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I would like to welcome you to the Kelly Society Resident Research Day. I am sure you will find the projects reflect outstanding planning and effort on the part of the investigators and I look forward to hearing the presentations.

This year’s Kelly Day Professor is Dr. Kevin Bozic. Dr. Bozic is truly a thought leader in musculoskeletal health policy and outcomes research. His insightful contributions to education and clinical research are indeed impressive. He recently accepted the position of inaugural Chair of the Department of Surgery and Perioperative Care at the newly formed Dell Medical School in Austin, Texas. On behalf of our residents and faculty I would like to thank Dr. Bozic for taking the time from his very busy schedule to be with us.

Alumni support through the Kelly Society is an integral component of the success of our department. Thanks to the current Kelly Society President, Dr. Jim Kercher and Secretary, Dr. Claude Jarrett for their efforts over the last two years.

Finally I am grateful to the number of people who put a great deal of effort into organizing this weekend’s events.

James R. Roberson, M.D.
Dr. Kevin Bozic is the inaugural Chair of the Department of Surgery and Perioperative Care, and a professor of Orthopaedic Surgery, at the Dell Medical School at The University of Texas at Austin.

Dr. Bozic is a graduate of the UCSF School of Medicine and the Harvard Combined Orthopaedic Residency Program. Additionally, he holds a Bachelor of Science degree in Biomedical Engineering from Duke University and a Masters of Business Administration from Harvard Business School. Dr. Bozic has fellowship training in Adult Reconstructive Surgery from Rush University Medical Center in Chicago and is also a Visiting Scholar in the Institute for Strategy and Competitiveness at the Harvard Business School.

Dr. Bozic’s clinical interests are in adult reconstructive surgery of the hip and knee, with an emphasis on primary and revision hip and knee replacement. His research interests are broadly in the fields of health policy and health care services research, and specifically in the areas of healthcare technology assessment, cost-effectiveness analysis, shared medical decision making, and the implementation and evaluation of value-based payment and delivery models. In addition to his clinical and research activities, Dr. Bozic is actively involved in numerous regional and national health policy initiatives, including the University of California Center for Health Quality and Innovation, the American Joint Replacement Registry, the Integrated Healthcare Association’s Episode of Care Payment Program, and the Institute for Healthcare Improvement/Harvard Business School’s collaborative Joint Replacement Learning Community.

Dr. Bozic also holds both regional and national leadership positions, including member of the Board of Trustees of the Orthopaedic Research and Education Foundation, Chair of the American Academy of Orthopaedic Surgeons Council on Research and Quality, and Chair of the California Joint Replacement Registry.

Dr. Bozic has been the recipient of numerous awards and honors, including the Orthopaedic Research and Education Foundation’s Clinical Research Award, the American Academy of Orthopaedic Surgeon’s Clinician-Scientist Traveling Fellowship Award, the American Orthopaedic Association’s American-British-Canadian Traveling Fellowship, the American Association of Hip and Knee Surgeon’s James A. Rand Young Investigator Award, and the Orthopaedic Research Society’s William Harris Award.
Letter from the 2015 Kelly Society President
James Kercher, MD

Dear fellow Emory alumni:

I have had the privilege of serving as the Kelly Society President now for the second year and I have been truly honored. I wholly agree with the most common sentiments relayed by the majority of our membership; that the relationships built between peers, faculty and mentors during residency are some of the most cherished.

I am amazed at how the quality of our residents continues to improve. This is a testament to our dedicated faculty and the quality of the research presented at last year’s Annual Kelly Day was proof. For those of you unable to attend, the presentations were fantastic and I expect this year’s Kelly Day will further showcase the talent ascending through the program.

Over the last year we have worked hard to reengage our alumni. We have several members taking advantage of the online library resources and directory. We have seen over a 100% increase in our membership, three new lifetime members, and the turnout at the AAOS reception in Las Vegas, was the best ever with 71 people in attendance. This is largely due to the many of you who have helped us reconnect our network. Although, quite possibly secondarily influenced by the generous distribution of Dr. Whitesides’ lost at sea single barrel bourbon.

Next year we will be naming new Kelly Society committee members and we will be looking for energetic, engaged alumni to volunteer. I hope you will continue to help spread the word and strengthen our numbers because I feel as a group; we are well-positioned to influence the program’s future. Joining the Kelly Society represents more than just a transaction – it’s a chance to become engaged with the residency program and support the training for future leaders.

Thank you again for allowing me the opportunity to serve as your Kelly Society President. I’m excited about the future and what it holds for us as we partner to grow our membership.
Friday, June 5, 2015

6:30 AM  Registration & Breakfast
7:00 AM  Welcoming Remarks: James Roberson, MD

Session I
7:15 AM  The Effect of FDP Advancement During The Primary Repair Of The Jersey Finger Injury: A Biomechanical, Cadaveric study  
Michael Smith, MD PGY-5

Ramsey Kinney, MD, PhD PGY-5

7:35 AM  A Retrospective Radiographic Review Of Fusion Rates At 3 Months For One And Two Level Anterior Cervical Decompression And Fusion With And Without Recombinant Bone Morphogenetic Protein-2  
Eli Garrard, MD PGY-3

7:45 AM  Case Presentation: PGY-4

7:55 AM  Panel Discussion

8:20 AM  Break

Session II
8:35 AM  Pediatric Supracondylar Humerus Fractures: Who’s Missing Needed Treatment?  
Bryan Sirmon, MD PGY-3

8:45 AM  Complications Of Carpal Tunnel Surgery: A Systematic Review  
Greg Faucher, MD PGY-5

8:55 AM  The Efficacy Of Interval Closure In Total Shoulder Arthroplasty: A Cadaveric Study  
Charles Daly, MD PGY-3

9:05 AM  Reusable Arthroscopic Transosseous Tunneling: Rational And Techniques For Value-Based Rotator Cuff Repair.  
Dr. Brett Sanders, Class of 2005

9:35 AM  Break
9:45 AM  Introduction of 2015 Kelly Visiting Professor/ James Roberson, MD

9:50 AM  2015 Kelly Visiting Professor Lecture
Kevin Bozic, MD, MBA
Chair, Department of Surgery and Perioperative Care
Dell Medical School The University of Texas at Austin

10:20 AM  BREAK

Session III
10:30 AM  Functional Outcome After Revision Surgery For Recurrent Cervical Radiculopathy
Timothy Borden, MD PGY-3

10:40 AM  Comparison of Initial Cobb Measurements in Medicaid vs Private Insured Patients
David Lazarus, MD PGY-5

10:50 AM  Repair Of Knee Extensor Mechanism Injury With Suture Anchors
Joel Huleatt, MD PGY-3

11:00 AM  Early Complications Following Posterior Spinal Fusion for Adolescent Idiopathic Scoliosis
F. Patterson Owings, MD PGY-5

11:10 AM  Panel Discussion

11:30 AM  Introduction of Reunion Class 2005 and Future of Kelly Society
James Kercher, MD, President of Kelly Society

11:50 AM  Closing Remarks
James Roberson, MD and Thomas Bradbury, MD

12:00 PM  LUNCH
2014 – 2015 Orthopaedic Surgery Residents

PGY-5

Gregory Faucher, MD
Administrative Chief

Fellowship Match: The Curtis National Hand Center at Union Memorial Hospital Baltimore, MD
Medical School: University of Florida College of Medicine
Hometown: Jacksonville, FL

Ramsey Kinney, MD, PhD

Career Plans: Staff Physician Orlando VAMC Orlando, FL
Medical School: Emory University School of Medicine
Hometown: Chino Valley, AZ

David Lazarus, MD

Fellowship Match: Rady Children’s Hospital San Diego, CA
Medical School: The University of Tennessee College of Medicine
Hometown: Nashville, TN

F. Patterson Owings, MD

Fellowship Match: The University of Tennessee Campbell Clinic Memphis, TN
Medical School: Medical College of Virginia
Hometown: Atlanta, GA

Michael Smith, MD
Administrative Chief

Fellowship Match: Brigham and Women’s Hospital Boston, MA
Medical School: Harvard Medical School
Hometown: Birmingham, AL
Gregory Faucher, MD  PGY-5
Administrative Chief Resident

UPCOMING FELLOWSHIP TRAINING:
Hand and Upper Extremity Fellowship
The Curtis National Hand Center at Union Memorial Hospital
Baltimore, MD

EDUCATION:
University of Florida College of Medicine, Gainesville, FL
Doctor of Medicine, May 2010
The College Of William and Mary, Williamsburg, VA
Bachelor of Science, Biology, May 2005

HONORS AND LEADERSHIP:
Administrative Chief Resident, Orthopaedic Surgery Residency 2014-2015
Resident Leadership Forum, 2014-2015
American Orthopaedic Association – Montreal, Canada
Resident/Faculty Committee Member 2014-2015
Residency Interviewing and Selection Committee 2010-2015

PUBLICATIONS


BOOK CHAPTERS

PRESENTATIONS
Biomechanical Comparison of Screw Trajectory To Fracture Pattern For Unstable Scaphoid Fractures. Faucher GK, Golden ML, Sweeney KR, Hutton WC, Jarrett CD
• American Society For Surgery Of The Hand, Residents And Fellows Meeting, San Francisco, CA Podium Presentation: 2013
• Southern Orthopaedic Association Annual Meeting, Palm Beach, FL, Podium Presentation: 2013
• Atlanta Trauma Symposium - Poster, Atlanta, GA, Poster Presentation: 2013
Complications of Carpal Tunnel Surgery and Outcomes of Revision
**Faucher GK, Seiler JG**
- American Society for Surgery of the Hand Annual Meeting, San Francisco, CA
Podium Presentation: 2013

Complications of Surgical Release of Carpal Tunnel Syndrome: A Systematic Review
**Faucher GK, Daruwalla J, Seiler JG**
- 6th Combined Meeting Of The American Society For Surgery Of The Hand And Japanese Society For Surgery Of The Hand, Maui, HI, Podium Presentation: 2015

**ACTIVE RESEARCH:**

Complications of Carpal Tunnel Syndrome: A Systematic Review
**Faucher GK, Seiler JG**
*Manuscript Submitted For Publication*

Anatomic Considerations in Preventing Complications In Carpal Tunnel Surgery
**Faucher GK, Daruwalla J, Seiler JG**

Resident Perceptions on Curriculum Development
**Faucher GK, Todd Dc, Bradbury Tl**

Laser-Guided Fluoroscopy and Intraoperative Radiation Exposure, A Randomized Controlled Trial.
**Faucher GK, Daly Ca, Labib SA**
Complications of Surgical Release of Carpal Tunnel Syndrome: A Systematic Review

Faucher GK, Daruwalla J, Seiler JG

ABSTRACT

PURPOSE
We hypothesize that there is no difference in major complications between open and endoscopic techniques of carpal tunnel release, and that the overall incidence of complications has decreased over time as each approach has been refined.

METHODS
We searched the PubMed database for articles involving complications associated with the surgical treatment of carpal tunnel syndrome. Articles were classified based on technique for release (traditional open, limited open, single-portal endoscopic, two-portal endoscopic) and then grouped by chronological periods based on years of data collection. We analyzed the incidence of specific complications, including major and minor nerve injuries, scar problems, and damage to vessels. We performed the same analysis on only Level I and II studies. We then analyzed incidence by time periods.

RESULTS
We identified 220 articles, and 59 met our inclusion criteria. Evidence ranged from level I to level IV. There was no difference between techniques in incidence of permanent nerve lesions, total scar complications, or total vessel lacerations. There was a significantly increased incidence of transient digital nerve and total transient nerve injuries in the endoscopic groups versus the open groups. The higher incidence of total transient nerve lesions was maintained when only level 1 and 2 studies were used for analysis. When endoscopic and open release groups were analyzed chronologically, the endoscopic period from 1960-1990 had a significantly higher rate of superficial palmar arch injuries when compared to the periods of 1991-2000 and 2001-2013. There was otherwise no significant difference in rate of permanent nerve or vessel injury, or scar complications in either group over time.

DISCUSSION
Analysis of literature of all levels involving endoscopic and open techniques for carpal tunnel release reveals that it is a relatively safe procedure, regardless of technique. There is a slightly higher incidence of transient nerve injury with endoscopic techniques.

Level of Evidence: Therapeutic, Level IV
INTRODUCTION

Surgical release of carpal tunnel syndrome is one of the most common procedures in hand surgery. Up until the early nineties, release was performed through an open incision. In 1989, Okutsu et al wrote the first paper describing endoscopic carpal tunnel release (ECTR). Since then both open and endoscopic techniques have been used with good success, and relatively few reported complications. Complications do occur, however, in both open and endoscopic release. The incision for open carpal tunnel release (OCTR) has undergone multiple iterations in attempts to limit scar complications, while still allowing for direct visualization of the transverse carpal ligament (TCL) as it is being divided. Endoscopic release has been associated with a higher frequency of incomplete release of the TCL, as well as more reports of major nerve and vessel lacerations, while allowing for earlier return to work. A survey comparing the two methods, published in 1999, showed a substantial number of major nerve and vessel injuries with both techniques.

There are few studies that attempt to systematically review the available literature for complications related to the surgical management of carpal tunnel syndrome. In 2006, Benson et al reported a systematic review comparing OCTR and ECTR complications. Their data revealed a statistically higher incidence of structural complications with OCTR (excluding transient neurapraxia), though in both groups structural complications occurred less than 1% of the time. Structural complications in this study included damage to nerves, tendons, or arch vessels. This study, however did not take into account how complications have changed over time. This study also included non-scientific review articles and questionnaire-type reports, which makes true incidence reporting difficult.

The goal of this study is to not only compare incidence of complications between OCTR and ECTR, but also to determine how this incidence of complications has changed over time. In order to obtain a more detailed comparison, we subdivided open technique into “traditional open” and “mini-open” categories. Endoscopic technique was subdivided into “one-portal” or “two-portal” groups. We also performed a separate comparison of incidence of complications between endoscopic and open technique using only Level 1 and 2 evidence. We hypothesized that there would be no major difference in complications between endoscopic and open techniques. Furthermore we surmised that there would be a decrease in complication rates reported for all techniques over time.

METHODS

This systematic review was performed in accordance with the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) guidelines. This template was created in an effort to standardize reporting amongst systematic reviews and meta-analyses. In this study a search was performed using the PubMed database to identify scientific articles related to carpal tunnel surgery complications. Our search was directed only towards articles that allowed definition of incidence of complications within a series of patients (i.e. no case studies, surveys, or non-scientific reviews). The key words carpal tunnel, surgery, neurapraxia, and complications were used. Our search returned articles dating from 1966 to 2010. Inclusion criteria included English language articles reporting complications due to open and endoscopic carpal tunnel release. Review articles (37 articles), foreign language articles (22 articles), anatomic/cadaveric studies (25 articles), articles not reporting on complications of primary release (26 articles), studies reporting complications of revision (12 articles), articles not related to surgical management (24 articles), and case reports (15 articles) were excluded. Our primary search
revealed 43 articles meeting our inclusion criteria. We then performed a secondary search of the references cited in our selected articles and identified 16 additional articles also meeting inclusion criteria. This gave us a total of 59 articles for analysis. (Fig. 1)

As part of the selection process, two independent reviewers studied each article to determine appropriateness for inclusion in accordance with criteria outlined above. A senior reviewer was available if disputes arose with article selection. In an attempt to prevent selection bias, all abstracts were then numbered, blinded, and compiled into a single document. The two reviewers then reviewed each abstract and assigned a level of evidence, again with a senior reviewer serving as a “tie-breaker”. Evidence levels were assigned as outlined by The Journal of Hand Surgery American.

Each study was then analyzed in full for complications. Complication subgroups were created in an attempt to stratify severity and type. Nerve damage, for example was classified into permanent and transient nerve lesions. Transient lesions were defined as lesions that had completely or almost completely resolved by three months. Both permanent and transient groups were further subdivided by specific nerve injured (i.e. median, ulnar, digital). Other categories for complications include scar complications (subdivided into scar dysesthesia, pillar pain, hypertrophic scar, and palmar fasciitis), vessel lacerations, tendon injuries, infection, and regional sympathetic dystrophy (RSD). A hypertrophic scar is defined as a raised scar, which develops within the margins of the original wound.9,10 The means test was used to compare average incidence of each complication between endoscopic and open groups.

Endoscopic release was further subdivided into one and two portal, while open release was subdivided into traditional and limited open. The traditional open technique was defined as a longitudinal incision that is at least as long as the transverse carpal ligament. The mini-open technique was defined as any type of incision that was shorter than the transverse carpal ligament. We also grouped complications by time period in order to quantify the evolution of complications over time. We chose the periods 1960-1990, 1991-2000, and 2001-2013 as our subgroups. This selection was made based on the introduction of endoscopic technique for commercial use in 1990. A biostatistician was consulted once data was extracted for assistance with analysis. Significance was established as $P < 0.05$.

RESULTS

Techniques for surgical incision included traditional open incision, limited open incision, single portal endoscopic, and two portal endoscopic. Twenty-seven studies were subcategorized as open, nine as limited open, seventeen as one-portal endoscopic, and nineteen as two-portal endoscopic. This gave a total of thirty-six studies in the open group and thirty-six in the endoscopic group. Articles selected for review ranged in date from 1966 to 2012. Twenty papers reported results between 1960-1990, forty between 1991 and 2000, and twelve between 2001 and 2013.

Quality of evidence ranged from level I to level IV. Seven papers were high quality, prospective randomized controlled trials, classified as level I. Seven additional prospective studies had a lower quality of randomization and were grouped as Level II. Four case-control studies were considered Level III studies. The remainder of the forty-three articles consisted of case series, which we classified as Level IV.

We used a two-group t-test to compare the mean incidence of complications between open and endoscopic techniques for carpal tunnel release (Table 1). There was a statistically significant increase in
transient digital nerve lesions (open: 0.1%, endoscopic: 1.4%, $P=0.04$) and total transient nerve lesions (open: 0.9%, endoscopic: 2.8%, $P=0.03$). We performed a similar analysis on only Level 1 and 2 studies (Table 2). We found that the endoscopic group had a significantly higher incidence of total transient nerve lesions (open: 0.9%, endoscopic 5.2%, $P=0.03$). Using an analysis of variance (ANOVA) test, we also compared complications between the four subcategories of surgical technique (Table 3), and found no difference in incidence of complications.

We also used an ANOVA test to compare the incidence of complications by time period in both the endoscopic (Table 4) and open (Table 5) groups. In the open group there was no significant difference in instance of any complication between the periods of 1960-1990, 1991-2000, and 2001-2013. In the endoscopic group there was a significant difference in the incidence of superficial palmar arch lacerations (1960-1990: 0.4%, 1991-2000: 0.04%, 2001-2013: 0, $P=0.05$) and total vessel lacerations (1960-1990: 0.4%, 1991-2000: 0.04%, 2001-2013: 0, $P=0.05$).

