of patellar tracking was performed under anesthesia. A tourniquet was placed, and the operative extremity was then prepped and draped in sterile manner. A diagnostic arthroscopy was then performed on all patients.

Our technique for the tibial tubercle osteotomy using a minimally invasive approach is shown in Figure 1. A 3 cm longitudinal incision through the skin was made just lateral to the tibial tubercle starting at the most proximal aspect of the tibial tubercle using a scalpel. The subcutaneous layer was dissected using Bovie electrocautery. A plane between the subcutaneous fat and anterior muscle compartment fascia was then bluntly dissected 2 cm proximal and 2 cm distal to the incision as well as over the medial aspect of the tibial tubercle. In this way, the original 3 cm skin incision could be moved around as a mobile window. Bovie electrocautery was then used to make a longitudinal incision on the lateral aspect of the tibial tubercle through the anterior compartment fascia and periosteum. This incision started 3 cm distal to the proximal aspect of the tubercle and 1 cm posterior to the anterior tibial crest (staying anterior to the anterior compartment musculature) and was carried up proximal to the capsule adjacent to the lateral side of the patella tendon. A saw and osteotome were then used to perform a 4 cm in length Emslie-Trillat osteotomy of the tubercle. The tubercle was then rotated medial approximately 11 mm (or the amount needed to return the TT-TG distance to 10 mm). The osteotomy was then secured with two 3.5 mm cortical screws with washers perpendicular to the osteotomy using lag by technique in standard AO fashion. Care was taken to offset the two drill holes in order to avoid fracture of the
osteotomy. Patellofemoral tracking was then examined to ensure proper tracking. If the patient had fixed lateral tracking of the patella or reproducible dislocation/subluxation of the patella, an MPFL reconstruction was also performed. The skin incision was then closed with 2-0 Vicryl and then 4-0 Monocryl. A sterile dressing was placed, and the patient was placed into a hinged knee brace locked in extension.

**Postoperative protocol**

Postoperatively, patients were placed in a hinged knee brace. They were allowed to weight bear as tolerated with the knee brace locked in extension during ambulation for the first 6 weeks. During this time period, they received physical therapy and followed a passive knee range of motion protocol to achieve 0-90 degrees of passive range of motion by 6 weeks. After 6 weeks, patients could weight bear as tolerated without the knee brace and were allowed to start active range of motion and strengthening, progressing to full activity as tolerated. Patients followed up at 2 weeks, 6 weeks, 3 months, and 6 months postoperatively (and later as needed), and they received postoperative X-rays at routine intervals, as seen in Figure 2.

**Results**

Sixty-four patients underwent consecutive TTO by a single surgeon between 2004 and 2016. Mean age for patients at the time of TTO was 23.5 ± 7.8 years old (mean ± SD). 44 patients (68.8%) were female, and 20 patients (31.2%) were male. Mean follow-up time was 4.0 ± 2.9 years. Mean preoperative TT-TG distance was 20.2 ± 3.7 mm. This data is summarized in Table 1.

Frequencies of the different surgical procedures are presented in Table 2. Isolated TTO was performed in 36 patients (56.2%), and TTO combined with MPFL reconstruction was performed in 28 patients (43.8%). Preoperative and postoperative IKDC scores are shown in Table 3. These scores increased significantly from 47.0 ± 12.3 preoperatively to 74.5 ± 15.9 postoperatively (p<0.0001).

The number of patients with recurrent dislocation, subluxation, and subsequent procedures are shown in Table 4. Three patients had recurrent dislocation, and five had recurrent subluxation for a total of eight patients (14.5%) with recurrent patellar instability. Four of these patients had isolated TTO (12.5% of patients that had TTO), and four of these patients had TTO combined with MPFL reconstruction (17.4% of patients that had TTO with MPFL reconstruction). There was no significant difference in recurrence rate between isolated TTO compared to TTO combined with MPFL reconstruction (p=0.612). Nine patients (16.4%) underwent subsequent procedures: 1 revision TTO due to non-union, 1 subsequent MPFL reconstruction with removal of hardware, 1 ORIF for tibial tubercle fracture, 1 removal of hardware, 1 manipulation under anesthesia with removal of hardware, 1 manipulation under anesthesia, 2 arthroscopic chondroplasties, and 1 irrigation and debridement for wound dehiscence.

Patients who had recurrent patellar instability were found to be significantly younger in age than those who did not have recurrence (18.0 ± 2.5 years old for those with recurrence compared to 24.3 ± 8.1 years old for those without recurrence, p=0.0001). There was no significant difference in age for patients who required subsequent procedures (22.0 ± 4.5 years old) compared to those who did not require subsequent procedure (23.8 ± 8.2 years old, p=0.323).
Discussion

Tibial tubercle osteotomy has been shown to have good clinical outcomes in the management of recurrent patellar dislocation. Multiple techniques for TTO have been described, and the biomechanical effects of TTO on patellofemoral kinematics depend on the type of TTO used. The Maquet osteotomy anteriorizes the tibial tubercle, which decreases the joint reaction forces within the patellofemoral joint, so historically it was used for patients with pain due to early patellofemoral arthrosis. However, because it does not significantly affect patellar tracking in the coronal plane, it does not correct patellar instability. The Hauser osteotomy medializes the tibial tubercle, which medializes the contact pressures of the patella to correct lateral patellar instability, but due to the anatomy of the proximal tibia, direct medialization of the tibial tubercle also translates the tibial tubercle posteriorly, which leads to increased patellofemoral contact pressures and can lead to accelerated patellofemoral arthrosis. Currently, the Elmslie-Trillat osteotomy (medialization of the tibial tubercle without posterior translation) and the Fulkerson osteotomy (anteromedialization of the tibial tubercle) are the most commonly used techniques for TTO when treating patellar instability.

Studies reporting outcomes after Fulkerson osteotomy have shown good results. Tsuda et al. reported outcomes after Fulkerson osteotomy in 62 knees (41 patients) with mean age of 20 years and mean follow-up of 9.6 years. Kujala scores improved significantly from 68 to 92, and the recurrence rate of patellar instability was 11.3%, with a complication rate of 1.6% (1 non-union that required bone grafting). Akgun et al. found a recurrence rate of 11.8%, and 11.8% of patients required subsequent surgery after Fulkerson osteotomy in 17 knees (16 patients) with mean age of 25 years and mean follow-up of 2.6 years. Dantas et al. had a 0% recurrence rate, but had a 16.7% subsequent surgery rate and 8.3% complication rate after Fulkerson osteotomy in 24 knees (19 patients) with mean age of 22 years and mean follow-up of 4.3 years. These outcomes are summarized in Table 5.

Similarly, studies reporting outcomes after Elmslie-Trillat osteotomy have shown good results. Barber and McGarry reported outcomes after Elmslie-Trillat osteotomy in 35 knees (35 patients) with mean age of 27.7 years and mean follow-up of 8.2 years. IKDC scores improved significantly, and the recurrence rate was 8.6%. Nakagawa et al. had a recurrence rate of 13.3% and an 11.1% rate of subsequent surgery after Elmslie-Trillat osteotomy in 45 knees (39 patients) with mean age 18.4 and mean follow-up of 13.4 years, while Rillmann et al. had an 11.1% rate of recurrent symptoms of instability and 8.3% rate of subsequent surgery after Elmslie-Trillat osteotomy in 36 knees (32 patients) with mean age of 23.2 years and mean follow-up of 5.2 years. These outcomes are also summarized in Table 5.

The purpose of this study was to evaluate outcomes of tibial tubercle osteotomy for the treatment of patellar instability using a minimally invasive technique, and we hypothesized that this technique could achieve good clinical outcomes. The results of our study showed a recurrent dislocation rate of 5.4% (3 patients) and recurrent subluxation rate of 9.1% (5 patients) for an overall recurrence rate of 14.5% (8 patients) after TTO. Subsequent surgery was performed in 16.4% of patients (9 patients). Subjective knee function scores using the IKDC questionnaire showed significant improvement from 47.0 preoperatively to 74.5 postoperatively. These results using a minimally invasive approach are comparable to the results in the literature (as mentioned previously) that use a standard open approach.

The standard surgical approach using a Fulkerson (anteromedialization) osteotomy involves a large longitudinal skin incision approximately 8-10 cm in length and a large osteotomy approximately 7-10 cm in length, while the standard surgical approach using an Elmslie-Trillat (medialization) osteotomy also involves a large skin incision approximately 8-10 cm in length and an osteotomy approximately 6-7 cm in
length. In this study, a minimally invasive approach was utilized for tibial tubercle osteotomy involving a longitudinal skin incision of approximately 3 cm in length and an Elmslie-Trillat medialization osteotomy approximately 4 cm in length. The benefits of a minimally invasive approach can be significant. In addition to improved cosmetic results and a decrease in patients’ scar-related concerns, we were able to avoid significant complications that have been reported in the literature after TTO that could potentially be related to larger incisions and larger osteotomy sizes. These include postoperative infection (rates between 0.9 – 7.4% in several studies), hematoma (rates between 2.2 – 4.2% in several studies), and peroneal nerve palsy (rates between 0.9 – 2.8% in several studies).

While MPFL reconstruction combined with TTO have shown good results in the treatment of patellar instability, the indications and effect of combining an MPFL reconstruction to a TTO when TTO is indicated are yet to be determined. Previous studies have looked at comparing MPFL reconstruction only to MPFL reconstruction combined with TTO, but to our knowledge, no studies to date have compared outcomes of TTO alone versus TTO combined with MPFL reconstruction in the treatment of patellar instability. One previous study by Vivod et al. did look at TTO only compared to proximal procedure only compared to TTO combined with proximal procedure. They found high re-dislocation rates (36.4% for isolated proximal procedure, 20% for isolated TTO, and 31.8% for combined procedure), but the proximal procedure done was a quadricepsplasty, medial retinacular reefing, or Insall proximal realignment procedure (which involves a lateral release and advancement of the vastus medialis insertion on the patella) – no MPFL reconstructions were done. The re-dislocation rate was high in this study, but the procedures were done many years ago between 1963-1994, and since then techniques and results have significantly improved. In our study, we did not see any significant difference in recurrent dislocation/subluxation rates after isolated TTO compared to TTO combined with MPFL reconstruction. However, this was a secondary outcome of the study, and it is likely that this study was underpowered to find any significant differences between these two groups. Future studies are needed to further delineate the effect of combined MPFL reconstruction with TTO compared to isolated TTO.

Limitations

There are several limitations to this study. One is the inherent limitation of being a retrospective study, although some of the data was collected prospectively. In addition, there are limitations with collecting data from patients through survey methods, which include incomplete follow-up that could lead to over or underestimation of data. Strengths of this study include the large number of patients in this study (compared to other similar studies that present outcomes after TTO, this study has one of the largest numbers of patients). Other strengths of this study are the high follow-up rate (86%) and the uniform surgical technique done by a single surgeon.