**DISCUSSION**

The purpose of this review was to create a comprehensive survey of the available literature to determine the incidence of complications resulting from carpal tunnel release surgery. We tailored our search to include all articles specifically reporting complications, while limiting the inclusion of irrelevant and non-scientific articles. We also conducted a secondary search of included articles to ensure a more complete review of the literature. In this way we were able to generate a highly focused review of the available evidence.

In this study we sought to determine the difference in mean incidence of complications related to release of the carpal tunnel based on surgical technique and time period. We found that ECTR has a higher reported rate of total transient nerve lesions and digital nerve transient lesions. There is, however, no difference in permanent injury to the ulnar nerve, the median nerve or its branches, tendons, or vessels. When we compared only the results from level 1 and 2 studies we found a significantly higher incidence of total transient nerve lesions in the ECTR group. These findings are similar to those found in a systematic review performed by Benson et al, which found a rate of transient neurapraxia in 1.45% of ECTR cases and 0.45% of OCTR cases ($P<0.05$). This trend was also present in studies directly comparing endoscopic and open release, which found transient digital ulnar nerve lesions in the endoscopic group, but not the open group. These findings, in part, support our hypothesis that there would be no major difference in complications between groups. The significant differences that we did find reflect a relatively low (though increased) incidence of transient nerve injury in ECTR that should be noted when deciding on technique.

Studies evaluating outcomes of ECTR and OCTR have shown that patients undergoing the less invasive ECTR have a quicker return of function post-operatively. Interestingly, we found no difference in the incidence of scar complications, including scar dysesthesia, pillar pain, and hypertrophic/keloid scars, between the two groups. The difference in early functional outcomes between the two groups can likely be explained by normal healing of a larger incision as opposed to complications related to an open procedure.

Our hypothesis that complications would decrease over time was partially supported in the endoscopic group, but refuted in the open group. The incidence of vessel injury peaked in the time period of 1960-1990, and decreased to a reported incidence of zero in the 2001-2013 period. This
coincides with the introduction of the technique for endoscopic release for widespread use. As with the implementation of any new surgical technique, there may have been a learning curve associated with endoscopic release, which lead to a higher incidence of vessel lacerations. This concept is further substantiated by the numerous case reports describing catastrophic complications of endoscopic release. These descriptions of complete median nerve laceration, ulnar motor branch laceration, superficial palmar branch laceration, and tendon injury all come from this nascent phase of endoscopic release in the early/mid 90’s. Improvement in the technique for endoscopic release and increased surgeon experience has likely led to the decrease in reported complications over time. Major complications have also been reported for open release, including median nerve, palmar cutaneous branch, and thenar branch laceration, as well as massive palmar necrosis. Unlike endoscopic technique, however, open release has been a mainstay of treatment for decades, and thus has not been subjected to a recent learning curve. This may explain the uniformity in incidence of complications between time periods in this group. Fortunately, with both techniques, major complications are rare.

This review is limited by the inherent disproportion of lower quality level 3 and 4 studies available in the literature compared with Level 1 and 2 studies. When we analyzed only high-level 1 and 2 studies however, we found fundamentally similar results. That is to say, the consistent difference between complications in OCTR versus ECTR seems to be transient nerve lesions. The accuracy of any review of complications is limited by reporting bias. Complications may be under-reported or are not reported at all. This issue has been noted in the case of investigators reporting on novel surgical methods with which they may have some conflict of interest.

The development of protocols such as PRISMA for reporting on multiple data available throughout the literature has improved our ability to reach reliable conclusions regarding specific scientific queries. Inherent to the task of reporting on complications, however is the subjectivity with which these complications are reported. Infection for example, can range from a superficial cellulitis requiring oral antibiotics to a deep abscess requiring surgical debridement and hospitalization. This spectrum of severity is lost when both of these outcomes are reported only as “infection”. We believe that standardized complication reporting is useful to all investigators in the research domain.

Surgical release of carpal tunnel remains one of the most frequently performed procedures in hand surgery. The single most important surgical element of the procedure is safe release of the transverse carpal ligament. Endoscopic techniques for transverse carpal ligament release have grown in popularity and with proper attention to detail can be reliable alternatives to the traditional open release. Both procedures can, however, also be associated with significant morbidity, and close attention to method seems to be paramount in limiting complications.
REFERENCES


Figure Legend

Figure 1A: Method of article selection.

Figure 1B: Number of cases grouped by technique.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Number of Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open</td>
<td>7288</td>
</tr>
<tr>
<td>Limited Open</td>
<td>2220</td>
</tr>
<tr>
<td>Endoscopic (one Portal)</td>
<td>4156</td>
</tr>
<tr>
<td>Endoscopic (two Portal)</td>
<td>4150</td>
</tr>
<tr>
<td>Total</td>
<td>17814</td>
</tr>
</tbody>
</table>
## TABLE I

### Mean Incidence of Complications in Endoscopic versus Open Techniques

<table>
<thead>
<tr>
<th>Complication</th>
<th>Endoscopic (N=36)</th>
<th>Open (N=36)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean Incidence (%)</td>
</tr>
<tr>
<td>Permanent Median Nerve Lesion</td>
<td>36</td>
<td>0.12</td>
</tr>
<tr>
<td>Permanent Thenar Branch Nerve Lesion</td>
<td>36</td>
<td>0.02</td>
</tr>
<tr>
<td>Permanent Digital Branch Nerve Lesion</td>
<td>36</td>
<td>0.27</td>
</tr>
<tr>
<td>Permanent Palmar Cutaneous Branch Nerve Lesion</td>
<td>36</td>
<td>0.003</td>
</tr>
<tr>
<td>Permanent Ulnar Motor Nerve Lesion</td>
<td>36</td>
<td>0.03</td>
</tr>
<tr>
<td>Total Permanent Nerve Lesions</td>
<td>36</td>
<td>0.5</td>
</tr>
<tr>
<td>Transient Median Nerve Lesion</td>
<td>33</td>
<td>0.09</td>
</tr>
<tr>
<td>Transient Thenar Branch Nerve Lesion</td>
<td>33</td>
<td>0</td>
</tr>
<tr>
<td>Transient Digital Branch</td>
<td>33</td>
<td>1.4</td>
</tr>
<tr>
<td>Nerve Lesion</td>
<td>N</td>
<td>Mean</td>
</tr>
<tr>
<td>------------------------------------</td>
<td>---</td>
<td>------</td>
</tr>
<tr>
<td>Transient Palmar Cutaneous Branch Nerve Lesion</td>
<td>33</td>
<td>0</td>
</tr>
<tr>
<td>Transient Ulnar Nerve Lesion</td>
<td>33</td>
<td>1.5</td>
</tr>
<tr>
<td>Total Transient Nerve Lesions</td>
<td>36</td>
<td>2.8</td>
</tr>
<tr>
<td>Tendon Laceration</td>
<td>36</td>
<td>0.03</td>
</tr>
<tr>
<td>Superficial Palmar Arch Laceration</td>
<td>35</td>
<td>0.07</td>
</tr>
<tr>
<td>Total Vessel Laceration</td>
<td>35</td>
<td>0.07</td>
</tr>
<tr>
<td>Scar Dysesthesia</td>
<td>21</td>
<td>12.5</td>
</tr>
<tr>
<td>Pillar Pain</td>
<td>21</td>
<td>13.6</td>
</tr>
<tr>
<td>Hypertrophic/Keloid Scar</td>
<td>11</td>
<td>0.1</td>
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<tr>
<td>Total Scar Complications</td>
<td>33</td>
<td>16.5</td>
</tr>
<tr>
<td>RSD</td>
<td>33</td>
<td>0.2</td>
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</table>

Table I: Table comparing mean incidence of complications between all endoscopic (one-portal and two-portal) and all open (mini and traditional) techniques. N denotes the number of articles that report a given complication. Analysis was performed using a two-group t-test.
## TABLE II

### Mean Incidence of Complications in Level I and II Studies

<table>
<thead>
<tr>
<th>Complication</th>
<th>Endoscopic (N=12)</th>
<th>Open (N=12)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean Incidence (%)</td>
</tr>
<tr>
<td>Permanent Median Nerve Lesion</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>Permanent Thenar Branch Nerve Lesion</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>Permanent Digital Branch Nerve Lesion</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>Permanent Palmar Cutaneous Branch Nerve Lesion</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>Permanent Ulnar Motor Nerve Lesion</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>Total Permanent Nerve Lesions</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>Transient Median Nerve Lesion</td>
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<td>0</td>
</tr>
<tr>
<td>Transient Thenar Branch Nerve Lesion</td>
<td>12</td>
<td>0</td>
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<tr>
<td>Transient Digital Branch</td>
<td>12</td>
<td>2.7</td>
</tr>
<tr>
<td>Complication</td>
<td>N</td>
<td>Mean</td>
</tr>
<tr>
<td>----------------------------------</td>
<td>---</td>
<td>------</td>
</tr>
<tr>
<td>Nerve Lesion</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>Transient Palmar Cutaneous Branch Nerve Lesion</td>
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Table I: Table comparing mean incidence of complications between all endoscopic (one-portal and two-portal) and all open (mini and traditional) techniques using only level I and II studies. N denotes the number of articles that report a given complication. Analysis was performed using a two-group t-test.
<table>
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<th>Complication</th>
<th>Traditional Open</th>
<th>Mini-Open</th>
<th>Endo1p</th>
<th>Endo2p</th>
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<td>0.1 (0.6) n= 19</td>
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<td>0.05 (0.2) n= 17</td>
<td>0.0 (0.0) n= 19</td>
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<td>0.006 (0.02) n= 17</td>
<td>0.5 (1.4) n= 19</td>
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<td>0.0 (0.0) n=9</td>
<td>0.006 (0.02) n= 17</td>
<td>0.0 (0.0) n= 19</td>
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<td>0.0 (0.0) n= 17</td>
<td>0.06 (0.03) n= 19</td>
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<td>0.05 (0.1) n=9</td>
<td>0.2 (0.4) n= 17</td>
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<td>0.0 (0.0) n= 17</td>
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<td>1.1 (1.9) n= 16</td>
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<td>0.0 (0.0) n=7</td>
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<td>0.07 (0.3) n= 19</td>
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<td>Scar Dysesthesia</td>
<td>4.2 (5.5) n= 14</td>
<td>7.5 (11.1) n=5</td>
<td>3.1 (4.9) n= 10</td>
<td>21.1(44.9) n= 11</td>
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<td>7.1 (5.6) n=4</td>
<td>8.5 (13.1) n= 10</td>
<td>18.7(30.7) n= 10</td>
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</table>
**Table III:** Table comparing the mean incidence of complications by subcategory. Traditional open, mini-open, endoscopic one-portal (Endo1p), and endoscopic two-portal (Endo2p) groups were compared using an analysis of variance (ANOVA) test. Incidence is given as a percentage while standard deviation is given in parenthesis. ‘n’ denotes the number of studies reporting a specific complication.

**TABLE IV**

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<td>0.0 (0.0) n=23</td>
<td>0.0 (0.0) n=5</td>
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<td>1.5 (3.0) n=23</td>
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### Table IV: Complications

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*Table IV: Table comparing the mean incidence of complications using all endoscopic techniques, subcategorized by time period. The time periods of 1960-1990, 1991-2000, and 2001-2013 were compared using an ANOVA test. Incidence is given as a percentage while standard deviation is given in parenthesis. ‘n’ denotes the number of studies reporting a specific complication.*
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<td>0.0 (0.0) n= 7</td>
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<td>Tendon Laceration</td>
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<td>0.0 (0.0) n=14</td>
<td>0.0 (0.0) n= 7</td>
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Table V: Table comparing the mean incidence of complications using all open techniques, subcategorized by time period. The time periods of 1960-1990, 1991-2000, and 2001-2013 were compared using an ANOVA test. Incidence is given as a percentage while standard deviation is given in parenthesis. ‘n’ denotes the number of studies reporting a specific complication in a given time period.
### APPENDIX A. Articles Meeting Inclusion Criteria for Systematic Review, Arranged Alphabetically by Author

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Note: MPR = Microperforation Rate; DFR = Dentin Failure Rate.
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1 Endo-1P: Single-portal endoscopic approach; Endo-2P: Dual-portal endoscopic approach

2 Includes wound dehiscence, postoperative hematoma, and palmar fasciitis.

3 Includes scar dysesthesia, hypertrophic scar, keloid, and pillar pain.

4 Includes
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PEER REVIEWED JOURNAL ARTICLES


PEER REVIEWED BOOK CHAPTERS

PATENTS


POSTER PRESENTATIONS
Kinney RC, Magill ME, Hutton WC, Jarrett CD (2015, September). Does suture augmentation of the rotator cuff to the locking plate improve resistance to varus collapse of two-part proximal humerus fractures? Accepted poster at: 70th Annual Meeting of the American Society for Surgery of the Hand; Seattle, WA.


ORAL PRESENTATIONS


The Development of Platelet Rich Plasma Coated Suture for Healing Augmentation of Musculoskeletal Soft Tissue Repair and Reconstruction

Kinney RC, Geisler, Herrmann T, Touchton S, Ongini E.

ABSTRACT

GOAL
Develop a method for coating commercially available sutures with platelet rich plasma (PRP) that could be translatable to the operating room. This would allow a delivery method for concentrated PRP to augment soft tissue repairs and reconstruction.

METHODS
A custom dipping tray and drying chamber were fabricated. Porcine whole blood was processed to extract PRP. Commercially available suture (3-0 vicryl) underwent 0, 1, 2, or 4 coating and drying cycles. 1 cm samples were excised from the coated suture both before and after passage through a bovine extensor tendon. The total protein content of samples was measured. The tensile load to failure of the sutures was also determined.

RESULTS
The total amount of protein increased with sequential number of coating and drying cycles, and was statistically significant after four cycles when compared to uncoated controls. Passage of the suture through a tendon did not result in stripping of the coating off the suture. The suture was not mechanically compromised by the coating process with no difference in tensile load to failure between groups.

CONCLUSIONS
Commercially available sutures were able to be coated with PRP successfully, and the coating was stable during simulated surgical use. Further testing should be performed to optimize the process and ensure biologic activity of the growth factors within the PRP coating.

INTRODUCTION
Orthopedic surgeons perform a variety of surgical procedures to repair and reconstruct soft tissue pathologies. These encompass acute traumatic injuries such as ligament ruptures and tendon lacerations, but also chronic degenerative conditions including various tendinopathies. Tendon and ligaments have relatively poor vascularity, and therefore have decreased and delayed healing potential. The rehabilitation of patients after surgery must be limited and carefully controlled following surgery to allow healing of the tissues and prevent failure of the repair or reconstruction.

Platelet rich plasma (PRP) is a component of a whole blood that is rich in growth factors. The blood is centrifuged initially to remove a majority of the cellular component that is comprised of erythrocytes and leukocytes. The remaining plasma is then centrifuged again to concentrate the
Platelets and growth factors. PRP is currently being used as an injectable therapy to treat tendonitis, arthritis, and various other degenerative musculoskeletal pathologies [1]. Animal studies have shown benefits of PRP therapies for soft tissue injuries [2, 3], but human clinical studies for the use of PRP have been mixed at best [4]. However, there is no standardized method of preparation and delivery of PRP which makes evidence based comparison difficult.

A method for delivery of PRP following repair or reconstruction could enhance the healing process, accelerate recovery and shorten rehabilitation. The patient would be able to return to work or sports quicker and with decreased risk of re-injury. A simple method of delivery would be coated sutures. Every surgeon is familiar with the use of sutures, and they are already used in repairs and reconstruction to sew the injured tissues together or secure grafts to muscle and bone. The coated suture could also be woven through the reconstructed ligament or repaired tendon to optimize the gradient of growth factors and promote migration of cells into the tissue.

The coating process would need to be integrated into the sterile operating room (OR) environment. Commercially available methods already exist for the processing of PRP within the OR. The purpose of this study was be to develop a method for coating commercially available sutures with PRP in the OR that would then be usable by the surgeon. There were multiple design limitations that needed to be addressed. The process would need to be efficient to prevent increasing surgical time. The apparatus would need to be small and portable to be used on a surgical back table. It would also need to be cheap and disposable, or easily sterilized with steam autoclave so that it is reusable and cost effective. The process needed to use utilities already available in the OR like vacuum and compressed air capabilities. Methods involving heat were avoided to prevent denaturing of proteins.

METHODS

Platelet Rich Plasma Preparation

One liter of porcine blood (Hollifield Farms, Covington, GA) was combined with 0.02 mg/ml of heparin sodium salt (VWR, Radnor, PA) to prevent coagulation. The whole blood was centrifuged as 50 ml aliquots at 40g for 10 minutes. The plasma, buffy coat, and red blood cells were easily identified after centrifugation. Approximately 75% of the top portion of the plasma layer was removed, and the remaining platelet rich portion was carefully aspirated without disturbing the buffy coat layer.

Suture Coating

Nine strands of non-expired 3-0 undyed braided vicryl 45 cm length sutures (Ethicon, Cincinnati, OH) underwent coating with PRP, and three sutures were used as uncoated negative controls. The three sutures in each experimental group underwent one, two, or four coating and drying cycles. Coating was performed using a custom fabricated dip tray and drying chamber (Figure 1). The entire length of the suture was submersed in the PRP for one second, and then placed in the drying chamber for five minutes. A convective airflow was obtained using standard wall suction. After coating, a 1 cm section was cut between the distal 30-31 cm of the suture and placed into 1 mL of distilled water for protein analysis.
Coating Integrity Testing

The remaining 30 cm length of suture was threaded onto a free needle and passed through a 6.5 mm diameter fresh bovine extensor tendon (Animal Technologies, Tyler, TX) to simulate use during a surgical procedure (Figure 2). A non-coated suture passed through the tendon serves as a control to determine how much protein would potentially be transferred from the tendon to the suture. Following passage through the tendon, a 1 cm section was cut between the middle 15 to 16 cm and placed into 1 mL of distilled water for protein analysis.
**Protein Quantification**

Samples were agitated overnight to dissolve the PRP coating into solution. Protein quantity was measured using the Pierce BCA protein assay (Thermo Scientific, Grand Island, NY) on samples prior to and after passage through the bovine tendon. The three data points in each experimental group were averaged for statistical analysis.

**Tensile Testing**

After coating, drying, and passing through the tendon, the remaining 15 cm of suture underwent tensile stress using a Instron 3345 universal testing system (Instron, Norwood, MA) until failure. The program parameters were an initial strain rate of 0.25mm/sec until a preload of 10N was reached, and then followed by a strain rate of 1mm/sec until failure. The tensile stress at failure was recorded for each suture and the average calculated for statistical analysis.

**Statistical Analysis**

Results from the BCA assay were analyzed via a 2x4 ANOVA followed by a Tukey’s post-hoc test. Tensile testing data was analyzed using a one-way ANOVA followed by a Tukey’s post-hoc test.

**RESULTS**

**Protein Coating Quantification**

The total protein content in each 1 cm section of suture showed a directly proportional trend with respect to the number of coating and drying cycles (Figure 3). This trend approached statistical significance (p = 0.06) for the suture before tendon passage, and was statistically significant (p = 0.03) for the suture after tendon passage. There was no trend or statistical difference when comparing protein content of the coating before and after tendon passage. This indicates the coating is stable and is not stripped off during standard handling and suturing.

![Protein Quantification](image)

Figure 3: Total protein content of each sample compared to the number of coating cycles. The measurements were made both before and after passage of the suture through a tendon. (#): p=0.06 when comparing before 0 or before 1 vs before 4; (*): p=0.03 when comparing after 0 or after 1 vs after 4.
**Tensile Testing**

The tensile load to failure showed no significant difference with relation to the number of PRP coatings (Figure 4). This indicates that the PRP coating does not affect the mechanical integrity of the suture.

![Tensile Testing Graph](image)

**DISCUSSION**

We have developed a method for coating commercially available suture with PRP that is easily translatable to the OR. The patient’s blood can be drawn at the time of anesthesia induction and the PRP prepared while draping. The coating process takes only 5 minutes per cycle and requires a single suction source which is readily available in the OR. The suture coating can be done during the approach and be ready for use once the repair site is prepared.

Although clinical applications of PRP have been inconclusive, several studies have shown the benefit of blood derived growth factors for tissues healing. The most relevant example is the enhancement of meniscus healing from concomitant ALC reconstruction [5]. This observation is thought to be the result of increased growth factor levels in the synovial fluid [6, 7]. The above studies suggest the use of PRP would be beneficial for meniscal repairs. However, research has shown no benefit when PRP is simply injected into the joint [8]. This failure could be related to inadequate penetration of the growth factors into the soft tissues. Coated sutures would be an elegant method to deliver PRP to the repair site and allow diffusion into the meniscus to enhance healing.

This concept of improved PRP delivery at the site of repair may also be advantageous for rotator cuff repairs, especially in elderly patients due to increasing age being a negative predictor for rotator cuff healing [9, 10]. Augmentation with a PRP gels sewn over the repair site has shown variable results [11, 12]. However, the use of a PRP gel for rotator cuff repairs results in a similar problem as injecting PRP into the knee joint for meniscus repairs; the growth factors are not delivered directly into the soft tissue but must instead diffuse in from the surrounding gel.

The use of PRP coated suture could also be beneficial for improving the temporal aspect of healing thereby accelerating the rehabilitation process. The area where this could be most valuable is ACL reconstruction. When a tendon is used to reconstruct a ligament, it undergoes a transformation termed “ligamentization” [13, 14]. There are three phases: an initial necrosis of the graft, followed by migration of cells from outside the graft with proliferation and revascularization, and then finally remodeling and maturation. This process takes months and rehabilitation is limited during this time to prevent rupture of the graft while it matures. The most time consuming step is the repopulation of the
graft with cells migrating from the bone tunnels. These cells are required to bring their own growth factors to stimulate revascularization of the graft and extracellular matrix deposition. PRP coated suture could be woven throughout the graft to create a gradient of growth factors to speed up the process and return the patient to activities faster.

PRP coated sutures offer the potential to improve clinical outcomes for several musculoskeletal pathologies by directly delivering concentrated growth factors at the repair site. Quantification of the biological activity of the growth factors within the coating is obviously critical and will be the focus of future experiments. Additionally, there are several parameters that still need to be optimized including the drying time, suture material, suture size, and number of coating cycles. These parameters can all affect the bio-availability of the growth factors within the healing tissues, and may be different depending on the tissue type and procedure.
REFERENCES
UPCOMING FELLOWSHIP TRAINING:

Pediatric Orthopaedics and Scoliosis Fellowship
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Bachelor of Science, May 2005

PUBLICATIONS


PRESENTATIONS

Children With Medicaid Requiring Spinal Fusion for Scoliosis Present with Larger Curves and Wait Longer for Surgery than Patients with Private Insurance. David E. Lazarus MD, Mihir Desai MD, Nick Patel MS, Robert W. Bruce MD, Nicholas D. Fletcher MD.

- Poster at International Pediatric Orthopaedic Symposium, Orlando, December 2013
- Podium Presentation at Southern Orthopaedic Association Annual Meeting July 2014
- E-Poster at Scoliosis Research Society September 2014

Implementation of an Accelerated Pathway Reduced Hospital Stay Following Posterior Spinal Fusion for Adolescent Idiopathic Scoliosis by Nearly 50%: A Multicenter Comparative Study. Nicholas D. Fletcher MD, Lindsay M. Andras MD, David E. Lazarus MD, Robert J. Owen BS, Benjamin J. Geddes BS, Jessica Cao BS, David L. Skaggs MD, Timothy S. Oswald MD, Robert W. Bruce MD.

- Podium Presentation POSNA 2014
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- Podium Presentation at Southern Orthopaedic Association Annual Meeting July 2014
- Submitted for publication

Early Complications in the First Year Following Posterior Spinal Fusion for Adolescent Idiopathic Scoliosis. F. Patterson Owings MD, **David E. Lazarus MD**, Robert J. Owen BS, Benjamin J. Geddes BS, Phillip Mitchell MD, Robert W. Bruce Jr. MD, Nicholas D. Fletcher MD.

- Podium Presentation POSNA 2014
Medicaid Insurance Was Associated with Larger Curves in Patients Requiring Surgery for Scoliosis

Lazarus DL, Desai M, Patel NN, Bruce RW, Fletcher ND

INTRODUCTION

The current climate of rising health care costs has led many health insurance programs to limit benefits, which may be problematic for children needing specialty care. Uninsured children have poorer access to specialty care than insured children. Children with public health coverage have better access to specialty care than uninsured children, but inferior access compared to privately insured children. It is well documented that children with government insurance have limited access to orthopaedic care for such conditions as fractures or ligamentous knee injuries. Adolescent idiopathic scoliosis (AIS) differs from many other conditions managed by pediatric orthopaedists as it may be progressive in nature with management becoming increasingly more complex as the curve magnitude increases. The ability to gain access to care earlier in the disease process may allow for earlier non-surgical interventions such as bracing. For patients requiring spinal fusion, earlier diagnosis and referral to a specialist could potentially result in shorter fusions and preserve distal motion segments. The ability to access the healthcare system in a timely fashion would therefore be of utmost importance for patients with scoliosis.

The existing literature on AIS lacks studies that focus on access to care based on insurance coverage and the potential impact that this may have on curve progression. The purpose of this study is to determine whether there is a difference in patients with and without private insurance presenting to a busy urban pediatric orthopaedic practice for management of scoliosis that eventually resulted in surgical treatment.

Methods:

After obtaining Institutional Review Board approval, patient charts from 2008-2012 were retrospectively reviewed of patients with newly diagnosed AIS between the age of 10 and 18 who were treated with spinal fusion (SF). Patients were excluded if they were treated with growing spine instrumentation (i.e. growing rods), were younger than age 10 or older than age 18 at presentation or did not have adequate radiographs or clinical data including insurance status. In order to evaluate the differences in patients with newly diagnosed scoliosis, patients were excluded if they were seen as a second opinion or had been managed elsewhere for their scoliosis in the past. Patients with syndromic, neuromuscular, or congenital scoliosis were also excluded.

Charts were evaluated to assess the time from initial evaluation to the determination for surgery, the time from the recommendation for surgery until the actual procedure, and insurance status. Distance travelled was calculated using the patient’s home address. Cobb angle was calculated from preoperative posteroanterior (PA) radiographs taken at the initial visit and at the final preoperative visit. Curves were classified using the Lenke classification using PA, lateral, and maximal effort supine bending thoracic and lumbar radiographs from the preoperative visit. Hospital records were queried to determine number of levels fused at surgery, number of implants placed, and length of stay. Patients were evaluated without prior screening of insurance status and without prior consultation with referring physicians. Surgical procedures were scheduled on a first come/first serve basis without preference for insurance status.
RESULTS

Between January 2008 and December 2012, there were 135 consecutive patients with newly diagnosed AIS that underwent SF by our group (Table 1). Of these, 61% were privately insured and 39% carried Medicaid insurance. There was no difference in age or ASA score between groups. The mean Cobb angle at initial presentation of the privately insured patients was 47.5±14.3° (range 18.0°-86.0°) and 57.2±15.7° (range 23.0°-95.0°) for the patients with Medicaid (p<0.0001). At time of surgery the Cobb angles were 54.6±11.7° and 60.6±13.9° for the private and Medicaid patients respectively (p=0.008). There was no difference in curve types as classified by Lenke et al10 between groups (Table 2, p=0.83). Patients with Medicaid insurance travelled less distance to seek care (56.3±57.0 miles vs 73.7±66.7 miles, p=0.05). There was no statistical difference in the surgical wait time from the clinic visit when surgery was recommended until spinal fusion was performed (103.1±62.4 days (private) vs 128.8±137.5 days (Medicaid), p=0.10). The difference in levels fused between patient groups did not reach statistical significance (10.3±2.2 Medicaid vs 9.7±2.3 Private, p=0.16). Patients with Medicaid had a greater estimated blood loss (445.7±415.9cc vs 335.1±271.5, p=0.06) although there was no difference in the use of posterior column osteotomies between groups. There was no difference in length of hospital stay between patient groups (2.6±0.8 days (Medicaid) vs 2.4±0.5 days (Private), p=0.11).

DISCUSSION

An extensive body of literature supports the limited access to specialty care that patients with government insurance must face.1,11,12 Children insured under Medicaid who are in need of orthopaedic care are no exception. Sabharwal et al examined a database of publicly and privately insured pediatric patients having sustained fractures and reported that 52% of patients with private insurance received orthopaedic care versus 22% of the publicly insured patients (p = 0.013).13 Using a fictitious 14-year-old patient with an ACL tear, Pierce et al reported that 38 of 42 orthopaedic practices called offered a privately insured patient an appointment within 2 weeks versus 6 of the 42 practices offering an appointment for a publicly insured patient.13,14 Skaggs et al surveyed 230 orthopaedic practices nationally and found that children with Medicaid insurance had limited access to orthopedic care as 18% (41/230) of offices would not see a child with Medicaid under any circumstances.4 Using a fictitious 10 year old boy with a forearm fracture, Iobst and others attempted to arrange an appointment with 100 orthopaedic offices using either Medicaid or private insurance. Eight offices gave an appointment within 1 week to the fictitious child with Medicaid insurance. Thirty-six of the 100 offices gave an appointment within 1 week to the child with PPO insurance.3

Little data exists regarding insurance status and scoliosis care in children. Spinal deformity differs from simple fractures and ligamentous injuries as timely care may result in a less invasive treatment (i.e. bracing) if the curvature is caught early. Goldstein et al recently evaluated 642 patients over a 10 year period that presented for scoliosis evaluation and failed to find a difference in curve magnitudes between patients with and without Medicaid insurance.9 32% of these patients presented were evaluated for a second opinion and the authors chose not to subdivide patients based on curve severity and treatment needed; only noting that there was no difference in groups. There was no discussion of the potential difference between patients with and without private insurance with regards to surgically treated curves or non-surgical curves. We sought to specifically focus on patients who required surgical intervention as our experience has been that many patients with government insurance present with either very mild scoliosis (i.e. 10 degrees) or very large curves which were not identified due to lack of primary care access or inadequate school screening. While the summation of these two groups would result in a similar average, they would represent a different cohort than patients with curves along a bell curve. Furthermore, it is the group of patients who would require surgical intervention that is so critical to identify early and intervene. Our data suggests that there is a difference in presenting curves between patients with and without private insurance. The approximately
10° difference seen between patient groups in this study could potentially represent the difference between bracing and surgery. Furthermore, Miyanji et al evaluated the relationship between Cobb angle and health care consumption and correlated larger curve magnitudes with increasing number of levels fused, longer surgeries, and higher rates of transfusion. Specifically, every 10° increase in curve magnitude resulted in a 7.8 minute longer operative time, 0.3 extra levels fused, and a 1.5 times increased risk of requiring a blood transfusion. Cho et al showed in a large series that 42.4% of surgeries for AIS on children with Medicaid had fusions involving 9 or more levels, while only 33.6% of privately insured patients had fusions of 9 or more levels. The mean difference in curve magnitude treated in our study was not greater than 10° between patients with and without Medicaid, perhaps explaining the lack of a statistically significant difference in number of levels fused between groups. While the groups were similar with regards to the percentage requiring posterior column spinal osteotomies, we did note a difference in estimated blood loss between groups. This is likely explained by the fact that a junior surgeon was added just prior to the initiation of this study period, potentially skewing the estimated blood loss as this surgeon gained experience. Payor status has been correlated to length of hospital stay in children with scoliosis. Vitale et al reviewed the effect of payer status on surgical outcomes in 3,606 scoliosis patients from a statewide database in California. They concluded that patients insured by Medicaid were found to have greater odds for complications and an increased length of hospital stay compared with patients with all other sources of payment. Our hospital has adopted a highly coordinated care pathway allowing for discharge on post-operative day two. A similar difference was not realized when comparing all patients with and without private insurance.

The disparity in curve magnitudes amongst patients with and without private insurance is striking and probably multifactorial. It is very likely that the combination of schools with limited screening program within the urban or rural school systems, a restricted access to pediatricians, and a longer wait to see an orthopaedic specialist all contribute to this disparity. It should be noted that school screening is mandatory in our state. This discrepancy may be related to a previously established tendency in minority populations towards waiting longer to seek care and refusing surgical recommendations, however we were unable to query socioeconomic factors such as race and household income. It is clearly important to increase access to care for underinsured patients with scoliosis. A comprehensive approach including better education at the schools, establishing communication with referring primary care providers, as well as increasing access through more physicians or physician extenders is likely needed. Orthopaedists should perhaps treat scoliosis evaluation with the same sense of urgency given to minor fractures and primary care providers should try and ensure that appropriate referrals for scoliosis are made. Also curious was the shorter travel distance seen in patients with Medicaid insurance when compared to those with Private insurance in this study. We hypothesize that this is related to our urban location with a large Medicaid population.

This study has several limitations. Our electronic medical record (EMR) does not store data on the time that a patient calls for an initial appointment, limiting our ability to determine how long patients waited for their initial consultation. Furthermore, the decision to pursue surgery is multifactorial and cannot be simply simplified into the time from initial recommendation until surgical date since some patients will delay surgery due to school or other obligations. This data should be reasonably consistent over time as patients seen in the early spring in both groups may delay surgery until the summertime and those diagnosed in June may prefer earlier surgery.

In summary, children with adolescent scoliosis are at risk for curve progression over time. As such, delays to timely care may result in worsening scoliosis. Patients with Medicaid insurance presented with larger curve magnitudes than those with private insurance. Further study is required in order to better delineate ways to improve access to patients with scoliosis communities with larger Medicaid populations.
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PODIUM PRESENTATIONS
Owings FP. Early Complications following Posterior Spinal Fusion for Adolescent Idiopathic Scoliosis. Southern Orthopedic Association, Beaver Creek, CO June 2014
Early Postoperative Complications Following Posterior Spinal Fusion for Adolescent Idiopathic Scoliosis

Owings FP, Lazarus DE, Owen RJ, Geddes BJ, Mitchell P, Bruce RW, Fletcher ND.

BACKGROUND
Few studies have reported specifically on the early complications related to posterior spinal fusion for correction of adolescent idiopathic scoliosis. The purpose of this study was to determine the types of complications, their prevalence and the rate of reoperation within the 1st year following posterior spinal fusion for AIS and to identify factors that increase the prevalence of complications.

MATERIALS AND METHODS
All patients who underwent posterior spinal fusion for adolescent idiopathic scoliosis between March 2006 to December 2012 at 2 hospital campuses within the same hospital system were included. Patient charts were retrospectively reviewed for demographic data and to determine length of surgery, number of fusion levels, curve size (proximal thoracic, main thoracic, thoracolumbar and additive), American Society of Anesthesiology score, estimated blood loss, length of hospital stay, and any subsequent complications that developed within 1 year of the date of surgery.

RESULTS
Of a cohort of 506 patients undergoing posterior spinal fusion for AIS, there were 50 complications for an overall prevalence of 9.9%. There were 17 surgical site/wound complications (3.4%) including deep surgical site infections, hematoma/seroma, and dehiscence, 24 medical complications (4.7%) including 1 death, and 9 hardware related complications (1.8%). Twenty-four patients required reoperation (15 with surgical site infections, 5 with hardware failure, 2 with painful hardware, 1 with malpositioned hardware, and 1 with postoperative paraplegia necessitating wound exploration and removal of hardware). Increased length of stay, time of surgery, ASA score and estimated blood loss each significantly correlated with a higher prevalence of complications. Age at time of surgery, number of levels fused and curve size did not.

CONCLUSIONS
The prevalence of early postoperative complications following posterior spinal fusion for adolescent idiopathic scoliosis in this study was 9.9%. 4.7% of our patients required reoperation. Factors associated with increased risk of complications within the 1st postoperative year include increased length of stay, time of surgery, ASA score and estimated blood loss.

Level of Evidence: Prognostic Level 1

INTRODUCTION
Surgical management of patients with adolescent idiopathic scoliosis (AIS) can positively influence quality of life and future development1. A recent review of complications of spinal fusion for adolescent idiopathic scoliosis using the Scoliosis Research Society morbidity and mortality database demonstrated a complication rate of 5.7% in 6334 patients2. Few studies have reported specifically on
the early complications related to posterior spinal fusion (PSF) for correction of AIS. The purpose of this study was to determine the types of complications, their prevalence and the rate of reoperation within the 1st year following posterior spinal fusion for AIS and to identify factors that increase the prevalence of complications. This information is important for two reasons. First, when planning surgical intervention this information may prove useful in counseling patients and their families preoperatively regarding the risks of surgical intervention and the nature and rates of complications. Second, postoperative complications have been demonstrated to correlate with significant increase in the mean length of stay, mortality, adverse outcome, and hospital charges3.

MATERIALS AND METHODS
Institutional review board approval was obtained prior to initiation of this study. A retrospective review of patients who underwent PSF for AIS treated at 2 hospital campuses within the same hospital system by 7 different surgeons between 2006-2012 was performed. Patients treated for AIS with PSF were identified by a query of hospital billing records based on ICD-9 codes for AIS and CPT codes related to PSF.

Patients between the ages of 10 and 18 met the inclusion criteria if they underwent PSF for AIS and had 12 months of documented follow up in order to chronicle any potential complications directly related to the surgery. Exclusion criteria included patients treated with anterior or combined anterior/posterior spinal fusion, those treated for congenital or neuromuscular scoliosis, those treated for early onset or juvenile scoliosis with growing spine instrumentation and those with inadequate follow up.