Conclusion

Multiple prior studies have shown that tibial tubercle osteotomy alone or in combination with proximal soft tissue procedures have good clinical outcomes in the treatment of recurrent patellar dislocation. This study showed that a minimally invasive approach for TTO using smaller incisions and smaller osteotomies can achieve good clinical outcomes, similar to those attained using a more traditional open approach.
References


Figures

**Figure 1.** Minimally invasive technique for tibial tubercle osteotomy. A 3 cm skin incision is made just lateral to the tibial tubercle (Panel a). Once a mobile window has been created through blunt dissection, an incision through the anterior compartment fascia and periosteum is made at the lateral aspect of the tibial tubercle. A saw is used to begin a 4 cm length Elmslie-Trillat osteotomy (Panel b). The osteotomy is completed with an osteotome (Panel c). The tibial tubercle is then rotated medial approximately 11 mm (or the amount needed to return the TT-TG distance to 10 mm). The osteotomy is then secured with two 3.5 mm cortical screws with washers perpendicular to the osteotomy using lag by technique in standard AO fashion (Panels d-f).
Figure 2. Postoperative X-ray of the knee AP (Panel a) and lateral (Panel b) after minimally invasive tibial tubercle osteotomy taken at the first postoperative follow-up visit.
## Table 1: Patient Characteristics

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<th>mean ± SD</th>
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<tr>
<td>Male sex</td>
<td>20 (31.2)</td>
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<td>Pre-op TT-TG distance (mm)</td>
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<td>Age at time of procedure (years)</td>
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<td>23.5 ± 7.8</td>
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<tr>
<td>Follow-up interval (years)</td>
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<td>4.0 ± 2.9</td>
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## Table 2: Procedures Performed

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<td>TTO</td>
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<td>56.2</td>
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<tr>
<td>TTO + MPFL</td>
<td>28</td>
<td>43.8</td>
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*TTO (Tibial tubercle osteotomy)*

*MPFL (Medial patellofemoral ligament reconstruction)*
<table>
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<tr>
<th></th>
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<td>Preoperative IKDC</td>
<td>47.0 ± 12.3</td>
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<td>Postoperative IKDC</td>
<td>74.5 ± 15.9*</td>
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**IKDC** *(International Knee Documentation Committee)*

*Statistically significant increase from preoperative to postoperative IKDC score (p<0.0001)*
### TABLE 4: Recurrence and Subsequent Procedures

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<tr>
<td><strong>Recurrence</strong></td>
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<tr>
<td>Recurrence</td>
<td>8 (14.5)</td>
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<tr>
<td>Recurrent Dislocation</td>
<td>3 (5.4)</td>
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<tr>
<td>Recurrent Subluxation</td>
<td>5 (9.1)</td>
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</table>

| **Recurrence by Procedure**   |                        |
| TTO                           | 4 (12.5)               |
| TTO + MPFL                    | 4 (17.4)               |

<table>
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<tr>
<th><strong>Patients requiring subsequent procedures</strong></th>
<th>Number of Patients (%)</th>
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</thead>
<tbody>
<tr>
<td>Revision TTO for non-union</td>
<td>1</td>
</tr>
<tr>
<td>MPFL reconstruction with removal of hardware</td>
<td>1</td>
</tr>
<tr>
<td>ORIF of tibial tubercle fracture</td>
<td>1</td>
</tr>
<tr>
<td>Removal of hardware</td>
<td>1</td>
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<tr>
<td>MUA with removal of hardware</td>
<td>1</td>
</tr>
<tr>
<td>MUA</td>
<td>1</td>
</tr>
<tr>
<td>Arthroscopic chondroplasty</td>
<td>2</td>
</tr>
<tr>
<td>Irrigation and debridement for wound dehiscence</td>
<td>1</td>
</tr>
</tbody>
</table>

**TTO** (Tibial tubercle osteotomy)

**MPFL** (Medial patellofemoral ligament reconstruction)

**MUA** (Manipulation under anesthesia)

Percentages were calculated using the patients that had full follow-up (55 patients).
<table>
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<th>Author (yr)</th>
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<th>Mean age (yrs)</th>
<th>Mean follow-up (yrs)</th>
<th>TTO type</th>
<th>Recurrence rate (%)</th>
<th>Complication rate (%)</th>
<th>Subsequent surgery rate (%)</th>
<th>Subjective knee function scores</th>
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<td>Present study (2017)</td>
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<td>23.5</td>
<td>4.0</td>
<td>minimally invasive</td>
<td>Elmslie-Trillat</td>
<td>14.5</td>
<td>-</td>
<td>47.0 to 74.5</td>
</tr>
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<td>62 (41)</td>
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<td>9.6</td>
<td>Fulkerson</td>
<td>11.3</td>
<td>1.6</td>
<td>-</td>
<td>68 to 92</td>
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<td>2.6</td>
<td>Fulkerson</td>
<td>11.8</td>
<td>-</td>
<td>11.8</td>
<td>-</td>
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<tr>
<td>Dantas et al. (2005)</td>
<td>24 (19)</td>
<td>22.0</td>
<td>4.3</td>
<td>Fulkerson</td>
<td>0</td>
<td>8.3</td>
<td>16.7</td>
<td>-</td>
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<tr>
<td>Barber and McGarry (2008)</td>
<td>35 (35)</td>
<td>27.7</td>
<td>8.2</td>
<td>Elmslie-Trillat</td>
<td>8.6</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Nakagawa et al. (2002)</td>
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<td>18.4</td>
<td>13.4</td>
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<td>13.3</td>
<td>-</td>
<td>11.1</td>
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<td>Rillmann et al. (1998)</td>
<td>36 (32)</td>
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<td>Elmslie-Trillat</td>
<td>11.1</td>
<td>-</td>
<td>8.3</td>
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Can A Visiting Surgeon Program Coupled With Implant Donation And Local Surgeon Training Increase In-Country Surgical Capacity?
Sandra L. Hobson, MD

Abstract

Introduction: Many orthopaedic surgeons travel to low- and middle-income (LMIC) countries for one- to two-week trips to provide surgical care. In some circles these short-term trips have come under criticism for not appropriately meeting local needs and not actually demonstrating efficacy. The Scoliosis Research Society (SRS) Global Outreach Program (GOP) has sponsored a visiting surgeon program for pediatric spinal deformity care and training at Tokuda Hospital in Sofia, Bulgaria since 2008. The SRS partnered with Orthopaedic Link in 2011 to establish a seed donation of surgical implants that could be stored in Bulgaria and used for the trips as well as for cases to be done by the local surgeons. We hypothesize that a seed donation of materials coupled with local physician training can improve capacity of spinal deformity surgical care in LMICs with a visiting surgeon program.

Methods: This study was a retrospective review of all pediatric spinal deformity correction cases performed at Tokuda Hospital by both visiting and local surgeons from 2008 to 2016. Most recent surgical capacity for Bulgaria was calculated utilizing cases performed per year and population data. For comparison, surgical capacity was calculated based on population data and published surgical volume data from the United States in New York state and California and in the United Kingdom.

Results: Bulgarian surgical capacity for operative treatment of pediatric spinal deformity increased from zero to 1.9 cases per 100,000 pediatric patients per year, compared to 10.4 cases, 3.4 cases, and 9.9 cases per 100,000 pediatric patients per year in New York state, California, and the United Kingdom respectively.

Conclusion: A seed donation of implants coupled with appropriate training provided within a visiting surgeon program can increase in-country capacity for operative treatment of pediatric spinal deformity.

Introduction

Many orthopaedic surgeons travel to low- and middle-income (LMIC) countries to provide surgical care. Programs where visiting surgeons travel to sites in LMICs for short clinically based trips for one to two weeks are quite popular and widespread. In many cases, they provide essential services to underserved communities. However, in some circles these short-term trips have come under criticism for a number of reasons, with one commentary specifically stating programs are often “falling short in patient selection, contextual appropriateness, and consideration for regularly scheduled activities, including the operating schedule and educational activities.” Additionally, few visiting surgeon programs report efficacy of their work. Because of these reasons, there are now an increasing number of programs where institutions from high-income countries partner with LMIC institutions over a longer period of time with the specific intention of improving education of local surgeons and capacity.
The procurement, shipping, and management of necessary orthopaedic implants can also be challenging for the visiting surgical team. These challenges include customs tariffs, equipment security, and limited supply of implants from the United States. The Scoliosis Research Society (SRS) Global Outreach Program (GOP) has sponsored a pediatric deformity surgical site at Tokuda Hospital in Sofia, Bulgaria since 2008. This program sponsors a group of surgeons, usually three to five, who travel to Sofia once or twice per year for one week at a time. After encountering some of the challenges noted above, the SRS partnered with Orthopaedic Link in 2011 to establish a seed donation of surgical implants that could be stored in Bulgaria and used for the trips as well as for cases to be done by the local surgeons. We hypothesize that a visiting surgeon program can increase in-country capacity for surgical management of pediatric spine deformity if augmented with implant donation and local surgeon training. If this hypothesis is true, then it would document the efficacy of a visiting surgeon program to a middle-income country. The importance of this is that it demonstrates that well-conducted short-term trips coupled with training and implant donation can still be beneficial to LMICs.

Materials and Methods

This study evaluated prospectively collected data in a retrospective manner. All pediatric spine deformity cases performed at Tokuda Hospital from the beginning of the SRS GOS program in 2008 until 2016 were recorded. Additionally, whether the case was performed by a visiting surgeon or local surgeon was also designated. Based on population data available from the Bulgarian National Statistical Institute, we calculated the number of surgeries performed per 100,000 persons in the pediatric age range. Because the Bulgarian National Statistical Institute only reported population data for children aged 14 and below and data specifically for people aged 18 and younger was unavailable, we calculated incidence per 100,000 for patients aged 14 and younger.

To determine the efficacy of this intervention, we compared the increase in Bulgarian capacity to current capacity in high-income countries. Previously published population-based surgical volume data for pediatric spine deformity surgery was scant on our review of the literature, and no data for capacity specifically was found. Therefore, we obtained surgical volume data from two previously published studies, one published in the UK and one in the US specifically examining New York state and California, then calculated capacity from this and appropriate population data.

Specifically Divecha et al reported 6128 spinal deformity surgeries performed over a five-year period in patients aged 16 and younger in the United Kingdom (UK). Vitale et al reported 5136 spinal fusions for scoliosis performed in New York state and 3357 in California over a 10-year period for patients aged 18 years old and younger. Using population data from the Office for National Statistics for the UK and the United States Census Bureau for New York state and California, we then estimated the incidence of surgeries performed per year in those populations. Because the reported age ranges are different, we calculated incidence using the age range reported in each article; 16 years old and younger for the UK and 18 years old and younger for the US (Table 1).

<table>
<thead>
<tr>
<th>Location</th>
<th>Surgeries (per year)</th>
<th>Population</th>
<th>Population Age Range</th>
<th>Calculated Incidence (per 100,000)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulgaria</td>
<td>19</td>
<td>975272</td>
<td>14 years old and younger</td>
<td>1.9 presented here</td>
<td></td>
</tr>
<tr>
<td>US, New York state</td>
<td>514</td>
<td>4947529</td>
<td>18 years old and younger</td>
<td>10.4 Vitale et al</td>
<td></td>
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<tr>
<td>US, California</td>
<td>336</td>
<td>9739832</td>
<td>18 years old and younger</td>
<td>3.4 Vitale et al</td>
<td></td>
</tr>
<tr>
<td>UK</td>
<td>1226</td>
<td>12365881</td>
<td>16 years old and younger</td>
<td>9.9 Divecha et al</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. A comparison of incidence of pediatric spinal deformity surgeries for various countries.
Results

A total of 103 operative pediatric spinal deformity corrections were performed during the study period: 46 by visiting surgeons and 57 by local orthopaedic surgeons previously trained by visiting surgeons. Cases per year increased from four cases performed by visiting surgeons only in 2008 to nineteen performed by visiting surgeons (5 cases) and local surgeons (14 cases) in 2016. Using census population data, we calculate that overall Bulgarian rate for surgical treatment of pediatric spinal deformity went from zero prior to the intervention, to approximately 0.4 cases per 100,000 people aged 14 and younger in 2008 to approximately 1.9 cases per 100,000 people aged 14 and younger in 2016. In comparison, calculated capacity for high-income countries was 10.4 cases, 3.4 cases, and 9.9 cases per 100,000 pediatric patients per year in New York state, California, and the UK respectively.