Patient charts were reviewed for demographic data and to determine length of surgery, curve size (proximal thoracic, main thoracic, thoracolumbar and additive) number of fusion levels, American Society of Anesthesiology (ASA) score, estimated blood loss taken from the anesthesia record, length of hospital stay, and any subsequent complications. Duration of surgery was calculated based on anesthesia records from the time of incision to the time of wound closure. Hospital stay was calculated from the time the patient left the operating suite to the time at which the nursing staff formally discharged the patient from the hospital floor. Complications were determined based on a review of both clinic and hospital records.

Complications following PSF were defined as any adverse event that required medical management, consultation with different specialties, readmission or reoperation within 1 year of surgery. Complications were classified as being medically related to surgery, medically unrelated to surgery, wound related (non-operative), wound related (operative), and hardware related.

Descriptive statistics and distributions for all variables were examined overall and by complication group. Categorical variables were tested by group using chi-square tests and continuous variables were tested by complication group using a two-sample t-test.

RESULTS
Of a cohort of 506 patients undergoing posterior spinal fusion for AIS, 392 were female (77.5%) and 114 were male (22.5%). The average age at time of surgery was 14.3 years old. There were 50 complications for an overall prevalence of 9.9%.

Table 1. Distribution of Complications.

Medically related complications were the most common with a prevalence of 4.7%. Of the 24 patients with medically related complications, 3 experienced respiratory difficulties requiring postoperative ventilatory support, 1 developed postoperative urinary retention, 1 developed acute pancreatitis, 2 developed perioperative urinary tract infections, 2 developed superior mesenteric artery
syndrome, and 8 patients had persistent lower extremity paresthesias. There was one episode of postoperative paraplegia necessitating immediate return to the operating theatre for wound exploration and removal of hardware and one death secondary to a pulmonary embolism. Five patients required medical treatment for a variety of medically unrelated issues. In addition to the aforementioned medical complications, 7 patients developed an ileus and 10 patients required transfusion in the perioperative period for acute blood loss anemia. Although these are recognized complications associated with PSF for AIS, we did not include them in our formal analysis given a lack of consensus as to the diagnosis and treatment of an ileus and the indications for transfusion.

Surgical site complications such as deep surgical site infections, hematoma/seroma, and dehiscence were the second most common with a prevalence of 3.6%. Of the 17 patients with documented surgical site complications, 1 required I&D of a suture abscess in the office, 1 required drainage of a hematoma and 15 required reoperation. In those patients undergoing reoperation, 10 were for deep infection, 3 were for prolonged, persistent drainage and 2 were for wound dehiscence. In addition to the 15 patients who required reoperation for surgical site complications, 8 patients required reoperation for hardware related complications. Five of these of these patients required reoperation for hardware failure, 2 required removal of hardware secondary to pain, and one had a malpositioned screw requiring revision. In total, 24/506 (4.7%) of patients required reoperation. In addition to aforementioned surgical site complications, 7 additional patients not included in this analysis were noted to have varying degrees of wound drainage and/or wound dehiscence managed with close observation, local wound care and oral antibiotics.

The distributions for all variables were approximately normal except for length of stay, time of surgery, and EBL which were right skewed. Increased length of stay (p=0.0018), time of surgery (p=0.0016), ASA score (p<0.0001) and estimated blood loss (p=0.0088) all correlated with a higher prevalence of complications.

DISCUSSION
The total complication rate for pediatric patients undergoing surgical correction of idiopathic scoliosis ranges from 0%-14.9%2-3. In our study, we retrospectively evaluated the charts of 506 consecutive patients undergoing posterior spinal fusion for correction of adolescent idiopathic scoliosis at two campuses within the same hospital system by 7 different surgeons between 2006-2012 to determine the types of complications that occur, their prevalence, and the rate of reoperation within the 1st year following surgery in order to determine which factors increase the prevalence of complications. In our study, the overall rate of complications was 9.9% and 4.7% of our patients required reoperation.

The most common complications in our cohort were medically related. Several reports in the literature validate that respiratory compromise is a common medical morbidity after corrective surgery for scoliosis with a recently reported incidence of 0.9%4. Three patients (0.6%) in our cohort experienced respiratory compromise resulting in delayed extubation in the PICU. In addition, other medical complications noted to specifically complicate scoliosis surgery including ileus, pancreatitis, superior mesenteric artery (SMA) syndrome and coagulopathy were observed in our cohort5. There were no cases of syndrome of inappropriate antidiuretic hormone (SIADH), fat embolism, choleithiasis, chylothorax, pneumothorax, or hemothorax.

Wound related issues were the second most common complication in our study. This is not surprising given the degree of soft tissue dissection required for surgical exposure. In a series of 4,369 patients in the SRS morbidity and mortality database undergoing posterior spinal fusion for AIS, Coe et al reported that wound complications accounted for most of their morbidity (1.35%)2. Carreon et al. reported a similar incidence of 1.42%6. In our series we experienced a 3.6% prevalence of wound related complications, the majority of which required operative intervention. In addition to the wound
related complications included in our analysis, there were multiple patients with other minor wound-related complications including suture abscesses, small seromas/hematomas and prolonged drainage that were followed on an outpatient basis and did not require operative intervention. These were not included in our analysis given the difficulty required to appropriately classify them and a wide variability of treatment methods (i.e. observation versus observation with antibiotics).

Our results indicate that risk factors for increased postoperative complications include increased length of stay (p=0.0018), time of surgery (p=0.0016), ASA score (p<0.0001) and estimated blood loss (p=0.0088). Similar to other studies, age at time of surgery, number of levels fused and curve magnitude were not predictive of the development of postoperative complications.

Prolonged operative/anesthesia time and increased blood loss have both been shown to increase the rate of complications in scoliosis surgery. Carreon et al reported a cut-point of 775ml of blood loss with posterior surgery and 368 minutes of total anesthesia time produced the best discrimination between patients with and without a complication. In our study, average blood loss was 549cc overall and 825cc for those with complications. Time of surgery averaged 252 minutes overall and 306 minutes for those with complications. In regard to estimated blood loss and transfusions, in the 11 patients who received a perioperative transfusion, the average blood loss was higher than average at 1395cc (Range 600cc-2500cc). Of those 11 patients, 9 went on to develop other complications including admission to the ICU for prolonged ventilatory support, wound complications, hardware failure and death. As expected, those patients who required transfusion also had longer than average operative times (5.6 hrs., Range 3.5-7.4hrs).

Our results demonstrated that ASA class is a significant risk factor for development of an early post-operative complication (p<0.001). Prior studies have shown that an ASA score greater than 2 is a significant risk factor for SSI after a spinal fusion procedure. In our study 96% of our cohort had an ASA score of 1 or 2 and only 21 patients had an ASA score of 3. Of those patients with an ASA of 3, 9 developed a postoperative complication.

There are several limitations of this study. First, it is retrospective in nature and is dependent on accurate charting among care providers at various levels of training across several practice groups at two different locations. Likewise, it is likely that more significant complications were better recorded whereas less significant ones were not. Therefore, the true incidence of early complications may in fact be greater than reported. The use of a single data collector could have mitigated this potential bias. Second, preexisting medical comorbidities and curve type/characteristics were not accounted for or controlled in this study.

When counseling patients regarding the surgical management of AIS, understanding the potential morbidity and mortality is of paramount importance. Our results may prove useful in counseling patients preoperatively regarding the risks of operative management and the nature and rates of complications. Furthermore, knowledge of risk factors for complications can assist in the patient selection and preoperative optimization. This may assist in prevention of complications and thereby reduce hospital stays and medical cost. Additional studies are needed to evaluate the effect of patient specific risk factors such as medical comorbidities; in particular BMI, curve type/characteristics, and the degree of correction have on the development of early postoperative complications.

ACKNOWLEDGEMENTS
Patricia Bush, MS; Laura Ward, MSPH
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REFERENCES


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PUBLICATIONS

BOOK CHAPTERS

PODIUM PRESENTATIONS


The Early Effect of Flexor Digitorum Profundus Tendon Shortening on Jersey Finger Surgical Repair: A Cadaveric Biomechanical Study

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ABSTRACT
Delayed diagnosis of jersey finger injuries often results in flexor digitorum profundus (FDP) retraction. Current practice recommends limiting tendon advancement to 1 cm in primary repairs. The purpose of this study was to investigate the biomechanical consequences of FDP tendon shortening on the force required to form a fist. The FDP muscle was isolated in ten cadaveric forearms and the force required to form a fist was recorded. Simulated jersey finger injuries to the ring finger were then created and repaired. The force required to pull the fingertips to the palm following serial tendon advancements were measured. This study provides evidence that there is a nearly linear increase in the force required for fist formation with shortening up to 2.5 cm. Our study does not support the current clinical practice of setting a 1 cm threshold as an absolute limit of “safe” tendon shortening in primary jersey finger repair.

LEVEL OF EVIDENCE: IV

INTRODUCTION
Jersey finger injuries are frequently encountered by the hand surgeon (Leddy, 1985). When diagnosed acutely, primary repair leads to a reported high success rate (Leddy et al., 1977). With a delay in presentation, tendon retraction often occurs. In this scenario, the treating surgeon often has to decide between advancing the tendon in order to perform a primary repair or conducting a staged tendon reconstruction which may prolong the patient’s recovery and lead to increased rates of complications (Mansat et al., 1985; Gaston et al., 2009; Tuttle et al., 2006; Momeni et al., 2010). A third management option would be to forgo any repair and allow the patient to go without the ability to flex the DIP joint. In discussing surgical repair, current literature recommends limiting primary flexor digitorum profundus (FDP) tendon advancement to under 1 cm (Malerich et al., 1987) however, the biomechanical consequences of advancing the FDP tendon less than versus more than 1 cm, in this setting, have yet to be truly elucidated. The primary purpose of this study was to investigate the biomechanical consequences of varying the extent of FDP tendon shortening on the force required to form a closed fist. We aimed to validate current clinical recommendations (Malerich et al., 1987). We hypothesized that the increase in flexion force required to form a fist would be insignificant when the FDP is advanced up to 1 cm. However, any further tendon shortening past 1 cm would result in a significant increase in flexion force necessary to obtain a closed fist.

METHODS
MATERIALS
Ten human upper extremities, cut at the distal humerus, were harvested from fresh cadavers (aged between 70-76 years). The specimens were examined grossly to rule out malignancy or fractures
that would interfere with the results. The specimens were then frozen at -20 C until the day before testing. After thawing to room temperature overnight, the FDP muscle belly was dissected from surrounding soft tissues in the forearm and the FDP tendon insertion on the ring finger was isolated and dissected meticulously to preserve the osseous and ligamentous structures. The specimens were then secured to the underlying workspace using three coarse thread drywall screws. The screws were placed at the radial diaphysis, the second metacarpal, and the fifth metacarpal in order to isolate motion at the MCP, PIP, and DIP joints. The specimens were kept moist throughout the entire procedure. All of the dissections were performed by the same individual. A diagrammatic representation of this experimental set-up can be seen in Figure 1.

MECHANICAL STUDY

The FDP muscle belly was dissected and isolated at its musculotendinous junction. The insertion site of the ring finger FDP tendon on the distal phalanx was also dissected and the flexor tendon exposed to the A4 pulley. The ring finger was chosen since approximately 75% of all jersey finger injuries occur in this finger (Leddy et al., 1977). A clamp was placed across the musculotendinous junction of the FDP as seen in Figure 1 with the fingers in full extension. The clamp, which consisted of two Kelly hemostatic forceps, was then connected to a force measuring transducer (Jennings/Scale UltraSport 50 Digital Utility Scale). The scale had a 50 kg (490 N) capacity and a resolution of 0.02 kg (0.196 N). The force required to pull the index, middle, ring, and small digits to the palm was measured and then, after fully extending the fingers to length, was measured again. This process was repeated four times by a combination of two of the authors.

JERSEY FINGER INJURY AND REPAIR

The FDP tendon of the ring finger was measured and marked at points 0.0, 0.5, 1.0, 1.5, 2.0, and 2.5cm from its insertion on the distal phalanx. Next, the FDP tendon was sharply divided from its attachment on the distal phalanx. The laceration was repaired with a 3-0 Arthrex FiberWire ultra high molecular weight polyethylene and polyester suture (Arthrex, Naples, FL) using a modified Kessler technique, which was then reinforced with two transosseous tunnels (Boyer et al., 2002). A force was then applied at the musculotendinous junction of the FDP muscle belly (Figure 2) and the force required to pull the fingertips of the middle, ring, and small fingers back to the palm after 0.0, 0.5, 1.0, 1.5, 2.0, and 2.5cm of tendon shortening was measured. Each force measurement cycle was repeated four times for each level of advancement. The force measurements were averaged and the standard deviations were calculated. The trials were closely observed to ensure that no gapping occurred at the repair site throughout the testing period. Each cadaveric specimen underwent serial tendon shortenings at the values given above.

STATISTICAL ANALYSIS

Four replicate measures of force were made at each level of tendon shortening and summarized with the mean, standard deviation, and coefficient of variation for each cadaveric forearm. Repeated-measures analysis for the force to form a fist was done with a means model with statistical software providing separate estimates of the means for each shortened tendon level. An unstructured variance-covariance form among the repeated measurements was assumed for force and robust estimates of the standard errors of parameters were used to carry out the statistical tests and construct 95% confidence intervals (Diggle et al., 2002). T-tests compared the pairwise differences between the model-based means (leastsquares means) at each shortened level. Change in mean force across shortened levels was tested for linear trend using orthogonal polynomial coefficients. Variability estimates for force were summarized using within-patient and between-patient variances and within-subject repeatability coefficient as described by Bland and Altman (1999). Statistical tests were two-sided. A Bonferroni
adjustment (0.05/5, 0.01) for multiple comparisons was used for the five post hoc statistical tests on force.

RESULTS

The average force required to form a fist before the creation of a jersey finger was 119.7N. After tendon division and repair, the average force to form a fist increased in a linear fashion after tendon shortenings of 0.0, 0.5, 1.0, 1.5, 2.0, and 2.5cm, respectively (p <0.001 , test for linear trend). These data are summarized in Table 1. There was a statistically significant difference in force at all levels between 0.0cm and 2.5cm (Table 2). After Bonferroni adjustments, the p-values between each shortened level reached statistical significance with values <0.01. No statistical difference was found between the initial flexion force before the creation of a jersey finger and with 0.0cm of tendon shortening.

DISCUSSION

Malerich et al. (1987) recommended limiting shortening of the FDP tendon to 1.0cm for delayed jersey finger repair. This limitation of shortening of the FDS tendon in the ulnar three digits was based on the extension loss and flexion lag (distance between the fingertips and the palm) seen in adjacent fingers, caused by the quadriga phenomenon (Verdan, 1960). Their results provided information about the potential limits to which those tendons could be advanced without affecting the excursion of the adjacent fingers. They did not measure the change in flexion force with tendon shortening. Additionally, a lack of statistical analysis potentially limits the application of their recommendation.

We found that the force required to form a closed fist increased in a nearly linear fashion after shortening of the FDP tendon with each 0.5cm increment from 0.0cm to 2.5cm (Figure 3). In stratifying our results between tendon shortening less than or more than 1cm, we did not find a statistically significant difference in the slope between the two lines of best fit. The increase in force going from 1cm to 1.5cm (11.2N), although significant, was not much different from the increase in force going from 0.5cm to 1cm (12.3N: significant), or the increase going from 1.5cm and 2.0cm (8.9N: significant). Thus the current recommendation of limiting FDP tendon shortening to less than 1cm (Malerich et al., 1987) may be valid, but must be considered to be subjective. Given these results, the clinical consequences of tendon shortening exist as a continuum, rather than occurring as a binary outcome at a specific value. Further shortening past 1 cm may be possible in clinical practice. However, an increase in tendon shortening may restrict full digital extension (Malerich et al., 1987). Shortening the tendon by more than 2.5cm was not performed in our study because we did not want to stretch the tendon past its elastic limit. In preliminary studies we found that advancement by more than 2.5cm resulted in plastic deformation in the tendon.

In vivo studies have shown that a strong grasp may generate up to 70N and firm tip pinch can generate up to 120N of force on the FDP tendon (Schuind et al., 1992; Strickland, 1995). In our study, forces greater than 120N were required to form a fist after FDP shortening. These were below the average threshold for breaking the A1 (329.5N) and A4 (197.1N) pulleys (Manske and Lesker 1977). We did not observe any iatrogenic pulley failure. The average force measured remained under the maximum physiological load of the muscles and tendons of the forearm as determined by Felder et al. (2013). It is likely that the measured forces in this cadaveric model were higher than the forces expected in in vivo repairs as a result of lack of normal synovial fluid and adhesion formation within the flexor sheath (Lin et al., 1989).

Numerous studies have looked at the excursion of flexor tendons (Horibe et al., 1990; McGrouther and Ahmed, 1981; Wehbé and Hunter, 1985). The exact limit of flexor tendon excursion is variable and dependent on an individual’s anatomy. Previous studies indicate that up to 9cm of
excursion might be necessary to produce full flexion of the wrist and digits (McGrouther and Ahmed, 1981; Wehbé and Hunter, 1985). To flex the combined metacarpophalangeal, proximal interphalangeal, and distal interphalangeal joints, an average tendon excursion of 3.02cm is required at the level of the metacarpal bone (Horibe et al., 1990). Using this knowledge, we advanced the FDP tendon up to 2.5cm and retained full digital flexion. However, this shortening may alter the balance of the flexor system, which has been shown to result in poorer clinical outcomes and complications such as quadriga (Guimberteau et al., 2007; Smutz et al., 1995; Verdan, 1960).

There are some limitations of our study. There was significant variability in the force required to form a fist between the cadaveric samples, which was often dependent on sample characteristics such as muscle mass and sex. There was also variability between individual specimens when measurements were repeated (Table 3). Another limitation was that there was no objective testing of the force with which the fingertips pressed into the palm. We felt that measuring the force required to bring the fingers to the palm would allow a more clearly defined comparison of endpoints than measuring the pressure generated. Our specimens had an average age of 73 years (range 70–76), which could bring into question the generalizability of our findings, since jersey finger injuries occur in patients of all ages. The specimens used in our experiment were also frozen and our methods may have been more physiological if fresh specimens had been used. The same specimens were used in a sequential order for each trial. This process could result in muscle creep from the repetitive forces on the muscles (Smutz et al., 1995). This creep would have an effect on excursion or the length of the FDP and we measured force to negate this. The results of this experiment only apply to the situation immediately after repair.

Our study demonstrated a linear increase in force required for fist formation after incremental shortening of the FDP tendon. Although the amount of shortening tolerated by patients is likely to be variable, we believe that these findings could challenge the current belief that up to 1 cm of shortening is well tolerated, while more than 1 cm is not. Although up to 2.5 cm of shortening may be possible, this may come at the cost of limiting digital extension (Malerich et al., 1987).
Figure 1. Force measurement transducer. (A, B) Force is applied to the force transducer, which is attached to the flexor digitorum profundus (FDP) tendon via a clamp construct. The fingers can be visualized contracting while the force is recorded on the digital screen. (C) Schematic representation of the force measurement.
Figure 2. Suture construct. (A) The FDP tendon on specimen 1 is marked at 0.5 cm intervals from insertion to 2.5 cm to guide tendon shortening. (B) Two transosseous tunnels are created with which to pass the suture for the FDP tendon repair in specimen 2. The tendon has been advanced to 2.0 cm and is unrepaired in this image. (C, D) Repair of the 2.0 cm shortening in specimen 2 is visualized on the flexor and dorsal sides respectively. (E) Schematic diagram of the repair technique.
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Outcomes after Revision Cervical Spine Surgery for Radiculopathy

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ABSTRACT

STUDY DESIGN
Retrospective analysis of prospectively collected data

OBJECTIVE
To compare pain and functional outcomes after surgery in patients who develop cervical radiculopathy following a previous cervical surgery to those who underwent primary surgery for radiculopathy.

SUMMARY OF BACKGROUND DATA
Surgical treatment of cervical radiculopathy provides significant improvement in pain and functional outcomes in patients with refractory pain and progressive neurologic deficits. Based on current literature, it is unclear if revision surgical intervention for cervical radiculopathy will result in similar outcomes.

METHODS
Data collected through chart review of 1,104 cervical spine surgeries identified 52 patients with a history of cervical spine surgery who underwent revision for radiculopathy. A cohort of 51 patients who had primary cervical spine surgery for radiculopathy were matched based on demographics and medical comorbidities. A minimum of 2 year follow up was required. Pre- and postoperative outcome measures were the Numeric Pain Rating Scale (NPRS), Neck Disability Index (NDI), and Short Form Heath Survey (SF-36).

RESULTS
Eighteen primary patients and 26 revision patients met the final inclusion criteria for the study. Both primary and revision cohorts’ demonstrated significant improvement in NPRS pain levels, NDI scores, and SF-36 Bodily Pain (BP) sub-scores (p< 0.05). There was no difference in the magnitude of improvement in pain and NDI between the primary and revision patients (p> 0.05). Primary patients demonstrated greater improvement in SF-36 BP and SF-36 Physical Component Summary as compared to the revision patients.

CONCLUSIONS
Patients with radiculopathy and a history of cervical spine surgery can expect relief in pain and improvement in neck-related disability that is similar to patients undergoing primary surgery. Primary patients, however, may have greater improvement in their general bodily pain as assessed by the SF-36.
INTRODUCTION
Cervical radiculopathy, characterized by pain radiating from the neck into an approximate nerve root dermatomal distribution, results primarily from cervical nerve root compression with potential contributions from nerve root traction and locally mediated chemical pain mediators. Cervical radiculopathy is relatively common with a prevalence of 0.3% and an age-adjusted incidence of 83 per 100,000. The natural history is favorable with symptoms improving significantly or resolving completely in up to 75% of patients with acute radiculopathy. At times, however, cervical radiculopathy manifests with severe, debilitating pain refractory to nonsurgical modalities or with progressive motor and/or sensory deficits. These situations may indicate surgical intervention.

Over the past two decades the number of patients undergoing cervical surgery has increased and is predicted to continue to rise with the aging population. Based on these trends some patients are likely to require additional cervical surgery for radiculopathy during their lifetime. Surgical decompression for cervical radiculopathy without history of cervical spine surgery has been studied extensively. Surgical treatment of cervical radiculopathy results in reproducible and significant improvement in pain as well as motor and sensory function in 75% to 90% of patients. The clinical and functional outcomes after surgical intervention for radiculopathy in those who have had prior cervical surgery is poorly understood.

The purpose of this study was to determine the long-term outcomes of revision cervical spine surgery for radiculopathy as compared to primary surgery for the same pathology. Specifically, we studied changes in neck and arm pain based on the Numeric Pain Rating Scale (NPRS), in the Neck Disability Index (NDI), and in the Short Form Health Survey (SF-36).

MATERIALS AND METHODS
After obtaining Institutional Review Board approval, medical records of patient who underwent cervical spine surgery at a single institution with one of five board-certified practicing spine surgeons over a six year period (2007 through 2012) were reviewed. For inclusion in the revision cohort of the study, the patient were required to have a diagnosis of cervical radiculopathy, have had at least one prior cervical spine procedure, be older than 18 years old, have completed the pre-operative functional outcome questionnaires, and have a minimum of 6 weeks of neck and arm pain that was recalcitrant to conservative treatment. Patients with myelopathy or myeloradiculopathy were excluded from the study. We identified a cohort of patients matched for age and medical comorbidities, who met the same inclusion and exclusion criteria with the exception that they had not had prior cervical spine surgery. Patients who met the inclusion criteria in these two cohorts were contacted by telephone. After consenting for enrollment in the study, they were sent a secure electronic survey to measure their post-operative functional status. Multiple attempts were made to contact and enroll patients in the electronic survey portion of this study. Final inclusion in the study required a minimum of a 2 year follow up.

Pre-operative functional outcomes were primary pain location, the worst and average Numeric Pain Rating Scale (NPRS), Neck Disability Index (NDI), and Short Form Heath Survey (SF-36). Post-operatively functional outcomes included current NPRS for the neck, right arm and left arm as well as the NDI and SF-36. The worst and average preoperative pain scores at the primary pain location were compared to the postoperative pain score at the same location (e.g. pre-op right arm pain compared to post-op right arm pain). Patient characteristics including age, gender, diabetes status, smoking status, Charlson Comorbidity Index (CCI), type of procedure, number of prior procedures, and number of levels of spinal decompression were recorded. In the revision cohort, the month and year or year alone of the prior surgery was recorded in the medical record. If the year alone was noted, the surgical date was assumed to be 7/1/xxxx for the purpose of estimating time between the last surgery and the revision
surgery. Statistical analysis of independent variables was performed using Microsoft Excel (Microsoft Corporation, Redmond, WA, USA). Probability values of <0.05 were considered statistically significant.

RESULTS
Cervical spine surgeries were performed on 1,104 patients at one institution between 2007 and 2012. After an extensive chart review, we identified 52 patients who underwent a revision cervical spine surgery for radiculopathy and met the inclusion/exclusion criteria. The primary matched cohort consisted of 51 patients with similar ages, gender distribution, medical comorbidities with cervical radiculopathy and no history of cervical spine surgery. Twenty-six of the 52 (50%) revision patients and 18 of the 51 (35%) primary patients met the final inclusion criteria of a minimum of a 2 year follow up, either through completion of the electronic survey or through information gathered in the medical record.

Patient demographics, duration of follow up, medical comorbidities including smoking and diabetes status as well as Charlson Comorbidity Index were well matched between the primary and revision cohorts (Table 1). There was no statistical difference in the mean duration of follow up. The mean follow up was 52.34 months (min 24.3 m, max 87.8 m) in the primary cohort and 54.8 months (min 26.7 m, 86.0 m) in the revision cohort. No statistically significant differences were found in the preoperative NPRS (pain at its worst and average pain), Neck Disability Index, and Short Form Health Survey (SF-36) Physical Component Summary and Mental Component Summary scores preoperative pain. The primary cohort patients had greater SF-36 Physical Function (p = 0.02), Role Physical (p = 0.05), and Social Function (0.03) sub-scores at baseline; however, these differences did not result in significant differences in the Physical or Mental Component Summary Scores.

In the primary cohort, 9 patients’ chief complaint was neck pain, 6 was left arm pain and 3 was right arm pain. Eleven patients in the revision cohort complained primarily of neck pain, 8 of left arm pain and 2 of right arm pain. In the primary cohort 88% of patients underwent anterior cervical discectomy and fusion, while only 42% of revision cohort cases were approached anteriorly. The mean time between the last recorded cervical spine surgery and the revision surgery was 39.4 months. Thirteen of the revision patients (50%) had an additional diagnosis of non-union and 2 (7.8%) had an additional diagnosis of deltoid palsy.

Outcomes after primary surgical intervention for cervical radiculopathy
The preoperative worst pain and average pain (NPRS) for the affected area (e.g. neck, right arm, left arm) was compared to the current postoperative pain score in the same anatomic area (Table 2). At a mean follow up of 4.4 years after surgical intervention of cervical radiculopathy, 72% of patients reported their pain was improved compared to their average preoperative pain level (p <0.01) and 83% stated their pain was improved compared to their worst preoperative pain level (p <0.01). Preoperatively, the mean pain score at its worst was 7.5 and on average was 5.2; the mean postoperative pain score was 2.7. NDI scores improved significantly in 81% of patients after surgical intervention (p = 0.01). The mean preoperative and postoperative NDI scores were 37.4 and 23.5 respectively. SF-36 Physical Component Summary scores were significantly improved after surgical intervention, going from a mean of 38.4 preoperatively to a mean of 46.6 postoperatively (p = 0.01). There was no significant change in SF-36 Mental Component Summary scores (mean 47.2 to 47.5). SF-36 sub-scores for Bodily Pain and Role Physical were 11.7 and 10.8 points higher postoperatively (p <0.01).
Outcomes after revision surgical intervention for cervical radiculopathy

In the revision cohort, 82% of patients reported their pain based on the NPRS was improved as compared to their average preoperative level, and 95% stated their pain was better than their preoperative pain levels (p < 0.01). The patient’s worst pain in the affected area preoperatively was a mean of 8.1 and an average of 5.9 (Table 2). Postoperatively, their mean pain score was 3.6. Four patients failed to report their preoperative pain; their pain scores were excluded from analysis. Eighty-one percent of revision patients reported improvement in mean NDI scores, improving from a preoperative mean of 46.3 to a postoperative mean of 34.6 (p < 0.01). Mean SF-36 MCS and PCS scores were unchanged after surgical intervention: preoperative means of 33.9 and 41.2 and postoperative means of 34.6 and 43, respectively. Mean SF-36 sub-scores for Bodily Pain increased by 4.38 points (p<0.01) and sub-scores for General Health decreased by 7.6 points (P<0.01).

Comparison of outcomes between primary versus revision surgical intervention for cervical radiculopathy

There was no statistical difference in the improvement in NPRS between the primary and revision cohorts. The mean pain score in primary patients improved 4.9 points from their worst preoperative pain and 2.7 points from their average preoperative pain. The revision cohort improved 4.5 points from their worst pain and 2.3 points from their average pain (both p>0.05). There was no difference in mean NDI improvement between the primary cohort which improved 13.9 points and the revision cohort which improved 11.7 points (p>0.05). The relative increase in SF-36 PCS was significantly greater in the primary cohort as compared to the revision cohort: 8.1 point increase versus 0.8 increase in mean SF-36 PCS scores. There was no significant difference in the change in SF-36-MCS scores between cohorts. Additionally, the mean Bodily Pain sub-score improved significantly more in the primary patients than in the revision patients (p=0.01). Figure 1 provides a summary of these results.

DISCUSSION

Radicular pain refractory to non-operative treatment as well as radiculopathy with progressive motor and/or sensory dysfunction may necessitate surgical decompression of compressed cervical nerve root1. Multiple studies have established that surgical treatment of radiculopathy without myelopathy significantly improves pain and functional outcomes including NDI at intermediate and long term follow up.6,7,8 Revision discectomy for lumbar disc herniation has been shown to yield similar clinical results when compared to primary discectomy. However, data regarding outcomes of cervical spine surgery for radiculopathy in the revision setting are lacking.

In our study, we compared long term outcomes of surgical intervention for cervical radiculopathy between patients with and without prior cervical spine surgery. Myelopathic patients were excluded as this pathology is distinct from radiculopathy and has a different natural history. At a mean follow up of approximately 4.5 years, the neck, right or left arm pain that patient’s found most bothersome on preoperative assessment improved significantly in the primary and revision cohort. Childs, et al 2005 determined that a change of 2 points on the NPRS represented a clinically meaningful change in pain for low back pain patients. We found that the mean reduction in neck/arm pain after surgical intervention in both cohorts surpassed the minimal threshold for clinical meaningfulness. The mean improvement in NDI scores in the primary (13.9 pts) and revision cohort (11.7 pts) were both statistically and clinically significant. In a systematic review of the application of the NDI, Vernon, et al (2008) recommended using a 7 point change in NDI score (of 100) as the minimal clinically important change. The SF-36 sub-score for Bodily Pain were significantly improved in both cohorts. In the primary cohort SF-36 PCS increased postoperatively, and the SF-36 MCS scores did not significantly change. Pre- and postoperative SF-36 PCS and MCS were not significantly different in the revision group. When we compared the outcomes of the primary to the revision cohort, there was no difference in the
improvement of pain or NDI between these two groups. The primary cohort demonstrated greater change in SF-36 Bodily Pain sub-scores and the PCS.

This study has several limitations. The inherent weakness of a matched cohort study design is its inability to account for unknown confounding variables. Additionally, the sample size is small; despite starting with a large database of surgical cervical spine patients at a tertiary referral center, only 52 patients meet the intentionally strict inclusion and exclusion criteria. The response rate of the electronic survey was low, particularly in the primary cohort. Every effort was made to enroll patients in the study and encourage them to complete the survey once it was distributed. The additional diagnosis of non-union in 50% of the revision patients may have served as a confounding variable.

Further study on this topic is warranted. Other areas of study might focus the complication rates and economic cost differences between the primary and revision groups, as these were not included in this study. Additionally, expansion to a multicenter study might be required to improve sample size. Furthermore, the natural history of cervical radiculopathy in patients with prior cervical spine surgery has yet to be established.

CONCLUSIONS

Surgical treatment of radiculopathy in patients with prior cervical spine surgery significantly reduces pain and improves functional outcomes. Primary and revision cervical surgery for radiculopathy yield equivalent improvement in pain and neck-related disability as assessed by the Neck Disability Index. Both primary and revision surgical patients can expect improvement in overall bodily pain as assessed by the SF-36 BP sub-score; however, the magnitude of improvement is likely to be greater in primary patients.
<table>
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<th>Characteristic</th>
<th>Primary Cohort (n=18)</th>
<th>Revision Cohort (n=26)</th>
<th>T-test p value</th>
<th>Chi² p value</th>
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<td>Age, yr.</td>
<td>51</td>
<td>51</td>
<td>0.84</td>
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<tr>
<td>Charlson Comorbidity Index (0-36)</td>
<td>1.22</td>
<td>1.04</td>
<td>0.57</td>
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<td>Preoperative pain score, at worst (0-1)</td>
<td>7.5</td>
<td>8.1</td>
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<td>Preoperative pain score, on average (0-10)</td>
<td>5.3</td>
<td>5.9</td>
<td>0.39</td>
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<tr>
<td>Preoperative Neck Disability Index, %</td>
<td>37.4</td>
<td>46.3</td>
<td>0.09</td>
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<tr>
<td>Preoperative SF-36 PCS</td>
<td>38.5</td>
<td>33.9</td>
<td>0.08</td>
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<tr>
<td>Preoperative SF-36 MCS</td>
<td>47.2</td>
<td>41.2</td>
<td>0.08</td>
<td></td>
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<tr>
<td>Number of levels decompressed</td>
<td>1.5</td>
<td>1.58</td>
<td>0.79</td>
<td></td>
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<tr>
<td>Mean follow up, years</td>
<td>4.4</td>
<td>4.5</td>
<td>0.65</td>
<td></td>
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<tr>
<td>Gender, n female (%)</td>
<td>9 (50%)</td>
<td>8 (31%)</td>
<td>0.42</td>
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<tr>
<td>Diabetes, n (%)</td>
<td>4 (22%)</td>
<td>2 (8%)</td>
<td>0.17</td>
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<td>Active smokers, n (%)</td>
<td>3 (17%)</td>
<td>7 (27%)</td>
<td>0.42</td>
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<td>ACDF (%)</td>
<td>16 (89%)</td>
<td>11 (42%)</td>
<td>0.01*</td>
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<tr>
<td>Posterior decompression +/- fusion (%)</td>
<td>2 (17%)</td>
<td>15 (58%)</td>
<td></td>
<td></td>
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* indicates statistical significance with p value less than 0.05
Table 2. Preoperative and Postoperative mean outcome scores
Pain, Numeric Pain Rating Scale; NDI, Neck Disability Score; SF-36 PCS|MCS, SF-36 Physical | Mental Component Summary

<table>
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<th></th>
<th>NDI</th>
<th>SF-36 PCS</th>
<th>SF-36 MCS</th>
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<tbody>
<tr>
<td></td>
<td>Pre-op</td>
<td>Post-op</td>
<td>Pre-op</td>
</tr>
<tr>
<td>Primary</td>
<td>7.5&lt;sup&gt;W&lt;/sup&gt;</td>
<td>5.3&lt;sup&gt;A&lt;/sup&gt;</td>
<td>2.6*</td>
</tr>
<tr>
<td>Revision</td>
<td>8.1&lt;sup&gt;W&lt;/sup&gt;</td>
<td>5.9&lt;sup&gt;A&lt;/sup&gt;</td>
<td>3.6*</td>
</tr>
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* indicates statistical significance between pre- and post-op means with p value < 0.05
<sup>NS</sup> indicates no significant difference between pre- and post-op means with p value > 0.05
<sup>W</sup> indicates worst pain | <sup>A</sup> indicates average pain
Figure 1: Differences in pre- and postoperative outcomes between the primary and revision cohorts. (A) Numeric Pain Rating Scale, (B) Neck Disability Index (C) Short Form Health Survey and sub-scores.

* indicates statistically significant difference in pre and postoperative outcomes ($p<0.05$). † indicates statistically significant differences in the magnitude of change between primary and revision groups ($p<0.05$)

BP = Bodily Pain, EF = Emotional Function, GH = General Health, PF = Physical Function, RE = Role Emotional
References

Biomechanical Effects of Rotator Interval Closure in Shoulder Arthroplasty

Daly CA, Hutton W, Carter B, Jarrett CD

INTRODUCTION

The rotator interval is the trapezoidal area of tissue in the anterosuperior shoulder between the supraspinatus and subscapularis that contains the coracohumeral ligament, superior glenohumeral ligament, biceps tendon, and joint capsule. The rotator interval is proposed to contribute to glenohumeral stability, stability of the biceps tendon, and limits excessive glenohumeral motion.

Total shoulder arthroplasty has been demonstrated to have good to excellent results in greater than 90% of cases at intermediate-term follow up, yet complications have been noted in a limited number of cases. These complications include stiffness, loosening, instability, fracture, rotator cuff tears, nerve injury, infection, and deltoid dysfunction. In a review of the literature, glenohumeral instability demonstrated a 4% prevalence (representing 30% of complications) and rotator cuff tear had a prevalence of 1.3%, with the majority (53%) involving the subscapularis tendon. A review of instability cases following total shoulder arthroplasty demonstrated anterior instability to be much more prevalent than posterior instability and noted that all anterior instability was the result of rupture of the repaired subscapularis tendon.