Figure 1. Capacity of Bulgaria compared to high-income countries

Discussion

The surgical capacity for operative pediatric spinal deformity care in Bulgaria increased from zero to approximately 1.9 cases per 100,000 people aged 14 and under per year from 2008 to 2016. This is approaching the calculated rate of pediatric scoliosis surgeries performed in California, at 3.4 cases per year (Figure 1). To our knowledge, no data exists describing the incidence of pediatric spine deformity or frequency of surgery for pediatric spine deformity in the Bulgarian population. There are some limitations to this study. Firstly, it examines only a single surgical discipline, pediatric spinal deformity surgery, in a single relatively small middle-income country. Therefore, it’s unclear how easily replicated this intervention could be in other countries or for other operations. Additionally, this study does not investigate outcomes. Future work by this group is in process to compare both short-term and long-term outcomes of patients who underwent operative treatment with either local or visiting surgeons. Anecdotally based on our experience, the local surgeons successfully managed the majority of pediatric deformity cases and reserved the handful of most difficult cases (three to five cases per year in the years 2014-2016) for the visiting surgeons. This seems to indicate that local surgeons can manage the majority of cases, although highly complex cases may still require out-of-country referral without visiting surgeons. Estimating capacity was also imperfect. Limited published data exists on the incidence of pediatric
deformity surgery, and the associated age ranges reported also vary by country. This makes direct comparison of capacity difficult. However, we believe it is still useful to examine as best as possible the Bulgarian capacity to high-income countries.

Despite its limitations, we believe this study offers valid and useful insights into designing and managing surgical missions. It is one of the only studies to investigate the efficacy of a recurring surgical mission intervention and to specifically report on increased local capacity. This study also highlights the essential component of involving local surgeons. With proper training, the surgeons in this study were able to complete an increasing number of pediatric deformity cases without visiting surgeon assistance. Therefore, we recommend that all group planning surgical missions strongly consider planned and dedicated training of local surgeons coupled with implant donation to increase in-country capacity for managing surgical disease.
References


Association Of A Modified Frailty Index With Postoperative Outcomes After Ankle Fractures In Patients Aged 50 Years And Older

Rishin J. Kadakia, MD, Cathy Vu, BS, Douglas Robertson, MD, Michael Gottschalk, MD, John Rhee, MD

Abstract

Background
Frailty, a multifaceted syndrome resulting from a decrease in physiologic reserves, has been previously shown to play a significant role in elderly morbidity and mortality. The literature on frailty within orthopaedic surgery is limited currently. No study to date has assessed frailty as a predictor of postoperative outcomes in elderly patients with ankle fractures. We hypothesized that increasing frailty would be associated with increased 30-day reoperation rates and increased postoperative complications.

Methods
The National Surgical Quality Improvement Project (NSQIP) was queried using the appropriate CPT codes to identify inpatients from 2005-2014 who were aged 50 years and older that sustained an ankle fracture and underwent operative fixation. Frailty was assessed using a modified frailty index (MFI), abbreviated with 11 variables from the Canadian Study of Health and Aging Frailty Index. The primary outcome was 30-day reoperation rate and secondary outcomes were postoperative surgical and medical complications, readmission rates, and length of stay. Bivariate and multivariate analysis was used to determine association between outcomes and MFI.

Results
6,749 patients were identified, and the mean age of these patients was 64.4 years. Patients with increased MFI scores had significantly higher rates of postoperative complications. In addition, increased MFI scores was also associated with significantly increased 30 day readmissions and reoperations. Multivariate analysis also demonstrated that MFI was a stronger predictor of 30 day reoperation rates (odds ratio of 17.7, P < 0.001) than age, wound class, and ASA class.

Conclusion
Frailty has the potential to be an important predictive variable of postoperative outcomes in patients aged 50 years and older who sustain ankle fractures. The modified frailty index can be a valuable preoperative risk assessment tool for the orthopaedic surgeon. Further work is necessary to examine the effect of the MFI in a larger prospective setting.

Level of Evidence: Level III

Key words: Geriatric, Trauma, Ankle, Frailty, Outcomes
Introduction

The number of Americans aged 65 years and older has increased from over 30 million in 2000 to 40 million in 2010, with projections estimating this segment of the population to reach 90 million by 2050. More and more attention is being devoted to the optimal management of orthopaedic injuries in this population. According to the CDC, one out of every three elderly patients experiences a fall annually and twenty percent of all falls result in serious injury such as a fracture. Ankle injuries are the third most common type of fracture seen in the geriatric population, and the incidence of geriatric ankle fractures is steadily increasing. Increased awareness of healthier lifestyles and medical advancements has created a generation of more active and physiologically fit elderly individuals. Previous literature has shown that geriatric patients with ankle fractures are likely healthier and more active in ways that are not captured by simply accounting for age and comorbidity. The idea of physiological age and well-being may play an increasing role in predicting morbidity and mortality after geriatric ankle fractures. Frailty is defined as a decrease in the physiologic reserves as well as multisystem impairments which are separate from the normal process of aging. Frailty metrics can be easily calculated in the acute setting, and have the potential to aid surgeons and families in decision making processes. A study on general surgery patients older than 60 years showed that frailty was associated with increased postoperative morbidity and mortality after emergent procedures, and that it was a better predictor of mortality than conventional metrics like age or ASA score. The frailty index in this aforementioned study was truncated from the Canadian Study of Health and Aging Frailty Index (CSHA-FI), which is a list of 70 items that analyze various aspects in physical, cognitive, functional, and social aspects of the patient’s life. Another recent publication examining the association between frailty and postoperative morbidity and mortality across several surgical subspecialties found that increasing frailty as measured by a truncated index was associated with increased 30 day mortality and morbidity rates. The literature on frailty within orthopaedic surgery is currently limited. Frailty has been shown to be an independent predictor of mortality among patients undergoing hemiarthroplasty and total hip arthroplasty for femoral neck fractures. However, no study to date has examined frailty as a predictor of post-operative outcomes after ankle fractures.

Accordingly, the purpose of our work was to use a modified frailty index (MFI) to measure frailty and demonstrate a relationship between frailty and postoperative outcomes in older patients with ankle fractures. We aimed to address the following questions: (1) Is there an association between frailty and 30-day reoperation rates in patients aged 50 years and older who sustain ankle fractures? (2) Is there an association between frailty and length of stay in patients aged 50 years and older who sustain ankle fractures? (3) Are certain post-operative complications associated with frailty? (4) Is increased frailty as determined by the MFI a better predictor of 30-day reoperation rates than other traditional variables (age, wound class, ASA)?

Methods

Patients included in this study were identified through the National Surgical Quality Improvement Program (NSQIP) database. The American College of Surgeons (ACS) NSQIP is a national database of surgical data collected from participating hospitals. The database contains 136 variables that include demographic information, preoperative factors and postoperative outcomes. Postoperative data is collected for thirty days after surgery. The NSQIP database was used to identify all inpatients who sustained an ankle fracture and underwent operative fixation between the years of 2005 and 2014 using the following CPT codes: 27814, 27792, 27822, 27823, 27828, 27766, 27827, 27829, 27826, and 27769.
From the original 70-item Canadian Study of Health and Aging Frailty Index (CSHA-FI), eleven variables were selected since they were present in both the CSHA-FI and in the NSQIP database. These eleven variables together are a truncated version of the CHA-FI, which has been used in the literature on studies examining outcomes after head and neck surgery and general surgery. This Modified Frailty Index (MFI) is depicted in Table 1. The functional status index is a variable in the MFI that measures the patient’s ability to perform activities of daily living (ADLs). The functional status index was separated into two variables: patients who are completely independent or partially dependent on others for ADLs and those are completely dependent on others for their ADLs. All variables were dichotomous.

The MFI score was calculated by summing the number of variables present for each patient and then dividing by the total number assessed (n/11, range 0.0 to 1.0). For this study, MFI scores of 0.27 and higher were grouped together as there were very few patients with MFI scores greater than 0.27 (greater than three of the eleven listed variables in the MFI). Figure 1 demonstrates the MFI scores and distribution of this patient population. Analysis of the distribution of MFI scores for this patient population revealed that approximately five percent of patients had MFI scores above 0.27. The majority of patients only had zero to two of the eleven listed variables in the MFI score.

From the NSQIP database, 30-day reoperation rates, postoperative complications, and hospital / intensive care unit (ICU) lengths of stay were identified. Primary outcome of interest was 30-day reoperation rate. Secondary outcomes analyzed were 30-day rates of postoperative infections, wound dehiscence, medical complications (myocardial infarction, pneumonia, pulmonary embolism, deep vein thrombosis, and renal failure), readmissions, hospital length of stay, and ICU length of stay.

In addition to the MFI, the American Society of Anesthesiologist (ASA) class, wound class, and age were also included in the multivariate analysis as predictors of thirty-day reoperation rates. The ASA classification system is used to assess the preoperative risk of patients undergoing surgical procedures, and the five point scoring system is based on baseline health status and the presence of certain comorbidities. Wound classes were graded using the following scale: class I is clean without infection or inflammation, II is clean-contaminated, III is contaminated, and IV is dirty wounds.

Bivariate analyses using simple logistic regression and chi square test were performed to determine relationship between secondary outcomes and MFI score. Multivariable logistic regression with stepwise approach was used to assess predictors of 30-day reoperation while controlling for MFI, ASA class, wound class, and age. All analyses were done using SAS 9.4 (Cary, NC) and a p<0.05 was considered significant.

Results

A total of 6749 patients were identified through the NSQIP database using the appropriate CPT codes. Patient characteristics and demographics are listed in table 2. The average age was 64.4 (±10.3) years. Of the sample, 2194 (32.5%) were male with a mean age of 62.7 (±9.5) years and 4552 (67.5%) were female with a mean age of 65.2 (±10.6) years. The majority of the study sample identified as white (4766/6655, 72.6%) followed by 450 (6.8%) who identified as black or African American. Mean MFI of patient population was 0.08.

As MFI scores increased, the incidence of most secondary outcomes also correspondingly increased (Table 3). Incidence of infection at MFI score of 0.27 was almost three times the infection level at MFI of 0.0 (4.8% vs. 1.6%). Wound dehiscence also increased from 0.6% at MFI of 0.0 to 2.7% at MFI of...
0.27. In addition, MFI scores above 0.27 were associated with increased incidence of postoperative medical complications with pulmonary complications being the most common (2.1% vs. 0.3%). 30-day reoperation rate increased from 1.2% in patients with an MFI of 0 to 6.0% in patients with an MFI score of 0.27 and above (p < 0.001). 30-day readmission rate increased from 1.7% in patients with an MFI of 0 to 11.1% in patients with an MFI score of 0.27 and above, however the incidence of readmissions was highest in patients with an MFI score of 0.18. This data is also depicted in Figure 2.

With each unit increase in MFI score, there was a significant increased odds of all secondary outcomes of interest. This is depicted in Table 4. Patients with an MFI of 0.09 had a 46% increased odds of infection compared to patients with MFI of 0 (95% CI 1.21-1.77, p<0.001) while there is a 59% increased odds of infection in wound dehiscence with each increase in MFI (95% CI 1.21-2.08, p<0.001). Of the medical complications, increase in MFI was associated with a three times increased odds of having renal complications (OR 3.08, 95% CI 1.45-6.54, p=0.003). Similarly, increase in MFI showed a 1.8 times increased odds of infection and 2.2 times increased odds of readmission (reoperation 95% CI 1.50-2.12, p<0.001, readmission 95% CI 1.57-3.10, p<0.001).

Patients also had increased hospital length of stay with increasing MFI levels (5.9 days at MFI 0.27+ compared to 2.0 days at MFI 0, P <0.001) and ICU length of stay (4.7 days compared to 1.7, P <0.001). This data is represented visually in Figure 3.

Multivariable logistic regression analysis on 30-day reoperation rates found that increased MFI scores was associated with increased 30-day reoperation rates with an odds ratio of 17.74 (p = 0.003). Age and wound classes III and IV were also significant predictors of 30-day reoperation rates however their odds ratios were much smaller than that of MFI. Multivariable analysis is depicted in table five.

Discussion

There is literature suggesting that older patients with ankle fractures are younger and healthier than those who have hip fractures, and accordingly they have a lower 1-year morbidity and mortality compared with those who sustained a hip fracture.7 As the elderly population continues to be more active, it is imperative to find better ways to assess physiological status and well-being besides simply accounting for age. The use of frailty indices which account for age, comorbidities, and functional status may be more representative of physiologic age and may prove to be more prudent. This is the first study to examine the impact of frailty on post-operative outcomes in older patients who sustain ankle fractures.

This work demonstrates an association between frailty and poor postoperative outcomes using a modified frailty index. Patients with increased MFI scores had increased 30-day reoperation rates, postoperative infection rates, wound complication rates, and medical complications. In addition, they also had longer hospital and ICU length of stay. Multivariate analysis also demonstrated that MFI may be a stronger predictor for 30 day reoperation rates than commonly used variables such as ASA and age. There is some concern that a modified version of the large seventy-item CSHA-FI may lead to a weaker assessment of frailty; however, the MFI is more practical for several reasons. It requires less time for a provider to assess frailty in the acute setting; where time is an important factor. Additionally, the variables that comprise the MFI do not require trained providers to conduct objective measurements (e.g. gait speed), thereby avoiding such issues with inter-rater reliability. Furthermore, this MFI has already been shown to be associated with postoperative outcomes in postoperative patients in several surgical fields.5,14 These results support the use of MFI in helping surgeons predict postoperative morbidity after
surgical fixation of a geriatric ankle fracture. It will serve as an additional tool to aid providers when making treatment decisions and discussing outcomes with patients and families.

There are several limitations that must be considered when interpreting the results of this work with the most prominent being the retrospective nature of this study. It is important to note that since CPT codes were used to identify patients – only those that had surgery were included and patients managed nonoperatively were not included. The variables that were analyzed were also limited to those that could be captured by the NSQIP data set. Furthermore, the NSQIP only gathers postoperative data for up to 30 days – so it’s possible that many postoperative outcomes were not captured. There are also several confounders that were not included in analysis because they were not in the NSQIP database and not included in our MFI such as polytrauma patients or smoking status.

Conclusion

The elderly population is steadily growing and come with several management challenges from an orthopaedic perspective. While traditional risk factors such as age and ASA class continue to be important in predicting outcomes, new metrics are needed as the elderly population has evolved thanks to modern medicine. Our study demonstrates that a modified frailty index may also be a useful tool for providers. Further study is necessary to examine the effect of the MFI in a larger prospective and controlled setting.

Tables and Figures

Table 1. Modified Frailty Index. The 11 variables used in the Modified Frailty Index
Table 2. Study Patient Population. Patient demographics and characteristics for the study population (N = 6749)
Table 3. Incidence of postoperative outcomes based on increasing MFI scores. Incidence of secondary outcomes associated with increasing MFI scores.
Table 4. MFI and postoperative outcomes. Bivariate analysis of the association between increasing MFI scores and postoperative outcomes.
Table 5. Multivariable Analysis of 30 day reoperation rates. Logistic regression analysis of several variables (including MFI) and their association with 30 day reoperation rates.
Figure 1. MFI scores. Chart and bar graph depicting the range of MFI scores for this patient population (N = 6749)
Figure 2. MFI and postoperative outcomes. Graph representing the incidence of postoperative complications with rising MFI scores
Figure 3. MFI and length of stay. Graph presenting the increasing hospital and ICU length of stay with increasing MFI scores
Table 1. **Modified Frailty Index.** The 11 variables used in the Modified Frailty Index

<table>
<thead>
<tr>
<th>Modified Frailty Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>History of Diabetes Mellitus</td>
</tr>
<tr>
<td>History of Congestive Heart Failure</td>
</tr>
<tr>
<td>History of Myocardial Infarction</td>
</tr>
<tr>
<td>History of Hypertension (requiring medication)</td>
</tr>
<tr>
<td>History of Cardiac Problems (previous coronary intervention or cardiac surgery or angina)</td>
</tr>
<tr>
<td>History of Cerebrovascular problems (history of transient ischemic attack)</td>
</tr>
<tr>
<td>History of Stroke</td>
</tr>
<tr>
<td>History of Impaired sensorium (delirium, cognitive impairment)</td>
</tr>
<tr>
<td>History of Lung Problems (Pneumonia, COPD)</td>
</tr>
<tr>
<td>History of decreased peripheral pulses (history of surgery for vascular disease)</td>
</tr>
<tr>
<td>Functional Status (measurement of ADLs)</td>
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Table 2. **Study Patient Population**: Patient demographics and characteristics for the study population (N = 6749)

<table>
<thead>
<tr>
<th></th>
<th>N (%)</th>
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<tbody>
<tr>
<td><strong>Total</strong></td>
<td>6749</td>
</tr>
<tr>
<td>Age, years (±SD)</td>
<td>64.4 (10.3)</td>
</tr>
<tr>
<td>Male</td>
<td>2194 (32.5)</td>
</tr>
<tr>
<td>Mean MFI</td>
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</tr>
<tr>
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<tr>
<td>White</td>
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</tr>
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<td>Black or African American</td>
<td>450 (6.8)</td>
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<tr>
<td>Asian</td>
<td>88 (1.3)</td>
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<td>American Indian or Alaska Native</td>
<td>42 (0.6)</td>
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<tr>
<td>Native Hawaiian or Pacific Islander</td>
<td>14 (0.2)</td>
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Table 3. **Incidence of postoperative outcomes based on increasing MFI scores**. Incidence of secondary outcomes associated with increasing MFI scores.

<table>
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<tr>
<th>MFI score</th>
<th>0.0</th>
<th>0.09</th>
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<th>0.27</th>
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<td>Incidence</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>Infection</td>
<td>1.55</td>
<td>1.43</td>
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<td>4.76</td>
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<tr>
<td>Wound</td>
<td>0.58</td>
<td>0.80</td>
<td>1.00</td>
<td>2.68</td>
</tr>
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<td>0.00</td>
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</tr>
<tr>
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<td>0.77</td>
<td>1.45</td>
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<td>0.04</td>
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<td>0.60</td>
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<tr>
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<td>3.89</td>
<td>5.95</td>
</tr>
<tr>
<td>Readmission</td>
<td>1.72</td>
<td>5.62</td>
<td>17.48</td>
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Table 4. MFI and postoperative outcomes. Bivariate analysis of the association between increasing MFI scores and postoperative outcomes.

<table>
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<th>Secondary Outcomes</th>
<th>Odds Ratio</th>
<th>95% CI</th>
<th>p value</th>
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<tr>
<td>Infection</td>
<td>1.46</td>
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<td>&lt;0.001</td>
</tr>
<tr>
<td>Wound</td>
<td>1.59</td>
<td>1.21-2.08</td>
<td>0.001</td>
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<td>Medical Complication</td>
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<tr>
<td>Cardiac</td>
<td>2.64</td>
<td>1.70-4.09</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Pulmonary</td>
<td>1.88</td>
<td>1.42-2.50</td>
<td>&lt;0.001</td>
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<td>Renal</td>
<td>3.08</td>
<td>1.45-6.54</td>
<td>0.003</td>
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<tr>
<td>Hematologic</td>
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<td>0.042</td>
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<tr>
<td>Reoperation</td>
<td>1.78</td>
<td>1.50-2.12</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Readmission</td>
<td>2.21</td>
<td>1.57-3.10</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>
Table 5. **Multivariable Analysis of 30 day reoperation rates.** Logistic regression analysis of several variables (including MFI) and their association with 30 day reoperation rates.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Odds Ratio</th>
<th>95% CI</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modified frailty index</td>
<td>17.74</td>
<td>2.63-119.66</td>
<td>0.003</td>
</tr>
<tr>
<td>Age</td>
<td>1.02</td>
<td>1.00-1.04</td>
<td>0.018</td>
</tr>
<tr>
<td>ASA Class</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Reference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1.21</td>
<td>0.47-3.10</td>
<td>0.690</td>
</tr>
<tr>
<td>3</td>
<td>1.98</td>
<td>0.76-5.15</td>
<td>0.160</td>
</tr>
<tr>
<td>4-5</td>
<td>2.34</td>
<td>0.77-7.09</td>
<td>0.132</td>
</tr>
<tr>
<td>Wound Class</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>Reference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>1.58</td>
<td>0.63-3.93</td>
<td>0.328</td>
</tr>
<tr>
<td>III</td>
<td>4.27</td>
<td>2.40-7.58</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>IV</td>
<td>6.91</td>
<td>3.28-14.57</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Gender (Reference=male)</td>
<td>0.79</td>
<td>0.55-1.13</td>
<td>0.195</td>
</tr>
</tbody>
</table>
Figure 1. **MFI scores.** Chart and bar graph depicting the range of MFI scores for this patient population (N = 6749)

<table>
<thead>
<tr>
<th>MFI score</th>
<th>Frequency (n)</th>
<th>Percent (n/6749)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00 (0/11)</td>
<td>2779</td>
<td>41.18</td>
</tr>
<tr>
<td>0.09 (1/11)</td>
<td>2735</td>
<td>40.52</td>
</tr>
<tr>
<td>0.18 (2/11)</td>
<td>899</td>
<td>13.32</td>
</tr>
<tr>
<td>0.27+ (&gt;3/11)</td>
<td>336</td>
<td>4.98</td>
</tr>
</tbody>
</table>
Figure 2. **MFI and postoperative outcomes.** Graph representing the incidence of postoperative complications with rising MFI scores.

Figure 3. **MFI and length of stay.** Graph presenting the increasing hospital and ICU length of stay with increasing MFI scores.
References


Tension Band Vs Acromial Plate Fixation: A Biomechanical Comparison Between The Locking Compression Plate And Tension Band Construct In The Fixation Of Type 3 Displaced Acromial Fracture After Reverse Total Shoulder Arthroplasty.

Jeff Konopka, MD, Abi Adenikinju, MD, William Hutton PhD Claude Jarrett, MD

ABSTRACT

Background: Displaced acromial fractures after reverse total shoulder arthroplasty (RTSA) significantly reduce functional outcomes. Type III acromial fractures, which occur near the base of the acromion have been associated with the worst outcome. Current literature provides case studies on fracture treatment, but no biomechanical study has been completed to evaluate surgical fixation methods and thus determine standard of care. The purpose of this study was to compare the biomechanical strength of tension band construct versus custom acromial plates for surgical fixation of Type III acromial fractures in the setting of RTSA.

Methods: 12 cadaveric shoulders underwent RTSA followed by creation of iatrogenic Type III acromial fracture. Fractures were then reduced and fixed using tension band construct or acromial plate. Each specimen subsequently underwent standardized cyclic loading with measurement of displacement at the fracture site and load to failure testing.

Results: There was no statistically significant difference between acromial plate and tension band construct in mean displacement at the fracture site after cyclic loading (0.56 mm vs 0.54 mm p = 0.89). Mean peak load to failure was also equivalent between the two groups (485 N vs 520 N, p = 0.72).

Conclusion: Our results suggest that the locking compression plate and tension band construct are equivalent in terms of biomechanical strength in fixation of a displaced acromial fracture after RTSA.

Level of evidence: Basic Science Study; Biomechanics

Keywords: acromial fracture; tension band; acromial plate; reverse total shoulder arthroplasty; biomechanics

INTRODUCTION

Since its inception, reverse total shoulder arthroplasty (RTSA) has greatly improved reconstructive shoulder surgery. Initially indicated for severe glenohumeral osteoarthritis with underlying rotator cuff arthropathy, RTSA now has widespread applications including complete rotator cuff tears without arthropathy, rheumatoid arthritis, and failed conventional arthroplasty.1,3,11,14,38 As popularity of this procedure has increased, complication rates have also increased. One complication that significantly diminishes the functional outcomes and quality of life after RTSA is a displaced acromial stress fracture involving the deltoid origin.3,5,11,14,15,21,23,25,36,38,40 Acromial fractures have been reported in up to 7% of
patients following RTSA, with the most severe fractures occurring at the acromial base, resulting in loss of deltoid tension. 2,5–7,11,12,14,15,21,39–41

Despite the adverse effect that these fractures can have on the outcome of RTSA, the optimal management course remains unclear. When managed non-operatively there is minimal functional improvement as compared to the pre-operative state. 2,5,10,14,21,35–37 Internal fixation has been achieved using locking compression plates and the tension band technique, as described in various case reports; however, the two methods have not been compared and thus there is no standard of care regarding operative management. 36,32,36–38 The purpose of this study was to compare the biomechanical strength of tension band wiring versus custom acromial locking compression plates for surgical fixation of displaced Type III acromial fractures in the setting of RTSA. We hypothesized that fixation achieved with acromial plates would be biomechanically superior to that of the tension band technique as evidenced by load to failure and resistance to displacement under a cyclic load.