Many patients show evidence of subscapularis dysfunction after total shoulder arthroplasty without dislocation and this also results in inferior clinical outcomes. Subscapularis tendon rupture has been demonstrated to lead to pain, weakness, decreased active motion, anterior instability, decreased functional outcome scores, and even premature glenoid loosening. Postoperative rupture of the subscapularis tendon has been reported to occur in 3-11% of patients, yet by physical exam Miller demonstrated that 66% of patients have persistent subscapularis dysfunction following total shoulder arthroplasty and the rate of postoperative rupture is thought to be underestimated.

Optimal methods for subscapularis repair have been studied in detail and include subscapularis peel, lesser tuberosity osteotomy, and subscapularis tenotomy. To date there is no consensus regarding an optimal technique of subscapularis mobilization and subsequent repair in total shoulder arthroplasty.

The effect of rotator interval closure for shoulder instability on motion has also been studied in detail. In most reports there is moderate evidence that rotator interval closure in these patients results in some postoperative limitation in terminal external rotation. Following subscapularis repair during total shoulder arthroplasty a “relaxing suture” is commonly placed within the lateral 1cm of the rotator interval in an attempt to reduce tension on the subscapularis repair site. External rotation especially in terminal abduction is critical to the success of total shoulder arthroplasty as it allows for activities of daily life such as combing hair but the effect of rotator interval closure on this motion has yet to be established. Additionally, despite volumes of literature regarding optimal methods of subscapularis repair strength, the effect of the addition of the commonly utilized suture within the rotator interval on repair strength has yet to be studied. In this study we hope to provide the first evidence based guidance regarding the utilization of the rotator interval suture and allow practitioners to make decisions in the dilemma between the loss of external rotation and increased subscapularis repair strength and decreased gap formation.
METHODS

10 matched (right and left) shoulders were obtained. Utilizing paired upper extremities allowed an internal control for tendon strength as well as bone density. All shoulders were dissected free of the deltoid musculature to expose the underlying rotator cuff musculature. A subscapularis tenotomy was performed 1cm from the tendon insertion on the lesser tuberosity. A total shoulder arthroplasty was then performed according to standard procedures utilizing a press-fit stem. The subscapularis tenotomy was then closed utilizing 3 #5 Fiberwire sutures in a Mason-Allen fashion.

The distal humerus was then potted and a custom jig was applied to the medial most aspect of the scapula. A MTS machine was then utilized to apply a torsional force of 1500 N/mm with the shoulder at neutral and 90 degrees of abduction and the angle at which this resistance was achieved was recorded. A single shoulder of the matched pair was randomly assigned to rotator interval closure which was performed via placement of a single #5 Fiberwire suture in a Figure-8 fashion within the lateral 1cm of the rotator interval between the tendons of supraspinatus and subscapularis. This specimen again subjected to torsional testing and maximal rotation at 1500 N/mm was recorded. Following this, the medial aspect of the subscapularis musculature was dissected free from the scapula and the proximal musculotendinous junction was secured to the MTS machine via suture, while the proximal 1/3 of the humerus was placed in a vice such that the machine would be able to apply load to the proximal musculotendinous junction of the subscapularis in line with its natural line of pull. The specimen was cyclically loaded to 100N at 1Hz for 1000 cycles, which has previously been shown to simulate postoperative rehab forces. Gap formation at the tenotomy site was measured by digital photography at 100, 200, 500, and 1000 cycles. Gap formation was analyzed through use of digital image measurement software (ImageJ 1.48, Wayne Rasband, NIH) allowing determination of the gap area and the average gap formation was determined at each time point. Following this a load to failure test was performed at a loading rate of 2mm/second and the maximal force at which failure occurred was recorded.

RESULTS

In all, 10 cadaveric shoulders from 5 individuals were analyzed. Analyzing matched pairs allowed for internal control and right and left shoulders were distributed equally between the two experimental arms. The rotator interval closing suture significantly increased the ultimate load to failure of the subscapularis repair (398.8 N versus 225.3 N) (P = 0.038). Cyclic loading of the specimen was performed and gap formation measured at regular intervals allowing comparison of those specimens both with and without rotator interval closure as demonstrated in Table 1. Rotator interval closure also decreased gap formation at the subscapularis repair site under cyclic loading in our samples at all-time points (7.8mm versus 4.0mm at 1,000 cycles). This difference approached but did not reach statistical significance. The average shoulder external rotation and arc of motion for shoulders with the rotator interval closure suture were 25.8 degrees and 53.5 degrees at neutral and 47.5 degrees and 86.1 degrees at 90 degrees of shoulder abduction. In comparison, the average external rotation and arc of motion for shoulders without the interval closure were 25.1 degrees and 53.7 degrees at neutral and 50 degrees and 85.1 degrees at 90 degrees of shoulder abduction. Data for differences in internal and external rotation following rotator interval closure was compared to both the same shoulder and the contralateral shoulder as demonstrated in Table 2. No significant difference was found between the two cohorts (P>0.05) in regard to external rotation or overall range of motion.
DISCUSSION

This is the first study to report the additional biomechanical benefit the rotator interval closing suture provides to the subscapularis repair site following shoulder arthroplasty. This technique has been widely described for subscapularis repair but has yet to be biomechanically evaluated in the peer-reviewed literature despite a significant interest in subscapularis repair strength and various methods of subscapularis mobilization in an attempt to increase strength and the propensity for healing of the subscapularis.

There have been significant questions as to the utility and detriment of the addition of the rotator interval closing suture. It has been widely thought that closure of this soft tissue defect could improve strength but likely resulted in decreased external rotation of the shoulder. External rotation of the shoulder in arthroplasty is critical to a successful outcome as it allows for restoration or preservation of important activities of daily living especially including hygiene of the head and face.

This study was able to demonstrate that this technique significantly improves the load to failure of the subscapularis repair as well as tended to decrease the risk of gap formation under cyclic load, all without detrimentally affecting shoulder external rotation or overall arc of rotation. Our findings support the application of this off-loading technique following subscapularis repair during shoulder arthroplasty.

It is currently unknown if the findings of minimal limitation of external rotation will hold true in vivo as scarring of the interval closure and postoperative immobilization are likely to potentiate the effects of rotator interval closure on motion. Further study is required to investigate whether the benefits of interval closure hold true following other modes of subscapularis repair such as lesser tuberosity osteotomy or subscapularis peel.
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Table 1. Gap Formation

<table>
<thead>
<tr>
<th></th>
<th>Interval Open</th>
<th>Interval Closed</th>
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<tr>
<td>Average Gap Formation at 100 Cycles (mm)</td>
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<td>1.88</td>
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<td>Average Gap Formation at 200 Cycles (mm)</td>
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<td>2.33</td>
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<tr>
<td>Average Gap Formation at 500 Cycles (mm)</td>
<td>8.39</td>
<td>3.04</td>
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<td>Average Gap Formation at 1000 Cycles (mm)</td>
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Table 2. Average Rotation

<table>
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<td>Average Neutral Total Rotation (degrees)</td>
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<td>53.51</td>
</tr>
<tr>
<td>Average 90° Abduction Total Rotation (degrees)</td>
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<td>86.06</td>
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<tr>
<td>Load to Failure by Matched Pair (N)</td>
<td>Interval Closed</td>
<td>Interval Open</td>
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<tr>
<td>------------------------------------</td>
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</table>

Table 3. Load to Failure

![External Rotation Graph]

- **External Rotation**
- **Degrees of External Rotation**
- **Neutral**
- **90° Abduction**
- **Interval Open**
- **Interval Closed**
A Retrospective Radiographic Review Of Fusion Rates At 3 Months For One And Two Level Anterior Cervical Decompression And Fusion With And Without Recombinant Bone Morphogenetic Protein-2

Garrard EC, Braly B, Simpson A, Heller, JG

ABSTRACT

DESIGN
Retrospective Radiographic Analysis

OBJECTIVES
Compare the ACDF fusion rate at 3 months with and without rhBMP-2 in one and two level cervical arthrodesis.

BACKGROUND
Using rhBMP2 during routine one and two level acdfs is still a controversial topic in current literature given the theoretical and documented complications. Fusion status has significant implications on patient return to presurgical activity, safe progression of range of motion and patient confidence. Currently there is no consensus on whether the use of rhBMP2 in routine one and two level acdfs results in a higher rate of fusion at the 3month follow up.

METHODS
65 consecutive patients status post ACDFs (cortical allograph with anterior cervical plates) at 96 cervical levels with 3 month postoperative dynamic flexion and extension radiographs were included. The radiographic criteria used to determine fusion status at each level were as follows: 1) less than 1 millimeter of change between spinous processes as seen on flexion and extension radiographs, 2) bridging trabeculae between cranial and caudal vertebrae, 3) lucency less than 50% of the cranial or caudal graft—vertebrae interface.

RESULTS
Based on the above radiographic criteria, the overall fusion rate at 3 months was 47%. The fusion rates with and without rhBMP-2 at 3 months were significantly different at 53% and 26%, respectively. There was also a significant difference in the fusion rates at 3 months between all male and female fusion levels, 35% and 63%, respectively and all levels in patients less than or greater than 45 years of age, 63% and 38%, respectively. There was no significant difference noted in ACDF fusion rates at 3 months for levels in patients who reported using tobacco, carried the diagnosed of diabetes mellitus or were obese at the time of their procedure (BMI greater than 30).

DISCUSSION
There was a significant difference in fusion rates at 3 months between the cervical vertebral levels augmented with rhBMP-2 and without rhBMP-2 during routine one and two level ACDFs in consecutive
patients from a single surgeon. Even while using a strict dynamic radiographic fusion criteria including less than 1 Millimeter of intraspinous process motion, bridging trabeculae and lack of lucency, 53% of all patients who had rhBMP-2 implanted at the time of the ACDF were radiographically fused at 3 months. This finding has significant clinical implications, as patients are not released to full activity by the senior author (J.H.) until solidly fused levels are appreciated both radiographically and clinically. This retrospective study demonstrates that rhBMP-2 implanted during routine ACDF resulted in a significantly higher rate of fusion at 3 months suggesting that future prospective studies comparing the application of rhBMP-2 in anterior cervical arthrodesis with clinical evaluation may show an earlier release from postoperative restriction in patients augmented with rhBMP-2 in one and two level cervical arthrodesis.

INTRODUCTION

The use of recombinant DNA technology to produce bone morphogenetic protein, specifically rhBMP-2, has led to an increased application of these proteins during both cervical and lumbar spine procedures by many orthopaedic and neurological surgeons throughout the country. This increase in off label use, specifically in the cervical spine, has spurred a scholarly debate regarding the need for such bone graft substitutes during cervical procedures and whether complications seen during this application warrant their continued use.

A prospective, randomized, controlled trial comparing cervical fusion using rhBMP-2 versus cancellous iliac crest autograft showed superior improvement at two years follow up in the rhBMP-2 group with both neck disability and arm pain scores. In this study by Baskin et al., all patients had solid fusions at 6, 12 and 24 months post—surgery. Conversely, several articles have been published detailing the acute complications involved with applying rhBMP-2 in the anterior cervical spine including neck swelling, dysphagia, airway obstruction, increased hospital stays, unplanned intubations and tracheostomies, respiratory failure, readmissions, and 90—day mortality rates.

In our study, we retrospectively reviewed a single surgeon’s consecutive series of one and two level anterior cervical disectomy and fusions with and without the application of rhBMP-2 to assess the fusion rate at three months using dynamic radiographs.

PATIENTS AND METHODS

We identified 65 patients with 96 cervical levels from a retrospective review of consecutive patients treated by a single surgeon (J.H.) for symptomatic cervical disk degeneration or radiculopathy over a three—year period from 2009 to 2012 after institutional review board (IRB) approval. All 65 patients underwent an anterior cervical disectomy and fusion by the Smith—Robinson technique with instrumentation using Atlantis plating (Medtronic, Memphis, TN) with or without the addition of rhBMP-2 at each cervical level (rhBMP-2 – Infuse Bone Graft, Medtronic, Memphis, TN). The patient’s medical charts were queried for specific demographic and medical information including age at time of procedure, gender, length of stay, body mass index (BMI) and a history of smoking or diabetes mellitus as well as flexion and extension radiographs at three months.

Inclusion criteria were as follows: one or two level ACDF between C2 and T1 with adequate flexion and extension radiographs at three months. All radiographs were taken with the patients in the upright position with the beam centered at C4. Flexion and extension radiographs were deemed adequate if greater than five degrees of motion was noted at either the superior or inferior adjacent vertebral segment. Patients were excluded if there were no three—month flexion or extension radiographs available for review.

For a cervical segment to be considered radiographically fused at the three month follow up, there must be less than one millimeter of change noted between spinous processes as seen on flexion and extension radiographs, bridging trabeculae seen between cranial and caudal vertebrae and less than
fifty percent lucency noted at the cranial or caudal graft–vertebrae interface. If one of the criteria was not present, a cervical level was not considered fused.

RESULTS
Of the 34 cervical levels performed as a single level arthrodesis and 62 cervical levels performed as a two level arthrodesis, rhBMP-2 was used in 23 (67.6%) levels and 50 (80.6%) levels, respectively. Fifty-five (57.3%) cervical levels were performed in male patients and 41 (42.7%) in female patients. At the time of the procedure, 17 (17.7%) cervical levels were in patients smoking, 9 (9.4%) cervical levels were in patients diagnosed with diabetes mellitus, 21 (21.9%) cervical levels were in patients diagnosed with obesity and 61 (63.5%) cervical levels were in patients older than 45 years. The average length of stay for the index procedure performed on all cervical levels was 1.6 days with 69.8% (67/96) of the cervical levels discharged on post-operative day one.

FUSION RATE
Based on the radiographic fusion criteria described above, the overall fusion rate at three months including all cervical levels was 46.9% (45/96). 14 out of 34 (41.2%) single level cervical procedures were fused radiographically at three months compared to 11 out of 31 (35.5%) two level cervical procedures.

BONE MORPHOGENETIC PROTEIN—2 USE
At three months, a statistical difference was found between the rate of fusion in all cervical levels with rhBMP-2 and those without, 53.4% (39/73) versus 26.1% (6/23), respectively (p = 0.0402). There was a trend towards significance in the fusion rate at three months between single level procedures with rhBMP-2 and those without, 52.2% (12/23) versus 18.2% (2/11), respectively (p = 0.1306). No significant difference was found at three months between two level procedures with Rhbmp2 and those without, 40.0% (10/25) versus 16.7% (1/6), respectively (p = 0.5501).

Tobacco Use At three months, no statistical difference was found between the rate of fusion in cervical levels where the patient was using tobacco at the time of procedure and cervical levels where the patient was not using tobacco, 47.1% (8/17) versus 46.8% (37/79), respectively (p = 0.8017). 57.1% (8/14) of the cervical levels in the patients using tobacco were radiographically fused with rhbmp-- use compared to 0.0% (0/3) without rhBMP-2 (p = 0.2452).

DIABETES MELLITUS
At three months postoperatively, no statistical difference was found in the fusion rate of the cervical levels where the patient carried the diagnosis of diabetes mellitus at the time of the procedure and those patients without that diagnosis, 22.2% (2/9) versus 49.4% (43/87), respectively (p= 0.2278).

OBESITY (BMI > 30)
At three months there was no statistical difference in the cervical vertebral fusion rate in those patients diagnosed with obesity and those without the diagnosis, 47.6% (10/21) versus 46.7% (35/75), respectively (p = 0.8650).

AGE GREATER THAN 45 YEARS
A statistical difference was found between the cervical levels fused at three months in patients less than or greater than 45 years of age, 62.9% (22/35) and 37.7% (23/61), respectively (p = 0.0304).
GENDER

At three months postoperatively, there was a statistical difference noted between the radiographic fusion rate in cervical levels found in male patients versus those found in female patients, 34.5% (19/55) versus 63.4% (26/41), respectively (p = 0.0094).

DISCUSSION

In this study, we compared the radiographic fusion rate at three months in patients undergoing one and two level anterior cervical discectomy and fusions with and without the application of recombinant bone morphogenetic protein 2. We found that the cervical levels in which rhBMP-2 was employed had a three-month fusion rate of 53.4 percent while those cervical levels in which no rhBMP-2 was employed had a fusion rate of 26.1 percent, which was statistically significant. These findings are clinically relevant given that if at three months the surgeon (J.H.) found the postoperative cervical levels to be radiographically as well as clinically fused, the patient was allowed to progress his or her activity. In patients where cervical levels showed questionable fusion at three months either radiographically or clinically, the surgeon’s standard restrictive postoperative protocol was followed.

This study of 96 cervical vertebral levels in 65 consecutive patients shows that cervical levels where rhBMP-2 was used were more likely to be fused at three months than those cervical levels without rhBMP-2. Other studies have shown that fusion can be expected in both cervical levels where rhBMP-2 was used and those where rhBMP-2 was not used at six months postoperatively, but we feel that this is the first study to show retrospectively that cervical levels fused with rhBMP-2 were more likely to be fused at an earlier postoperative time of three months when compared to those vertebral levels not fused with rhBMP-2.

LIMITATIONS

This retrospective review of one and two level ACDF procedures performed by a single surgeon has several weaknesses. Firstly, the retrospective nature of the study opens it to biases that may overestimate the fusion rate even with a stringent objective radiographic criterion for fusion. Secondly, there was no incorporation of the clinical fusion objective findings such as alleviation of pain with range of motion and improvement in radicular symptoms or subjective findings such as if the surgeon concluded that the patient was fused at the operative cervical level. By including these clinical findings with the radiographic findings, further conclusions could be drawn using the actual quantity of patients and cervical levels where the rehabilitation protocol was accelerated or altered secondary to belief by the surgeon that the level was solidly fused. Thirdly, a recent article by Park et al. as well as Epstein et al. Discussed the various radiographic criteria for determining solid cervical arthrodesis including both dynamic x-rays and axial computed tomography (CT) imaging. By using axial CT images, bridging trabeculae and quantity of graft-vertebrae interface lucency could be confirmed. By not incorporating the axial CT images in this study, an over estimation of arthrodesis may have occurred.

CONCLUSION

Although this study has several weaknesses including the retrospective nature of the data and the inclusion of only dynamic radiographic data, a significant difference in fusion rates was found between one and two level cervical vertebral arthrodesis with and without the use of rhBMP-2. Further prospective studies comparing the fusion rates between cervical levels with and without rhBMP-2 at early postoperative time points will need to be performed to confirm this retrospective study. These further comparative studies may lead to a change in the rehabilitation protocol for cervical levels fused with rhBMP-2.
REFERENCES

Repair of Knee Extensor Mechanism Injury with Suture Anchors

Huleatt J, Premkumar A, Gebrelul A, Bush P, Xerogeanes J

Investigation performed at the Emory Orthopaedics & Spine Center, Atlanta, Georgia

ABSTRACT

BACKGROUND
The standard treatment for quadriceps tendon (QT) and patellar tendon (PT) ruptures has been repair with sutures that are pulled through transpatellar tunnels. The use of suture anchors as an alternate technique requires less dissection. The purpose of this retrospective study was to report on patient-reported function, range of motion (ROM), and failure rate of patients treated with a suture anchor technique.