MATERIALS & METHODS

Due to the vagaries of post mortem collection we were only able to harvest 6 matched pairs of suitable shoulders (mean age 69 years). The shoulders were kept frozen until the day before testing when they were thawed overnight at room temperature. The deltopectoral approach was initially used to expose the anterior aspect of the glenohumeral joint capsule. The humerus was separated from the forearm slightly above the level of the supraglenoid crests. All soft tissue was dissected with the exception of the deltoid, proximal 2/3 of the muscles of the anterior and posterior compartments of the arm, and the muscles occupying the subscapular and infraspinous fossae of the scapula. Provided that there was no pathology of the deltoid or previous conventional shoulder arthroplasty, each shoulder underwent reverse shoulder arthroplasty per the DJO Reverse surgical technique guide (DJO, Vista, CA, USA).

Creation of Type 3 acromial fracture (Figure 1) was initiated using a bone saw, and completed using an osteotome and mallet. Fractures were created at the medial edge of the acromion, near the origin of the scapular spine. The shoulders were subsequently repaired using a six-hole precountoured acromial locking plate (Figure 2A; Acumed, Hillsboro, OR, USA) or tension band construct (Figure 2B) according to standard procedures reported in current literature. 2,24,31 We intended to test each fixation technique in six shoulders.

Biomechanical testing was conducted using Mini Bionix testing machine (MTS Systems, Eden Prairie, MN, USA). One hole was drilled in the supraspinous fossa, followed by insertion of a screw that would hold the proximal end of the specimen in place. Another hole was drilled through the distal humerus. A 2.5 mm drill bit was placed in the proximal humerus hole and a wire ring was used to hold the distal end of the specimen in place. The specimens were placed in the testing machine such that the machine was able to apply a load to the deltoid in line with its natural line of pull. During testing, the position of the shoulders simulated an anatomic position of 0 degrees of abduction with neutral rotation. Since there is no validated protocol for acromial fracture testing described in current literature, our testing parameters were modified from protocols for subscapularis testing. 15,14

Each specimen was subjected to a 100 N preload, and then cyclically loaded from 70 N to 130 N at 0.5 Hz for 1000 cycles. The space between the fracture fragments was measured: 1) prior to applying the preload; 2) after applying the 100 N preload; 3) after 250 cycles had been applied; 4) after 500 cycles; 5) after 750 cycles; and 6) after 1000 cycles. Measurements of displacement between the fracture fragments were taken using a digital caliper (Fowler High Precision, Newton, MA, USA). Then, maintaining the same load...
configuration, a load to failure test was then performed as follows: the load on each shoulder was reset to 100 N and then increased in increments of 100 N until failure occurred. The load to failure and the mechanism of failure were recorded. Failure was determined by visual inspection. Primary failure was defined as >5 mm displacement of separation of the fracture fragments from measurement at initial 100 N preload. All other failure mechanisms were described as secondary failure.

Statistical analysis was performed using the unpaired student t test via Excel (Microsoft, Redmond, WA, USA).

RESULTS

In all, 11 cadaveric shoulders were analyzed. One shoulder was excluded because it had a conventional arthroplasty. Six shoulders were tested using the acromial plate, and five shoulders were tested using the tension band construct. The mean displacement after 1000 cycles was 0.56 mm for the acromial plate group and 0.54 mm for the tension band group (p=0.90, Figure 3A). There was no statistically significant difference in displacement between the two groups at any point during the cyclic loading (Table 1).

The mean peak loads to failure were 485 N and 520 N for the acromial plate and tension band groups respectively (p=0.72, Figure 3B). Failure mechanisms observed during the experiment included: primary failure (>5 mm displacement at fracture site); screw cutoff, which disconnected the specimen from the testing machine; excess stretching and tearing of the deltoid in conjunction with shoulder dislocation that prevented the shoulder from taking further load. Primary failure occurred in one specimen in the acromial plate group, whereas the remaining specimen exhibited secondary failure (Table 2). All specimens in the tension band group exhibited secondary failure (Table 2). The most common failure mechanisms were shoulder dislocation in the tension band group and shoulder dislocation and screw cutoff in the acromial plate group.

DISCUSSION

The main result to come from this experiment is that the locking compression plate and the tension band construct are equivalent in terms of biomechanical strength in fixation of a displaced acromial fracture after RTSA.

Acromial fracture remains a significant complication adversely affecting the success of RTSA, however, ideal management remains controversial. Whereas some acromial fracture patterns heal uneventfully with conservative management, others ultimately result in reduced shoulder function and quality of life. Given the technical difficulty of achieving a stable fixation at the acromion as well as variability of results, there is often caution against surgical management. However, there exists a subset of patients for which surgical fixation is recommended, including those with significant pain, loss of function, failure of conservative management, and displaced fractures.

Case series have demonstrated the efficacy of the locking compression plate in restoring range of motion and strength, improving patient satisfaction and decreasing pain in patients with acromial fractures. Similar results have been exhibited with tension band wiring.

Both fixation constructs would also withstand the forces on the shoulder during activities of daily living. Current literature shows that the shoulder is typically loaded with less than 300 N of external force during everyday activities. For example, Westerhoff et al. found that the glenohumeral joint faced the
highest loads during weighted arm abduction or elevation, with a peak load of 131.5 N in a 100 kg patient. Pandis et al. demonstrated that mean maximum forces on the deltoid muscle in various driving positions peak at 162.59 N. Additionally, in wheelchair-bound patients, the cumulative anterior, inferior and posterior forces on the shoulder during the start-up push is reported to be 234 N. These numbers are substantially less than the mean peak load to failure for both fixation methods examined in this study. Also, the majority of the specimens did not undergo primary failure, further speaking to the strength of the two techniques.

Additionally, both techniques exhibited less than one millimeter of displacement after cyclic loading, suggesting that each construct can withstand repetitive load, which may be required by patients in their post-operative rehab and resumption of daily activities. Given similar patient outcomes as well as biomechanical strength, the choice of which fixation method to utilize can be based on cost, associated complications, and technical difficulty.

Various studies have demonstrated that the tension band method is significantly cheaper than the locking plate technique; however it is associated with more complications such as implant migration and prominence. Amini et al demonstrate that even if all patients with tension band undergo reoperation versus no patients with locking plates, the tension band method is still significantly more cost effective. Furthermore, implant removal also occurs after plate fixation; with varying results concerning a statistically significant difference between the two fixation methods in the current literature. Additionally, variations in the tension band technique, such as the transcortical method of K-wire insertion as well as the use of cannulated screws in lieu of K wire have reduced these complications. Lastly, the locking plate method has been associated with longer operative times, suggesting more technical difficulty involved with this method. Given the superior cost-effectiveness, decreasing complication rate with variations in technique, and reduced operative time, the tension band method may be the better choice.

Considering that this is a cadaveric study, it is limited by an imperfect model that may not fully represent what would be seen in vivo. Additionally, the small number of specimens subsequently reduces the power of the study. It took many months of careful selection to be able to acquire 12 suitable shoulders. However, even with weak power, our statistics seem compelling. Another limitation is the older age of the cadavers used, which may have resulted in weaker deltoid muscles and decreased bone densities at baseline, resulting in premature secondary failure; however, most RTSA patients are in this age group, therefore our results can be extrapolated to the average RTSA patient. Also, given the exclusion of one of the shoulders secondary to the presence of a conventional arthroplasty, one of the shoulders tested in the acromial plate group was not matched; thus we had suboptimal internal control. Lastly, we only compared two fixation techniques, whereas there are various other techniques that have been described in the literature, such as tension band with lag screws, multiple plate fixation, and the use of bone grafts. Future studies could further examine these techniques to evaluate for differences in biomechanical strength and clinical outcomes, and ultimately determine the ideal fixation technique for acromial fracture after RTSA.

CONCLUSION

Our results suggest that the locking compression plate and the tension band construct are equivalent in terms of biomechanical strength in fixation of a displaced acromial fracture after RTSA.
REFERENCES


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FIGURE & TABLE LEGENDS

Figure 1. Classification of acromial fractures. Type I represents involvement of a portion of the anterior and middle deltoid origin; type II, involvement of at least the entire middle deltoid origin; and type III, involvement of the entire middle and posterior deltoid origin.


Figure 2. Schematic presentations of fixation techniques (superior view). A. Acromial fracture reduction using acromial locking compression plate. B. Acromial fracture reduction using tension band fixation method.

Figure 3. Results of biomechanical testing comparing acromial plate and tension band fixation methods. A. Mean total displacement at fracture site after 1000 cyclic loads. B. Mean load (Newton force) at which failure occurred.

FIGURES

Figure 1
Figure 2

A.

B.
Figure 3

A. B.

![Graph showing mean total displacement after cyclic loading](image)

![Graph showing mean load to failure](image)

**TABLES**

**Table 1. Mean displacement after cyclic loading**

<table>
<thead>
<tr>
<th>Time (# cycles)</th>
<th>Acromial Plate</th>
<th>Tension Band</th>
<th>P value</th>
</tr>
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<tbody>
<tr>
<td>0</td>
<td>0.19</td>
<td>0.27</td>
<td>0.3866</td>
</tr>
<tr>
<td>250</td>
<td>0.21</td>
<td>0.13</td>
<td>0.4407</td>
</tr>
<tr>
<td>500</td>
<td>0.15</td>
<td>0.14</td>
<td>0.9263</td>
</tr>
<tr>
<td>750</td>
<td>0.12</td>
<td>0.13</td>
<td>0.7173</td>
</tr>
<tr>
<td>1000</td>
<td>0.09</td>
<td>0.13</td>
<td>0.2617</td>
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</table>

**Table 2. Failure Mechanisms**

<table>
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<th></th>
<th>Acromial Plate</th>
<th>Tension Band</th>
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<tbody>
<tr>
<td>Primary</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Shoulder dislocation</td>
<td>3</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>Deltoid Stretching</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Screw Cutoff</td>
<td>3</td>
<td>1</td>
<td>4</td>
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</table>
Outcomes Following Anterior Cruciate Ligament Reconstruction with Allograft—A Comparison of Allograft Sterilization Methods and Source Tissue

Tim McCarthy, MD

Abstract

Background: Many surgeons advocate the use of allogenic tissue for the reconstruction of the anterior cruciate ligament (ACL) due to shorter operating room time, reduced harvest site morbidity, theoretical cost savings, and equivocal outcomes; however, there exists a paucity of data evaluating the effect of the sterilization technique during tissue procurement on postoperative failure rate.

Purpose: To investigate the influence of graft source and sterilization method on failure rate and patient outcomes.

Study Design: Retrospective, comparative case series; Level of evidence, 3

Methods: The medical records of consecutive patients who underwent allograft ACL reconstruction between May 2006 and November 2012 in a single surgeon’s practice were reviewed to collect data regarding graft source, graft supplier, and indication of failure in the records. Patients filled out online IKDC, Tegner, and Lysholm evaluations of knee function. Failure rate and patient outcomes were compared to evaluate the influence of grafts source and sterilization method.

Results: In the tibialis anterior (TA) group, there were 97 patients and 100 knees. Eight tibialis anterior allografts failed (8.0%). Forty-five patients and 47 knees received a patellar tendon (BPTB) allograft. A total of 10 patients failed BPTB allograft reconstruction (21.3%). Failure rates were higher in younger patients (P=0.04). After adjusting for age, failure rates were similar (11.7% and 7.3% for BPTB and TA respectively, P=0.39). From the BPTB group, 38.5% (5/13) of the Community Tissue Service’s (CTS) grafts and 20.0% (5/25) of RTI grafts failed (P = 0.15). Pooled data from both groups showed failure rates of 19.5% for CTS, 15.0% for RTI, 5.9% for AlloSource, and 5% for ATS. These failure rates were not statistically significant (p = 0.46) but clinically important. Mean (± SD) Lysholm scores were 81.8 ± 9.8 for the BPTB group and 83.8 ± 16.3 for the TA group (p = 0.48). Mean IKDC scores were 80.8 ± 9.8 and 83.9 ± 17.20, respectively (p = 0.74).

Conclusion: The results of this study indicate that patellar tendon allografts fail at a higher rate when implanted in young adults. Also, tissue-processing technique may affect the integrity of the graft. Our results did not implicate a specific procurement method; however, we advise prudent evaluation of soft tissue allografts processing prior to implantation.

Key Terms: ACL reconstruction, allograft, processing, sterilization, failure

What is known about the subject: There exists a paucity of information comparing allograft procurement techniques and possible influence on ACL outcomes. A recent study suggested Biocleanse processed grafts may fail at an increased rate; however, that review looked at all surgeons contributing to the registry and did not correct for those with fellowship training, operative technique (trans-tibial vs. anatomic reconstruction), or variations in post-operative protocol. Furthermore, they evaluated the effect of AlloTrue™ and AlloWash® solutions and not the entire sterilization technique for each company.
What this study adds to existing knowledge: This review evaluated all of the steps during tissue processing for multiple suppliers of allografts rather than just one component of the technique and provides a detailed report of these procurement methods. Also, this reports minimized variables in surgical technique and post-operative protocol by evaluating a single surgeon’s practice. The results did not show statistically significant differences with regards to failure or outcomes based on sterilization technique; however, the reported information can be used to further educate surgeons regarding graft processing and potential risks.

Introduction

The incidence of primary anterior cruciate ligament (ACL) reconstruction continues to grow in the United States 35. Despite volumes of research dedicated to the reconstruction of the ACL, debate lingers regarding the appropriate use of allograft versus autogenous tissue. Previous studies have revealed inferior outcomes when using allografts for ACL reconstruction, especially in younger patients with high activity levels 6, 28, 39, 42, 46. Advocates of cadaveric graft tissue suggest that patients have comparable functional outcomes, without harvest site morbidity and at a reduced overall medical cost due to decreased operating room time 4, 12, 13, 17, 19, 31, 41. These prior studies indicate that allograft reconstruction does play a viable, although potentially limited, role for ACL reconstruction.

The use of allogenic tissue carries the inherent risk of disease transmission. Bacterial and viral infections, such as pseudomonas aeruginosa and hepatitis C, can be transmitted via these tissues, leading to significant morbidity and mortality 10, 11. Rigorous donor screening, nucleic acid testing, and aseptic processing techniques help minimize the risk of transmission. Many advocate the use of secondary sterilization because aseptic processing does not eliminate the possibility of subsequent colonization, nor does it remove occult infection or post-mortem contamination 51. Tissue banks also use low dose gamma-irradiation (1.0 to 2.5 Mrad) to decrease the biological burden of the graft, without compromise of its mechanical properties 3, 20-22. Unfortunately, post-harvest processing of allogeneic tissue may adversely affect its biomechanical properties, thus increasing tissue’s susceptibility to failure. For example, ethylene oxide preparation was considered a viable option for secondary sterilization. However, subsequent studies revealed multiple failures and chronic synovitis that resolved after removal of the graft associated with ethylene oxide sterilization 27, 44. However, low dose gamma-irradiation may not be virucidal to HIV-1 47. Also, other authors have shown equivocal failure of allografts versus autografts in ACL reconstruction once the data for irradiated grafts was removed from the test group 30, 38. Newer terminal sterilization techniques have emerged, including BioCleanse, AlloWash, AlloTrue, and PASCO2. Table 1 summarizes the details of each of these techniques and the companies that utilize them. The purpose of this study is to retrospectively review allograft ACL reconstructions performed by a single surgeon (XXX) at a single institution, thus minimizing intraoperative and postoperative variables. The patients were divided into groups based on sterilization technique (BioCleanse, AlloWash, AlloTrue, PASCO2®) and graft source (tibialis anterior [TA] allograft or bone-patellar tendon-bone [BPTB] allograft). We hypothesize that the graft’s anatomic source and sterilization technique will influence failure rates and patient outcomes.

Patients and Methods

Patient population

With the approval of our institutional review board, we retrospectively reviewed the electronic medical records of adult patients who had undergone ACL reconstruction from May 2006 through November 2012. The patients were consecutively drawn from the senior author’s academic practice and were identified using the Current Procedural Terminology code for ACL reconstruction (code 29888) and the International Classification of Diseases, ninth revision, code for ACL rupture (code 844.2). The senior author performed all reconstructions. The inclusion criteria included skeletally mature patients undergoing single bundle, anatomic ACL reconstructions using TA allograft or BPTB allograft. We included primary and revision reconstructions, as well
as multi-ligamentous knee injuries (i.e. concomitant non-surgical MCL or LCL injuries); however, we excluded patients that underwent multi-ligament reconstructions. Patients that had double bundle reconstructions and open physes were also excluded. We reviewed the patients’ electronic medical records and documented the mechanism of injury, age at the time of surgery, additional procedures performed, graft type, graft processing, ACL failure in the reconstruction knee or contralateral knee, and determined whether the patient had met the inclusion and exclusion criteria.

Postoperative Protocol
All patients followed the same post-operative rehabilitation protocol. Patients were kept non-weight bearing for 48 hours until the first postoperative appointment. At that time, the patient was allowed to bear weight with crutch assistance and initiated physical therapy. A gradual return to full weight bearing occurred during the following 2-3 weeks. Therapy consisted of three phases: regaining range of motion, strengthening, and sports specific agility. Three to four months after surgery, patients began light jogging. Return to sports was determined using objective physical exam findings, the patient’s subjective self-assessment of the knee (i.e. the presence or absence of kinesiophobia), and review of the physical therapist’s assessment. Patients returned to sports and rigorous activities approximately 9-12 months after surgery.

Outcome Measures
All patients were contacted by phone. We obtained informed consent, asked patients if the ACL reconstruction had failed, and requested that they fill out three online surveys. If the patient underwent multiple surgeries and received the same graft, we requested that he or she complete the surveys once. If the patient underwent multiple surgeries and received both grafts, we requested that he or she complete the survey twice. We ceased contacting the patient if he or she did not respond after three attempts. The International Knee Documentation Committee Subjective Knee Evaluation Form (IKDC) was used as a validated outcomes measure.16, 23, 24, 26 This tool provides a patient reported evaluation of knee-specific assessment of symptoms, function during daily activity, and the level of symptom free sports activity. We also incorporated the Lysholm and Tegner scores as a validated assessment specific to knee ligament surgery.8, 34, 49 The Lysholm score corresponds with the patient’s subjective evaluation of function and instability.34 The Tegner activity scale complements the Lysholm score and is a graded activity scale based on work and sports activities.49

Statistical Analysis
The statistical analysis of ACL reconstruction outcomes required an analysis that accounts for the correlation between multiple observations from the same patient (4 patients received both TA and BPTB allograft and 5 patients had bilateral ACL reconstruction). ACL failure rates were estimated and compared using the generalized estimating equations (GEE) approach that uses an exchangeable correlation structure with a modified Poisson model for binary data.33, 52. Univariable results from this model were summarized with the estimated ACL failure rates and 95% confidence interval (for all patients and by graft source, sterilization technique and age at surgery). The multivariable analysis of ACL reconstruction outcome included simultaneous adjustment for graft source, sterilization technique, and age at surgery. The ACL reconstruction failure rate and its 95% confidence interval were calculated for each covariate in the presence of others in the final model. All analyses of ACL reconstruction failure were implemented using SAS Proc Genmod (version 9.4). Statistical tests were two-sided. A p value <0.05 was considered statistically significant. An independent statistician affiliated with our university performed the above statistical analysis.

Results
In the tibialis anterior group, there were 97 patients (53 males, 44 females) and 100 knees. The mean age at surgery was 32.8 +/- 9.0 years with a median follow-up of 27.9 weeks (range 0.3 to 392.1 weeks). Two patients
sustained a contralateral ACL rupture and underwent reconstruction with TA allograft. One patient failed a TA allograft and was revised with an additional TA allograft. The TA grafts were obtained from AlloSource (32), ATS (16), CTS (28), RTI (15), LifeLink (3), Joint Restorations (2), Conmed (1), Regen (1), and Bacterin (1). The source for one graft could not be identified. Eight tibialis anterior allografts failed (8.0% of knees). Table 2 summarizes the patient data for the TA group and Table 3 summarizes the sources and failure rate of each graft.

Forty-five patients (34 males, 11 females) and 47 knees received a BPTB allograft. The mean age at surgery was 27.1 +/- 8.7 years with a median follow-up of 31.1 weeks (range 1.1 to 193.1 weeks). Four patients crossed over from the TA allograft group, as that graft failed, and they were revised with a BPTB allograft. One of those patients went on to fail the BPTB allograft and underwent revision with another BPTB allograft. One patient injured the contralateral ACL and was reconstructed with a BPTB allograft. The BPTB grafts were obtained from AlloSource (2), ATI (4), CTS (13), RTI (25), OsteoTech CTS (1), LifeLink (1), Joint Restorations (1). A total of 10 patients failed BPTB allograft reconstruction (21.3% of knees). Table 2 summarizes the patient data for the BPTB group and Table 3 summarizes the sources and failure rate of each graft.

Our statistical analysis of patient demographics showed significant difference in the mean age between the TA and BPTB group (p = 0.003). This initial evaluation looked at the actual mean age using the age at the time of each ACL reconstruction. These means are not comparable because the standard statistical test (two-sided two-sample equal-variance t-test) does not adjust for clustering by patient (i.e., patients with bilateral ACL reconstructions and patients that received both types of allograft). The 2-sample t-test assumes independence (i.e., each knee is assumed to be from a different patient). Table 4 summarizes the raw age data. We reviewed the data using model-based means which are estimated means taking into consideration that some patients had more than one knee reconstructed at different ages (the statistical model estimates both the within-patient and between-patient variance). This analysis did not show a statistically significant difference in age (p = 0.41). Table 5 summarizes the model-based mean age data.

We also evaluated how allograft type, sterilization technique, and age influenced the overall failure rate. The model-based failure rate estimate also adjusted for clustering by patients to account for patients with bilateral ACL reconstruction and patients that had an initial ACL reconstruction with a TA allograft that failed and were subsequently revised with a BPTB allograft (Table 6). These data showed that the sterilization technique did not influence the pooled failure rate; however, age and graft type may be risk factors for failure. The BPTB group failed at an increased rate (p = 0.03). However, when adjusting for age, there was no significant difference in failure rates between BPTB and TA allograft (p = 0.39). From the BPTB failures, RTI distributed 5 of the grafts and the other 5 were processed by CTS. Community Tissue Services had a failure rate of 38.5% and RTI had a failure rate of 20%. The difference in failure rate by sterilization technique within the BPTB group did not reach statistical significance (p = 0.15). Pooling data from the two groups showed 8 of 41 (19.5%) CTS grafts, 6 of 40 (15.0%) RTI grafts, 2 of 34 (5.9%) AlloSource grafts, and 1 of 20 (5.0%) ATS grafts failed. The differences in sterilization technique for the pooled data did not reach statistical significance (p = 0.17).