DESCRIPTION OF TECHNIQUE
QT and PT repairs were performed using modified Mason-Allen sutures in the ruptured tendon secured to the patella with suture anchors.

METHODS
Consecutive patients who were 18 years of age or older and that had isolated QT or PT ruptures treated with a suture anchor repair technique performed between 2004 and 2014 were identified. Patients were included if pre-operative and minimum six month post-operative International Knee Documentation Committee (IKDC) scores and/or ROM had been collected. Appropriate t tests were used to assess the difference in outcomes between the QT and PT groups and between the types of suture anchors used. The effects of patient age, interval between injury and surgery, and length of follow-up period on post-operative IKDC scores were analyzed with Pearson correlation.

RESULTS
QT repair was performed in 28 patients with mean post-operative IKDC score of 64.7 in 15 patients, and mean ROM of -0.29° to 115.2°. PT repair was performed in 24 patients with mean post-operative IKDC score of 64.4 in 19 patients and mean ROM of 0.0° to 116.0°. The failure rate of 52 repairs was 6%. No significant difference in IKDC score and ROM was found between QT and PT repairs. There was a negative correlation between IKDC score and increasing age (r = -0.63, p = 0.004).

CONCLUSIONS
Suture anchor repair of QT and PT injuries has comparable functional outcomes to the traditional transpatellar bone tunnel technique. Average IKDC score of 64 at follow-up indicates continued functional deficits, with poorer results in older patients and higher failure rate in delayed repairs.

LEVEL OF EVIDENCE
Therapeutic Level IV
MANUSCRIPT

Quadriceps tendon (QT) and patellar tendon (PT) ruptures are relatively rare (1.37 and 0.68 per 100,000 patients/year), but devastating injuries to the extensor mechanism of the knee that occur most often as a result of low velocity injury during athletic activity or a fall (Clayton 2008, Kasten 2001). QT ruptures are typically seen in males who are over the age of 40 (Clayton 2008, Siwek 1981), whereas PT ruptures most commonly occur in males in the 30-40 year age group (Kasten 2001, Siwek 1981). These injuries are best treated with immediate repair (Ciriello 2012). Historically, this has been done with running locked sutures in the tendon that are pulled through transpatellar tunnels. PT repairs have often been augmented with a cerclage wire or relaxing suture looped through transverse tunnels in the tibial tubercle and patella (Ciriello 2012, Kasten 2001, Siwek 1981, Shelbourne 2001, West 2008).

The use of suture anchors has gained popularity for addressing quadriceps and PT ruptures in the last two decades because less dissection has to be performed on the opposite side of the patella from the tendon requiring repair, and there is likely a lower risk of perforating the articular surface of the patella with shorter drill holes. There may also be less risk of gap formation between the patella and repaired tendon (Bushnell 2006, Ettinger 2013, Petri 2014). The current published literature on clinical outcomes of the suture anchor technique is limited to case reports and small cases series of two to 14 patients.

The purpose of this retrospective study was to report on patient-reported function, range of motion (ROM), and failure rate of a larger case series of patients treated with a suture anchor technique for comparison with outcomes of patients treated with the historical standard of suture repair through bone tunnels.

SURGICAL TECHNIQUE

This technique for repairing a ruptured QT or PT involves placing modified Mason-Allen sutures into the ruptured tendon that are then tensioned and secured to the patella with suture anchors. Prior to the case, a femoral nerve block may be performed to assist with post-operative pain control. IV antibiotics are given within 30 minutes before the incision. The patient is placed in a supine position with the ability to flex the knee to 90°. General anesthesia is administered and a knee exam is performed under anesthesia. The patient is then prepped and draped in a sterile fashion. A proximal thigh tourniquet may be inflated prior to incision.

To gain exposure, a three-centimeter midline incision is made on the superior aspect of the patella for QT repair, and on the inferior aspect of the patella for PT repair [Figure 1]. Once through the skin, identify the patella bursa, and dissect in the tissue plane between the tendon and bursa. For a QT repair, one must be able to sweep a finger around the patella, the medial and lateral retinaculum, as well as the quadriceps tendon, vastus medialis oblique, and vastus lateralis. For a PT repair, be able to sweep a finger around the patella, the patellar tendon, and its insertion on the tibia. Blunt dissection is used to mobilize the ruptured tendon ends, the wound is irrigated, and the frayed tendon ends are debrided back to sturdy tissue. The patella insertion or origin is also debrided.

Modified Mason-Allen sutures are placed using one FiberTape® and one FiberWire® (Arthrex, Naples FL) per anchor, with the sutures placed from medial to lateral [Figure 2]. Pilot holes for the suture anchors are then drilled into the patella to a depth of 22 mm using a drill guide and threaded pins adjacent to the superficial surface at the tendon insertion footprint. For QT repairs, two holes are drilled at approximately the 11 and 1 O’clock positions within the footprint that is on average 46 mm wide and just over 7 mm thick (Xerogeanes 2013). A third suture anchor may be placed at the 12 O’clock position in larger individuals or when a more robust repair is desired. In order to be within the anatomic footprint, the pilot holes must enter the superficial third of the patella. For a non-dysplastic patella, one can angle 30 degrees away from the superficial surface to ensure adequate tunnel length [Figure 3]. For
PT repairs, two holes are drilled at approximately the 5 and 7 O’clock positions within the footprint that is on average 31 mm wide and 3.7 mm thick (Chang 2009, Andriakoula 2006, Svensson 2004, Basso 2001, Xerogeanes 2013) [Figure 4]. Palpation of the articular surface or the patella or fluoroscopy may be used to ensure no breach into the patellofemoral joint.

One FiberTape® suture and one FiberWire® suture from the tendon repair are threaded through each 4.75 SwiveLock® suture anchor (Arthrex, Naples FL). The sutures are pulled until the tendon edge is within 1 cm of the suture anchor [Figure 5]. Place the knee in full extension, and while holding tension on the suture, place the tip of the anchor inserter into the pilot hole. Adjust the tension as needed. Lock the sutures on the inserter and tap the device into the pilot hole until the tip of the screw meets the edge of the pilot hole [Figure 6]. Holding the paddle, turn the handle clockwise to screw the anchor into the bone. When the anchor is nearly fully seated, turn the paddle clockwise while holding the handle. This will disengage the plastic cuff from the anchor and allow one to visualize the head of the anchor [Figure 7]. Then continue to insert the anchor until it is fully seated. This is repeated for each suture anchor. The repair is then palpated for gaps, which if present are closed with additional sutures [Figure 8]. The remaining sutures from the suture anchor can be used to reinforce the repair if desired. The knee is then ranged from 0°-90° to ensure that a stable repair has been performed. Once the repair has been found to be satisfactory, cut any remaining sutures.

The incision is closed with an interrupted 2-0 absorbable suture in the subcutaneous tissue, a running 4-0 absorbable suture in the subcuticular dermis, and the skin sealed with a skin glue [Figure 9]. After a sterile dressing is secured, the patient’s leg is placed in a hinged knee brace locked in full extension.

Patients are allowed weight bearing as tolerated in a knee brace locked in extension for six to eight weeks. Rehabilitation can be divided into phases, with immediate protected active knee flexion to 30°, passive knee extension, and patellar mobility exercises. After two weeks quadriceps sets are initiated with the permitted passive knee range of motion increased to 0-90° as tolerated. Progressive quadriceps strengthening begins at 6-8 weeks. Running and sport specific training may start at four months with release to jumping and contact sports when strength is 85-90% of the contralateral extremity after six months.

MATERIALS AND METHODS

After institutional review board approval was obtained, consecutive patients who were 18 years of age or older and had isolated QT or PT ruptures treated with a suture anchor repair technique by a single surgeon at an academic outpatient medical center between 2004 and 2014 were identified. Patients were included if all of the following data points could be obtained: pre-operative International Knee Documentation Committee (IKDC) score and ROM, and minimum six month post-operative IKDC score, ROM, ability to actively extend leg, and whether patient had failure requiring surgical revision. Patients were excluded if they had sustained a concomitant injury to the bones or ligaments about the treated knee, or if they initially presented after failure of a prior repair.

Appropriate t tests were used to assess the difference in outcomes between the QT and PT repair groups, and between knot-tied repairs using titanium Super Revo® FT or ThRevo® suture anchors (Linvatec, Largo, FL) and knotless repairs using biodegradable SwiveLock® suture anchors (Arthrex). The effects of patient age, interval between injury and surgery, and length of follow-up period on post-operative IKDC scores were analyzed with Pearson correlation.

RESULTS

A total of 73 consecutive patients who met the inclusion criteria were identified. Of those, 20 were excluded because no pre-operative IKDC scores were available. One patient who had presented after failure of a prior repair was also excluded. The remaining 52 patients were included in the study.
QT repair was performed in 28 patients with two patients requiring revision for re-injury or failure. The average age (and standard deviation) of patients at time of QT repair was 54 ± 15 years (range, 19 to 82 years), and 86% were male. Delayed repair (> 21 days after injury) occurred in 8 cases (28.6%), with interval between injury and surgery uncertain in one patient. Knotless suture anchors alone were used in 12 repairs (42.9%), and one repair utilized both knotless and knot-tying suture anchors. Post-operative IKDC scores were gathered from 15 patients at an average of 4.26 years (range, 0.87 to 7.38 years). The mean IKDC score was 64.7 ± 20.1 (range, 32.2 to 98.9), improving an average of 39.5 points (range 9.2 to 83.9) from before repair with all patients except one stating they could actively extend and hold their knee fully extended. Post-operative ROM was measured in all 28 patients at an average of 97 days (range, 48 to 195 days). The mean ROM was from -0.29° ± 1.74° (range, -5° to 5°) of extension to 115.2° ± 13.0° (range, 90° to 140°) of flexion.

PT repair was performed in 24 patients with one patient requiring subsequent revision. The average age of patients at time of PT repair was 37 ± 11 years (range, 22 to 64 years), and 75% were male. Delayed repair (> 21 days after injury) occurred in 3 cases (12.5%), and knotless suture anchors were used in 10 repairs (41.7%). Post-operative IKDC scores were gathered from 19 patients at an average of 2.93 years (range, 0.88 to 7.03 years). The mean IKDC score was 64.4 ± 16.4 (range, 37.9 to 85.1), improving an average of 41.7 points (range -4.6 to 70.1) from before repair with all patients stating they could actively extend and hold their knee fully extended. Post-operative ROM was measured in all 24 patients at an average of 136 days (range, 18 to 410 days). The mean ROM was from 0.0° ± 1.38° (range, -4° to 5°) of extension to 116.0° ± 23.5° (range, 40° to 140°) of flexion.

Comparatively, no significant difference was found between QT and PT repairs for final IKDC scores (p = 0.97), improvement in IKDC scores (p = 0.76), and final ROM extension (p=0.53) and flexion (p = 0.87). When comparing the knotless to the knot-tying suture anchors, there was no significant difference in post-operative IKDC scores (66.0 vs. 64.6, p = 0.82) or IKDC improvement (42.4 vs. 39.4, p = 0.64). There was a statistically significant but likely clinically insignificant increased extension (-0.8° vs. 0.2°, p = 0.03) and decreased flexion (106.9° vs. 122.2°, p = 0.005) with knotless suture anchors. For post-operative IKDC scores, Pearson correlation analysis found a significant negative correlation with increasing age (r = -0.63, p = 0.004). No significant correlation was found with increasing interval between injury and surgery (r = -0.26, p = 0.28) or with length of follow up period (r = 0.05, p = 0.85).

DISCUSSION

In biomechanical studies, suture anchor repair of the knee extensor mechanism has been reported to provide equivalent to superior results in terms of gap formation compared to transpatellar sutures. Bushnell et al performed a study on sectioned cadaver patellar tendons and reported significantly less gap formation after 250 cycles of loading and no difference in ultimate load to failure using suture anchors compared to suture loops placed through transpatellar tunnels (Bushnell 2006). Ettinger et al also reported suture anchors yielded significantly less gap formation during cyclic loading (4.3 mm for titanium anchors, 4.9 mm for hydroxyapatite anchors, and 27.5 mm for the trans-osseous sutures) and that they resisted significantly higher ultimate failure loads (597 N, 689 N, and 301 N respectively) in cadaveric patella tendon repairs (Ettinger 2013). These authors repeated the study on QT repairs and reported similar findings with suture anchors yielding significantly less gap formation during cyclic loading (5.1 mm for titanium anchors, 5.4 mm for hydroxyapatite anchors, and 45.5 mm for the trans-osseous sutures) and significantly higher ultimate failure loads (740 N, 572 N, and 338 N respectively) (Petri 2014). Lighthart et al reported no significant difference in displacement between the two techniques with loading of 150N after 1000 cycles, with mean displacement of 4.65 mm in the suture anchor repairs and 4.50 mm in the bone tunnel repairs (Lighthart 2008). On the other hand, Hart et al reported that trans-osseous repairs of the QT were stronger than a double row suture
anchor repair, but noted that repair stiffness and gap formation were similar between groups and that both repairs were sufficiently strong (Hart 2012).

There have been no randomized clinical trials comparing suture anchors to transpatellar sutures for knee extensor mechanism repair. A systematic review of the recent English literature of QT repair reported that surgical technique did not appear to influence outcomes, with only delay to surgical repair and age of the patient having a negative influence in some of the included studies (Ciriello 2012). In the included studies, 50% of ruptures were treated with a transpatellar tunnel technique, while mid-substance ruptures were often treated with simple suture repair (Ciriello 2012). Overall, most patients treated with early repair had good or excellent outcomes with mean Lysholm scores of 87-92.5, knee ROM of 0-120°, and the majority returning to pre-injury activities (Ciriello 2012, Verdano 2014). No systematic reviews could be found on PT repairs, but smaller studies report similar results with most athletes returning to pre-injury level of sports with early repair (Kelly 1984, Kuechle 1994, West 2008, Boublik 2011).

The current published literature on outcomes of suture repair of QT and patella tendon ruptures is limited to case reports and small case series of two to 14 patients. Ho reported on the outcomes of a single patient with bilateral concurrent PT ruptures treated with suture anchor repair. The patient had bilateral knee ROM of 10° hyperextension to 130° flexion, and returned to contact sports (Ho 2003). Richards reported on a single patient who underwent QT repair with suture anchors, who had knee ROM of 0-125° with a Lysholm score of 88 at follow-up 11 months postoperatively (Richards 2002). Bushnell reported on a series of 14 patients treated with suture anchor repair for PT rupture in which 11 patients had excellent ROM, strength, and returned to preoperative levels of function but three patients had failure of the repair (Bushnell 2008).

This study used IKDC scores as an outcome measure with a mean score of 64 for both QT and PT repairs. There is no standardized conversion factor or equivalency between the IKDC score and the Lysholm score, which has been used in most published studies on extensor mechanism repair with an average score of around 90 for early repairs (Ciriello 2012). We chose to use the IKDC functional outcome measure because it was designed to be self-administered with less potential for bias than the Lysholm instrument that was designed to be clinician-administered (Ra 2014). The Lysholm score has also been criticized for producing erroneously generous scores with a larger ceiling effect due to the simplicity of the tasks it queries, whereas the IKDC system produces less generous scores and has found to be a valid, reliable, and a more sensitive measure of knee function across a wider span of knee disorders (Ra 2014, Tilley 2010). A study on normative data for IKDC scores reported that a score between 71 and 77 was average for a person in their mid-50’s. Therefore, the mean IKDC score of 64 found in this study indicates continued modest deficits compared to age matched peers.

The failure rate of 6% found in this study is higher than the reported average of 2% reported in a systematic review, but within the range of 0-8.3% of included studies (Ciriello 2012). Two of the three failures were in patients who had delayed repairs months after the initial injury, and the other failure was due to a traumatic skydiving re-injury.

Knotless suture anchors entered the market in 1999 to alleviate the technical difficulty of arthroscopic knot tying, with the purported advantage of shortening operative time and decreasing postsurgical scarring and irritation at the repair site (Cox 2014, Pietschmann 2010, Ng 2014, Kocaoglu 2009). The current published literature on knotless suture anchors varies widely with reports of superiority, equivalency, and inferiority to knot-tying suture anchors in comparative cadaveric and clinical studies of tendon and labral repairs of the shoulder, knee and ankle (Burkhart 2009, Cho 2006, Cox 2014, Kocaoglu 2009, Leedle 2005, Ng 2014, Sileo 2009, Thal 2001). The finding in this study of no significant difference in final IKDC score or change in IKDC score and likely clinically insignificant increased extension but decreased flexion with knotless compared to knot-tying suture anchors does not support any strong conclusions regarding this matter.
Rehabilitation protocols have varied significantly in published studies of QT and PT repairs. In the systematic review by Ciriello of repairs performed with transpatellar tunnels or simple sutures, patients were immobilized in full extension for a variable period ranging from 3 to 10 weeks. In two included studies, patients were allowed partial weight bearing in the cast. In another two studies early mobilization (Continue Passive Motion: 0–55 and 0–60) was employed along with partial weight bearing and full weight bearing (Ciriello 2008). Rougraff et al. found no difference in the functional outcome when comparing the results between patients immobilized for 3 weeks patients immobilized for 6 weeks (Rougraff 1996). West reported on a series of 50 QT and PT repairs that were allowed early mobilization. Patients were treated in a locked hinge brace for 7 days. From that point through postoperative week 6, the braces were removed daily for limited (0°-55°) active motion, and the patients were allowed to do straight-leg raises and be full weight bearing with the brace locked in extension. Six weeks after surgery, they were allowed to ambulate brace free and to push for full active flexion of their knees. Results were good to excellent with no complications (West 2008). It appears that early, protected motion can be allowed safely with negligible effect on failure rates.

We believe the described technique of QT and PT repair using suture anchors requires less exposure than the traditional transpatellar tunnel technique, may reduce the risk of articular surface perforation, and has at least equivalent strength and low degree of gap formation between the repaired tendon and its footprint on the patella. This study found an average final IKDC score of around 64 and ROM of around 0° to 115° for both QT and PT repairs with suture anchors, with a 6% failure rate and negative correlation between IKDC score and increasing patient age, which is analogous with prior published literature on other repair techniques. Patients undergoing suture anchor repair of the knee extensor mechanism can expect continued modest functional deficits, an increased risk of failure with delayed repairs, and poorer functional outcomes with advancing age.
REFERENCES


12. 


Pediatric Supracondylar Humerus Fractures: Who’s Missing Needed Treatment?