Overall, 138 different patients fulfilled the inclusion criteria with four patients crossing over from the TA group to the BPTB group. Eighty of the 138 patients responded to the survey (58.0%). Fifty-seven patients responded from the TA group (58.8%) and 23 patients responded from the BPTB group (51.1%). These patient interviews did not reveal additional ACL failures that went undocumented in the electronic medical chart. Numerous patients left the Tegner activity scale incomplete leading the authors to drop the scale from final analysis (20 did not indicate activity level prior to surgery and 14 did not indicate current activity level). Mean Lysholm scores were 81.8 +/- 9.8 for the BPTB group and 83.8 +/- 16.3 for the TA group (p = 0.48). Mean IKDC scores were 80.8 +/- 9.8 for the BPTB group and 83.9 +/- 17.20 for the TA group (p = 0.74). Tables 7 and 8 summarize this data.
Discussion

With the various iterations in tissue procurement and sterilization, we hypothesized that the tissue processing technique would influence failure rates of allograft ACL reconstruction. We also critically reviewed the patient population to determine if graft source also played a role in failure of the reconstructed ACL. Our results showed a significantly higher failure rate in the BPTB group (21.3%) when compared to the TA group (8.0%). These estimated failure rates achieved statistical significance when using model-based estimates to account for patients undergoing bilateral reconstruction or those crossing from the TA to the BPTB group. Using the raw data, a younger population received BPTB allografts compared to the TA group (32.8 +/- 9.0 years vs. 27.1 +/- 8.71 years, p = 0.003). Younger age likely contributed to the increased pooled allograft failure in our cohort and may have contributed to the increased failure rate in the BPTB group since there was no difference in failure rate between groups when adjusting for age. Despite the increased failure rate of patellar tendon allografts, functional outcome surveys (Lysholm and IKDC) did not show statistical significance between the two groups.

Graft choice for ACL reconstruction remains a source of contention. Many studies demonstrate the virtues of autograft reconstructions when compared to allograft in younger populations 5, 7, 30, 38, 42. Other studies contend that no difference exists between the two 9, 17, 32, 36, 48. Our results show a high failure rate in young patients who received a chemically processed or irradiated allograft.

The pros of allograft reconstruction include decreased operative times and no harvest site morbidity, while the cons include the potential for disease transmission. To address this issue, numerous companies have developed processing techniques for allograft tissue to achieve a sterile assurance level (SAL), the probability of a viable microorganism being present after sterilization, of 10-6. The BioCleanse tissue sterilization process claims to effectively remove biologic contaminants without compromising mechanical properties 15, 43 by using several dozen rapidly oscillating pressure and vacuum cycles above and below atmospheric pressure, during which the grafts are exposed to various chemicals including alcohol, hydrogen peroxide, detergents, and rinses 45. Community Tissue Services employs AlloWash® solution, isopropyl alcohol, antibiotics, and saline to process its tissues. There is no mechanical cleansing of its soft tissue grafts and all grafts received 1.2-1.7 Mrad gamma irradiation 14. AlloSource uses treatments of AlloTrue™ solution, antibiotics, alcohol, multiple water rinses, and 0.9-1.4 Mrad of gamma irradiation for terminal sterilization2. No peroxide is used during the AlloSource treatment. ATS exposes its grafts to a prewash (peracetic acid, peroxide, and alcohol) followed by treatment with supercritical carbon dioxide (PASCO2®). There is no mechanical cleansing or radiation exposure1. We obtained information for RTI, CTS, AlloSource, and ATS processing by directly contacting the companies and discussing the techniques with a product manager, customer service representative, or scientific liaison. CTS processed patellar tendon allografts failed at a rate of 38.5% while 20.0% of RTI processed patellar tendon grafts failed. This difference was not statistically significant. Pooling of the TA group and BPTB group data showed that 19.5% of CTS grafts, 15.0% of RTI grafts, 5.88% of AlloSource grafts, and 5.0% of ATS grafts failed. Statistical analysis of this pooled data did not indicate a difference in failure among the four techniques. This may be due to the limited power to detect clinically important differences due to low sample size and number of failures.

Despite the detailed information regarding tissue processing, it remains difficult to determine a specific cause of increased failure. For the patellar tendon cohort, CTS and RTI supplied over 80% of the allografts. The combined failure rate of these grafts was 26.3%. A mechanical study by Conrad et. al showed that BioCleanse tissue processing did not significantly alter load to failure for Achilles allograft when compared to an untreated control 15. However, this cadaveric study cannot replicate the biomechanical changes that in vivo ligamentization and subsequent remodeling induces on an implanted allograft. Another randomized prospective study assessed patient who underwent ACL reconstruction with BioCleanse treated patellar tendon allografts vs. aseptically harvested grafts 25. The authors reported no difference between groups with IKDC, ROM, and KT1000 and one patient from each group underwent revision. However, many patients were lost to
follow-up, RTI funded the study, and two authors report being consultants for RTI. Placement of the graft in an anatomic position may play a role in failure. Anatomic reconstruction results in increased in situ forces on the graft 29, potentially exceeding the failure load for a patellar tendon allograft. Mayr et. al retrospectively evaluated outcomes at 2 and 5 year follow-up for nonirradiated BPTB allografts versus BPTB autografts in the revision ACL reconstruction 37. These authors obtained their patellar tendon allografts from RTI and performed an anatomic revision reconstruction. They reported no failures though the groups were small (15 in allograft group and 14 in autograft group). The authors concluded that avoiding irradiation contributed to improved results. Another study performed by the Research and Development Department of CTS compared the mechanical properties of aseptic non-irradiated control grafts and those terminally processed with gamma radiation or electron beam doses of radiation 18. The authors obtained 40 tibialis allografts (tibialis anterior and tibialis posterior) and 40 BPTB allografts. Each graft was processed as described above in the CTS technique. Terminal sterilization was randomized to 1.7-2.1 Mrad gamma irradiation, 1.7-2.1 Mrad electron beam sterilization, 9.2-12.2 Mrad electron beam sterilization, and a non-irradiated control. Their results showed no statistically significant differences in mechanical properties between the controls or the experimental groups; however they did not directly compare patellar tendons to tibialis tendon allografts. The maximum stress of the patellar tendon grafts in this study (around 20 MPa) replicated findings of a previous study 3. Community Tissue Services recently changed to electron beam sterilization instead of gamma irradiation 14. Also, graft irradiation occurs in the presence of free air, theoretically leading to increased free radical exposure and oxidative degradation that continues after terminal sterilization. A study by Park et. al., systematically reviewed 21 publications evaluating the effect of radiation exposed allografts for ACL reconstruction. They evaluated the results of 1453 patients, 415 of whom received an irradiated graft, and determined that exposure below 2.5 Mrad remained a risk for revision surgery when compared to non-irradiated grafts. 40. The effect of graft type and surgical technique could not be determined because of insufficient data according to the authors. A recent study by Tejwani et. al. sought to determine risk factors contributing to allograft failure by retrospectively reviewing the Kaiser Permanente ACL Reconstruction Registry 50. They evaluated what role irradiation, AlloTrue solution, AlloWash solution, and BioCleanse had on 5968 primary ACL reconstructions. The authors determined that graft irradiation greater than 1.8 Mrad, BioCleanse graft processing, younger patient age, male patients, and BPTB allograft were all associated with a higher risk of clinical failure and subsequent revision surgery. This review looked at all surgeons contributing to the registry and did not correct for those with fellowship training, operative technique (trans-tibial vs. anatomic reconstruction), or variations in post-operative protocol. Furthermore, they evaluated the effect of AlloTrue™ and AlloWash® solutions and not the entire sterilization technique for each company as described above. Our review minimized variability by having one surgeon perform all procedures without significant changes in technique or postoperative protocol over time. We also took into account the full sterilization technique and confirmed this technique with each company that supplied the majority of our grafts. Compared to the aforementioned studies, our results reflected similar risks for failure including use of patellar tendon allograft in young patients and potentially a lower threshold of radiation exposure.

There are multiple limitations to this study. We collected data retrospectively without randomization of the two groups. Four patients crossed over from the tibialis anterior group to the patellar tendon group. There was a low response rate (58%) for the patient interviews and surveys despite numerous attempts to contact all eligible patients; however, those that did respond report good functional outcomes regardless of graft type with a mean Lysholm and IKDC in the 80’s. Also, with a low response rate, some failures may have been missed, though no new ruptures were discovered through 80 patient interviews. Despite thorough questioning of each company’s tissue processing technique, some steps are patent protected and the exact formulation of solutions or procedures remain unknown. The strengths of this study include one sport medicine fellowship trained surgeon performing all of the procedures with the same postoperative protocol for all patients thus minimizing the bias between the two groups. We directly compared two types of allograft tissue used for ACL reconstruction. We
also evaluated all of the steps during tissue processing for the main suppliers of our institutions allografts rather than just one component of the technique.

In conclusion, the results of this study indicate that patellar tendon allografts fail at a higher rate when implanted in young adults. Also, tissue processing may play a role in maintaining the integrity of the graft. Our results did not implicate a specific procurement method; however, we advise prudent evaluation of soft tissue allografts processing prior to implantation. Due to the increased failure of BPTB allografts seen in our clinic, we changed our protocols and no longer use patellar tendon allografts for ACL reconstruction. However, the results of this study indicate BPTB allografts may still be a viable option for older patients. Further studies are needed to critically assess potential factors that contribute to ACL reconstruction failure with allografts.
References
1. Alamo Tissue Service RP, San Antonio, TX 78249.

17. Edgar CM, Zimmer S, Kakar S, Jones H, Schepsis AA. Prospective comparison of auto and allograft hamstring tendon constructs for ACL reconstruction. Clin Orthop Relat Res. 2008;466(9):2238-2246.


45. RTI Surgical RC, Alachua, FL 32615.


### Tables and Figures

#### Table 1: Patient Data

<table>
<thead>
<tr>
<th></th>
<th>Tibialis Anterior Allograft</th>
<th>Patellar Tendon Allograft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients (Males/Females)</td>
<td>97 (53/44)</td>
<td>45 (34/11)</td>
</tr>
<tr>
<td>Total Knees</td>
<td>100</td>
<td>47</td>
</tr>
<tr>
<td>Mean Age at Surgery (SD)</td>
<td>32.8 +/- 9.0 years</td>
<td>27.1 +/- 8.7 years</td>
</tr>
<tr>
<td>Median Follow-Up (range)</td>
<td>27.9 (0.3—392.1) weeks</td>
<td>31.1 (1.1—193.1) weeks</td>
</tr>
</tbody>
</table>

#### Table 2: Graft Processing Data—total allografts, number of failures (if applicable), percent failure (if applicable)

<table>
<thead>
<tr>
<th>Graft Source</th>
<th>Tibialis Anterior Allograft</th>
<th>Patellar Tendon Allograft</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTS</td>
<td>28, 3 failures (10.7%)</td>
<td>13, 5 failures (38.5%)</td>
</tr>
<tr>
<td>RTI</td>
<td>15, 1 failure (6.7%)</td>
<td>25, 5 failures (20.0%)</td>
</tr>
<tr>
<td>AlloSource</td>
<td>32, 2 failures (6.2%)</td>
<td>2</td>
</tr>
<tr>
<td>Alamo</td>
<td>16, 1 failure (6.2%)</td>
<td>4</td>
</tr>
<tr>
<td>LifeLink</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Joint Restoration</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>ConMed</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Regen</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Bacterin</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>OsteoTech CTS</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Unable to Determine</td>
<td>1, 1 failure (100%)</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>100, 8 failures (8.0%)</td>
<td>47, 10 failures (21.3%)</td>
</tr>
</tbody>
</table>

#### Table 3: Raw age at procedure by type of allograft (knees=147)

<table>
<thead>
<tr>
<th>Allograft Group</th>
<th>N</th>
<th>Raw Mean Age (years)</th>
<th>Standard Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>PT</td>
<td>47</td>
<td>27.1</td>
<td>8.7</td>
<td>15.9</td>
<td>48.9</td>
<td>0.0003</td>
</tr>
<tr>
<td>TA</td>
<td>100</td>
<td>32.9</td>
<td>9.0</td>
<td>13.3</td>
<td>57.3</td>
<td></td>
</tr>
<tr>
<td>Overall</td>
<td>147</td>
<td>31.0</td>
<td>9.3</td>
<td>14.3</td>
<td>57.3</td>
<td></td>
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</table>
Table 4: Model based mean age at procedure by type of allograft (knees=147)

<table>
<thead>
<tr>
<th>Allograft Group</th>
<th>N</th>
<th>Model based mean (years)</th>
<th>95% Confidence Interval (years)</th>
<th>P</th>
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<tr>
<td>PT</td>
<td>47</td>
<td>30.8</td>
<td>27.5 to 34.0</td>
<td>0.41</td>
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<tr>
<td>TA</td>
<td>100</td>
<td>31.8</td>
<td>29.0 to 34.6</td>
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</table>

Table 5: Univariable Analysis of Covariates Potentially Associated with ACL Failure

<table>
<thead>
<tr>
<th></th>
<th>Knees</th>
<th>#Failed</th>
<th>Failure rate % (95% Confidence Interval)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Patients</td>
<td>147</td>
<td>18</td>
<td>12.2*</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10.3 (6.4—16.5)</td>
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<td></td>
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<td></td>
<td>This estimate is the model-based failure rate. The estimate is adjusted for clustering by patient to account for patients with bilateral ACL reconstruction and patients that had an initial ACL reconstruction with a TA allograft that failed and were subsequently revised with a BPTB allograft.</td>
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<tr>
<td>Allograft</td>
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<tr>
<td>BPTB</td>
<td>47</td>
<td>10</td>
<td>21.2 (12.3—36.6)</td>
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<tr>
<td>TA</td>
<td>100</td>
<td>8</td>
<td>8.0 (4.1—15.5)</td>
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<tr>
<td>Sterilization</td>
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<td></td>
</tr>
<tr>
<td>CTS</td>
<td>41</td>
<td>8</td>
<td>19.5 (9.9—38.6)</td>
<td>0.17</td>
</tr>
<tr>
<td>RTI</td>
<td>40</td>
<td>6</td>
<td>15 (7.3—30.8)</td>
<td></td>
</tr>
<tr>
<td>Allosource</td>
<td>34</td>
<td>2</td>
<td>5.9 (1.5—22.6)</td>
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<tr>
<td>Alamo</td>
<td>20</td>
<td>1</td>
<td>5 (0.7—33.8)</td>
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<tr>
<td>Age (continuous)</td>
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<td>20 yr</td>
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<td>30 yr</td>
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<td>40 yr</td>
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</table>

*The failure rate is calculated as a simple fraction (18/147, 12.2%).

ϮThis estimate is the model-based failure rate. The estimate is adjusted for clustering by patient to account for patients with bilateral ACL reconstruction and patients that had an initial ACL reconstruction with a TA allograft that failed and were subsequently revised with a BPTB allograft.
Table 6: Lysholm score by allograft group

<table>
<thead>
<tr>
<th>Allograft Group</th>
<th>N</th>
<th>Mean</th>
<th>Std Dev</th>
<th>Minimum</th>
<th>Maximum</th>
<th>P</th>
</tr>
</thead>
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<tr>
<td>BPTB</td>
<td>29</td>
<td>81.8</td>
<td>9.8</td>
<td>65</td>
<td>100</td>
<td>0.48*</td>
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<tr>
<td>TA</td>
<td>55</td>
<td>83.8</td>
<td>16.3</td>
<td>43</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

Table 7: ICKD score by allograft group

<table>
<thead>
<tr>
<th>Allograft Group</th>
<th>N</th>
<th>Mean</th>
<th>Std Dev</th>
<th>Minimum</th>
<th>Maximum</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>BPTB</td>
<td>29</td>
<td>80.8</td>
<td>9.8</td>
<td>52.9</td>
<td>98.9</td>
<td>0.30*</td>
</tr>
<tr>
<td>TA</td>
<td>55</td>
<td>83.9</td>
<td>17.2</td>
<td>36.8</td>
<td>100.0</td>
<td></td>
</tr>
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2016 – 2017 Orthopaedic Surgery Residents
PGY4 – PGY1

PGY4

Laura Bellaire
Emory University School of Medicine
Hometown: Atlanta, GA

William Carpenter
University of Texas San Antonio
Hometown: Waco, TX

Jimmy Daruwalla
Emory University School of Medicine
Hometown: Rockville, MD

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University of South Alabama
Hometown: Gulf Shores, AL

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Thomas L. Bradbury, MD  Assistant Professor, Adult Reconstruction, Dir. Ortho Residency
James R. Roberson, MD  Professor & Chairman, Adult Reconstruction
Hicham Drissi  Acting Professor & Vice Chairman, Research
John G. Heller, MD  Baur Professor; Spine
William Hutton, Ph.D  Professor, Research
Gerald Rodts, MD  Professor, Spine
John ‘X’ Xerogeanes, MD  Professor, Sports Medicine
Spero Karas, MD  Associate Professor, Sports Medicine
Sameh (Sam) Labib, MD  Associate Professor, Sports Medicine/Foot & Ankle
Thomas Moore Sr., MD  Associate Professor, Trauma
Thomas Moore Jr., MD  Assistant Professor, Trauma
John Rhe, MD  Associate Professor, Spine
S. Tim Yoon, MD  Associate Professor, Spine
Dheera Ananthakrishnan, MD  Assistant Professor, Spine
Jason Bariteau, MD  Assistant Professor, Foot & Ankle
Robert W. Bruce, Jr., MD  Assistant Professor, Pediatrics
Greg Erens, MD  Assistant Professor, Adult Reconstruction
Nicholas Fletcher, MD  Assistant Professor, Pediatrics
Matthew Gary, MD  Assistant Professor, Spine
George Guild, MD  Assistant Professor, Adult Reconstruction
Michael Gottschalk, MD  Assistant Professor, Hand & Upper Extremity
Kyle Hammond, MD  Assistant Professor, Sports Medicine
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John Louis-Ugbo, MD  Assistant Professor, Foot & Ankle
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Daniel Refai, MD  Assistant Professor, Spine
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Mara Schenker, MD  Assistant Professor, Trauma
Richard Thomas, MD  Assistant Professor, Trauma
Nick Willett, PhD  Assistant Professor, Research
Brent Wise, MD  Assistant Professor, Trauma
George Wright, MD  Associate Professor, Trauma
Kelly Day Visiting Professors

1978  William Murray MD  
       Professor & Chairman of The Department of Orthopedic Surgery at UCSF.
1979  Robert E. Leach MD  
       Boston University
1980  Carl L. Nelson MD  
       Chairman of the Department of Orthopaedic Surgery at the University of Arkansas for Medical Science
1981  Sir John Charnley  
       Wrightington Hospital  
       Professor Emeritus of the University of Manchester, the Royal College of Surgeons of England and Ireland, and the Universities of Edinburgh and Glasgow.
1982  Howard H. Steel MD  
       Shriners Hospital-Philadelphia
1983  Robert H. Fitzgerald, Jr. MD  
       Chairman - Wayne State University
1984  Joseph Schatzker MD  
       Professor Emeritus of Surgery at the University of Toronto
1985  Larry Matthews MD  
       The University of Michigan
1986  John P. Kostuik MD  
       Professor Johns Hopkins University School of Medicine
1987  Richard H. Gelberman MD  
       Washington University, Department of Orthopaedic Surgery
1988  J. Leonard Goldner MD  
       Duke University
1989  Henry J. Mankin MD  
       Massachusetts General Hospital
1990  Bernard F. Morrey MD  
       Professor & Chairman, of Orthopaedics at the Mayo Clinic
1991  Gary G. Poehling MD  
       Professor of Orthopaedic Surgery at Bowman Gray School of Medicine
1992  Michael W. Chapman MD  
       Professor & Chairman, Department of Orthopaedic Surgery University of California at Davis
1993  Michael F. Schafer MD  
       Ryerson Professor & Chairman Department of Orthopaedic Surgery Northwestern School of Medicine
1994  James R. Urbaniak MD  
       Virginia Flowers Baker Professor & Chief of Orthopaedic Surgery, Duke University Medical Center
1995  Dan M. Spangler MD  
       Professor & Chairman of Orthopaedic Surgery & Rehabilitation, Vanderbilt University
1996  James H. Herndon MD  
       David Silver Professor & Chairman of Orthopaedic Surgery, University Pittsburgh’s Medical School & Chief of Orthopaedics & Rehabilitation at the UPMC.
1997  S. Terry Canale MD  
       Professor, Department of Orthopaedic Surgery, University of Tennessee College of Medicine.
1998  Angus M. McBryde, Jr. MD  
       Professor & Chairman, Orthopaedic Surgery, The Medical University of South Carolina.
1999  L. Andrew Koman MD  
       Professor & Chairman, Department of Orthopaedic Surgery, Duke University Medical Center
2000  Louis U. Bigliani MD  
       Frank E. Stinchfield Professor & Chairman Department of Orthopaedic Surgery College of Physicians & Surgeons
2001  Robert S. Adelaar MD  
       Professor & Vice-Chairman, Department of Orthopaedic Surgery Medical College of Virginia
2002  John S. Gould MD  
       Alabama Sports Medicine
2003  Freddie H. Fu MD  
Professor & Chairman,  
Department of Orthopaedic Surgery  
University of Pittsburgh

2004  Peter Stern MD  
Professor & Chairman, University of Cincinnati

2005  James N. Weinstein DO  
Chairman Department of Orthopaedics Dartmouth

2006  Marc F. Swiontkowski MD  
Chairman Department of Orthopaedics University of Minnesota

2007  Michael Coughlin MD  
Coughlin Foot and Ankle Clinic at St. Alphonsus Hospital, Boise, Idaho

2008  Michael Simon MD  
Chairman, Department of Orthopaedics University of Chicago

2009  Richard J. Hawkins MD,  
Clinical Professor, University of Colorado Clinical Professor,  
Team Physician: Denver Broncos, Colorado Rockies & UT Southwestern. Principal, Steadman Hawkins Clinic of the Carolinas

2010  Joseph A. Buckwater, MD  
Professor & Head of The Department of Orthopaedic Surgery

2011  Jesse B. Jupiter, MD  
Professor of Orthopaedic Surgery at Massachusetts General Hospital at the University of Iowa Hospitals & Clinic

2012  J.A. “Tony” Herring, MD  
Chief of Staff, Emeritus at Texas Scottish Rite Professor of Orthopaedic Surgery University of Texas Southwestern Medical School

2013  Steven Garfin, MD  
Professor and Chair Department of Orthopaedic Surgery at UCSD

2014  William Levine, MD  
Frank E. Stinchfield Professor and Chairman, Department of Orthopedic Surgery Columbia University Medical Center

2015  Kevin Bozic, MD, MBA  
Inaugural Chair of the Department of Surgery and Perioperative Care, and Professor of Orthopaedic Surgery at the Dell Medical School University of Texas at Austin

2016  Samir Mehta, MD, MBA  
Associate Professor, Department of Orthopaedic Surgery  
Chief, Orthopaedic Trauma and Fracture Service University of Pennsylvania

2017  Mark E. Baratz, MD, M  
Program Director, Orthopaedic Surgery Hand Fellowship, Clinical Professor and Vice Chairman, Department of Orthopaedics, University of Pittsburgh Medical Center

2018  Michael Vitale, MD  
Ana Lucia Professor of Pediatric Orthopaedic Surgery & Neurosurgery  
Vice Chair, Quality & Strategy, Orthopaedic Surgery, Columbia University Medical Center
**PUBLICATIONS**

**Peer-Reviewed Journals: 2016 - 2017**