Sirmon B, Mansour A, Carpenter W, Fletcher ND

ABSTRACT

BACKGROUND
Pediatric supracondylar humerus fractures are the most common pediatric fracture of the elbow. While operative management remains the standard of care for Gartland Type 3, controversy persists for the optimum treatment option for Gartland Type 2 fracture type (referred to as type 2). Treatment options include closed reduction with casting versus closed reduction and percutaneous pinning. While many surgeons recommend that all displaced type 2 fractures be surgically pinned, close follow up is required for patients discharged from the emergency department after initial splinting to ensure stability, and diagnose early loss of reduction. Multiple studies have found no difference in major complication rates between early versus delayed treatment of type 2 fracture pattern allowing outpatient surgery and potentially lower costs to the healthcare system. Limitations in access to care can jeopardize the safety of delayed surgery as patients requiring close follow up may not be able to obtain access to a provider in time to have surgery. This study aims to evaluate the subset of patients with either no insurance or government/public insurance and whether they suffered a lapse or loss in care due to their insurance status versus patients with private insurance.

HYPOTHESIS
There are a number of injured children with either no insurance or government/public insurance with Gartland Type 2 supracondylar humerus fractures who do not receive appropriate or timely surgical intervention of their fracture and are at risk of inferior outcomes

STUDY DESIGN
Retrospective review

METHODS
We performed a retrospective chart review of patients with isolated, unilateral type 2 supracondylar humerus fractures who were treated within the Emergency departments at a large metropolitan children’s healthcare network between January 1, 2008 until December 31, 2012. A total of 2,620 patients were identified during this time period with the ICD-9 code 812.41 correlating to a fracture of the supracondylar region of the humerus. Patients with ipsilateral forearm or wrist injuries were excluded, leaving a total of 2,584 patients with isolated injuries to the supracondylar humerus. These fracture types were identified and classified according to the modified Gartland classification based on the dictated operative note if applicable, orthopaedic consult note, Emergency Department documentation, or radiologist interpretation. The dictated operative notes from the attending staff were used as definitive classification if available. If no surgery was performed, the orthopaedic resident consult note was next evaluated and this classification was employed. If neither of these existed, the determination of classification was decided upon by the radiologist read of any displacement noted. And finally, if all else unavailable, the Emergency Department attendings interpretation was used. Insurance status at the time of initial presentation was determined from the electronic medical record. Private
insurers included Blue Cross/Blue Shield, Humana, United Healthcare, Aetna, Kaiser, Piedmont Wellstar. Governmental insurance included Medicaid, Wellcare, Georgia Better Health, and Peachstate/Peachcare insurance. Patients without insurance were identified as NULL. Time to surgery was determined from the operative records. The times, reported in days, were determined from the date of the initial evaluation of the injury in the Emergency Department to the date of any surgical intervention for the initial injury.

RESULTS

2584 supracondylar humerus fractures were reviewed. Of these, there were 1,204 (47%) fractures identified in females and 1,379 (54%) identified in males. 1,088 fractures occurred in children four years of age and younger, 1,200 fractures in children 4-8 years of age, 250 fractures in children 8-12, and 46 fractures in children >12 years of age. The mean age of the cohort was 5.26 ±2.77 years (Table 1.) There were 1,085 Type 1 (42%), 633 Type 2 (24%), and 866 Type 3 (34%) fractures (Table 2.). 1,508 patients (58%) were identified as having Private payor insurance. 920 patients (36%) had public insurance and 156 (6%) of patients were uninsured (Table 1.).

Table 1. Descriptive Statistics of Patients with isolated closed fracture of the distal humerus

<table>
<thead>
<tr>
<th>Variable</th>
<th>Category</th>
<th>Total Patients [n=2584] N (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, mean (std. dev.) (n)</td>
<td></td>
<td>5.26 (2.77), (n=2584)</td>
</tr>
<tr>
<td>Age</td>
<td>0-4</td>
<td>1088 (42%)</td>
</tr>
<tr>
<td></td>
<td>4-8</td>
<td>1200 (46%)</td>
</tr>
<tr>
<td></td>
<td>8-12</td>
<td>250 (10%)</td>
</tr>
<tr>
<td></td>
<td>&gt;12</td>
<td>46 (2%)</td>
</tr>
<tr>
<td>Sex</td>
<td>Female</td>
<td>1204 (47%)</td>
</tr>
<tr>
<td></td>
<td>Male</td>
<td>1379 (54%)</td>
</tr>
<tr>
<td></td>
<td>Unknown</td>
<td>1 (0%)</td>
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<tr>
<td>Insurance Status</td>
<td>Private(^1)</td>
<td>1508/2584 (58%)</td>
</tr>
<tr>
<td></td>
<td>Non-Private(^2)</td>
<td>1076/2584 (42%)</td>
</tr>
<tr>
<td></td>
<td>NULL</td>
<td>156/1076 (6%)</td>
</tr>
<tr>
<td></td>
<td>Public, Not Identified as NULL</td>
<td>920/1076 (36%)</td>
</tr>
<tr>
<td>Insurance Status of Type 2 Patients</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Private</td>
<td>357/633 (57%)</td>
</tr>
<tr>
<td></td>
<td>Non-Private(^1)</td>
<td>267/633 (43%)</td>
</tr>
<tr>
<td></td>
<td>NULL</td>
<td>28/267 (4%)</td>
</tr>
<tr>
<td></td>
<td>Public, Not Identified as NULL</td>
<td>239/267 (38%)</td>
</tr>
</tbody>
</table>

\(^1\) Private: Blue Cross/Blue Shield, Humana, United Healthcare, Aetna, Kaiser, Piedmont Wellstar.


\(^3\) Public: Medicaid, Wellcare, Georgia Better Health, and Peachstate/Peachcare.
Of the 2,584 fractures, the 1,951 patients with either type 1 fractures or type 3 fractures were excluded from analysis as all type 3 fractures were admitted for surgery and all type 1 fractures were treated with closed management. Of the 633 type 2 fractures, 626 had complete records available for review. 383 (61%) patients were admitted at the initial encounter for surgery and 243 were discharged with plans for outpatient follow up. There was no difference in insurance status between patients admitted for immediate surgery (OR 1.11 (95%CI 0.80-1.53, p=0.53) and patients with neither private insurance (OR1.44 (95%CI 0.66-3.12) nor public insurance (OR1.32 (95%CI 0.60-2.89). Patients with private insurance were no more likely to have immediate surgery than those without insurance (p=0.49).

Of the 243 patients who were discharged with classified type 2 fractures, 134 (55%) had private insurance, 109 (44.5%) had public insurance, and 13 (0.5%) of these had no insurance. 42 patients (31%) with private insurance eventually had surgery compared to 17 patients (16%) with public insurance and 1 patient (8%) with no insurance. Patients with private insurance were 2.46 times more likely to have surgery than patients with public or no insurance (0=0.005) (Table 3b). There was no difference in time to delayed surgery between groups (5.38±0.64 days private vs 6.07±1.07 non-private, p=0.58) (Table 3a).
Table 3- Breakdown of treatments, immediate vs delayed, totals

- Total isolated Supracondylar Humerus fractures: 2,584 patients
- Total isolated Type 2 fractures: 626 patients
- Surgery total vs treated Non-operatively: 442 patients vs 184 patients
- Patients Treated with Immediate Surgery: 383 patients
- Patients treated operatively on a delayed basis: 59 patients

Table 3- Flowchart of Patients treated on delayed basis

- 243 Patients discharged with outpatient follow up for Type 2 fracture
- 59 patients total ultimately underwent surgical fixation on a Delayed basis

- 42/357 patients with Private Insurance
- 17/269 Patients with Non-Private Insurance
Table 3. Descriptive Statistics of Type 2 Fractures, Overall and by Insurance Status

<table>
<thead>
<tr>
<th>Variable</th>
<th>Overall Type 2 (n=626)</th>
<th>Private Insurance(^1) (n=357)</th>
<th>Non-Private Insurance(^2) (n=269)</th>
<th>NULL (n=28)</th>
<th>Public Insurance(^3) (n=241)</th>
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</thead>
<tbody>
<tr>
<td>Surgery Overall</td>
<td>No surgery</td>
<td>184/626 (29%)</td>
<td>92/357 (26%)</td>
<td>92/269 (34%)</td>
<td>12/28 (43%)</td>
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<tr>
<td></td>
<td>Yes</td>
<td>442/626 (71%)</td>
<td>255/357 (71%)</td>
<td>177/269 (66%)</td>
<td>16/28 (62%)</td>
</tr>
<tr>
<td>Immediate Surgery,</td>
<td>No</td>
<td>243/626 (39%)</td>
<td>134/357 (38%)</td>
<td>109/269 (41%)</td>
<td>15/28 (46%)</td>
</tr>
<tr>
<td>overall(^4)</td>
<td>Yes</td>
<td>383/626 (61%)</td>
<td>223/357 (62%)</td>
<td>160/269 (60%)</td>
<td>15/28 (54%)</td>
</tr>
</tbody>
</table>

\(^1\) Private insurance includes Blue Cross/Blue Shield, Humana, United Healthcare, Aetna, Kaiser, Piedmont Wellstar.
\(^2\) Non-Private insurance includes NULL, Medicaid, Wellcare, Georgia Better Health, and Peachstate/Peachcare.
\(^3\) Public Insurance includes Medicaid, Wellcare, Georgia Better Health, and Peachstate/Peachcare (NULL excluded).
\(^4\) Immediate surgery overall.

---

Table 3a. Descriptive Statistics of Type 2 Fractures treated on Delayed basis, Overall and by Insurance Status

<table>
<thead>
<tr>
<th>Variable</th>
<th>Overall Type 2 (n=626)</th>
<th>Private Insurance(^1) (n=362)</th>
<th>Non-Private Insurance(^2) (n=269)</th>
<th>NULL (n=28)</th>
<th>Public Insurance(^3) (n=241)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surgery Status Breakdown</td>
<td>No surgery</td>
<td>184/626 (29%)</td>
<td>92/357 (26%)</td>
<td>92/269 (34%)</td>
<td>12/28 (43%)</td>
</tr>
<tr>
<td></td>
<td>Immediate</td>
<td>383/626 (61%)</td>
<td>223/357 (62%)</td>
<td>160/269 (60%)</td>
<td>15/28 (53%)</td>
</tr>
<tr>
<td></td>
<td>Delayed</td>
<td>59/626 (9%)</td>
<td>42/357 (12%)</td>
<td>17/269 (6%)</td>
<td>1/28 (4%)</td>
</tr>
<tr>
<td>Time to Delayed surgery (N=59)</td>
<td>5.56(4.12), (n=57)</td>
<td>5.38(4.02), (n=42)</td>
<td>6.06(4.49), (n=15)</td>
<td>2.00(1.61), (n=14)</td>
<td>6.36(4.52), (n=14)</td>
</tr>
</tbody>
</table>

\(^1\) Private insurance includes Blue Cross/Blue Shield, Humana, United Healthcare, Aetna, Kaiser, Piedmont Wellstar.
\(^2\) Non-Private insurance includes NULL, Medicaid, Wellcare, Georgia Better Health, and Peachstate/Peachcare.
\(^3\) Public Insurance includes Medicaid, Wellcare, Georgia Better Health, and Peachstate/Peachcare (NULL excluded).

---

Table 3b. Adjusted statistical analysis of the relationship between surgery (overall and immediate) and insurance status (private v. non-private)

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Odds Ratio, Private Insurance(^1) v. Non-Private(^2)</th>
<th>95% Confidence Interval</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surgery</td>
<td>1.47</td>
<td>1.04, 2.08</td>
<td>0.0291</td>
</tr>
<tr>
<td>Immediate Surgery</td>
<td>1.11</td>
<td>0.80, 1.53</td>
<td>0.5432</td>
</tr>
<tr>
<td>Delayed surgery</td>
<td>2.46</td>
<td>1.31, 4.64</td>
<td>0.0053</td>
</tr>
</tbody>
</table>

\(^1\) Private insurance includes Blue Cross/Blue Shield, Humana, United Healthcare, Aetna, Kaiser, Piedmont Wellstar.
\(^2\) Non-Private insurance includes NULL, Medicaid, Wellcare, Georgia Better Health, and Peachstate/Peachcare.
DISCUSSION/CONCLUSION

Supracondylar humerus fractures are among the most common operative pediatric elbow injuries. In 2011 the AAOS performed a systematic review of the literature to provide a clinical guideline to treatment of pediatric supracondylar fractures. The guidelines made moderate recommendations for the treatment of Gartland type II and type III displaced pediatric supracondylar fractures of the humerus be closed reduction with pin fixation. Most authors agree that completely displaced Gartland type 3 supracondylar humerus fractures be addressed surgically within 24 hours and true Gartland Type 1 fractures be treated with casting alone. Controversy remains in a consensus approach to treatment of Gartland type 2 supracondylar humerus fractures. While the Gartland Classification system has been shown to have excellent inter and intra observer reliability it has been shown that the most difficult types to differentiate between are the Type 1 vs Type 2’s. Some type 2 fractures may have medial or lateral comminution, subtle rotational deformity, or obliquity at the fracture site necessitating operative management that can be difficult to reliably diagnose. Many fractures of this type can be evaluated in the emergency department, splinted, and discharged home to be followed in clinic and safely undergo operative treatment on an outpatient basis avoiding a hospitalization. As the healthcare environment evolves there may be an impetus for treatment in this fashion as it has been proven to be a safe manner in which to handle this fracture pattern. The aim of this paper was to look at the subset of patients with a type 2 supracondylar humerus fracture with differing insurance coverage at the time of injury and if this played a part in the child receiving proper evaluation and treatment after discharge from the emergency department.

There was no difference in payor status between patients treated surgically at the time of initial presentation suggesting that payor status had no impact on initial treatment. This was true for both type 2 and 3 fractures. Patients with public or no insurance were 2.46 times less likely to have resultant surgery than those with private insurance when discharged from the hospital with plans for outpatient follow up were. As this was a retrospective analysis, our data does not account for surgeon preference regarding treatment of type 2 fractures. Nonetheless, the drastic difference in the number of patients who underwent delayed surgery suggests that limited access to care may impact the ability of patients with type 2 fractures to have their fractures surgically managed. Only one patient without insurance who was discharged went on to have surgery. It is common practice for practices to charge patients without insurance for initial consultation and our hospital system often requires up-front payment for surgical care if scheduled as an outpatient unless the patient qualifies for charity care. Patients may need to be admitted through the emergency department in order to bypass this barrier, adding further cost to the system.

The Emergency Medical Treatment and Active Labor Act (EMTALA) was enacted in 1986 to limit patient “dumping” and requires that emergency departments provide care to patients within their capabilities, regardless of insurance status. The act does not address non-urgent medical conditions such as type 2 supracondylar humerus fractures where outpatient care has been shown to be equivalent to immediate surgery as long as care is provided. It is generally frowned upon, although certainly not illegal, for surgeons to perform a “chart biopsy” and check on the patient’s insurance status before making a decision regarding care for a patient with a non-emergent condition as long as care is not denied. The majority of the orthopaedic literature in regards to centers around trauma and transfer to a Level 1 center. We found no literature in regards to EMTALA and pediatric orthopaedics. While we are certainly not suggesting that all physicians screen patient charts to determine whether they need to be admitted or could be discharged with close follow up, the current data does suggest that insurance status alone can impact the patient’s ability to achieve definitive care. As such, a treating physician should take into account the patient’s ability to follow up, and consideration to surgery at the initial point of care should be given. This is especially true as most type 2 fractures may be treated with...
discharge within a couple of hours of surgery. It is our feeling that a discussion of the patient’s insurance status should not be taboo if it is used to provide care for children who may not be able to follow up for outpatient care.

The primary limitation of this study comes from the retrospective nature as we are unable to determine whether patients who did not receive follow up actually contacted one of our offices. Our center was the only provider of pediatric surgical care in our region during this time period and it is unlikely that surgery was performed elsewhere in the city. Nonetheless, patients could have seen non-pediatric orthopaedists for care. It is unlikely that patients without insurance were more likely to obtain surgical intervention at outside facilities as our center provides the majority of indigent care in our region, however this is also possible. The marked difference in delayed surgical care based on insurance status is different than that seen in those who underwent surgery at the initial time of injury (where no difference was seen), suggests that insurance status had a large impact on access to care.

In summary, insurance status was directly associated with access to outpatient surgical care with privately insured patients being 2.46 times more likely to have outpatient surgery than those public or no insurance. Consideration should be given to evaluating the patient’s insurance status in order to provide the best and most appropriate care. If outpatient follow-up is unlikely given insurance limitations, than surgical management at the time of initial consult may be appropriate.
REFERENCES


## Emory Orthopaedics Surgical Faculty

<table>
<thead>
<tr>
<th>Name</th>
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<tbody>
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<tr>
<td>Diane Payne, MD</td>
<td>Assistant Professor, Trauma/Hand &amp; Upper Extremity</td>
</tr>
<tr>
<td>Mathew Pombo, MD</td>
<td>Assistant Professor, Sports Medicine</td>
</tr>
<tr>
<td>Daniel Refai, MD</td>
<td>Assistant Professor, Spine</td>
</tr>
<tr>
<td>Nickolas Reimer, MD</td>
<td>Assistant Professor, Musculoskeletal Oncology</td>
</tr>
<tr>
<td>William Reisman, MD</td>
<td>Assistant Professor, Trauma</td>
</tr>
<tr>
<td>Christopher Sadlack, MD</td>
<td>Assistant Professor, Adult Reconstruction</td>
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<tr>
<td>Richard Thomas, MD</td>
<td>Assistant Professor, Trauma</td>
</tr>
</tbody>
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PUBLICATIONS & PRESENTATIONS


Peer-Reviewed Journals continued


Peer-Reviewed Journals continued


Peer-Reviewed Journals continued


Honors & Awards
2014-2015

Listed as one of Atlanta’s Best Doctors by Atlanta Magazine
  Scott Boden, M.D.
  Robert Bruce, M.D.
  David Hubbell, M.D.
  Spero Karas, M.D.
  James Roberson, M.D.
  Gerald Rodts, M.D.
  John Xerogeanes, M.D.

Reported at or above the 90th percentile in Press Ganey
  Dheera Ananthakrishnan, M.D.
  Greg Erens, M.D.
  William Beckworth, M.D.
  Thomas Bradbury, M.D.
  Susan Dreyer, M.D.
  Greg Erens, M.D.
  Kyle Hammond, M.D.
  Gary McGillivary, M.D.
  Daniel Refai, M.D.
  John Rhee, M.D.
  James Roberson, M.D.
  Gerald Rodts, M.D.
  John Xerogeanes, M.D.

Alpha Omega Alpha Honor Medical Society
  John Xerogeanes, M.D.

Regional Office
  Thomas Bradbury, M.D., President Elect of the Atlanta Orthopaedic Society

Becker’s Spine Review
  Scott Boden, M.D. Selected as 1 of 55 spine surgeons on the forefront of biologics & stem cells

Top 100 Papers
  Scott Boden, M.D. Author of 1 of the “Top 100 Papers” Feature Review in Lumbar Spine Surgery